Dokuz Eylül University
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BOOK OF ABSTRACTS

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A DESIGN OF ORTHOPEDIC SUPPORT MATERIAL CONTAINING DICLOFENAC SODIUM MICROPARTICLES

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ABSTRACT

The aim of this study is preparation and characterization of sustained release diclofenac sodium microparticles and their application to the orthopedic support materials. The microparticles were obtained using spray drying method involving ethyl cellulose as shell material. The morphology, particle size, drug loading capacity and in vitro release characteristics of the drug microparticles were optimized for impregnation diclofenac sodium microparticles onto the orthopedic support materials.

Scanning electron microscopy (SEM) were used to characterize the drug microparticles and the treated fabrics with microparticles. SEM images illustrated that the microparticles were spherical in shape and also fixed onto the orthopedic support materials. Furthermore, the release properties of materials containing microparticles and resistance to washing were investigated.

This study suggested that textile slow-release systems containing diclofenac sodium microparticles could have a potential for long-term therapy for rheumatic disorders.

Key words: microencapsulation, spray drying, diclofenac sodium, orthopedic support materials

1. INTRODUCTION

In recent years, functional textiles used in medical and related healthcare are an important and rapidly growing segment of the textile field [1]. Logically, textile materials have found their way in the medical field as well, e.g., artificial aortas and bandages. However, advanced functional textile drug delivery systems were not developed until the end of the last millennium.

In oral delivery systems (e.g. tablets, pills, capsules), the drug is absorbed in the stomach or intestinal tract. As some drugs are metabolised, they might lose their activity before being able to fulfil their medical purpose. Moreover, one can imagine situations where oral administration is less applicable or impractical, e.g., with children, people with swallowing difficulties or in the case of dementia [2, 3]. Several technologies have been developed and used in preparing transdermal drug delivery systems and one of these is the use of medicated textiles for delivering drugs to specific body sites [4].

Diclofenac sodium is a non-steroidal anti-inflammatory (NSAIDs) drug commonly used for the long-term treatment of rheumatic disorders, such as osteoarthritis, rheumatoid arthritic and anky-losing spondylitis. Several unwanted adverse effects are generally associated with the long term oral administration of NSAIDs, including stomach ulcerations, abdominal burning, pain, cramping, nausea, gastritis, and even serious gastrointestinal bleeding and liver toxicity. The diclofenac sodium is completely absorbed following oral administration, but its elimination half-life is relatively short, 1-2 h. Due to its biopharmaceutical and pharmacological properties, sustained release formulations of diclofenac sodium are desirable which should maximize therapeutic benefit and reduce the unwanted side effects since the frequency of administration is lower, improving the therapeutic efficacy and patients compliance [5-10].

Spray drying is by definition the transformation of a feed from a fluid state (solution, dispersion or paste) into a dried particulate form by spraying the feed into a hot drying medium. Spray drying technique has been widely used for drying heat-sensitive foods, pharmaceuticals and other substances. This technique can also be used as an encapsulation method when it entraps active material within a protective matrix, which is essentially inert to the material being encapsulated [11]. Spray-drying encapsulation has a number of advantages. It is a well established technology, involves

readily available equipment and comparatively low-cost encapsulation [12]. The potential use of spray drying microencapsulation for pharmaceutical applications, particularly the preparation of microparticulate drug delivery systems [11].

Orthopedic support materials are used for protection and as support joints in various zones of the body. General examples of such applications are knee supports, wrist supports, ankle supports, elbow supports, shoulder supports, back supports. These supports are used for cure or protection. Medical application usually happens in the areas listed below:

- after operation or traumatic irritations,
- in the joint illnesses of degenerative and inflammatory,
- over forced ligaments and tendons,

special problems of various joints [13].

The aim of this study is preparation and characterization of sustained release diclofenac sodium microparticles and their application to the orthopedic support materials. The microparticles were obtained using spray drying method involving ethyl cellulose as shell material. The morphology, particle size, drug loading capacity and in vitro release characteristics of the drug microparticles were optimized for impregnation diclofenac sodium microparticles onto the orthopedic support materials.

2. MATERIALS AND METHODS

2.1. Materials

Diclofenac sodium of pharmaceutical grade (IUPAC name: sodium 2-[2-(2,6-dichlorophenyl)aminophenyl]acetate, CAS Number: 15307-79-6, Chemical formula: $C_{14}H_{10}C_{12}NNaO_2$), acquired from Amoli Organics, India, was the active material used.

Aqueous formulations based on ethyl cellulose (Surelease®, aqueous dispersion of ethyl cellulose, plasticizer and stabilizers at 19% w/w, Colorcon, England) were used as controlled release polymer. The polymer were blended with the excipients propylene glycol (Sigma, USA), as a plastifying agent, colloidal silicon dioxide (Turkey), as a glidants and distilled water.

The textile fabric composed of wool+acrylic 65%, polyester 21% and elastane 14% mixture was used as orthopedic support material supplied by Interfarma (Ankara, Turkey).

2.2. Methods

2.2.1. Characterization of bulk drug

Bulk drug was characterized by UV spectrophotometric method (Shimadzu UV-Visible Spectrophotometer UV-1208) at 276 nm in aqueous medium, FTIR analysis (Perkin Elmer, Massachusetts, USA) and DSC analysis (Perkin Elmer, Massachusetts, USA) was compared with that of the standard.

For FTIR analysis, diclofenac sodium was added into the KBr and grinded until it is uniformly distributed throughout the KBr. The KBr-diclofenac sodium was prepared with the die set under a pressure of 10000 pounds for obtaining the FTIR spectra. The FTIR spectra of this blend were recorded with a FTIR spectrophotometer (Perkin Elmer, Massachusetts, USA) by a direct trasmission method scanning from 4000 to 400 cm^{-1} at a resolution of 2 cm^{-1}.

DSC instrument (Perkin Elmer, Massachusetts, USA) was used for the thermoporosimetry experiments under nitrogen atmosphere. The stainless steel pans were not sealed and the sample was first equilibrated at 0˚C. Then a temperature ramp from 0˚C to 350˚C was applied at a cooling rate of 10˚C/min and at a flow rate of 50 mL/min.

2.2.2. Spray dryer

The microencapsulating runs were carried out in a bench-top spray dryer model SD-04 (Lab-Plant, North Yorkshire, England), with concurrent flow regime. The drying chamber has 110 mm in diameter and height of 380 mm. The main components of the system are the feed system of the microencapsulating formulation, constituted by a peristaltic pump, a two fluid atomizer (nozzle diameter of 0.5 mm) and an air compressor; the feed system of the drying air, constituted by a blower, an air filter and a temperature control system. The dried product was collected in a Lapple cyclone. Figure 1 shows the schematic diagram of the spray dryer used.

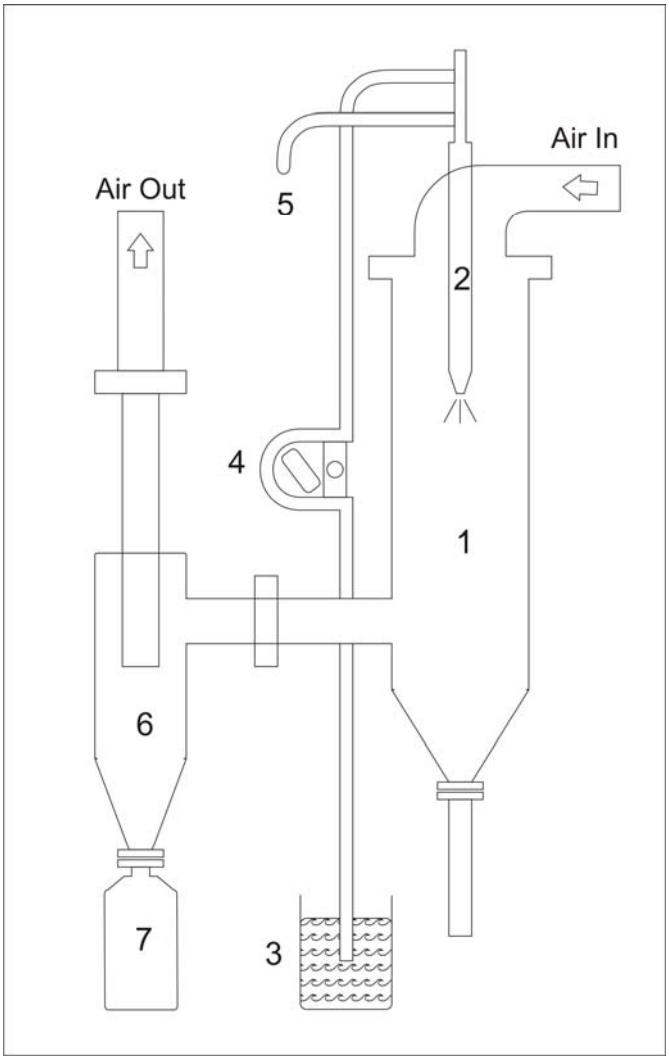


Figure 1. Schematic diagram of the spray dryer used: (1) drying chamber; (2) atomizer; (3) fluid; (4) peristaltic pump; (5) compressed air; (6) cyclone; (7) dry product collector.

2.2.3. Microencapsulation process of diclofenac sodium

Aqueous dispersion of ethyl cellulose (Surelease®) was evaluated as controlled release polymer. Diclofenac sodium and the polymer dispersion were suspended in distilled water. The drug:polymer ratios in the microencapsulating compositions were maintained in 1:1, 1:2 and 1:4 (dry base), respectively. Propylene glycol at concentration of 0.6% w/w and 0.75% w/w of colloidal silicon dioxide were then added to the drug/polymer suspension and maintained under agitation for 30 min. The resulting compositions were then fed to the spray dryer at the following conditions: feed flow rate of microencapsulating composition, W_s, 10 g/min; inlet air temperature, T_{ai}, 125°C and outlet air temperature T_{ao}, 60-66°C. Samples of the spray dried microparticles were collected during the experiments.

The samples were used for the physical and chemical characterization of the dried product (total drug load, encapsulation efficiency, particle size and size distribution and particle morphology), and for the *in-vitro* drug release studies.

Table 1. Contents of formulations (for 250 g)

Drug:Polymer ratio / Content (g)	1:1	1:2	1:4
Diclofenac sodium	7.5	3.75	1.875
Surelease®	39.267	39.267	39.267
Propylene glycol	1.5	1.5	1.5
Colloidal silicon dioxide	1.875	1.875	1.875
Distilled water	199.86	203.608	205.483

2.2.4. Physical and chemical characterization of the spray dried microparticles

The effects of spray drying conditions and composition of the microencapsulating formulation on physical and release properties of diclofenac sodium microparticles were assessed by determining particle size and size distributions, particle morphology, diclofenac sodium content and encapsulating efficiency, and X-Ray analysis. The methods used in these determinations are presented following.

2.2.4.1. Particle size and size distributions

The particle size and size distributions of the microparticles were measured by laser diffractometer (Malvern-Mastersizer 2000) using a dry powder feeder.

2.2.4.2. Particle morphology

The morphology of the spray dried microparticles were evaluated through Scanning Electron Microscopy (SEM). Powder samples were attached to double-sided adhesive carbon tabs mounted on SEM support, coated with a thin layer of the gold. Measurements were taken in vacuum at different magnifications.

2.2.4.3. Determination of diclofenac sodium content and encapsulation efficiency

Diclofenac sodium content of microparticles was determined spectrophotometrically. 5 mL of buffer solution (pH 7.4) was added on 20 mg of microparticles and shaken for 23 hrs. Then, 5 mL of buffer solution (pH 7.4) was added and shaken for another 1 hr. After filtration, 0.1 mL of filtrate was diluted to 10 mL with buffer solution (pH 7.4). The absorbance of the solution was measured at 276 nm by a spectrophotometer against the blank, and drug concentration was determined from the calibration curve (n=3). The following equation was used as a calibration curve:

$y = 30.187x - 0.3828$ (in which y is concentration [µg/mL], x is absorbance, and r^2 is 0.9997).

Encapsulation efficiency for each formulation was determined by using following equation:

$$\text{Encapsulation efficiency, } \varepsilon(\%) = 100 \times \text{Actual diclofenac sodium content} / \text{Theoretical diclofenac sodium content}$$

2.2.4.4. X-Ray analysis

X-ray powder diffraction (XRPD) patterns of pure drug and microparticles were obtained with a Rigaku X-RAY diffractometer equipped with a personal computer for data acquisition and analysis in the 2θ range between 3° and 90° using Cu$K\alpha$-radiation (40 kV; 36 mA). Samples were mildly pre-ground with a pestle in an agate mortar to make them homogeneous, to control crystal size and to minimise preferred orientation effects.

2.2.5. Impregnation of microparticles on orthopedic support material

Microparticles were applied to orthopedic support materials at a laboratory scale, reproducing the industrial application conditions. The microparticles were applied in the finishing process of textiles fabrication using a foulard, in which the textile to be treated is impregnated using a finishing bath containing (i) microparticles and (ii) a self-cross-linking agent (Baypret USV, Bayer). The conditions

required for this procedure are shown in Table 2. The pick-up (expressed in %) is just the ratio: (mass of bath solution taken by the textile /mass of dry textile) x 100.

Table 2. Conditions of textile impregnation process

Finishing Conditions	
Substrate	Orthopedic support material
Process	Foulard
Pressure	0.9 bar
Bath volume	1 L
Diclofenac sodium microparticles	40 g/L
Baypret® USV (self-cross-linking agent)	40 g/L
Drying conditions	100 °C, 2 hours
Thermofixing conditions	130 °C, 10 min

2.2.6. Scanning Electron Microscopy (SEM) of textile impregnated with microparticles

The analyzed samples correspond to the impregnated textiles with microparticles. Impregnated textile samples were coated with a thin layer of sputtered gold prior to examination, using an ion sputter device. Samples were observed using a scanning electron microscope JEOL JSM 6060 (Tokyo, Japan) at 15 kV.

2.2.7. Laundering test

To test laundering durability specimens wereu treated on a short time program in a Atlas Linitest or 30 min at 30˚C, in accordance with ISO Standard 105 C06 [14]. At the end of the cycle samples were dried at room conditions. All samples were examined after cycles.

2.2.8. Drug release studies

2.2.8.1. Preparation of pH 7.4 buffer solution

The preparation of buffer solution according to USP XXX (2007) is indicated as follows [15]:

pH 7.4 buffer solution (200 mL):

Potassium phosphate, monobasic 0.2 M	50 mL
Sodium hydroxide, 0.2 M	39.1 mL
Distilled water	qs 200 mL

2.2.8.2. Determination of diclofenac sodium in the textile impregnated with microparticles

For determination of diclofenac sodium concentration of 100 mg textile materials, samples taken from different part of textile material were used (n=3). Drug concentration was determined as described in section 2.2.4.3.

2.2.8.3. In-vitro drug release

1 g (about 6 x 2.5 cm^2 which was contained approximately 1% diclofenac sodium) of the textile impregnated with diclofenac sodium microparticles was suspended in glass vessels containing 100 mL of buffer solution (pH 7.4) and incubated on a shaking bed at 37˚C, 70 rpm. At appropriate time intervals the solutions were withdrawn and the amount of diclofenac sodium released from the textile impregnated with microparticles was evaluated spectrophotometrically at 276 nm. Then an equal volume of the same release medium was added back to maintain a constant volume.

For comparison among means of drug release, one-way ANOVA test and student t-test were used.

3. RESULTS and DISCUSSIONS

3.1. Characterization of bulk drug

3.1.1. UV, FTIR and DSC analysis

Diclofenac sodium shows a characteristic spectrum with two absorption band with maxima at λ=212 nm and λ=276 nm.

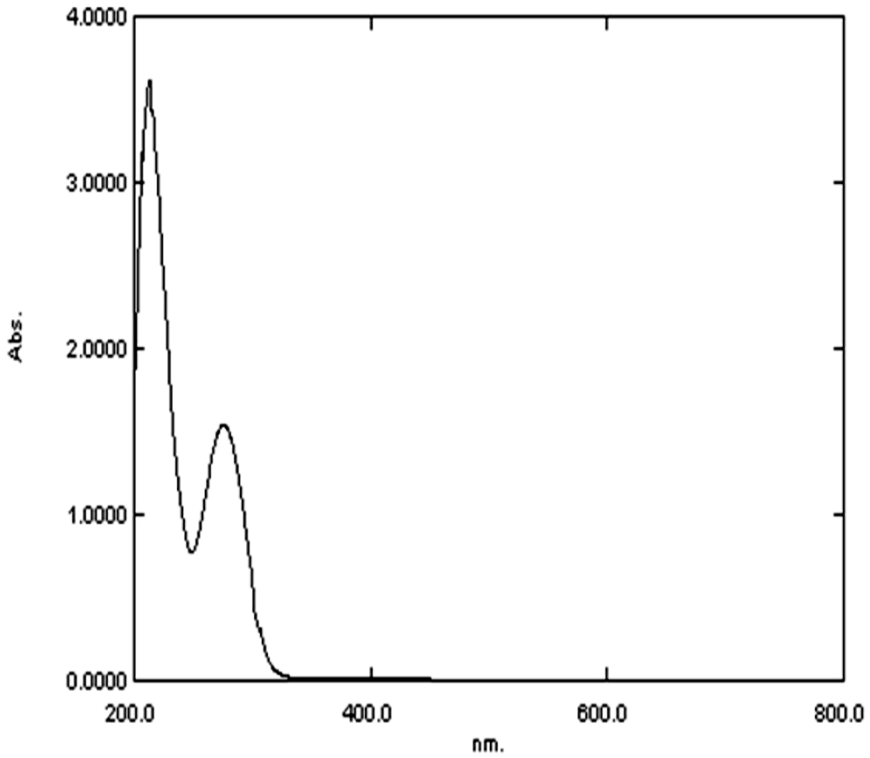


Figure 2. UV spectra of the diclofenac sodium.

The infrared spectra (FTIR) of diclofenac sodium is shown in Figure 3. This figure shows at 1600 a signal of a carbonyl group appeared. At the same time, FTIR spectra of diclofenac sodium is in conformity with the literature [16].

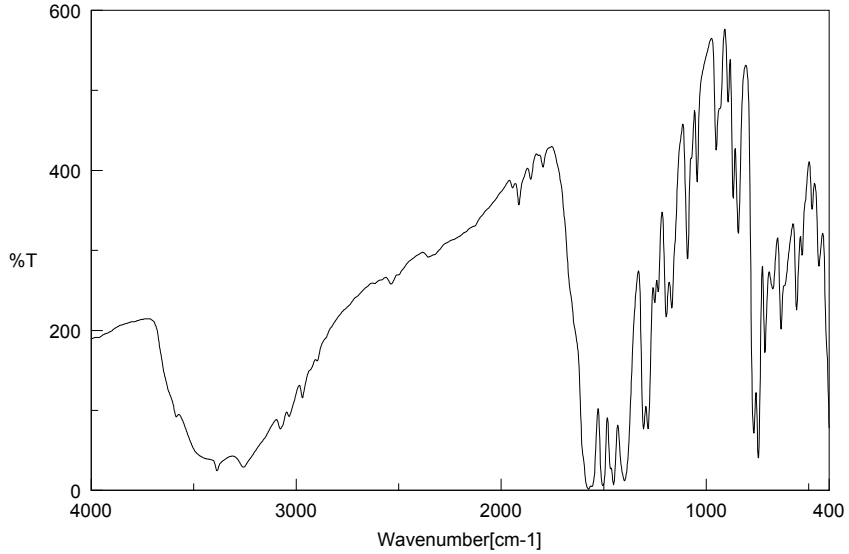


Figure 3. FTIR spectra of the diclofenac sodium.

The DSC analysis of diclofenac sodium is shown in Figure 4. The DSC curve of diclofenac sodium (active substance) showed an exothermic peak of melting at 280°C followed by an endothermic peak of decomposition as mentioned in the literature [17]. An accurate measurement was performed and the exothermic peak was found in the interval from 288.4 to 299.92°C.

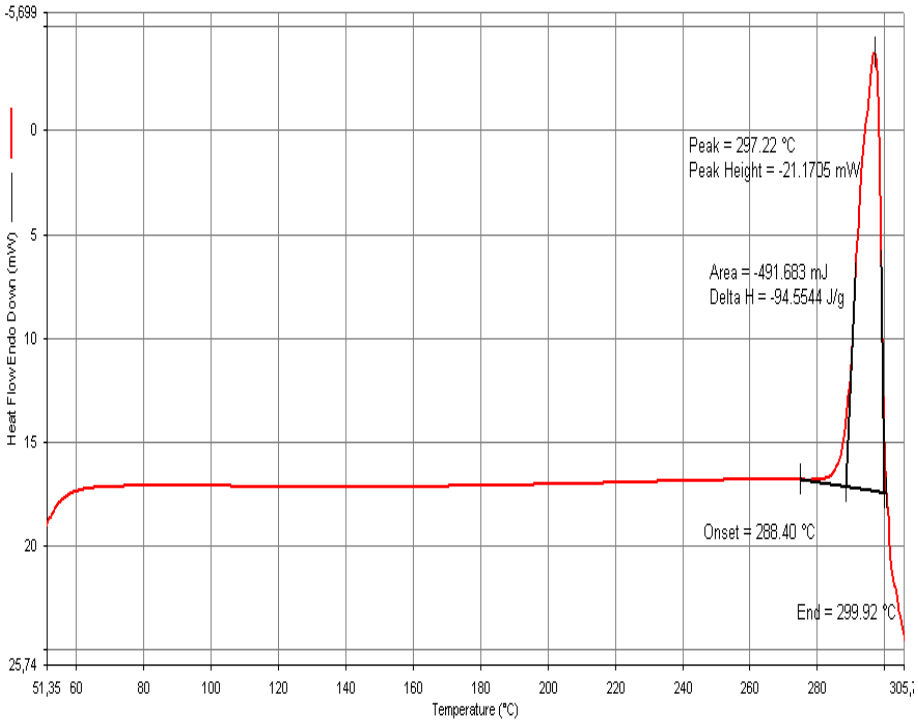


Figure 4. DSC analysis of diclofenac sodium

3.2. Physical and chemical characterization of the spray dried microparticles

3.2.1. Particle size and size distribution

Figure 5 shows the particle size distribution of the prepared microparticles. The mean size (based on volume distribution) of microparticles formed by [1:1], [1:2] and [1:4] formulations is 6.978, 6.942 and 7.343 μm, respectively.

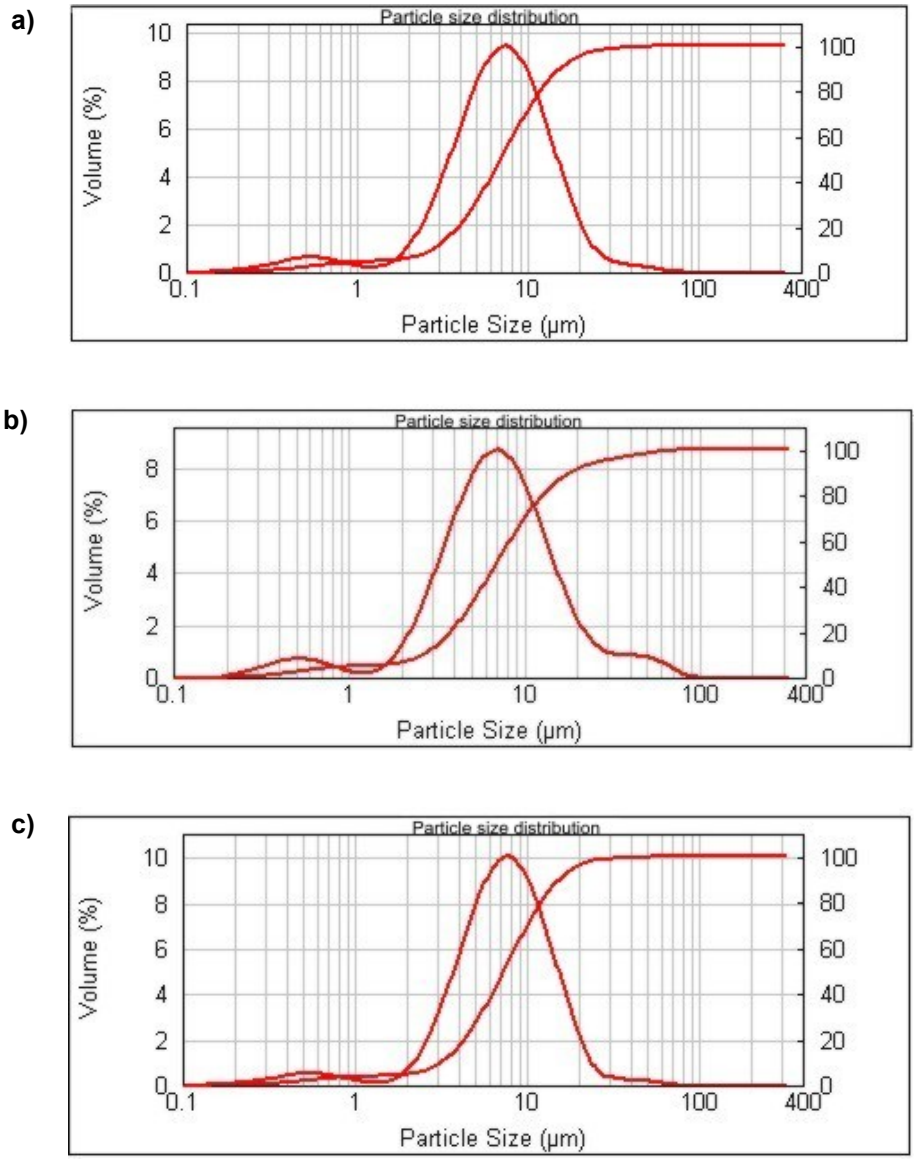
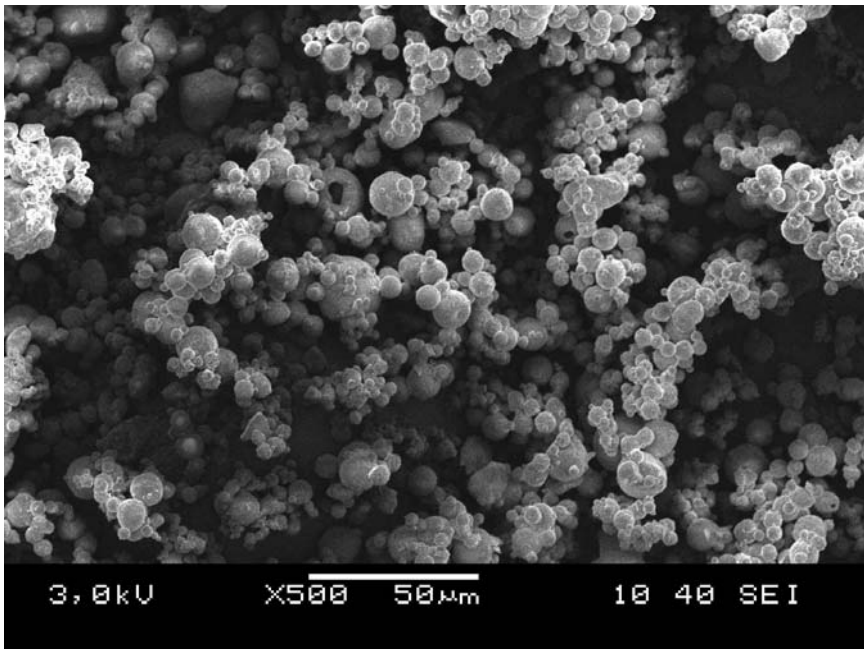


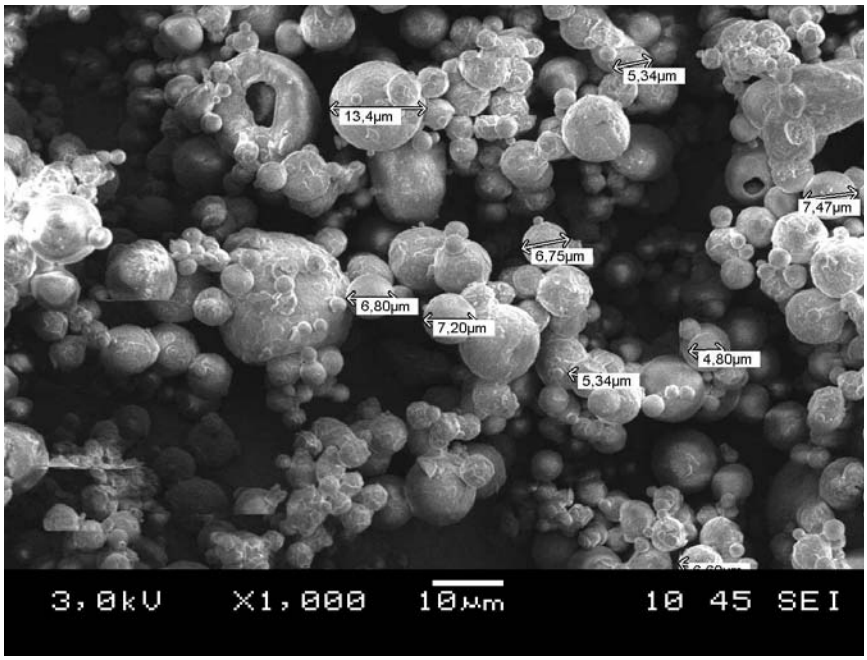
Figure 5. Particle size distributions of microparticle formulations: a) 1:1, b) 1:2 and c) 1:4.

3.2.2. Particle morphology

Figure 6a and 6b show typical photomicrographs obtained by scanning electronic microscopy of spray dried microparticles (1:1) with magnification of 500 and 1000 times and of the spray dried microparticles (1:2) with magnification of 1000 and 5000 times, respectively. It can be seemed in the figures that the spray-dried product is composed mainly by rounded-shape particles, and one can notice also the absence of agglomerates. They also indicate the formation of microparticles with homogeneous characteristics and smooth appearance, and do not show the presence of free drug on the microparticles surfaces. In general, these morphological characteristics point out that the drug is dispersed through the microparticles.

a)


3,0kV X500 50µm 10 40 SEI


13,4µm
5,34µm
7,47µm
6,75µm
6,80µm
7,20µm
4,80µm
5,34µm
3,0kV X1,000 10µm 10 45 SEI

b)

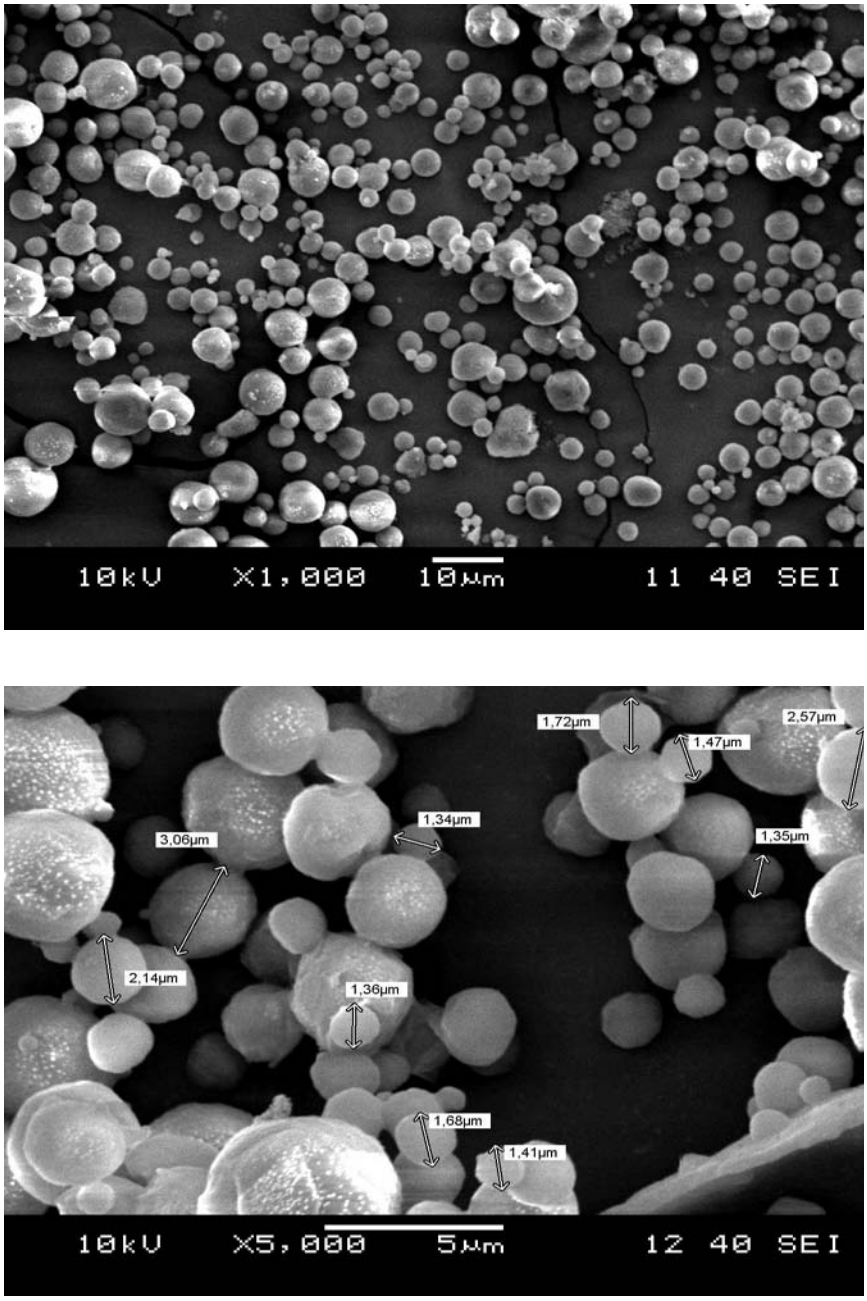


Figure 6. SEM photomicrographs of spray dried microparticles.

3.2.3. Determination of diclofenac sodium content and encapsulation efficiency

Table 3. Encapsulation values as a function of drug:polymer ratios

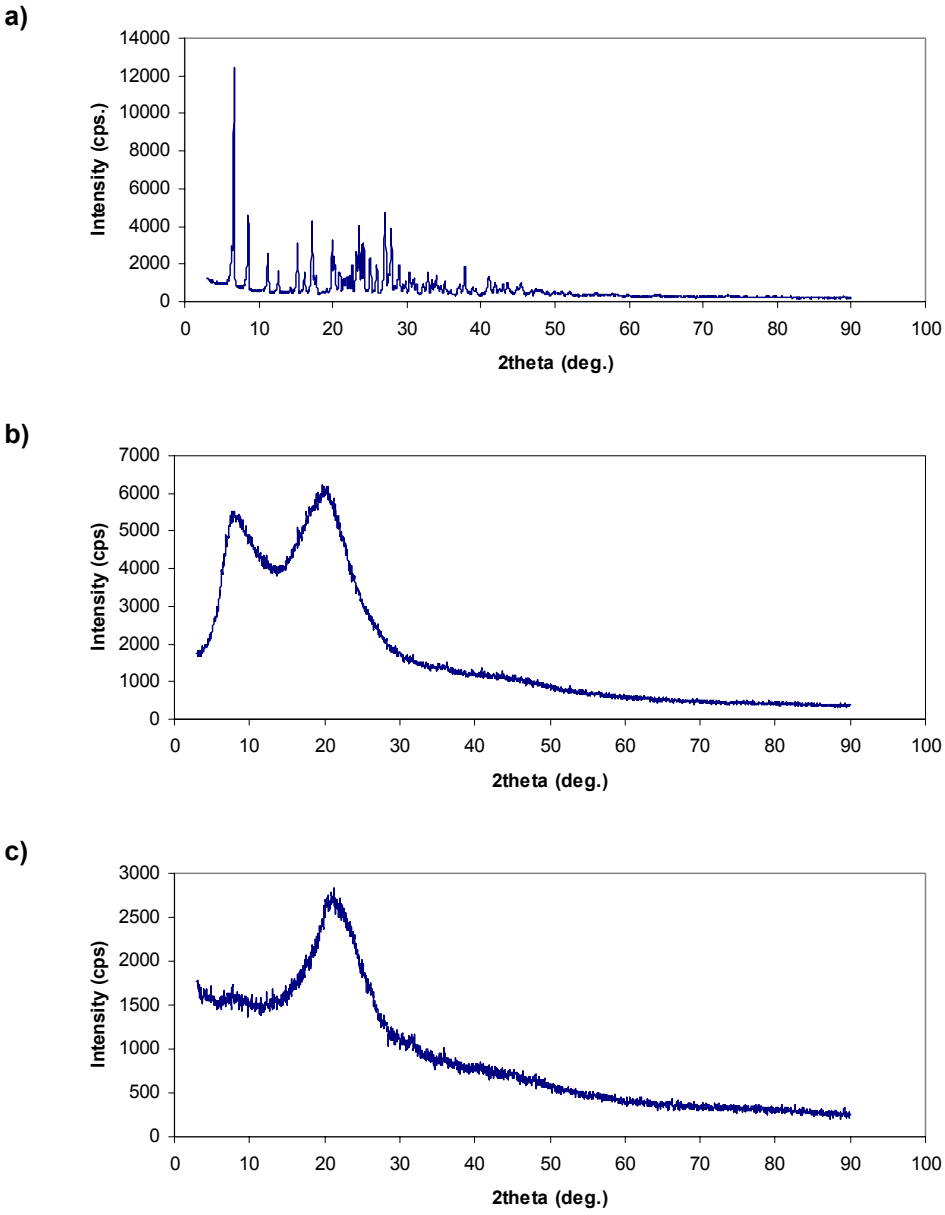
Drug:Polymer ratio	Theoretical	Actual	Encapsulation efficiency ε (100)
1:1	39.41	36.82±2.51	93.42±6.37
1:2	24.55	19.09±0.53	77.76±2.17
1:4	13.99	10.77±0.40	76.98±2.86

Values are mean ± S.E. (n = 3).

Higher encapsulation efficiency values were obtained for the microparticles composed of drug:polymer ratio of 1:1. When the diclofenac sodium load of the microparticles was decreased from 39.41% to 13.99%, the encapsulation efficiency dropped from ~94% to ~77% [18-19].

3.2.4. X-Ray analysis

It can be observed that the X-ray diffraction patterns of diclofenac sodium were showed sharp peaks due to crystalline nature of the drug. However, these drug peaks were disappeared in the X-ray diffraction patterns of diclofenac sodium loaded ethylcellulose microparticles and the textile impregnated with microparticles (Figure 7). It was thought that the diclofenac sodium showed its specific crystal peaks when existed in a crystalline form but after drug entrapped into the microparticles, the drug can be existed as a molecular dispersion in the microparticles.



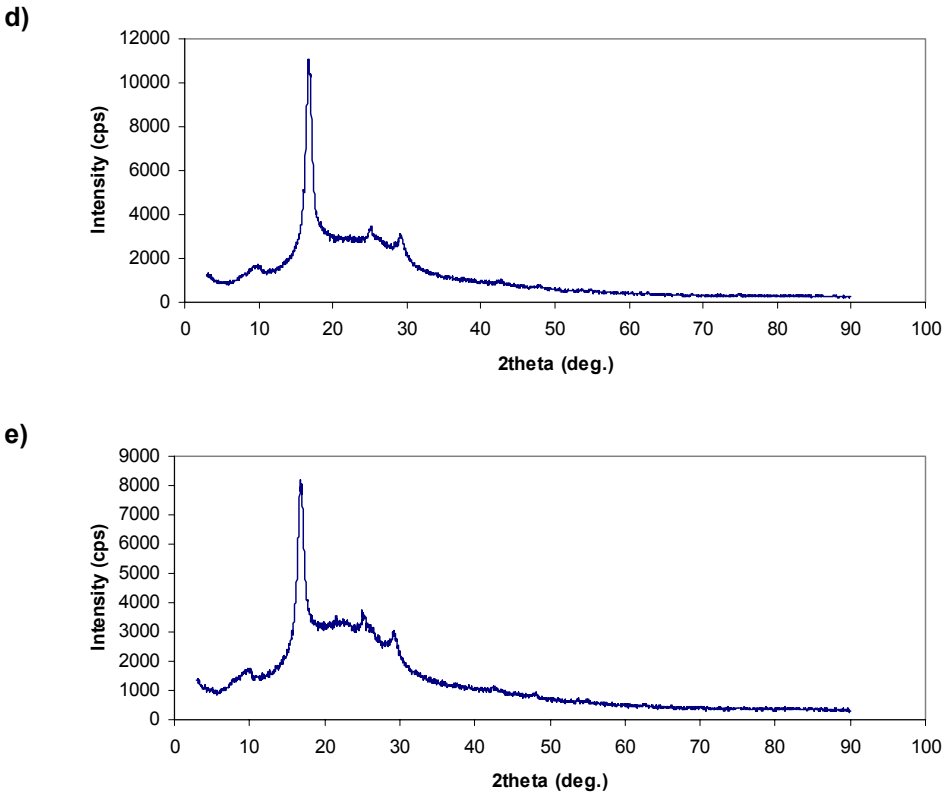


Figure 7. X-ray diffraction patterns of diclofenac sodium (a), ethylcellulose (b), microparticles composed of drug:polymer ratio of 1:1 (c), textile fabric without microparticles (d) and textile fabric impregnated with microparticles composed of drug:polymer ratio of 1:1 (e).

3.3. Scanning Electron Microscopy of textile impregnated with microparticles

Textile substrates have been analyzed by SEM after being impregnated with microparticle dispersions. SEM photomicrographs confirmed that the adhesion between textile fiber and microparticles was effective, as can be observed in Figure 8.

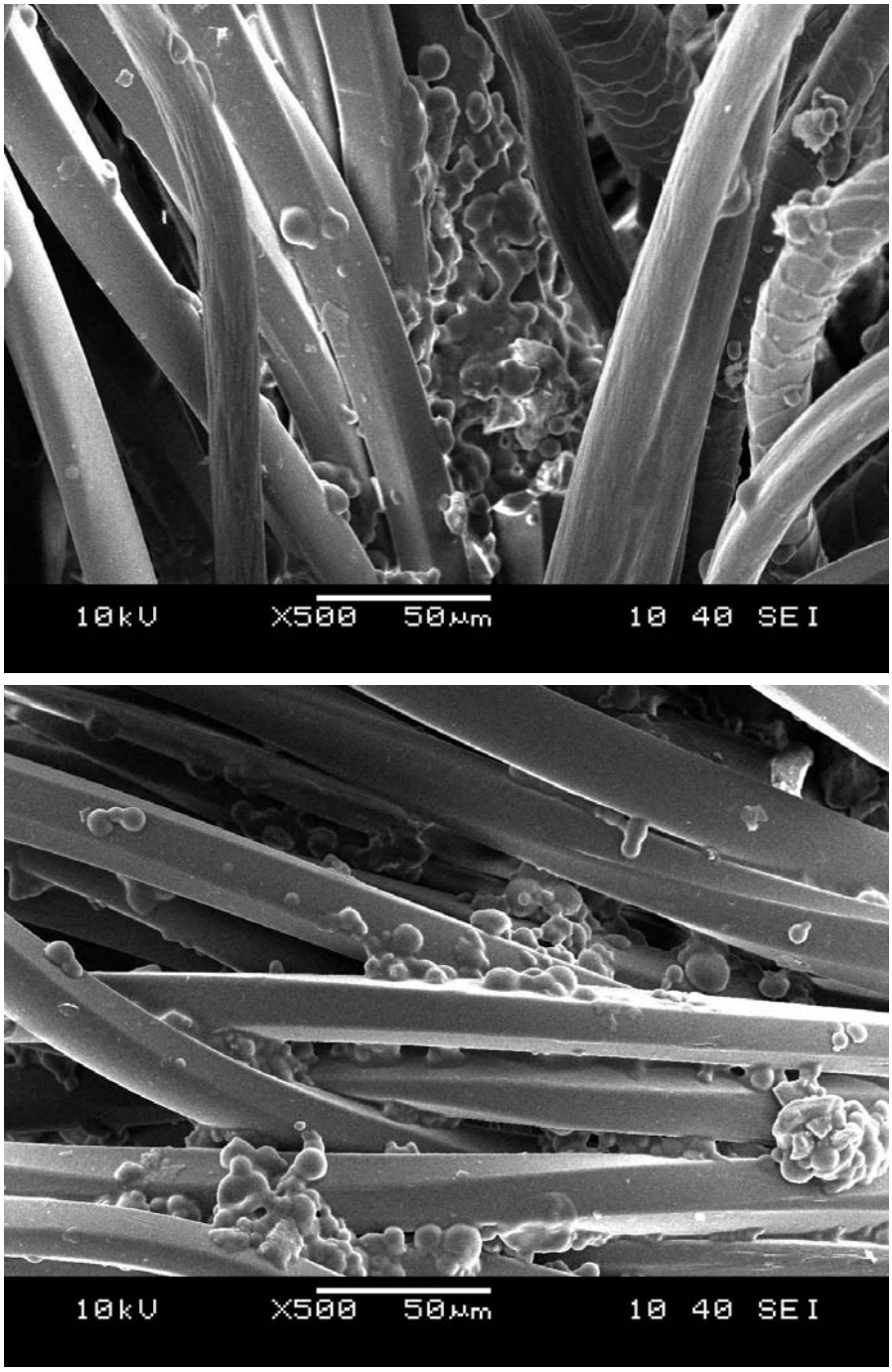
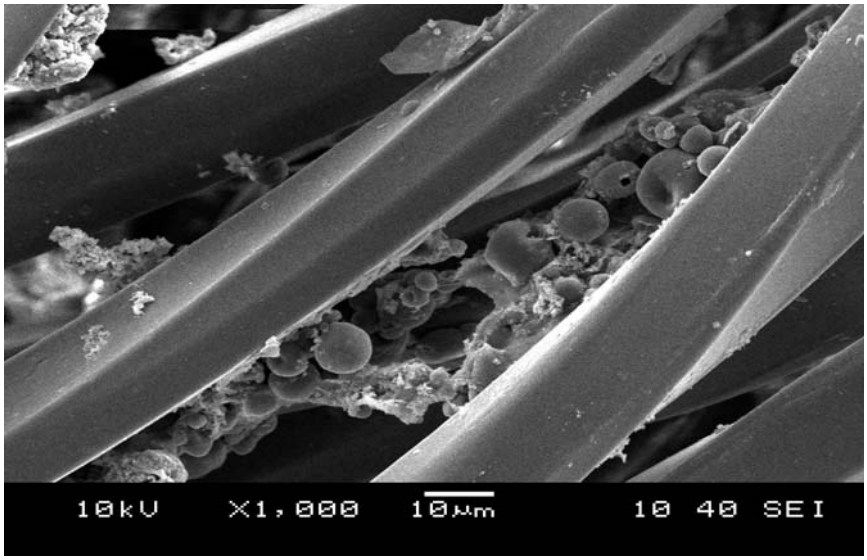


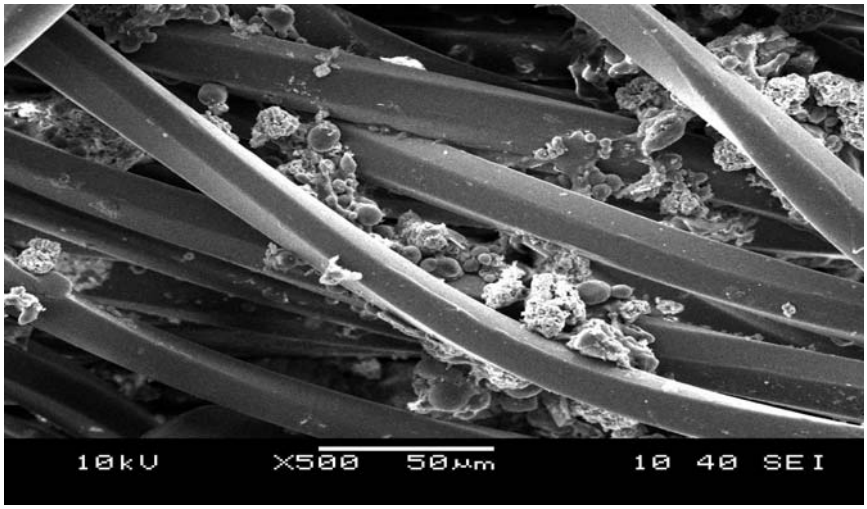
Figure 8. SEM photomicrographs of textile impregnated with microparticles.

3.4. Laundering test

SEM photomicrographs of textile containing microparticles that were washed 10 and 20 times are shown in Figure 9a and 9b, respectively. It can be observed that microparticles remained on textiles after the application of washing cycles. Even after 20 washing cycles some microparticles still remained on the fabric. The results showed that the microparticles were not adsorbed on the surface of textile, but absorbed by textile material in the presence of the binder and formed bonds between microparticles and fibers were durable against 20 launderings. These results are very important in the drug delivery system.

a)





b)

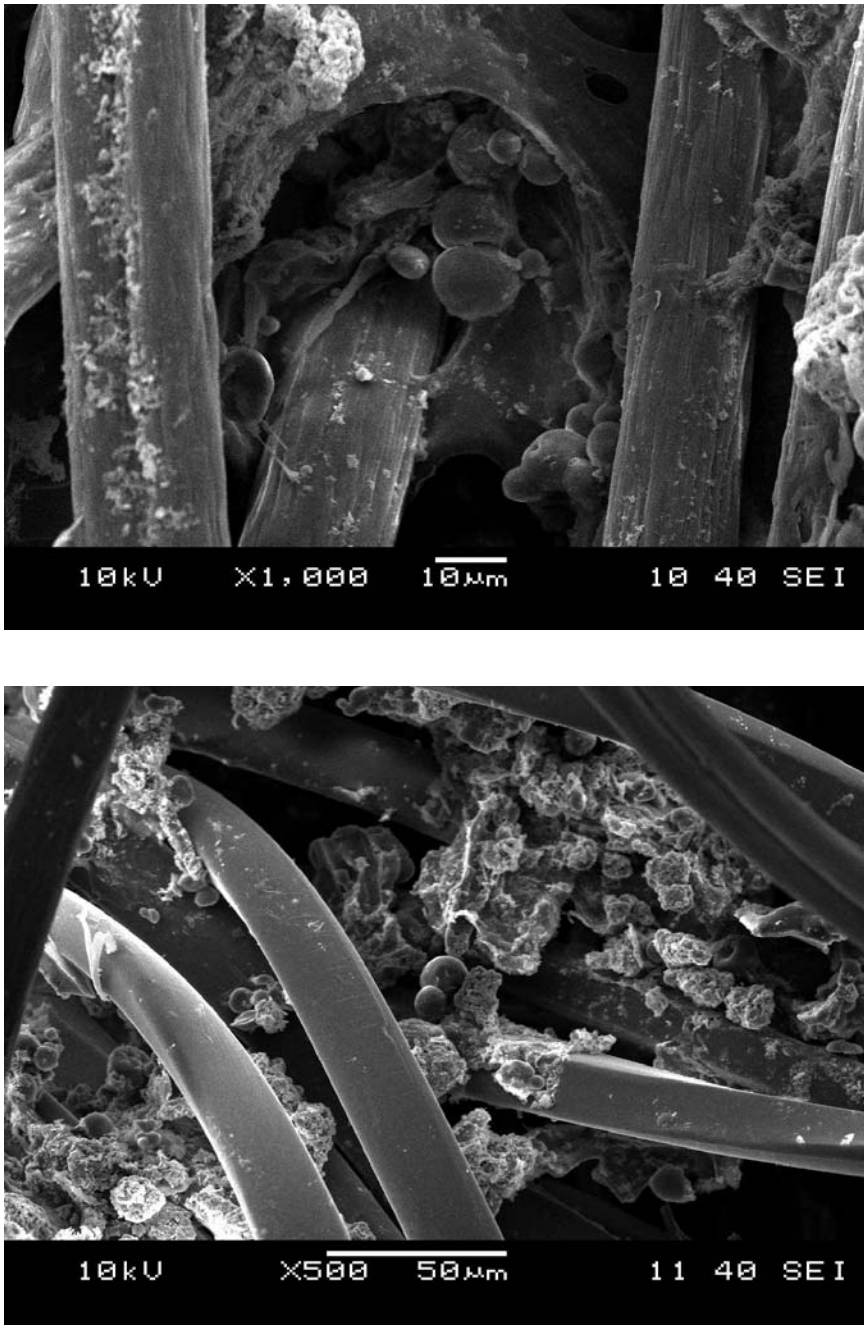


Figure 9. SEM photomicrographs of textile impregnated with microparticles washed a) 10 cycles b) 20 cycles of Standard ISO 105 C06

3.5. Drug release studies

3.5.1. Determination of diclofenac sodium in the textile impregnated with microparticles

As a result of the quantification studies on the samples taken from different points of the fabric, content uniformity was observed.

3.5.2. In-vitro drug release

The in-vitro release of textile impregnated with microparticles with different drug:polymer ratios in pH 7.4 buffer solutions at 37°C are presented in Figure 10. It can be seen that at the beginning of the drug release study for all formulations larger amount of diclofenac sodium was freed from the surface of the textile (about 60-90%). t_{50} values of formulations were calculated 0.358 h, 0.724 h and 1,952 h for 1:1, 1:2 and 1:4, respectively. This fast release may be attributed to the small size of the microparticles

(6.942-7.343 μm) and the vast surface area. Therefore, fast dissolution of the encapsulated drug could take place immediately when the drug particle was exposed to the aqueous environment. A burst effect was exhibited in all drug release profiles at the first hour. Since diclofenac sodium is soluble in pH 7.4 buffer solution, the burst effect is probably caused by the fast dissolution of the drugs located on the surface of the microparticles. The dissolution of the surface drug will result in channels, allowing the aqueous medium to penetrate into the matrix, leading to drug dissolution and subsequent drug release via the medium-filled channels.
After 1 hour, there was a steady release of drug into the release medium for all formulations. When we compare the formulations with each other, drug release ratio was higher in 1:1 according to 1:2 and 1:4 in the first three hours ($p<0.001$ for each point). Drug release was completed in the third hour in the formulation 1:1, was completed in the fifth hour in the formulation 1:2. Completion of the drug release in the formulation 1:4 was longer than eight hours. In the formulation 1:2 drug release were higher than formulation 1:4 in the fourth and fifth hours ($p<0.001$ and $p<0.0001$, respectively) (Table 4). As a result, it can be implied that the increase of drug loading caused a more rapid drug release.

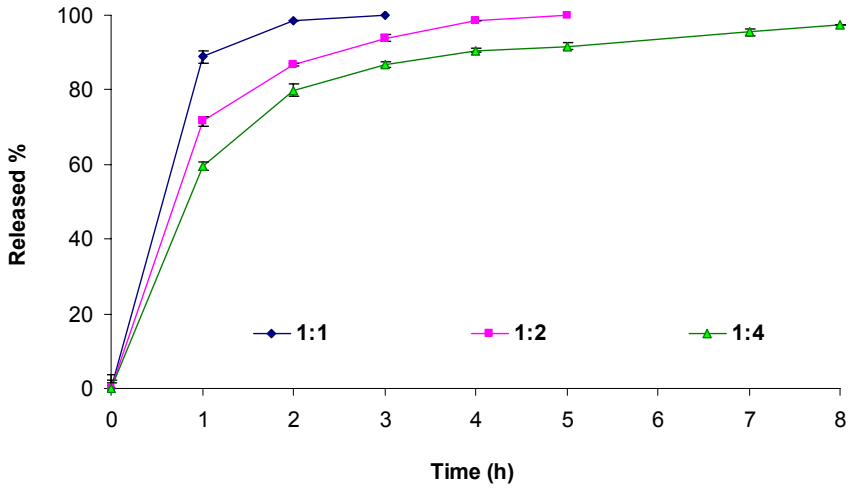


Figure 10. In-vitro diclofenac sodium release profiles of textiles impregnated with microparticles.

Table 4. Statistical analysis of release studies

	Formulations			
Time (h)	1:1	1:2	1:4	p
1	88.8±1.8***###	71.5±1.1†††	59.5±0.8	<0.0001
2	98.4±0.8***###	86.7±0.7†††	79.9±0.6	<0.0001
3	100.0±0.0***###	93.9±0.1†††	86.9±0.9	<0.0001
4		98.5±0.4†††	90.5±0.4	<0.001
5		100.0±0.0††††	91.6±0.3	<0.0001
6			93.6±0.7	
7			95.4±0.8	
8			97.5±0.8	

*** p<0.001 (1:1 vs 1:2), ###p<0.001 (1:1 vs 1:4), †††p<0.001 (1:2 vs 1:4), †††† p<0.0001 (1:2 vs 1:4)

CONCLUSIONS

In this study, diclofenac sodium microparticles were successfully prepared using a spray drying method that included aqueous dispersion of ethyl cellulose. Morphology, size, and *in vitro* release behaviour of microparticles from textiles were assessed. The effect of polymer:drug ratio used in the preparation of the microparticles and factors like determination of drug content, drug loading capacity

and encapsulation efficiency was evaluated. Diclofenac sodium microparticles were seen to be spherical and smooth in structure with a mean diameter in the range of 6.942 and 7.343 μm. Laundering test showed that microparticles remain on fabric after the application of washing 10 and 20 cycles. As a result of release studies, at 1 hour there was a rapid release profile has been seen for all formulations. After this point steady release profile of drug was obtained up to 8 hours. Statistically release profiles of formulations were significantly different at each time point ($p<0.001$) according to the one-way ANOVA analysis and student t-test.
Finally, we have produced diclofenac sodium microparticles and applied them to the orthopedic support materials successfully. Our future project is to obtain prolonged drug release from orthopedic support material containing microparticles and studies for this purpose are going on.

ACKNOWLEDGEMENTS

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ACTIVE T-SHIRT

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ABSTRACT

Functional products combining textile, electronics and the software have attracted great attention in recent years. The integration of the electrical and electronic devices on the garment surface using conductive threads is a challenging issue considering conductiveness, long durability, washability and manufacturing process.

The aim of this study is to realize an electronic circuit design on the fabric surfaces to form a fully-integrated functional active t-shirt structure. As an application, a group of light emitting diode (LED) lights controlled by a light sensor, accelerometer and related electronic control circuits were placed on a fabric construction. The brightness of LED lights is controlled by using a light sensor depending on the perceived ambient light intensity. LED lighting patterns are controlled by means of an accelerometer which senses the physical activities of the wearer, such as walking, running, and standing.

In this study, new construction methods have been successfully implemented and the active t-shirt has been realized with its related hardware and software.

Key Words: e-textile, conductive threads, accelerometer, light intensity, LEDs.

1. INTRODUCTION

Multi-disciplinary studies which integrate various physical and technological properties on a single product are getting more common and their success will increase within the coming years by the help of advanced technological developments. The products with multi-functional structures have been developed rapidly and lots of materials and systems with different functions have been produced [1,2]. Active textile products give some technological advances to the wearer thanks to the embedded electronic circuits which evaluates sensory informations [3,4].

Here, two types of technology are available. The first one is mounting electronic devices such as conducting wires, ICs, LEDs and batteries into garments. The second one is the creation of wires or electronic functions such as diodes, transistors, and LEDs on the textile fibers. The most common preferred approach is the first category because of its technical simplicity and applicability.

Construction of the electronic circuits on a cloth surface is possible using conductive threads [5,6]. Conductive threads can carry electric current as power and electronic signals between the electronic circuits. The idea is very similar to printed circuit boards (PCB) on the electrical and electronic devices except using copper layer based conductive pathways. Making those PCBs are very easy, cost effective and also highly reliable. Small PCBs for electronic circuits and sensors can be used in e-textile applications. However it is not an overall solution for the textile projects because of their non-flexible structure [7,8,9].

2. IMPLEMENTING THE ACTIVE T-SHIRT

2.1. The conductive threads

Three parameters are important for the conductive threads: electrical resistance, fray resistance and elasticity. The conductive thread has an electrical resistance proportional to its length, resistivity of the material and inversely proportional to its cross-sectional area. In this study, the selected thread is continous stainless steel filament yarn and its characteristics are given below [10].

Table 1. Characteristics of stainless steel yarn [10].

Standardtypes Type	Tex (g/1000m)	Av. Breaking load (N)	Elongation %	Average Linear resistivity (Ω/m)	Variation Linear resistivity %
VN 12/2x275/175S/316 L/HT	500	67	1	14	±7

Fray resistance is important and it is related to the durability of the product and also must be high enough to avoid short circuits between adjacent thread lines. If elasticity is low, the thread can easily be broken and possibly open circuits may occur.

Another problem is the thickness of the thread. Thickness is directly related to the electrical resistance value. The more thick threads have lower resistance values which is very important for higher conductiveness to deliver battery power at exact voltage and the electrical signals without weakened. On the other hand, they are not easily sewed on the garment surface and also tend to fray easily. In our study, instead of sewing the conductive threads into the garment, we preferred attaching them to the interior surface of the cloth using interlinings. Interlinings cover and fix the conductive threads, also supports sufficient isolation between them. If more insulation required, another layer of interlining can be used, or initially they can be painted with insulating fabric paint before covering the threads.

Voltage drop due to the thread resistance must be eliminated by choosing the most possible shortest pathways. Especially the power supply must be close to the microcontroller board to avoid the voltage drop at the conductive threads. For example, the voltage drop for a microcontroller with 100mA current draw from a 5V power supply located at 50cm distance is about 1.4 V with a 14 ohm/m conductor thread resistance value. This means the microcontroller gets only 3.6 volts from the 5V power supply. This is a very critical case since the microcontroller cannot run safely under 3 volts. This problem can be overcome by either shortening the distance between the electronic components or using twisted threads with lower resistance values.

The contact between the conductive threads and electronic circuit pads must be properly provided. In this study, the hot silicone gluing technique was used. The heavy parts, especially the microcontroller can also be fixed with a glue or interlinings.The most heavy part, the polymer lithium ion battery was inserted to a pocket located at the upper left arm area.

2.2. The clothing design

The first design idea is shown in Figure 1.

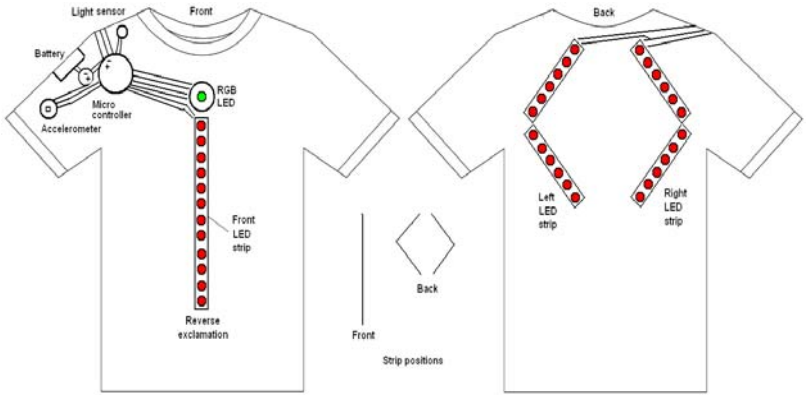

Figure 1. The first design idea.

The first stage of the study is to develop the electronic control unit with sensors and LED interfaces. In this stage, LED driving software was realized to obtain basic light effects. In the second stage, all electronic components were placed into the garment construction. The connections between

components were provided by textile based conductive threads. In the third stage, the tests of the active t-shirt integrated with electronics hardware and software was performed.

The main aim for using light sensors is to determine the light intensity and to optimize the illumination amount of LEDs. As it is known, the lights with low intensity can be visible in dark environment. In contrast to this, it's necessary to use the intense lights in bright fields. In this way, the energy requirements, or in other words, battery savings can be provided. The accelerometers are used to measure the acceleration. Single- and multi-axis models are available to detect magnitude and direction of the acceleration as a vector quantity, and can be used to sense orientation, vibration etc.

The LEDs are placed in the fabric construction into a band form. Textile based conductive materials will be used for transferring the current for activating the LED lights. On the other hand, the functional requirements should be considered. In this study new generation batteries such as Lithium Ion and Polymer Lithium Ion were examined for power supply selection.

2.3 Electronic Circuit Design

The electronic hardware of the active t-shirt consists of Lilypad modules [7] and the LED strips mounted on a flat flexible printed board material. The most important component of the system is ATMEL AVR ATmega328V microcontroller. It has 10 bit analog to digital converter (ADC) for six analog inputs, 12 digital outputs, a serial port, two 8 bit and one 16 bit timers, six pulse width modulation (PWM) modules for digital to analog conversions (DAC). The microcontroller unit has wide operating voltage from 2.7 V to 5.5 V. For this application 5 V is choosen as a main supply voltage to provide sufficient LED brightness.

Battery power regulator regulates the voltage from the polymer lithium ion battery to 5V. The polymer lithium ion batteries are powerful and lightweight batteries. Two sensors are present in this study. The first one is the light sensor to analyze the light intensity level of the environment. The second one is the three axes accelerometer to analyze the body movements. A vibration module and a buzzer module were used as warning devices to the wearer. Three colors LED module has capable to show different colors for different situations. Sewing the entire electronic units through the pad holes is very easy due to the Lilypad circular structures. The LED strips were inserted into sewed transparent fabric bands.

Electronic hardware has three data transferring options between the active t-shirt and the computers or personal digital assistants (PDA). All options use the same serial port on the microcontroller unit to transfer sensory data The first option uses serial to universal serial bus (USB) conversion module with an USB cable. The second connection option is the wireless data transfer with available add-on Bluetooth module. The third one is an SD card data storage module to save data to be analyzed offline on computers.

3. Software

3.1 Microcontroller Software

Basically the microcontroller C software code checks the sensors in every 20 msec and defines the condition flags comparing the sensory data with user defined set points. If computer connection or SD card write operation permitted the calculated data updated at every 20 msec sensor scan periods. This scan period can be adjusted to define the sensor data sampling frequency. Then, the defined flag conditions activate or deactivate the LEDs. For power saving and increasing the visibility the LEDs are blinked at every LED scan periods. Here this period is defined as 100msec.This infinite loops continues till either the user toggles the button on the upper middle button on the front t-shirt side or power switch turned off. The whole software flowchart is given in Figure 2.

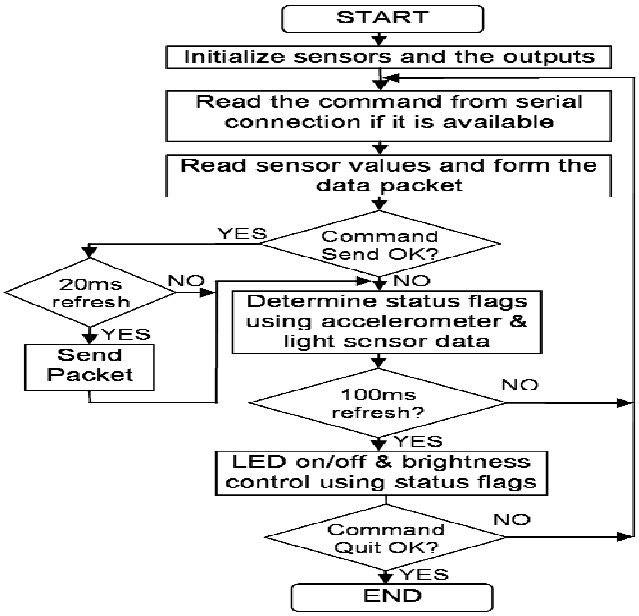

Figure 2. The microcontroller software general flow chart.

3.2 Analysis Software on MATLAB

This software is to analyze the sensory data from the active t-shirt to modify the t-shirt software in a proper way.

4. RESULTS

In this study, an active t-shirt concept has been perfomed by combining textile and electronics. Various measurements, tests and analysis have been performed for the purpose of working on a textile-based structure. Following components have been mounted on the fabric surface;

- Microprocessor,
- Power module,
- Vibration module,
- Light sensor,
- Speaker,
- Acellerometer,
- 3-color LED,
- LED lights in strip form,
- On/off switch were placed on the t-shirt.

- All modules are connected by using electrically conductive stainless steel yarn. On the fabric surface, the conductive threads were covered and fixed by interlinings to ensure the insulation. This method is entirely different to the other insulation processes such as sewing, embroidery, 3D fabric paints etc. The advantages of using interlinings are their technical simplicity, rapid applicability and their cost. The front and back view of the t-shirt are seen on Figure 3.

Figure 3. The active t-shirt

- Stainless steel yarns with electrically conductive characteristics have been applied to the electronic circuit.
- There are two types of LED light on the garment. 3-Color LED light was placed on the front side of the t-shirt.
- Instead of using single LEDs which were connected by conductive threads, group of LEDs are on a flexible strip mounted both on front and back side of the prototype t-shirt.
- The light intensity of the environment is a key factor for LED lights. The light sensor, mounted on the shoulder area, optimizes the illumination amount of LEDs.
- All LED lights on the front and back side of the garment are activated by the wearer's rate of movements which is perceived by the accelerometer.
- Various measurements and tests have been realized and the results show that polymer lithium ion batteries are convenient selection in terms of their light weight and high power capacity.
- Because of the light weight of the electronic component and conductive threads, there is no significant weight increase for the t-shirt after the implementation process.
- The electronic circuit placement with thread contacts on the outer t-shirt surface is shown in Figure 4. The inner surface of the electronic circuitis shown in Figure 5.

Figure 4. Modules on active t-shirt

Figure 5. Conductive threads and connections in the inner side of the prototype

- Three accelerometer channels and the light sensor data graphics is shown in Figure 6. The x axes of the accelerometer shows the arm movements from standing to the running action. As seen from Figure 6, the wearer has different actions in different time intervals. The person is in the standstill state until 4 seconds, walking slowly between 4 and 6 seconds, quickly walking from 6 to 13 seconds, and running after 13 seconds. The light intensity information obtained from the light sensor is very oscillatory becaue of the fluorescent lighting. The lamps were turned of at about 10 seconds. The measurements have shown that for daylight the measured light intensity is very stable.

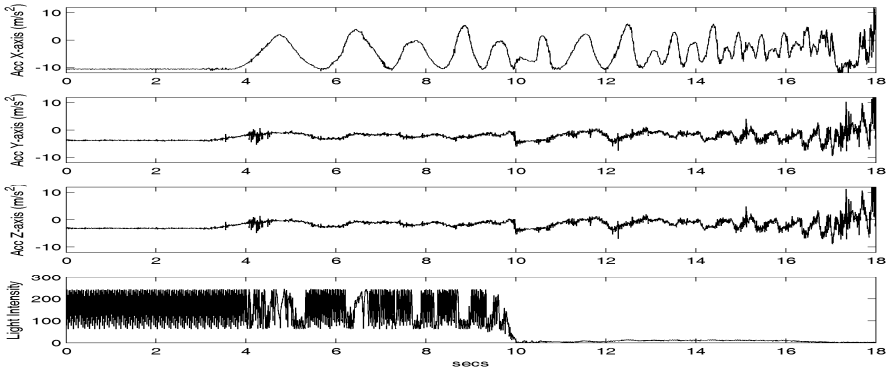

Figure 6. The sensory data from active t-shirt microcontroller.

As seen from Figure 6, the recorded data especially the light intensity has some fluctuations. For reliable decision on sensor data, these undesirable fluctuations must be removed by some signal processing algorithms. Figure 7 shows running average algorithm results using 200 msec windows. This algorithm or other filtering algorithms can also be implemented easily with the available microcontroller.

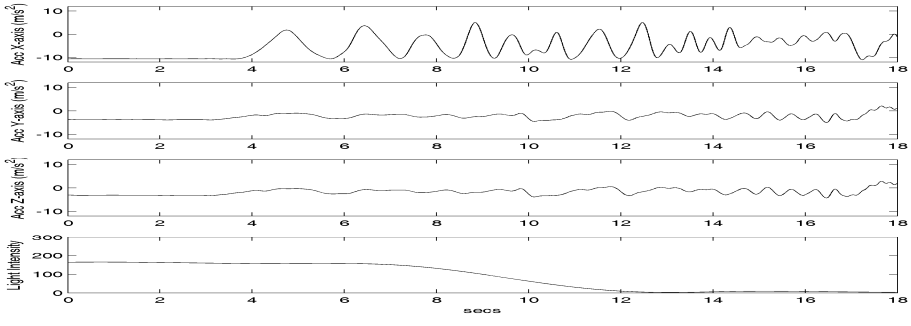

Figure 7. Filtered sensory data using running average method

5. CONCLUSIONS

The obtained results have shown that various electronic sensors, which are available in the market, can be installed on garment to sense various signals such as body temperature, heart rate, CO_2 value of the surrounding environment, motion and the light.

In this study, the realised circuit design to the active t-shirt will certainly enhance the visibility and appearance features of the product and the wearer as well. Therefore, the system can be preferably used by the security staff or the people who needs such requirements.

The active t-shirt prototype consists of 9 different electronic modules that mentioned above. In future studies, the desired functions for the prototypes can be supplied by using only necessary modules, so that, the final product can be formed much more easily and effectively.

The connections and lines between the electronic components and the locations and mounting procedures of the modules can be improved in future works.

Various signals can be obtained from the installed sensors in respect to body movements. With related sgnal analysis techniques, these signals can be converted into functional results.

Being a casual garment, design studies have a critical role in developing such a prototype. Improvements can be resulted in a fully-integrated garment in terms of weight and volume i.e.

Data collection softwares on PC can be converted to mobile equipments such as PDA or cell phone. So that data logging and analyzing can be performed wirelessly with Bluetooth add-on module without need any PC.

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AL_2O_3 NANOCOMPOSITE FILM DEPOSITION ON COTTON FABRICS BY LAYER-BY-LAYER DEPOSITION METHOD

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ABSTRACT

Al_2O_3 nanoparticles were used for fabrication of multilayer nanocomposite film deposition on cationic cotton fabrics by layer-by-layer (LbL) deposition method to improve the mechanical and flame retardancy properties of cotton fabrics. Cotton fabrics surface modified with a chemical reaction for impart cationic charge that's named as cationization. After cationization process Al_2O_3 nanoparticles deposited on the cotton fabric surface and 10 and 16 multilayer nanocomposite film generated on the fibre surfaces. Attenuated Total Reflectance Fourier Transform Infrared Spectroscopy (FTIR-ATR), X-ray Photoelectron Spectroscopy (XPS) and Scanning Electron Microscopy (SEM) were used to verify the presence of deposited nanolayers. Aluminum amount determined as % 13,9 and % 17,6 for 10 and 16 multilayer Al_2O_3 nanoparticle film supported cationized cotton fabrics, respectively. Cotton fabrics properties (air permeability, whiteness value, tensile strength) and Limited Oxygen Index (LOI) properties analyzed before and after the treatment with Al_2O_3 nanoparticles by layer-by-layer deposition method. LOI value of untreated fabric determined as % 18,17, after LbL deposition % 21,03 and % 22,05 LOI values obtained for 10 and 16 multilayer Al_2O_3 nanoparticle film supported cationized cotton fabrics, respectively. The durability of the self-assembled multilayer films on the cotton fabrics functional properties analyzed after 10 and 20 washing cycles at 40 °C for 30 min. It is proved that with LbL process the flame retardancy of cotton fabrics can be further improved by introduction of Al_2O_3 nanoparticle additive.

Key Words : layer-by-layer self assembly, aluminum oxide nanoparticle, nanocomposite

1. INTRODUCTION

Polymer-based multilayer films created by layer-by-layer (LbL) deposition are currently used to modify the surface properties of materials used in various fields of science. The sequential adsorption of oppositely charged colloids was reported in a seminar paper in 1966 by R. Iler. Starting in early 1990s, Decher's group rediscovered Layer-by-Layer (LbL) processing to fabricate multilayer thin films from oppositely charged polyelectrolytes [1]. Mostly types of charged molecules, nanoparticles, dyes, proteins and other supramolecular species seemed to be suitable for deposition by the LbL method, but generally polyelectrolytes have been employed [2-13]. The LbL process is based on the alternating adsorption of charged cationic and anionic species.

Multilayers containing nanoparticle have been studied extensively for their potential use in various fields of science (Anti-static coating for plastics, sensors, light emitting diode, fuel cells, polymer capsules etc.). Hyde *et al* [12] examined the possibility of creating polyelectrolyte thin film coatings on

textile materials by using The LbL deposition process. Ding *et al* [13] fabricated self-assembled LBL ultrathin hybrid TiO_2/PAA film coated CA nanofibrous mats by a combination of electrospinning and electrostatic LbL self assembly techniques. Jantas and Polowinski [14] obtained very thin polyelectrolyte nanolayers on PET fabric to change its properties connected with the fibre surface. Dubas et al [15] have demonstrated and characterized the possible deposition of polyelectrolyte multilayers thin films assembled from cationic poly(diallyldimethylammonium chloride) and Scarlet dye onto nylon fibers. Dubas et al [16] used LbL process for coating silk fibers with polyelectrolyte multilayer thin films to improve their color fastness to washing. Polowinski [17] obtained polymeric complex layers onto polypropylene and polyester nonwoven fabrics via the layer by layer method. Chunder *et al* [18] fabricated ultrathin fibers comprising poly(acrylic acid) and poly(allylamine hydrochloride) by using the electrospinning technique with LbL process. Dubas et al [19] have demonstrated coating of silk or nylon fibers with silver nanoparticles for antimicrobial property by following the layer-by- layer method. According to literature, nanoparticle multilayers can be formed on textile fiber surfaces with the use of LbL process.

Our research group had been investigated the possibility of nanoparticle film deposition on cotton fabrics with LbL deposition in previous studies. We showed that LbL process could be used to obtain functional textiles with antimicrobial and UV-protective properties by using TiO_2 and ZnO nanoparticles [20-22].

The application of Al_2O_3 nanoparticles to textile and various (cable, wires etc.) materials has been the object of only a few studies aimed at producing functional properties with different performances such as antibacterial, flame retardant, thermal conductivity and higher tensile strength properties [23-26].

In this work, we present the reformer strategy of electrostatic layer-by-layer deposition of Al_2O_3 nanoparticles to the previously charged cotton fibre. Cationic cotton was prepared by cationization process. Al_2O_3 nanoparticles were incorporated onto cotton surface and the new functionalized cotton fabric was analyzed in terms of UV protective, flame retardancy and tensile strength properties. Attenuated Total Reflectance Fourier Transform Infrared Spectroscopy (FTIR-ATR), Scanning Electron Microscopy and X-ray photoelectron spectroscopy (XPS) measurements were used to verify the presence of the deposited nanolayers. Air permeability and whiteness value analyses were performed to examine LbL process effect on the cotton textile fabric properties.

2. EXPERIMENTAL DETAILS

Aluminum oxide nanoparticles (particle size < 50 nm, specific surface area 40 m^2/g) were purchased from Aldrich and 0.1 wt % Al_2O_3 nanoparticle suspension was prepared at 40 Watt for 1 hour by Sonics Vibra-Cell Ultrasonic Homogenizer. The isoelectric point of Al_2O_3 nanoparticle was at pH 9.2 as seen in Figure 1[27]. The pH of nanoparticle suspensions was adjusted to 13.0 and 2.5 by using

NaOH and HCl. Mercerized and bleached cotton woven fabric was used as substrate for the LBL process.

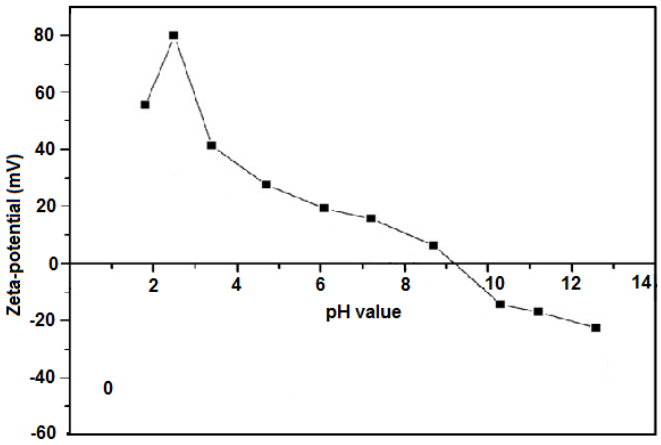


Figure 1. Al_2O_3 nanoparticles zeta potential graphic

Cationic cotton was prepared by using 2,3-epoxypropyltrimethylammonuium chloride (EP3MAC). EP3MAC was prepared in aqueous solution by reacting 3-chloro-2-hydroxy propyl trimethyl ammonium chloride (CHP3MAC) with NaOH [28]. EP3MAC reacts with the hydroxyl groups of cellulose creating cationic charges on the surface of the sample. CHP3MAC, 65 % and NaOH crystals were obtained from Aldrich. EP3MAC solution was pad applied to the cotton specimens at 100 % wet pick-up and fabric samples kept for 24 h at ambient conditions (20 ^{0}C and 65 % RH) in Ziploc bags.

For multilayer deposition process, polypropylene transport trays (20 cm x 30 cm) were used. In the deposition process, the pre-treated cotton fabrics were immersed into the following solutions alternately for 5 minute periods; (a) the anionic Al_2O_3 colloid solution, (b) the deionized water, (c) the cationic Al_2O_3 colloid solution, (d) the deionized water. This deposition cycle was repeated until 10 and 16 multilayer Al_2O_3 nanoparticle films were deposited on cotton fibers. Multilayer film coated cotton fabrics were dried at 60 °C and cured at 130 °C for 3 min.

Bruker IFS 66/S FTIR spectrometer was used to obtain the infrared spectra of surfaces using an ATR sampler. The spectra were taken over a wave number range of 4000–400 cm^{-1} with a resolution of 2 cm^{-1}. XPS measurements were conducted using a SPECS spectrometer with an Mg source and a spherical mirror analyzer working in spectrum mode. The chemical elements present on the samples were identified from survey spectra and high resolution scans were performed around peaks of interest. QUANTA 400F Field Emission high resolution scanning electron microscope (SEM) was used to examine the surfaces of woven cotton samples. The cotton fabric samples were coated with 10 nm Au/Pd prior to SEM observation.

LOI (Limited Oxygen Index) was measured for Al_2O_3 nanoparticle multilayer deposited cotton fabrics according to ASTM D 2863-77 by using the LOI instrument. For determining the durability of flame retardancy properties, cotton fabric samples were washed 10 and 20 times at 40 °C for 30 min. with

laboratory type washing machine Gyrowash. UV Penetration and Protection Measurement Systems, Camspec M350 UV/visible Spectrophotometer (SDL/ATLAS) was used to obtain Mean UPF, Mean UV-A and Mean UV-B values of the multilayered cotton fabrics. TexTest Instruments FX 3300 Air Permeability Tester III instrument was used to obtain the air permeability values of the untreated and Al_2O_3 nanoparticle deposited cotton fabrics at 100 Pa pressure according to EN ISO 9237 Standard. Minolta 3600d spectrophotometer was used to obtain the whiteness values of the untreated, cationized and Al_2O_3 nanoparticle deposited cotton fabrics as Stensby index with using D 65 light source to examine the LbL process effect on the yellowing properties of the fabrics. The mechanical tests were performed on a Lloyd LR5K Plus electronic tensile strength machine according to EN ISO 2062 Standard. The breaking strength and elongation of warp and weft yarns at fracture were tested in this work. Twenty samples were used for each test and the test results were evaluated with SPSS 16.0 statistical analysis program.

3. RESULTS AND DISCUSSION

X-ray photoelectron spectroscopy was used to examine the surfaces of the cationized and multilayer film deposited woven cotton samples. Figure 2 illustrates a survey spectrum of a cationized woven cotton fabric. As expected, distinctive peaks at 283.95 and 530.11 eV indicate the presence of carbon and oxygen, respectively. A trace amount of N (nitrogen), generated during the cationization process, was also detected at 399.6 eV. Nitrogen amount is determined as 0.8 % on the surface of the cationized sample.

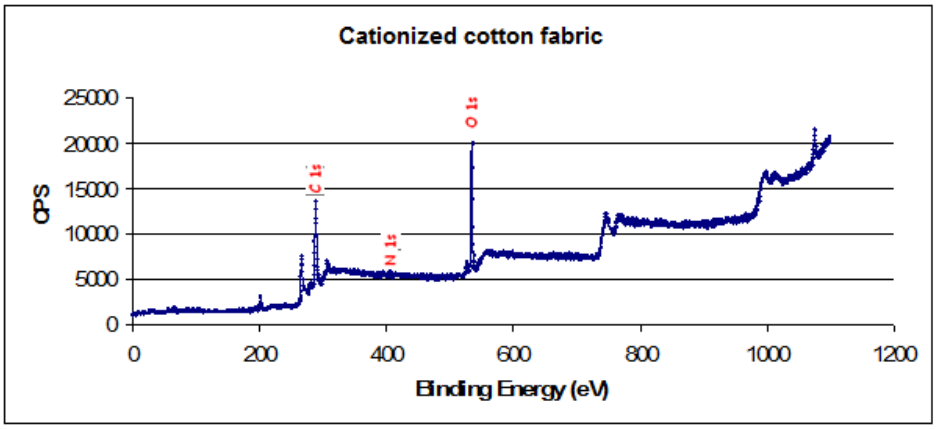


Figure 2. XPS spectra for cationically charged woven cotton fabric

Figure 3 shows a survey spectrum of 10 and 16 multilayer Al_2O_3 nanoparticle film supported cationized cotton fabric substrates. Distinctive peaks at 121.3, 283.95 and 530.11 eV indicate the presence of aluminum, carbon and oxygen, respectively. With LbL deposition process the Aluminum peak shows increase in intensity with increase in layer number. Aluminum amount is determined as 13.9 % for 10 multilayer Al_2O_3 nanoparticle film supported cationized cotton fabric and 17.6 % 16

multilayer Al_2O_3 nanoparticle film supported cationized cotton fabric on the surface of the cotton fabrics. O is mainly originated by the OH groups on the surface of the cotton fabric, with LbL deposition of Al_2O_3 nanoparticles the percentage of oxygen is expected to increase as the number of layers deposited increases.

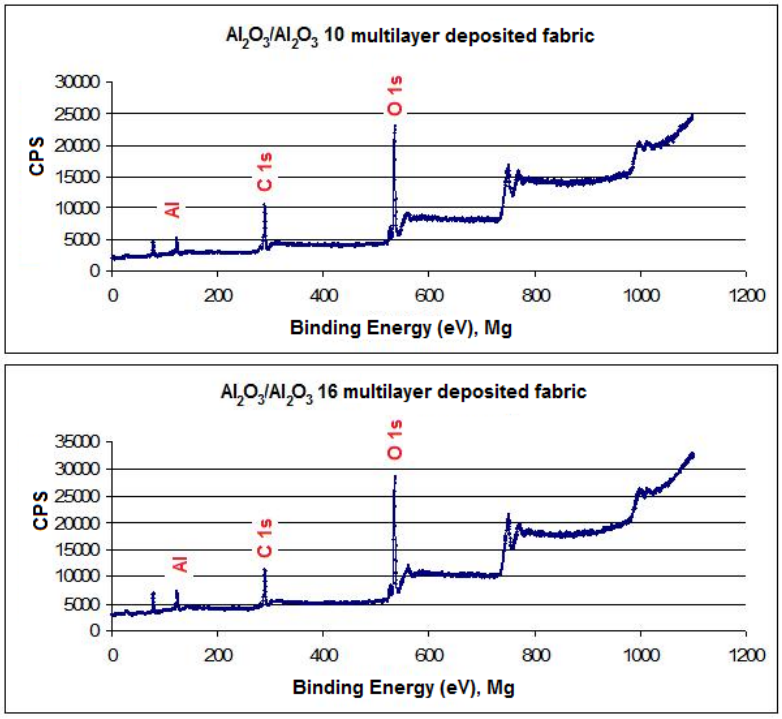
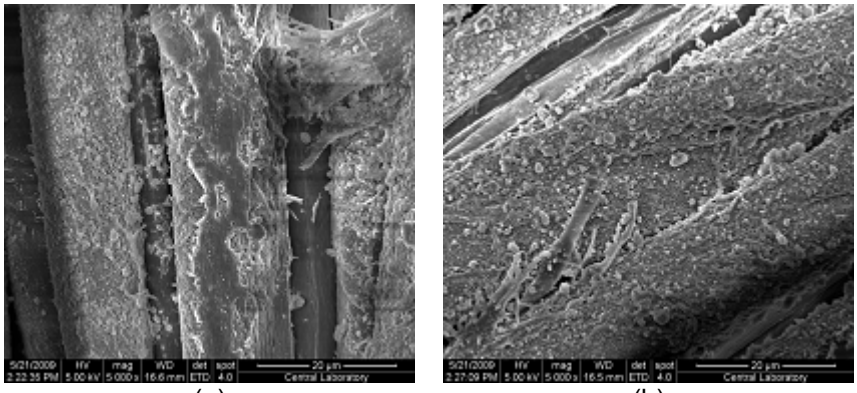


Figure 3. XPS spectra for cationically charged woven cotton fabrics supporting 10 and 16 self-assembled layers of Al_2O_3 nanoparticles

Scanning Electron Microscopy was used to verify the presence of the deposited nanolayers on cationized cotton fabrics. Figure 4 illustrates SEM images (5000 x magnification) of 10 and 16 multilayer Al_2O_3 nanoparticle film deposited cationized cotton fabrics. Especially for 16 multilayer film deposited cotton fabrics image, the surface of the cotton fibers appears to be covered by Al_2O_3 nanoparticles. With the increase in the number of layer, nanoparticle density is increases, too. The crystalline phase of Al_2O_3 remained unchanged in the resultant film coated cotton fibers and Al_2O_3 nanoparticle film deposited fibres showed rough surfaces with grains due to the deposition of aggregated Al_2O_3 particles.



(a) (b)

Figure 4. SEM images of cotton fabric deposited with 10 (a) and 16 (b) multilayer Al_2O_3 nanoparticles

The FTIR-KBr spectra of Al_2O_3 nanoparticles is shown in Figure 5. Al_2O_3 nanoparticles exhibited a strong Metal-Oxygen (M-O) adsorption band between 830-550 1/cm wavenumbers.

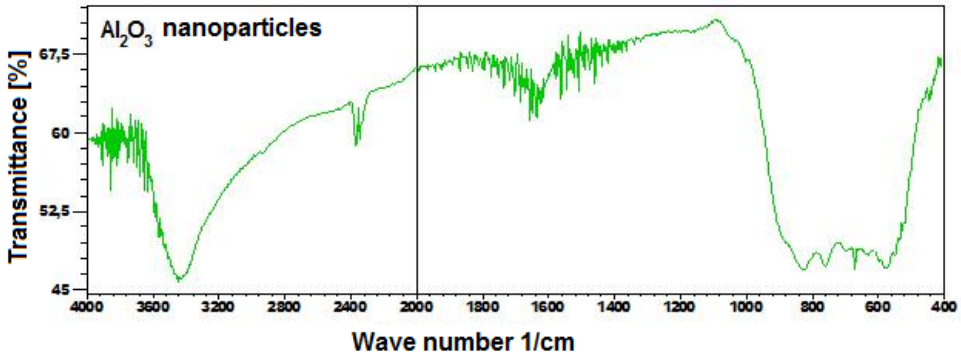


Figure 5. FTIR-KBr spectra of Al_2O_3 nanoparticles

The FTIR-ATR spectra of untreated, 10 layer and 16 layer Al_2O_3 nanoparticle deposited cotton fabrics are shown in Figure 6. The untreated cotton fabric exhibited a number of FTIR-ATR spectra absorption features. It can be seen that Al_2O_3 nanoparticle deposited cotton fabrics maintained the FTIR-ATR features of untreated cotton fabric. For all samples a broad band between 3100-3700 1/cm centered around 3360 1/cm illustrated characteristics of OH functional groups in cellulose. A strong adsorption band with a maximum at 1030 1/cm is a result of the overlapping bands attributed to functional groups of cellulose, namely the C-C, C-O and C-O-C stretching vibrations. With LbL deposition process this band shows increase in intensity as the number of layers deposited increases, suggests that the C-O groups were occupied with Al_2O_3 nanoparticles. A strong absorption peak around 600 1/cm on the 10 and 16 nano- Al_2O_3 multilayer deposited cotton fabrics FTIR-ATR spectra can be attributed to Al_2O_3 nanoparticle according to the FTIR-KBr spectra of Al_2O_3 nanoparticles which was shown in Figure 5. With LbL deposition process this band shows decrease in intensity as the number of layers deposited increases, suggests that the Al_2O_3 nanoparticles intensity level on the LbL deposited fabrics are increased.

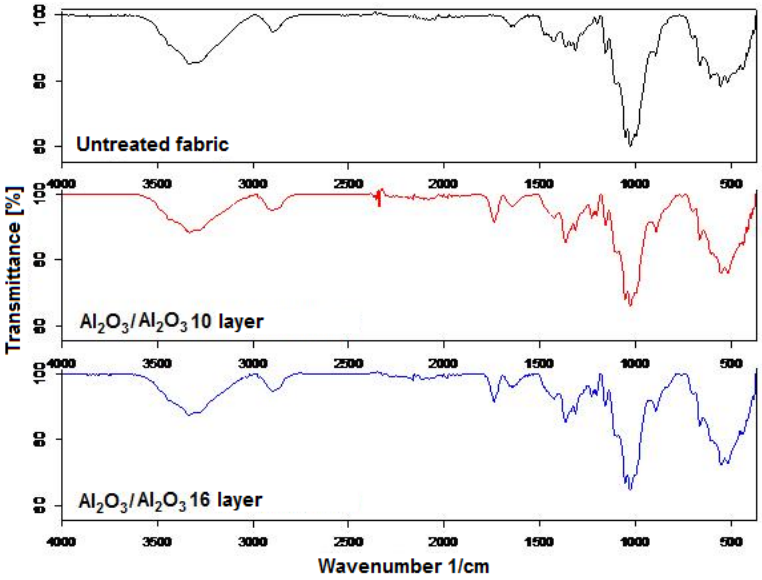


Figure 6. FTIR-ATR spectra for a untreated cotton woven fabric, cotton fabrics deposited with 10 and 16 multilayer Al_2O_3 nanoparticles

The presence of Al_2O_3 nanoparticles on the cotton fabric after LbL process is verified with SEM, FTIR-ATR and XPS analysis. Table 1 shows the Mean UV-A, Mean UV-B and Mean UPF values of Al_2O_3 nanoparticle deposited cotton fabrics which were obtained from UV-visible Spectroscopy. The values of percent blockings of UV-A (315 nm – 400 nm) and UV-B (280 nm – 315 nm) regions are 30.7 % and 22.3 % for the untreated fabric, 17.6 % and 8.2 % for 10 Al_2O_3 nanoparticle multilayer film deposited fabric and 16.9 % and 7.7 % for 16 Al_2O_3 nanoparticle multilayer film deposited fabrics. From this data, it can be seen that the Al_2O_3 nanoparticle multilayer film deposited cotton fabrics showed efficient blocking of UV radiation in both regions. It can be concluded that the presence of higher amount of Al_2O_3 nanoparticle has led to the higher absorption of UV rays in both regions as the deposited layer numbers are increased on fabrics.

Table 1. UV transmission of Al_2O_3 nanoparticle multilayer film deposited on fabrics and untreated fabric for different UV ranges

UV-Range	Untreated fabric	10 Al_2O_3 multilayered fabric	16 Al_2O_3 multilayered fabric
Mean UV-A	30.7	17.6	16.9
Mean UV-B	22.3	8.2	7.7
Mean UPF	4.16	10,4	11

Table 2 shows air permeability values and whiteness values according to Stensby index of untreated and multilayer film deposited fabrics. Air permeability tests showed that with the multilayer film deposition process, the air permeability values of the fabrics were decreased. These results verified the presence of the deposited layers on the cotton fiber. Whiteness value of the fabrics is decreased as the number of layers increases.

Table 2. Air permeability and Whiteness values of untreated cotton fabric, cotton fabrics deposited with 10 and 16 multilayer Al_2O_3 nanoparticle

	Air Permeability ($l/m^2/s$)	Whiteness Value (Stensby, D65)
Untreated Fabric	56.68	85.549
Al_2O_3 10 multilayer	39,55	75.276
Al_2O_3 16 multilayer	41,59	70.255

By considering the fabric tensile properties can be greatly affected by solution pH values changes during the LbL process alternate dipping procedures and Al_2O_3 nanoparticles natural properties, the twenty weft and warp yarns from the fabrics were selected for tensile test. Table 3 shows the tensile strength of the untreated, cationized and 10 and 16 Al_2O_3 nanoparticle multilayer deposited fabrics weft and warp yarns. The warp yarns tensile strengths increased statistically. With Al_2O_3 nanoparticles multilayer deposition, weft and warp yarns tensile strength values were increased. Al_2O_3 nanoparticles enhanced mechanical stability of the fabrics.

Table 3. Tensile strength of yarn from the untreated cotton fabric, cotton fabrics coated with 10 and 16 multilayer Al_2O_3 nanoparticle

Tensile Strength		**Mean**	**Standard Deviation**	**Sig.**
Weft Yarn	Untreated Fabric	0,783	0,098	0,21
	Cationized Fabric	0,777	0,086	
	Al_2O_3 10 multilayer	0,789	0,087	
	Al_2O_3 16 multilayer	0,857	0,091	
Warp Yarn	Untreated Fabric	0,817	0,088	0,01*
	Cationized Fabric	0,829	0,090	
	Al_2O_3 10multi layer	0,819	0,063	
	Al_2O_3 16 multilayer	0,906	0,056	

* Mean values are statistically significantly different at sig. < 0.05 in the tensile strength between the control and treated yarns.

LOI is a measure of the minimum oxygen concentration of an O_2/N_2 mixture required to support complete combustion of a vertically held fabric that burns downward from the top. The higher the LOI value, the more effective is the flame retardant treatment. LOI values of Al_2O_3 nanoparticle deposited cotton fabrics were analyzed after LbL process. Table 4 show LOI values of untreated, cationized, 10 and 16 Al_2O_3 nanoparticle deposited cotton fabrics. LOI values are classified as LOI<21, flammable; LOI=21, marginally stable; LOI:21-28, slow burning and LOI:28-100 self extinguishing. The results show that the LOI values of the Al_2O_3 nanoparticle deposited cotton fabrics are increased, thus an improved flame retardancy of the compositions. The values of 18.17, 18.17, 21.03 and 22.05 LOI are untreated, cationized, 10 and 16 Al_2O_3 nanoparticle multilayer deposited cotton fabrics, respectively. The data indicate that the combustibility of the cotton treated with flame retardant is reduced. With LbL process the flame retardancy of cotton fabrics can be further improved by increasing the amount of Al_2O_3 nanoparticle additive.

Table 4. LOI values of the untreated cotton fabric, cationized cotton fabric, cotton fabrics deposited with 10 and 16 multilayer Al_2O_3 nanoparticle films

Fabrics	Process	Oxygen value (%)	LOI value (%)
Untreated Fabric	-	18	18,17
Cationized Fabric	-	18	18,17
Al_2O_3 10 multilayer	Coating	21	21,03
	10 washing	20	20,01
	20 washing	19	19,20
Al_2O_3 16 multilayer	Coating	22	22,05
	10 washing	21	21,03
	20 washing	20	20,01

4. CONCLUSIONS

This work has investigated the surface modification of woven cotton fabrics by Al_2O_3 nanoparticles assembly. With pre-treatment of the cotton samples with 2,3-epoxypropyltrimethylammonium chloride, cationic charges were created on the fibre surfaces. By using LbL technique, 10 and 16 multilayer films of Al_2O_3 nanoparticles were deposited on the cotton fabrics and a new nanocomposite form obtained. The surface morphology of Al_2O_3 nanoparticle multilayer film deposited cotton fabrics were characterized by scanning electronic microscopy (SEM) and X-ray Photoelectron microscopy (XPS). The SEM and XPS observations revealed the formation of the Al_2O_3 nanoparticles on the fiber surface. The crystalline phase of Al_2O_3 nanoparticle was retained in the resultant nanocomposite multilayer film coated fibres. The nano-Al_2O_3 multilayer film deposition was also confirmed by Fourier transform infrared (FTIR-ATR). LbL deposition process with Al_2O_3 nanoparticles does not considerable effects on the air permeability and whiteness value properties of cotton fabrics. The fabrics deposited with the Al_2O_3 nanoparticles exhibit better UV-protection and significant flame retardancy properties, which could render them useful in applications such as multifunctional or technical textiles. The mechanical properties of the multilayer film deposited woven cotton fabrics were investigated using a tensile strength test and the results showed that the mechanical properties were improved after surface film deposition.

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AN INVESTIGATION OF DAMAGE INITATION AND PROGRESSION PROPERTIES IN MULTI-LAYER WOVEN CARBON-EPOXY COMPOSITE MATERIALS IN UNI-AXIAL TENSION

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ABSTRACT

Textile composites are steadily gaining positions in aeronautic, automotive, ground transportation and other applications, offering weight reductions and cost saving over metal alternative. While the design for stiffness of textile composite parts can use validated
predictive modelling, related to the unit cell structure of textile reinforcements, the reliable design for strength with not-that-exaggerated safety factors has to be based mostly on experimental information, with modelling approaches being developed. But still it has not
reached to a satisfy state. Most important parameters influential on stiffness of textile composites are damage initation and development properties. Validation of the modelling methods asks for adequate experimental characterisation of the damage processes on different scale and hierarchical levels (from micro level to macro level) of the composite, as the damage phenomena in textile composites are much more complicated then in UD laminates, and involves processes and parameters on different scale levels: macro (overall strength and strain-to failure of the sample and stiffness reduction), meso (damage initiation sites inside the textile structure of the reinforcement) and micro (local damage mode inside yarns and fibrous plies).
In this study, the damage threshold and development properties of 2x2 twill woven fabric carbon-epoxy composites produced with resin transfer method will be invesitgated. For this purpose uni axial tensile loading of the test sample produced in certain fiber volume fraction will be used as most common testing procedures. It ensures well-controlled plane stress–strain state of the sample and the set-up allows easy monitoring of the deformations of the sample with full-field optical strain measurement on the sample surface, thus stress concentration fields will be determined on sample surface. Damage initation phenomena or crack threshold properties will be obtained with acoustic emission records. Attention is drawn to the damage initation and development of the material in meso-scale. So damage can be studied ‘‘post-mortem’’ with x-ray and optical microscop.

ANTISTATIC PROPERTIES OF METAL COATED PP FIBERS PREPARED BY MAGNETRON SPUTTERING

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Various techniques have been developed to functionalize textile materials. Physical vapor deposition (PVD) has been applied to modify textile materials. High vacuum physical vapor deposition method due to its inherent merits, such as environmental friendly properties, to modify and functionalize textile materials started to find new applications. Magnetron sputter coating is one of the most commonly used techniques in PVD, which has been widely used in glass, ceramic and micro-electronic industries. Magnetron sputter coating can produce very thin metallic or ceramic coatings (nanometer thickness) onto a wide range of substrates, which can be either metallic or non-metallic in different forms. In this study, the surfaces of polypropylene fibers (80 um in diameter, multifilament) have been coated by magnetron sputtering in high vacuum with electrical conductors such as Ag and Cr metals. The electrical conductivity has been measured as a function of deposition thickness. It is found that as small as 10 nm deposition increases the conductivity five orders of magnitude with surface resistance of 2.1 x 10^7 ohm/sqr. A fabric can be defined as an antistatic, if it shows 10^6-10^8 ohm/sqr surface resistance. Therefore, the fibers can be coated with thin enough Ag or Cr to provide antistatic properties. Addition to electrical properties of fibers, the mechanical properties of the coated fibers will be presented as well.

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COMFORT AND QUALITY PROPERTIES OF ELASTICIZED SINGLE JERSEY KNITTED FABRICS

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ABSTRACT

The material composition and the yarn structure influence comfort and quality parameters of knitted fabrics and knitwear and also contribute to the aesthetic appearance factors such as lustre, surface evenness, pilling, curling, spirality, etc. The objective of the research was to compare measured and calculated parameters of knitted fabrics made from conventional and elasticized yarns respectively and to evaluate the comfort and quality properties of the investigated knitted fabrics.

Key Words: knitting, comfort, aesthetics, quality, elasticized knitted fabric

1. INTRODUCTION

The appearance and performance properties of various knitted products differ mainly because of the differences in material composition and structure parameters of knitted fabrics. Knitted structure and its parameters have great influence on appearance, comfort and quality of knitted fabrics and knitwear. The material composition and the yarn structure influence comfort and quality parameters of knitted fabrics and knitwear and also contribute to the aesthetic appearance factors such as lustre, surface evenness, pilling, curling, spirality, etc

2. THEORETICAL

2.1. Knitted structure

Open to normal knitted structure can usually be made from conventional yarns. Knitting with core-spun elastomeric yarns usually results in a compact to very compact e.g. supercompact structure because of the yarn extension in the knitting zone, fabric relaxation after taking-off and yarn compression. Different structures made from core-spun yarns compared to conventional yarns differ by the following knitted fabric parameters: loop length, horizontal, vertical and area density, density coefficient, fabric thickness, mass per unit area, loop modules, Munden constants and Knapton constant. Knitted fabric parameters influence the aesthetic look and aesthetic properties of the knitwear during wear and care, performance properties of the fabric and also mechanical and comfort properties. The knitted structure density as the most regularly monitored characteristic, and consequently the porosity of the knitted structure are expected to be closely connected to air permeability and heat transfer [1, 2, 3, 4].

2.2 Quality

The quality of knitted fabrics and knitwear mainly depends on the quality of design, incorporated material, production technology, after-treatment and preservation of the nice look and shape during wear and care. It is very hard to predict the behaviour of the knitted product during use because of the many raw material, knitting process and environement parameters which influence the product final properties. The quality has to be planed in advance within the prototype collection development phase. Additionally, it has to be monitored and controlled during the production process from a sketch to a final product [5].

2.3. Comfort

Comfort is a neural sensation, when the wearer is physiologically and psychologically unaware of the garment he is wearing. Discomfort, on the other hand, arises when the wearer is conscious of the garments he is wearing and the experience is unpleasant. In the case of the physiological discomfort the body feels uncomfortable, as for example too warm, too cold or sweaty as a result of the perspiration transport away from the skin. Too tight fit or power stretch can also cause discomfort. In many cases more than one physical property contributes to producing a sensation. Thermo-

physiological comfort is determined by the heat and moisture transfer through the textile layers and the air layers in between. In addition, the thermo-physiological comfort also depends on the heat and moisture absorption of the textiles in the end use product. It can be expected that the porosity of the knitted structure, e.g. its compactness which is described by loop modules and constants, has an impact on comfort properties of knitted fabrics made from elasticized yarns [6, 7].

3. EXPERIMENTAL

3.1 Research objective and test methods

The objective of the research was to compare measured and calculated parameters of knitted fabrics made from conventional and elasticized yarns respectively and to evaluate the comfort, aesthetic and quality properties of the investigated knitted fabrics, e.g. water vapour and thermal resistance, surface apperance and spirality.

Samples (Table 1) of single jersey were made from two different kinds of structured yarns, each made of viscose and acrylic fibers respectively. One kind of yarns included elastane (core-spun) while the other comparative yarns were conventional without elastane. All the yarns were produced with the same linear density – 100 tex and had similar twist (core-spun – 280 m^{-1}, conventional – 221 m^{-1}). All the yarns were produced with Z twist. Furthermore, knitted fabric samples were produced under same conditions and loadings in two density levels which are defined as dense and open. After knitting, all the knitted samples were dry and wet-relaxed by laundering and tumble drying. Combining two yarn structures, two fiber types, and two density levels, eight different knitted samples were prepared in all.

Table 1. Samples

sample	material composition	yarn structure	fabric structure
5 Mg	97.8 % CV 2.2 % EL	core-spun	dense
5 Mr			open
6 Mg	97.8 % PAN 2.2 % EL		dense
6 Mr			open
7 Mg	100% CV	conventional	dense
7 Mr			open
8 Mg	100 % PAN		dense
8 Mr			open

Basic yarn and knitted fabric parameters were determined by laboratory tests. From the measured basic parameters the following knitted structure parameters were calculated: density coefficient C, cover factor K, loop modules δ (linear), δpl (planar), δv (volume), Munden constant K1 and Knapton constant K5 [4].

Comfort properties as water vapour and heat permeability were assessed by measuring the water vapour resistance Ret and thermal resistance Rt on the PERMETEST measuring device developed by Czech SENSORA Company [8]. The instrument provides measurements very similar to the ISO Standard 11092 and the results are evaluated by the identical procedure while the samples are smaller.)

4. RESULTS AND DISSCUSION

As expected, the values of the parameters for knitted fabrics made of conventional and elasticized yarns differ significantly. Moreover, the calculated values of the investigated knitted fabric parameters differ from the recommended ones.

As seen from the Table 2 the loop modules δ, δpl, δv of the elasticized fabrics are substantially higher in comparison with the conventional fabrics. The last differ significantly form the optimal values for normal structure: δ=16,6, δpl1,0, δv =1,0. On the other hand the cover factor K and Munden constant K1 of the conventional fabrics are substantially smaller in comparison with fabrics made from core-spun yarns. If the ideal cover factor for the normal structure is K=1,4 , the conventional fabrics can be described as generally open and the elasticized fabric as generally compact. The Knapton constant indicates that the structure is more dense in the thickness direction for the CV fabrics than for the PAN

fabrics. It is also seen that structure is more dense for elasticized fabrics than for the conventional fabrics of the same material composition.

Table 2. Calculated knitted structure fabric parameters

sample	*C*	*K* ($\sqrt{\text{tex}}/\text{mm}$)	*δ*	*δpl*	*δv*	*K1*	*K5*
5 Mg	0.49	1.89	6.49	0,10	0.22	62.15	1.68
5 Mr	0.52	1.37	8.92	0.11	0.26	81.99	1.89
6 Mg	0.51	1.72	7.10	0.14	0.36	50.88	2.00
6 Mr	0.53	1.32	9.52	0.15	0.43	61.30	2.26
7 Mg	0.55	1.22	11.93	0.65	1.52	18.48	1.84
7 Mr	0.66	0.92	15.90	0.89	1.97	17.94	1.74
8 Mg	0.73	1.13	13.67	0.61	1,76	22.36	2.26
8 Mr	0.87	0.86	17.91	0.82	2.34	21.90	2.25

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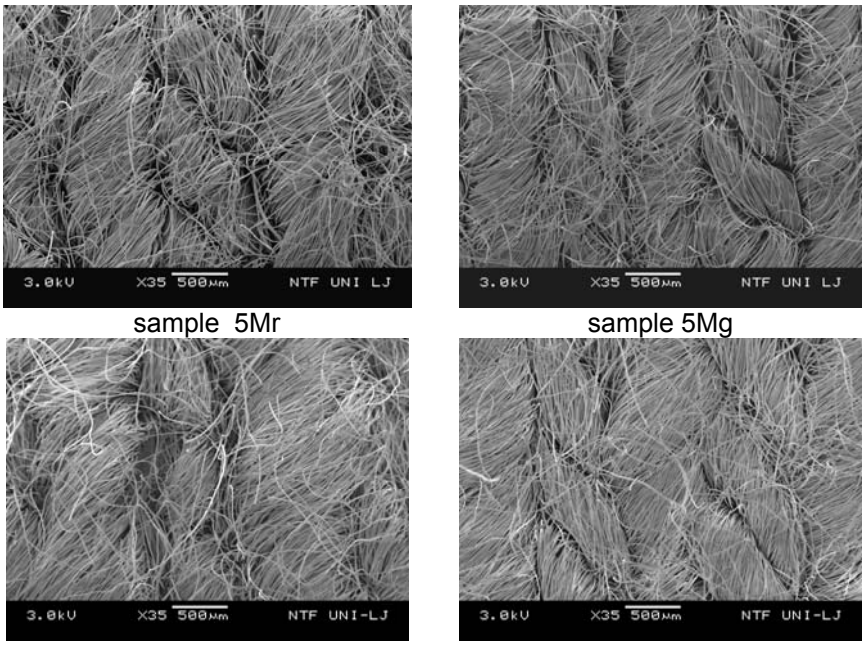
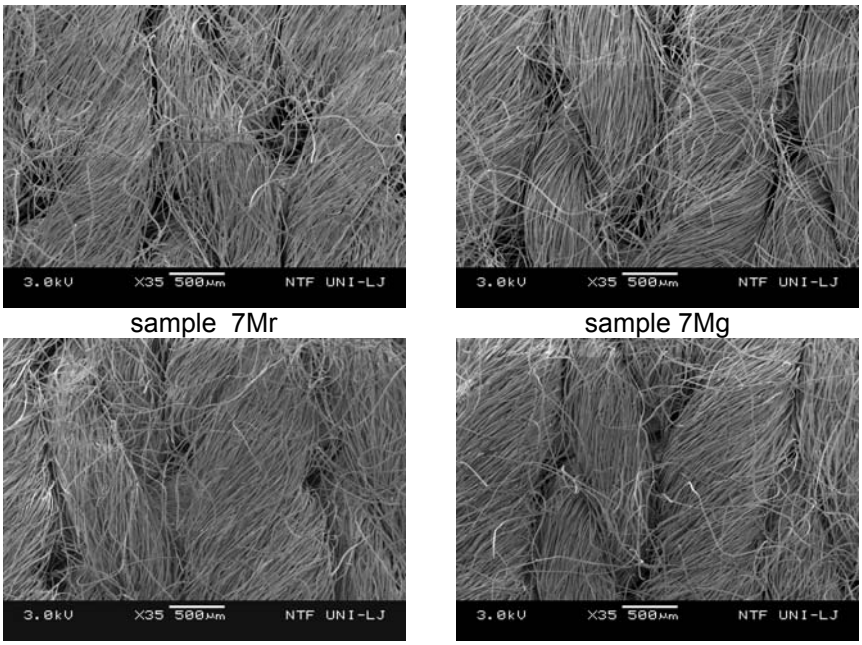


sample 5Mr sample 5Mg

sample 6Mr sample 6Mg

Figure 1. SEM pictures of elasticized knitted fabrics made of core-spun yarns



sample 7Mr sample 7Mg

sample 8Mr sample 8Mg

Figure 2. SEM pictures of non-elasticized knitted fabrics made of conventional yarns

The difference in structure of the investigated conventional and elasticized knitted fabrics is also evident from the Figures 1 and 2. The elasticized structures (samples 5 Mg, 5 Mr, 6 Mg, 6 Mr) are much more compact than the structures of the fabrics made from conventional yarns without elastane (samples 7 Mg, 7 Mr, 8 Mg, 8 Mr). The compactness is especially distinctive in the vertical direction which leads to the changed loop geometry and influences the pattern preparation, productivity and fabric thickness.

The SEM pictures also show the loop inclination and the difference in loop limb lengths which consequently leads to knitted fabric spirality and uneveness of the knitted surface and influences fabric quality. The difference in loop limb lenghts is more evident with elasticized structure, while loop inclination is more distinctive with conventional structure.

Comfort properties shown in Table 3 differ with regard to the yarn structure, material composition and density level. It can be seen that the water vapour resistance Ret of the fabrics made form core-spun yarns is higher than from the conventional yarns. The water vapour resistance Ret increases substantially with the fabric density decrease. The thermal resistance Rt also increases with the fabric density decrease.

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Table. 3. Knitted fabric comfort properties

sample	***Ret*** *(m^2Pa/W)*	***Rt*** *(m^2°C/W)*
5 Mg	2.62	0.0422
5 Mr	3.94	0.0464
6 Mg	1.57	0.0626
6 Mr	3.00	0.0735
7 Mg	0.38	0.0505
7 Mr	1.36	0.0563
8 Mg	0.83	0.0608
8 Mr	2.07	0.0698

5. CONCLUSIONS

It can be concluded that measured and calculated parameters of knitted fabrics made from conventional and elasticized yarns differ respectively. The knitted fabric structure parameters influence the comfort properties, the aesthetic appearance and thus the quality of the investigated knitted fabrics.

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COMFORT AND SAFETY IN KNITTED TEXTILES PRODUCTS FOR FIRE AND HEAT PROTECTION OF THE HUMAN BODY*

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ABSTRACT

Today there are various kinds of hazards which workers are faced. Personal protective equipments are one of the most important factors for protection of them. Therefore the researches and introduction of new products to the market keep going continuously. According to European Norm, EN 340 2003, protective clothing is defined as clothing which covers personal clothing or replaces clothing, and protect against one or more hazardous risks. Thus, the primary function of protective clothing is protection of wearer from the hazards. However if only this is regarded, the clothing must be thick, bulky and even rigid. While the clothing protects the wearer at high levels, it can completely prevent people's mobility. Therefore, it causes discomfort. Accordingly, when developing protective clothing, the balance between protective properties and comfort is very important. There are a number of standards defining several protective clothing and requirements for these (Table 1). Today protective textiles against fire and heat are an important branch of technical textiles consisting mainly of thermal protective clothing and other protective uniforms. Protective underwear is the last protection layer of the skin against burns. Their requirements are similar but not the same as protective uniforms. Underwear is dressed at direct contact with the body skin and they must perform the best possible comfort level at the human body. Comfort is defined in EN ISO 7730 as a condition of mind which expresses satisfaction with the thermal environment. The term 'thermal comfort' describes a person's psychological state of mind and is usually referred to in terms of whether someone is feeling too hot or too cold. So comfort is subjective, but it can be defined in terms of objective parameters. Comfort must itself be considered as a safety asset. The factors that influence the comfort can be divided into two main groups: Environmental factors (humidity, air temperature, air velocity, radiant temperature) and personal factors (clothing insulation, metabolic heat). There is still little awareness about the benefits of wearing protective underwear except of firemen, air force pilots and crew, elite police and elite army, riders racing, but the use of protective underwear in the industrial sector is low, even where there is a substantial risk of burns.

This study is considering protective underwear and its purposes are to identify and make correlations between fire and heat protection and level of comfort of knitted fabrics produced using raw materials - fibers already available on the market, and to identify the synergy that it would be possible to obtain blending different fibers, with the goal to allow the industrial production of more comfortable fire and heat protective underwear in short/medium term. The study consists of following main points; determination of fire and heat protection priorities, comparison of the protection levels offered both by the current products mainly used and some products under development, determination of comfort level priorities, comparison of the comfort level offered both by the current products mainly used and some products under development.

For this purpose, various fibers (Table 1) were used to develop yarns for producing protective knitted underwear. In Table 2, the yarn types produced for this study can be shown. The first 7 yarns are the

* *This study was presented in the 48th Dornbirn Man-Made Fibres Congress, in Austria, in September 16-18, 2009.

conventional yarns which have already used in production of protective underwear, the twelfth yarn is a conventional cotton yarn and yarns numbered 8, 9, 10 and 11 are the new yarns developed for this study. The yarns have been produced in the same yarn count, if it is possible for the spinning system. All of the fabrics manufactured for protective knitted underwear were produced with the same construction (1/1 rib) in the similar weight (185-190 g/m^2).

Materials in this research were evaluated in per stage of the fabric production. These are fiber, yarn and then knitted fabric. All the products were evaluated in terms of physical and mechanical properties. Fibers were tested by Textechno Favimat and Leica microscope. Yarns were tested by Uster UT5, Uster Tensorapid 3 and Uster Tensojet 4. Besides physical and mechanical properties, fabrics were also tested for comfort behaviors and behaviors against heat. In Table 3, the test methods applied to fabrics can be seen.

Table 1. Properties of fibers used in this study

FIBRE - Type and nominal data.	Linear density dtex	Linear density CV.%	Tenacity CN/tex	Tenacity CV.%	Elongation %	Elongation CV.%	Ten. 5% Elong. cN/tex	Ten. 10% Elong. cN/tex
Meta-aramid - dtex 2,2 - 50 mm	2,17	17,36	46,68	14,58	35,18	19,96	7,4	16,03
Para-aramid - dtex 1,7 - mm 50	1,6	12,06	191,1	10,7	5,75	9,9	159,6	Max El. < 10%
Polyamideimide - dtex 2,2 - 50 mm	1,85	12,2	41,67	4,71	23,68	5,73	5,18	7,03
H.T cellusose fr _modal	2,28	16,31	26,87	16,31	15,55	14,28	10,98	17,9
Modacrylic LOI > 34 dtex 2,2 mm 40	2,31	18,1	24,36	12,01	27,99	10,16	7,76	9,37
Nylon 66 - dtex 1,7 - mm 40	1,76	9,43	47,26	9,43	80,36	17,42	6,06	12,48
PSA - Polysulfonamide - dtex 2,2 mm 51	2,25	20,44	31,92	13,98	23,06	10,43	5,4	8,55
PBO - P-phenylene-benzobisoxazole dtex 1,5 mm 51	1,43	11,29	Test not possible	Test not possible	Test not possible	Test not possible	Test not possible	Test not possible

Table 2 The yarns types produced for this study

Sample no	Yarn count (tex)	Raw material	Spinning technology
1	19.7	95% meta-aramid / 5% para-aramid	Short staple ring traditional
2	19.7	50% meta-aramid / 50 % HT-FR modal	Short staple ring traditional
3	19.7	40% meta-aramid / 50 % HT-FR modal / 10%nylon 6.6	Short staple ring traditional
4	19.7	35% meta-aramid / 55 % HT-FR modal / 10% nylon 6.6	Short staple ring traditional
5	19.7	55% modacrylic (LOI 34) / 45 % long staple cotton	Short staple ring traditional
6	19.7	50% polyimide-amide / 50 % HT-FR modal	Short staple ring traditional
7	19.6	50% polyimide-amide long staple / 50 % HT-FR modal	Long staple ring traditional
8	19.7	65% HT-FR modal / 35 % poly (p-phenylene-benzobisoxazole) (PBO)	Short staple modify ring
9	24.6	100% polysulfonamide (PSA)	Short staple modify ring
10	19.7	95% polysulfonamide (PSA) / 5% para-aramid	Short staple ring traditional
11	19.7	78% HT-FR modal / 22% nylon 6 (core-spun yarn)	Short staple modify ring
12	19.7	100% cotton	Short staple ring traditional

Table 3. Standard test methods applied to knitted fabrics in this study

Standard No	Standard Name
EN ISO 5084	Fabric Thickness
EN ISO 13938-2	Bursting Strength
EN ISO 12947	Abrasion
EN ISO 12945-2	Pilling-Martindale
EN ISO 6330-EN 20577	Dimensional Stability
AATCC 79	Water Absorbency
EN ISO 92337	Air Permeability
BS 7209	Water Vapor Permeability
ISO 5085-1	Thermal Resistance
EN 367	Protective clothing; protection against heat and flames determination of heat transmission on exposure to flame.
EN 532	Protective clothing - Protection against heat and flame. Method of test for limited flame spread. (Brittle char length of burned fabrics)
EN 469	Requirements for fire-fighters' protective clothing (Annex A – Heat resistance)

In the scope of this study, knitted fabric properties were measured in terms of mechanical, physical, comfort properties and properties against heat. As a consequence, the most suitable knitted fabric for protective underwear were tried to be determined by regarding all these properties together.

Keywords: Protective clothing, thermal protective tests, comfort, protective underwear

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CURRENT CHALLENGES IN SMART TEXTILE RESEARCH

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ABSTRACT

Research topic Smart Textiles has existed for more than 10 years. Many Universities, companies and research institutes have spent countless person-hours on this topic. Results so far include conceptual plans, technical details and components, but not so many finalized consumer products. Textile Intelligence, a spin-off from the Economist Intelligent Unit, estimates that of all smart textile products developed so far 77 % are input and intermediate components and only 23 % are finished products. The market, however, is growing fast. Textile Intelligence forecasts that the total market for smart textiles will be 1.1 billion US$ in 2010.

This paper discusses the current challenges in developing smart textiles. The aim is to define how far we are in developing thermo-regulating, color change and shape memory fabrics, which really function as promised. Imbedding energy sources to textile structures is a special challenge. And, how long do we need to wait until garments and home textile products made of smart fabrics fill the shelves in the stores.

Key Words: smart textiles, smart textile market, smart textile challenges

1. INTRODUCTION

Intelligent systems consist of three parts: a sensor, a processor and an actuator, all managed by controlling data. For example, body temperature monitored by the sensor is transferred to the processor, which on the basis of the received information computes a solution and sends a command to the actuator for temperature regulation. Such functional properties are also included in so called intelligent or smart textiles. Terminology, however, varies from one speaker to another. As standards are only now being developed for smart textiles, it is understandable that the term intelligent textiles is used in different contexts. Attempts by different experts to define the terminology can be summarized as (1) Smart textiles are textile materials which interact with the environment by, on the basis of information received, perform a pre-determined action repeatedly and often reversibly, (2) Wearable technology products are textiles where electronic or mechanical components are attached to the textile material and the textile part does not have any intelligent properties, and (3) Technically advanced textiles are materials which have non-interactive special properties but the material itself stays unchanged despite of environmental change. Shape memory fabric Diaplex is a good example of smart textiles. The molecular structure of the fiber changes due to temperature change increasing or decreasing ventilation and permeability of moisture. Musical jackets and similar products introduced already some years ago are examples of wearable technology, although some parts such as user interface may be directly embedded in the textile part. GORE-TEX is an example of technically advanced material. It could not be referred to as smart textile product as it does not interact with the environment in any away.

Research and development of smart textiles is often very cross-scientific. Many other skills, such as electronics, telecommunications, biotechnology, medicine, etc., are needed beside textile know how. Networking various types of institutes is often the only way to carry out successful smart textile research. The complexity and broadness of knowledge required makes smart textile research interesting but also challenging (Mattila, 2006).

There have been high hopes among the scientific community for commercially successful products to enter the market. But we have not really seen any. Why is that? Have the numerous research labs, both private and public, failed in developing smart textile products? Or is it so that consumers do not recognize the smart textile part, which may be hidden into the product, and therefore believe that such

products do not exist? Or could it be that we have not been able to understand what consumers as well as the public interest groups really want?

2. SMART TEXTILES

Phase change materials (PCMs) are thermal storage materials used for regulating temperature fluctuations. By using chemical bonds for storing and releasing heat when a material changes from solid state to liquid and back, these materials can cool or warm the user when attached to textile structures next to the skin (Mattila, 2006). Thermal regulation in phase change fabrics currently available commercially, such as Outlast, Comfortemp and Schoeller-PCM, is based on microcapsules filled with paraffin wax. These capsules are embedded in textiles either in the spinning process or by laminating. By applying paraffin wax of different crystallization point the preferred temperature, where cooling or warming starts, can be selected. The main problem with the current phase change materials is the weak and short impact of cooling and warming. This is due to the low quantity of phase change material, proportionally 20-25 %, that by current technology can be embedded in the textile structure.

NOTEREFIGA is a collaborative project financed through EU's seventh framework programme. The objective is to develop new type of fibers for enhanced temperature management by using two alternative methods. One is based on bi-component melt spinning where the core of the fiber is made of phase change material. The second one incorporates PCM directly to the cellulose fiber during the wet spinning process. The objective is to have proportionately 70-75 % phase change material, and as result gain a long-lasting and strong cooling and warming impact (Noterefiga).

Shape memory materials (SMMs) can, due to external stimulus, change their shape to a programmed new shape and return back to the original, once the stimulus is removed. The activating stimulus can be temperature, stress, magnetic field, electric field, pH-value or UV light (Mattila 2006). Textile applications of SMMs are based on shape memory polymers, gels or shape memory alloys. Diaplex is a shape memory fabric developed by Mitsubishi International. Based on shape memory polymers, the molecular configuration changes due to increased temperature, and transfer of heat and vapor through the garment is intensified. Smart sutures, ascending and descending curtains are among the useful applications of shape memory textiles, while several prototypes of less feasible properties have been produced, i.e. shirt sleeves that curve up when hot air is blown to them, etc. The Shape Memory Textile Center of Hong Kong Polytechnic University is one of the research centers concentrating in smart textile research. It has produced an impressive collection of research articles on shape memory textiles. Books have been written on the subject as well. But practical applications are rare.

Stress-responsive materials change their shape, flexibility or color due to stress applied to them. The change is reversed once stress is removed. Auxetic material swells when stretched. 3dolab has developed specially engineered material for impact protection, which normally is flexible, but upon a hit hardens instantly. Intelligent molecules flow with the motion of the user, but on shock lock together and absorb the impact energy. This material can be used for protection in athletic and work wear. Beckman Institute at the University of Illinois has developed elastomers made with mechanophore-linked polymers that change color when stretched. The amber-colored elastomer turns progressively more orange as it is stretched and finally becomes red right before it snaps. This material could be used as added protection in cords and ropes (Davis et al.).

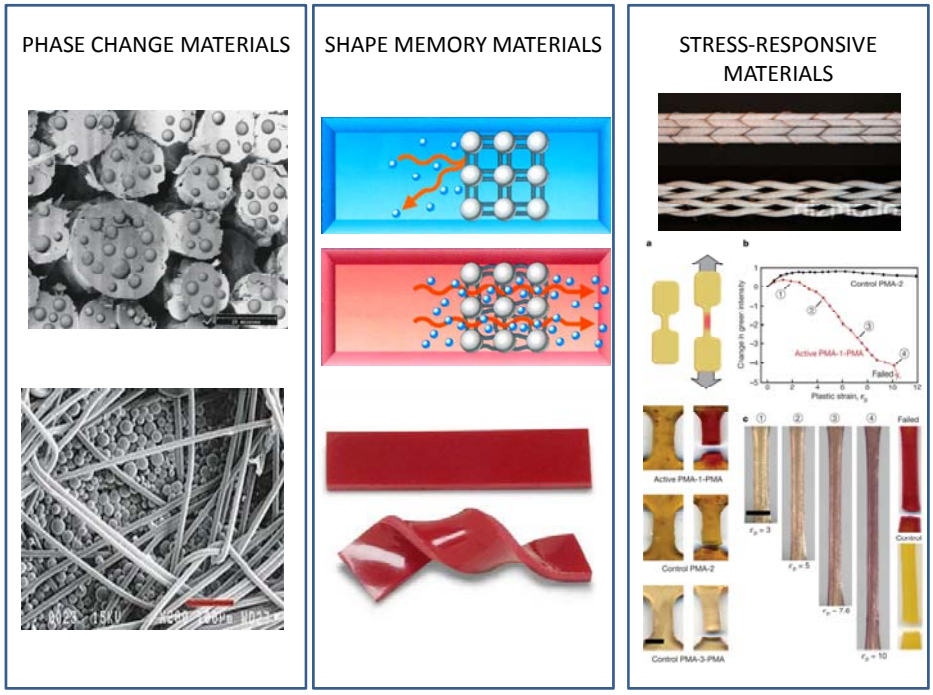

Figure 1. Examples of smart textile materials (Outlast, Mitsubishi International, Beckman Institute)

Chromic materials change, radiate or erase color. Color change is caused by external stimulus and once the stimulus cease to exist the change is reversed. Photochromic materials, which change color due to change of light intensity, are the most common type of chromic materials. Paints, inks and dyes are used for making textiles to change color (Mattila 2006). Color change properties have primarily been used for fun applications. Embroidered logo or front print on a T-shirt will become visible in bright colors when brought to sunlight to disappear again when brought inside. Chameleon-like camouflage fabrics are being developed by defense forces. The outfits made of such material will change color according to the environment making the soldier invisible.

Biologically inspired textiles are an interesting research initiative. The lotus leave effect has been studied and mimicked into self-cleaning textiles and windows. Sandia National Laboratories of the US Government researches the ability of certain fish species to change color and in this way blend with the environment. The power source for this relies on the basic cellular fuel called ATP, which releases energy as it breaks down. Fifty percent of this energy is absorbed by motor proteins, which aggregate and disperse skin pigment crystals in the cells, and by these means the color display is rearranged. Sandia believes that in five to ten years time they will be able to develop a fabric that automatically changes color to fit different environments by using the same cellular fuel (Sandia). This would make a soldier less visible in the battle field. Other interesting biomimetic research topics at the moment are the strength of spider silk, gecko's ability to walk on ceiling, shark's skin for reducing friction in water, butter-fly wing for ultra-light structures and the ability of certain type of animal fur to keep the skin warm and dry even in arctic water.

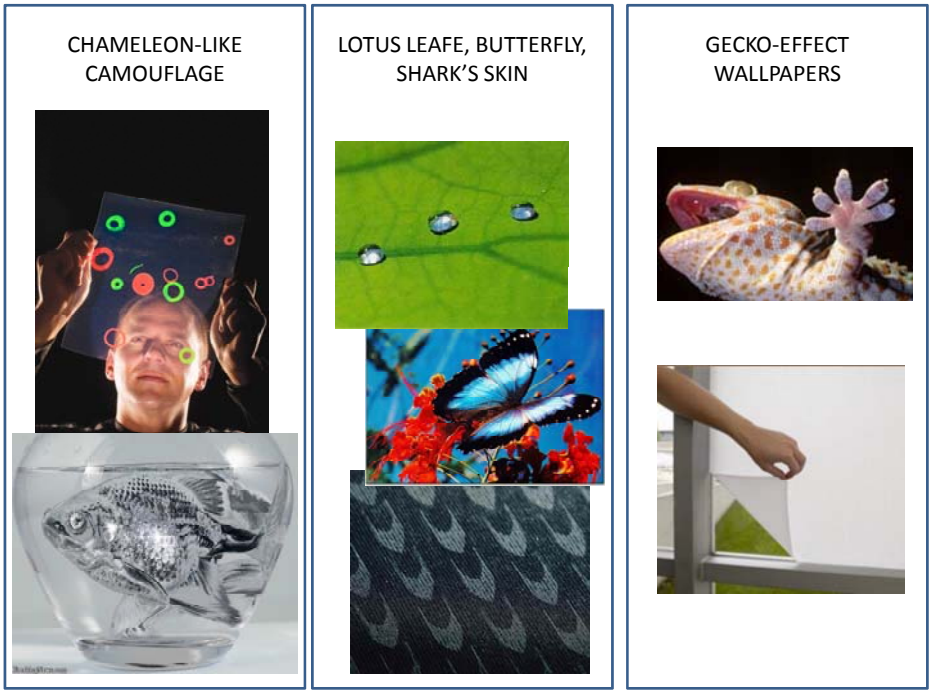

Figure 2. Examples of biologically inspired textiles (Sandia, Speedo, CreationBauman)

Conductive textile materials are strictly speaking not intelligent. They do not react to their environment. But they make many smart textile applications possible especially when body functions are monitored. They are widely used in smart textile applications, such as sensors, communication, heating textiles and ESD clothing. A heart rate monitoring system for runners by the Finnish company Polar is based on conductive fabric on a strap, which is wound around the runner's chest. The system has been in the market for several years and is selling well. A few years ago Adidas and Polar joined forces and brought a system called Fusion to the market. Heart rate monitoring was integrated into a T-shirt or a bra. Even the running shoes were connected to the system. This, however, was not a huge commercial success, and it has been replaced by new developments as Adidas acquired Textronics of the USA, a company whose mission is to seamlessly integrate micro-electronics with textile structures (Textronics).

Figure 3. Applications made possible by conductive textiles (IF Machines, Polar, Eleksen, Cute Circuit)

3. APPLICATION AREAS

Health and wellness is obviously one of the main areas for smart textile applications. In medical and health care segment there are great hopes for smart textile applications. Smart textile products seamlessly integrating to many life situations are expected to genuinely transform the concept of health care in the future (van Langenhove). Sensors and textile based diagnostic systems are great tools in monitoring patients, managing risk and making diagnoses more accurate. Smart textile applications may help the aging population to stay home longer, and they are used for rehabilitation of injured or disabled patients. Infant monitoring, mobile health monitoring, drug releasing textiles, surgical implants, wound care, and even human spare parts are among current medical applications. VivoMetric's LifeShirt is one of the best known products for continuous monitoring of physiological data, including blood pressure, blood oxygen saturation, periodic leg movement, core body temperature, skin temperature and patterns of coughing. SmartShirt by Sensatx is able to transmit further the collected biometric data (Textile Intelligence).

Sports and fitness can be regarded as another main area for smart textile applications especially for consumer use. Monitoring of exercise performance in terms of heart rate, body temperature, motion details etc., is interesting to amateur and active sports people. Position and motion sensing can be used for monitoring training and rehabilitation. Use of electroactive polymer actuators for producing artificial muscles could be interesting for enhancing sports performance.

Smart textile applications for military and occupational safety include sensors incorporated into base layer clothing for monitoring user's vital signs, and other sensors attached to the outer layer for monitoring outside conditions, such as heat, gases, etc. The information can then be transmitted wirelessly to the command center. Monitoring can be done without interference and the command center can use them for preventing injuries, exhaustion and stress (Textronics). Applications are being developed for the military, fire fighters, police, fishermen and other people working in hazardous and dangerous environment. Both US military and NATO have actively developed wearable computing applications for the solders in battlefield. The Future Force Warrior Program of the US military will develop and introduce a smart battle suit by 2020 including GPS and network communications, sensors that monitor physiological indicators, such as heart rate, blood pressure and hydration. Liquid body armor and exoskeleton are applied for enhancing soldier's strength (Science.howstuffworks).

There are numerous examples of smart textile products for entertainment. One of the first ones was the musical jacket by Philips and Levi's in 2000. This was followed by the AMP jacket and backpack for iPod control by Burton and Apple in 2003, Rosner's MP3 player jacket in 2004, O'Neill's Hub jacket in 2005, CuteCircuit's hug shirt in 2006, Ermenogildo Zegna's solar powered jacket in 2007, and more iPod clothing by several companies including M&S, Bagir, Koyono, Kempo, Jansport, Quicksilver and Carghoppers. O'Neill's NavJacket with GPS, Bogner-Osram LED lightning jacket, Zanier's Heat-GX heating gloves and the heat transfer sock by Therm-ic and X-Technology Swiss are some of the most recent developments (McCann et al). None of these have so far turned into real commercial success.

4. MARKET OPPORTUNITY

There are various estimates for the value of smart textile market. Textile Intelligence classifies various types of smart textiles into three categories. (1) Input components or enabling components for smart fabrics and interactive textiles (SFIT) include various kinds of devices, such as electronics, conductive cables and power supplies, which must be built into a textile to produce intermediate SFIT components. (2) Intermediate SFIT components or SFIT-based modules are textiles obtained by incorporating input components, such as electronics etc. (3) Finished SFIT-based textiles refer to garments and other textile products for sale to consumers and other end-users. According to Textile Intelligence the market was US$ 329,2 million in 2006 and is forecasted to be 1 129,5 million in 2010, as show in Table 1. The largest category is intermediate SFIT components, but the fastest growth is forecasted for finished SFIT-based textiles.

Table 1. Global market for smart fabrics and interactive textiles (SFITs) (US$ million)

	2006	**2007(f)**	**2008(f)**	**2009(f)**	**2010(f)**	**Annual change % 2006-10**
SFIT input components	121,7	137,9	157,7	182,1	213,8	+15,1
Intermediate SFIT components	221,5	258,3	318,4	431,7	678,1	+32,3
Finished SFIT –based textiles	26,0	44,6	77,4	133,5	237,5	+73,8
Total	**369,2**	**440,9**	**553,4**	**747,3**	**1 129,5**	**+32,3**

Source: Textile Intelligence (f = forecast)

The Industrial Fabrics Association International (IFAI) estimates that the US market for smart textiles was US$ 193 million in 2008 (Technical textile net). Report Buyer, a UK based market information company is more conservative and estimates the U.S. smart and interactive textile market to be US$ 193 million only in 2012. But they also estimate very rapid growth, close to 20% annually (Newswire). The forecasts of these three estimates cannot, however, be compared as definition for smart textiles may be different and Textile Intelligent estimates global demand while the other concentrate on USA only. Table 2 shows the market value by function as forecasted by Textile Intelligence. Conduction and distribution of electric current is the largest category. The next one is conduction and distribution of thermal energy. Table 3 shows Textile Intelligence's forecast by application. Sensing and monitoring, computing and communications and heat and energy management are estimated to be the main categories.

Table 2. Global market for smart fabrics and interactive textiles (SFITs) by function (US$ million)

	2006	2007(f)	2008(f)	2009(f)	2010(f)	Annual change % 2006-10
Transfer of thermal energy	155,5	170,5	190,2	217,2	258,4	+13,5
Transfer of electric current	141,6	184,3	258,9	401,6	706,1	+49,4
Transfer of light energy	71,4	84,7	102,2	125,6	160,9	+22,5
Transfer of matter	0,7	1,3	2,1	3,0	4,1	+55,6
Total	**369,2**	**440,9**	**553,4**	**747,3**	**1 129,5**	**+32,3**

Source: Textile Intelligence (f = forecast)

Table 3. Global market for smart fabrics and interactive textiles (SFITs) by application (US$ million)

	2006	2007(f)	2008(f)	2009(f)	2010(f)	Annual change % 2006-10
Heat and energy management	155,5	170,5	190,2	217,2	258,4	+13,5
Sensing and monitoring	76,7	100,7	141,8	218,9	380,9	+49,3
Lighting	71,4	84,7	102,2	125,6	160,9	+22,5
Computing and communications	51,7	68,3	99,4	162,0	300,9	+55,6
Actuation and response	13,8	16,7	19,7	23,6	28,3	19,7
Location and position	0,1	0,1	0,1	0,1	0,1	0,0
Total	**369,2**	**440,9**	**553,4**	**747,3**	**1 129,5**	**+32,3**

Source: Textile Intelligence (f = forecast)

5. CHALLENGES

So called textronics and fibertronics are the most challenging areas for wearable technology and smart textile research as illustrated in Figure 4. Textronics refers to manufacturing of electronic components by textile manufacturing techniques. Electronics and textile structure are integrated and the product can be treated as textile. Fibertronics is the same regarding fibers. Electronics are part of fibers and can be spun into yarns. Catrysse et al define the main challenges when integrating electronics in textiles as (1) how to attach electronic components to textile structures, (2) power management and (3) washable, flexible and user-friendly packaging of electronic components.

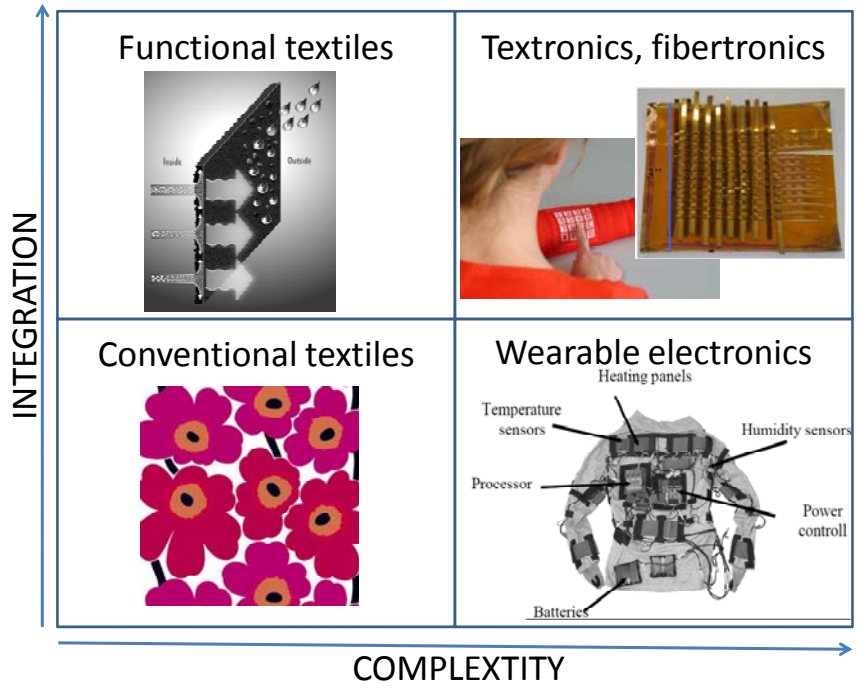

Figure4. Textronics and fibertronics are the most complex applications where intelligent properties are directly embedded to textile structures (Marimekko, Gore-tex, Paquet B, van Langenhove).

McCann et al emphasize the importance of design, i.e. the end-user should appreciate and find the product attractive and worth the money. Malmivaara argues that some of the main challenges as well as problems are related to the current sourcing-production-retailing value chain. Large sports goods brands like Nike and Adidas are not manufactures and they have to rely on outsourced production. The garment manufacturing base in Europe starts to be very thin and products, including smart garments, have to be made in East Europe and Asia, where it is difficult to carry out product development. Warranty issues, product life span and recycling may be different for the textile and electronic parts. And finally, personal electronics are sold in different stores than textiles and garments, and sometimes it may be difficult to select the best channel of distribution.

Challenges regarding technology relate often to the complexity of integrating flexible textile structures and rigid electronic components. Although flexible electronics already exist there are still problems in embedding them into textiles. Current development of digital printing with conductive inks, printed electronics and miniaturization of electronics pave way for improved textronic products. Inserting electronics inside fibers would be an ideal solution. Electronic components would become totally invisible and also encapsulated. A transponder and antenna melt-spun inside a fiber would eliminate the need to attach or sew on a RFID label on the garment. Another solution is that such components can be directly embedded on textile structures, like Elastolite, the crushable, washable, mouldable and printable electro-luminescent technology developed by Oryon Technologies (http://oryontech.com/).

When electric power is required by the system the source of power becomes a challenge. Carrying batteries in coat pockets is a very primitive solution. Solar cells have been applied to certain smart textile applications, for example Zegna Sport jacket. Kinetic energy perhaps in combination with solar energy is an interesting option. Excess body heat could be recovered and used for powering embedded electronics by capitalizing on the Seebeck effect. Kinetic energy could also be harvested from flexible piezoelectric textiles. Several research projects have been carried out regarding textile based fuel cells. Fexible nanocomposite thin film batteries are a new interesting invention. These paper-like energy storing devices could be laminated on textile structures (Pushparaj et al). Printing of organic high-efficiency solar cells on fabrics and light-activated flexible and lightweight power plastics are among the latest developments (Konarka Technologies).

Improving thermoregulation of phase-change materials is a future challenge. The cooling and warming impact of current phase change materials is so weak that it can hardly be noticed. NOTEREFIGA is an exciting new opening in this area, but more will be needed in order to deliver the thermo-regulating promise given by the currently available materials.

One of the main challenges for future smart textile products is how to manage and guide the design process and how to understand the real demand in the market. Prototyping is expensive especially when we try to put on properties that are not possible to achieve with current technology. Perhaps multimedia presentations can replace a prototype when testing the reactions of the potential users towards new products, like demonstrated by project MeMoGa (Mattila). How can we make sure that new technological innovations can be turned into culturally accepted final products? It seems that many of the final products brought to the market between 2000 and 2010 aroused a lot of attention, but at the end they did not sell. How can the rapidly growing number of input and intermediate SFIT components be turned into commercially successful final products? Product managers and designers need to be aware of technical solutions, product positioning, price, promotion, branding, channel of distribution, cross-sector product testing, functionality of the product and the sustainable design issues in relation to the whole product life cycle. At the same time electronics industry is very technology driven and wearable technology solutions may not always fulfill the aesthetic requirements consumers relate to garments (McCann).

The electronic systems incorporated in smart textiles produce complications regarding sustainability and environmental protection. Disposing of a garment containing electronic components cannot be done in a similar way as before. Electronic components may be a problem during washing and cleaning of the garment as well as at the end of the life cycle. The retailers for smart textiles may have to set up schemes to receive back used smart textile products and arrange safe disposal of the electronic components in them (Timmins).

6. CONCLUSIONS

Smart textile technology is developing fast. It is hard to keep track of how many different companies are involved in developing especially the so called input and intermediate components for smart textiles. Technical solutions for various kinds of smart properties are available, and they are even sold in Internet like by Smart Fabric Shop (http://www.plugandwear.com/). Numerous finished smart textile products have also been brought to market, but nearly all of them have turned out to be commercial flops. Is it because customer awareness, the precondition of demand creation in smart textiles as in any other consumer product, has not been considered? Or have we not paid attention to the other dynamics that play a central role in creating demand for smart textile products, such as the extent to which the product is able to solve the problem of the consumer, the comfort and mobility issues and the price (Textile Intelligence). How the technology is communicated to the consumer is especially important with emerging technological market. The message, however, must be correct and honest. Creating false expectations, as with current phase-change materials, will only heart the product.

There are many challenges in developing smart textile products. Integrating electronics and other hard components to flexible textile structures was an immense problem at early stage. Today several flexible, printable and mouldable solutions are available. Fibertronic innovations may be the ultimate solutions for making smart textile a true textile product. Designing, commercialization and marketing of smart textile products is the other main challenge. It is necessary to understand what consumers really want and to offer genuine and well-functioning products that are value for money. An area of growing concern is sustainability and waste management of smart textile products.

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DESIGN OF HYBRID BRAIDED STENTS

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Most of the deaths that occur due to heart disease are due to atherosclerosis of the coronary arteries. Nowadays one of the principal treatments of obstructive coronal atherosclerosis is the coronal transluminal percutaneous angioplasty (APTC) with the use of stents. Stents are metallic tubular structures that are inserted in the arteries with the purpose of performing an adequate radial strength to reduce the acute or chronic retraction on the vessel wall, and so re-establishing the normal blood flowing. However, long-term success of coronal stent has been limited by the restenosis or reocclusion of stents. It consists on a complex process as well as multi factorial, which lead to the growth of cells in the stent interior. The reoclusion of the arteries has as consequence significant high rates of mortality and huge expenses in medical treatments. In this context, the main goal of this work consisted in the development of hybrid braided stents based on textile materials, namely polyester and polyamide combined with a shape memory material – nitinol. A 16 yarns vertical braiding machine was used. Several braided stent models were developed varying the composition (PES, PA, Nitinol), braiding angle (25º, 35º, 45º) and diameter of the yarn (0.27mm, 0.35mm, 0.55mm, 0.3mm, 0.4mm, 0.5 mm). Tests were undertaken concerning tensile, compression and wrinkle resistance. Achieved results showed that textile braided fabrics have enough potential to be used as stents, since they present an excellent mechanical behaviour and are also biocompatible.

DETERMINATION OF BALLISTIC PERFORMANCE OF MULTILAYERED ARAMID FABRIC STITCED STRUCTURES BY YARN PULL OUT TEST

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ABSTRACT

The aim of this study is to understand the energy absorption mechanism and failure modes of the newly developed layered fabric structures which resist the certain threat types.

For these reason, paraaramid woven fabrics based multilayered structures were developed. It is try to understand the energy absorption mechanism of the developed structures after the ballistic shooting is performed. The bullet is 9 mm full metal jacketed and its speed between 300-400 m/s. Yarn pull out fixture was developed to understand the energy absorption mechanism and yarn pull out test was performed to the paraaramid single woven fabric. After shooting, bullet applies the kinetic energy to the structure for certain type of threat. If this energy level is under the yarn breaking extension, crimp in the orthogonal yarns at the fabric structure is firstly removed and thereafter yarn pull out takes place in the structure plane which is called longitudinal wave propagation and later stage fabric deformation was occurred to the out of plane direction of the structure which is called transverse wave propagation. This phenomenon continues from outside layers to the inside layers depending upon applied kinetic energy level. If the applied kinetic energy level is above the yarn breaking extension, in this case partial and total filament breakages occurs. After that, crimp removal and yarn pull out stages occur. These phenomenon take place multiple yarn failure in the outer layers and, crimp removal and yarn pull out towards the inside layers.

Energy absorption level of the stitched structures was slightly higher than that of the unstitched structures. The reason is that some amount of the energy was absorbed to delaminate the interlayer which was locked by the stitching yarns. Also, conical depth in the stitched structure was low compared to that of the unstitched structure. As a result, energy absorption mechanism of the layered fabric structures was somehow understood for low threat types. For future study in this field should be concentrated on understanding the fiber friction and possibility to use nano material to enhance the ballistic performance of such structures.

Key words: Ballistic fabric, Stitched multilayered structures, Yarn pull out test, Crimp recovery, Energy absorption mechanism.

1. INTRODUCTION

Ballistic fabrics with higher pull-out force perform favorable in impact tests [1]. Studies showed that the mechanism of yarn pull-out is to understand the role of yarn pull-out friction in fabrics and engineering frictional properties to enhance their ballistic performance. Yarn pull-out is defined as one end of the yarn pulled out the fabric structure by the motion of the penetrator. The force required to pull the yarn from the fabric structure is the sum of the frictional forces between yarn sets at all the intersecting points [2, 3]. The three distinct modes of fabric failure observed under the slow penetration test as yarn pull-out, local yarn rupture and remote yarn failure [4]. Ballistic performance depends upon friction and material properties such as elastic modulus and strength of the yarn. While friction improves ballistic performance by maintaining the integrity of the weave pattern, material properties of the yarns have significant influence on the effect of friction [5]. It is also reported that energy transferred to fibers increased with the volume of the pull-out zone. Water reduces the impact absorption capacity of the ballistic fabrics because of the reduction in the frictional forces between yarn sets in the fabric surface [6].

Another study revealed that very high inter-yarn friction can lead to premature yarn rupture during impact load and eventually reducing the energy absorbing ability of the fabric. The crimp in the woven fabric could be considered another factor [7, 8]. Also, the tensile tests showed that para-aramid base fiber is strain rate sensitive; the modulus, failure strain and stress increase with increasing strain rates. For instance Twaron® fibers are observed to fracture with more lengthy fibrils splitting axially at low strain rates, while exhibiting fewer and shorter fibrils at high strain rates [9].

Modeling studies show that the friction contributed to delaying fabric failure and increasing impact load allowing the fabric to absorb more energy. Also, it is indicated that fabric boundary conditions are a factor that influences friction [10]. Projectile-fabric and yarn to yarn friction were investigated and reduction of lateral yarn mobility allowed the projectile to load and bring more yarns so that fabric possessing a high level of friction absorbed more energy than fabric with no friction. The projectile-fabric friction delays yarn breakage by distributing the maximum stress along the periphery of the projectile-fabric contact zone. The delay of yarn breakage substantially increases the fabric energy absorption during the later stages of the impact. The yarn-yarn friction hinders the relative motion between yarns and thus resists decrimping of fabric weave tightness. It induces the fabric to fail earlier during the impact process [11].

The effect of yarn slippage at cross over point as well as within the clamp was modeled and yarn fracture during impact in single ply woven fabric was determined using a kinetic energy relation [12].

A review of the factors that influence ballistic performance outlined as the material properties of the yarn, fabric structure and multiple plies, projectile geometry and velocity, friction between fabric to projectile and yarn to yarn in the fabric and far field boundary conditions [13].

The effect of stitching on the ballistic performance on half natural rubber coated and half uncoated multilayered structure was investigated and results showed that stitched structures had lower back face deformation compared to that of the unstitched structures [14].

Various computational models on multilayered woven fabric structures were developed to investigate ballistic behavior using a finite element model based on commercially available programs such as LS-DYNA, DYNA3D and TEXTIM [15, 16, 17, and 18]. A simulation technique based on small deflection theory was proposed to calculate the required number of fabric layer stopping the projectile. The technique considers global tensile force-deflection response to find progressive damage in the fabric. However, during impact phenomenon, the compression between fabric-projectile and fabric bending do not taken account [19].

Kevlar fabric impregnated with shear thickening fluid which has silica particles (450 nm) dispersed in ethylene glycol yields a flexible and demonstrates a significant enhancement in ballistic penetration resistance [20]. The ballistic performance of material was defined as its capability to absorb energy locally and to spread out energy fast and efficiently [21]. For this reason, fibers demonstrate low density and high strength properties [22]. It is pointed out that energy absorption rate increases with fiber modulus but that decreased ductility at high modulus may result in optimum fiber stiffness for transverse critical velocity [21]. Previous work also showed that multidirectional stitched multilayered Kevlar woven fabric structures have low back face signature compared to that of the unstitched structures [23, 24].

The objective of this study is to develop better ballistic structures with the insight into the previous work and experimentally understand the ballistic event in the structure upon impact and data generated by developed yarn pull-out test.

2. MATERIALS AND METHODS

2.1 Ballistic Structure

Ballistic structures have been designed and implemented by using the woven fabric. Woven fabric consists of para-aramid type of fibers (Twaron® of Teijin). Two types of fabrics were used. These are Twaron CT® 714 (CT714) and Twaron CT® 716 (CT716). Both types of fabrics were received from Teijin / Japan. Both fabrics are plain weave and warp and filling yarn counts are 110 tex. Density of the warp and fillings are 8.5 and 12.2 ends/cm respectively. The weights of fabric unit areas are 190 and 280 g/m^2, respectively. Water repellent treatment was also applied to both fabrics. Ballistic structures developed are presented in figure 1 and 2. They have been divided in two main groups as unstitched and stitched structures. The unstitched structures have further two substructures. One of them is totally layered by CT714 fabric and the other is CT716 fabric oriented at 0˚ (warp) and 90˚ (filling) to each other. The stitched structures have further three substructures. One is one directional stitched totally layered by CT714 and CT716 fabric oriented at 0˚ (warp) and 90˚ (filling) to each other. The second one is two directionally stitched and totally layered by CT714 and CT716 fabric oriented at 0˚ (warp) and 90˚ (filling) to each other. The last one is four directional stitched totally layered by CT714 and CT716 fabric oriented at 0˚ (warp) and 90˚ (filling) to each other. The nylon 6.6 is used as

stitching yarn to all structures. Also, Kevlar® 129 fiber is used as stitching yarn for only four directional stitched structures. As seen in figure 2, the structure density (unit area weight) is the heaviest for totally layered by CT716 and the lightest for the totally layered by CT714. As seen in the figure 1, stitched layered structures are sewn to only the warp, the warp and filling, and the warp, filling and ± bias directions, respectively. They are called one directional, two- and four directional (or multidirectional) stitched structures, respectively. The distance between adjacent stitching lines is 3 cm. It is chain stitched and stitching density 4 stitch/cm. The stitching yarns are 44.4 tex nylon 6.6 which density is 1.14 g/cm^3; minimum diameter is 14 micron; average tensile strength is 59.8 MPa; tensile modulus is 2.46 GPa; average breaking extension is 41%; melting temperature is 250˚C [25, 26] and 110 tex Kevlar® 129.

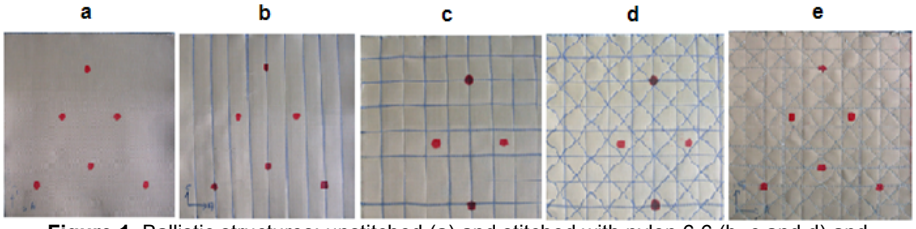

Figure 1. Ballistic structures; unstitched (a) and stitched with nylon 6.6 (b, c and d) and stitched with Kevlar® 129 (e).

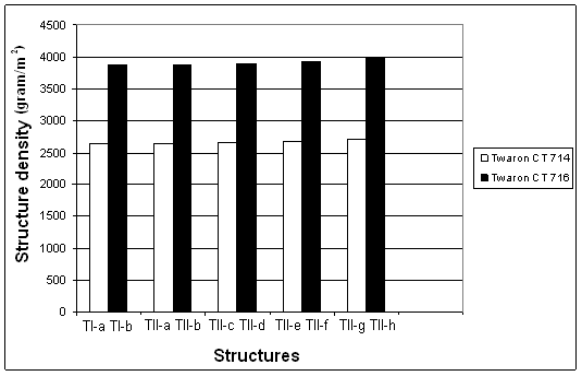

Figure 2. Multilayered ballistic structure densities from Twaron® CT 714 ve Twaron® CT 716 fabrics.

2.2 Ballistic threat

One type of ballistic threat with three different velocities is chosen to test the developed ballistic structures. They are labeled as Ia (9 mm full metal jacket and round nose, average projectile velocity 370 m/s), IIa (9 mm full metal jacket and round nose, average projectile velocity 380 m/s) and IIIa (9 mm full metal jacket and round nose, average projectile velocity 400 m/s). Kinetic energy on each projectile is calculated by following equation.

$$E_k = [0.5 m_p \cdot v_p^{\,2}]$$

where E_k is kinetic energy of the projectile (joule), m_p is mass of the projectile (kg) and v_p is speed of the projectile (m/s).

2.3 Pull-out tests

Pull-out tests were conducted to find out the yarn to yarn friction over and under crossing areas in the plain fabric structure. The fixture was developed in where it consists of basement to hold the testing instrument; sliding frame to adjust the position of the yarn end to be pulled from the testing instrument; fabric holder which has nine screw apply the required pressure to the fabric sample via metal plate. Figure 3 shows the pull-out test carried out in the testing instrument. The testing instrument is Instron 4411 and testing speed 100 mm/min.

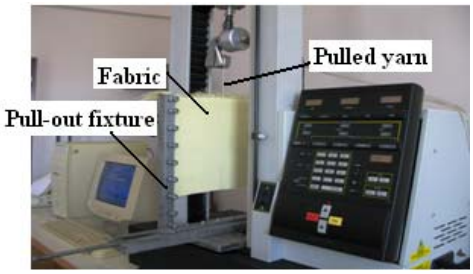

Figure 3. Pull-out fixture with fabric on the tensile testing instruments.

2.4 Ballistic tests

Ballistic tests are conducted on the front of the each structure surface. All threat types are impacted to the structure corresponded to each shooting places and repeated twice. Behind the structure, clay which is Roma plastilina given in NIJ standards is employed to detect the back face signature of the each threat on the ballistic structure after impacting. The shooting tests were conducted in Savar Ballistic and Composites Inc. shooting polygon.

3. RESULTS AND DISCUSSIONS

3.1 Pull-out results

3.1.1. Single fabric pull-out result

Single fabric yarn pullout test was carried out on both CT 714 and 716 fabrics. The measured values are yarn pullout force, fabric displacement and crimp extension. Figure 4 shows the single and consecutive yarn and multiple ends pullout from the fabric.

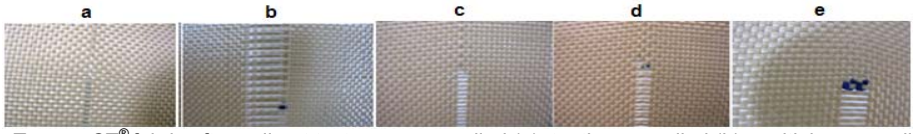

Figure 4. Single Twaron CT® fabric after pull-out test; one yarn pulled (a); tenth yarn pulled (b); multiple yarn pulled as two yarns pulled together (c); three yarns pulled together (d); four yarns pulled together (e).

First yarn pulled from the fabric CT714 shows high pullout force whereas second to tenth yarn pullout force reduced dramatically, and force level is almost the same. It is found out that the pullout force in the warp is higher than that of the filling. Although similar trend get in the case of CT716, both warp and filling pullout force in the CT716 is higher than that of the CT714. This is because higher yarn densities in both warp and filling directions, which results in more crossing between yarn sets at unit area in the fabric and leads also high crimp level in the yarn directions. This creates high internal pressure between yarn sets in the crossing section of the fabric structure and results in high pullout force.

In the case of pulled multiple yarn ends, 2 to 8 and 2 to 4 ends are pulled together from the single CT714 and 716 fabrics, respectively. The results showed that pullout force is extremely nonlinear for both warp and filling directions. In the CT714 fabric, pullout forces in the filling is higher than that of the warp 2 to 6 pulled ends. This may have resulted from high crimp level in the filling compared to that of the warp. But after the 6 ends, yarn pull out force is changed and forces in the warp becomes high. In the CT716 fabric, only 2 and 3 ends are pulled from the warp direction because of the breakages of the 4 and 6 yarn ends, mainly on account of high density. The result showed that pullout force in the warp is higher than that of the warp 2-3 pulled ends. Because crimp level in the warp is high compared to that of the filling. For two type of fabrics, it can be concluded that fabric density is basic parameter which influences multiple pullout results. When fabric density increases, crimp level in the yarn sets increases and this effects the friction level on the yarn crossover points in the fabric structure. It is interesting to see that the pullout forces in the single and multiple yarn ends show large differences especially when the number of the yarn ends increases.

Crimp extension results are given in figure 5 both single and multiple yarn pullout for CT714 and CT716 fabrics to warp and filling directions. Crimp extention in single fabric pullout to the warp

direction at CT716 fabric is the highest. In multiple yarn pullout case, crimp extension in warp direction at CT716 is higher than that of the filling direction. All crimp extentions in the CT714 are lower than that of the CT716. This phenomenon relates to the directional crimp ratio of the fabrics and proportional to the crimp extension if the yarn extension does not occur. Generally if the crimp ratio in particular yarn direction in the fabric is high, the crimp extension is also high.

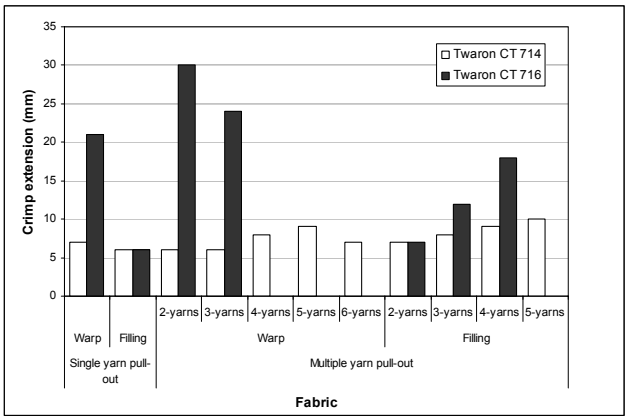

Figure 5. Yarn pull-out force from pulled single and multiple yarn ends at single Twaron CT® 714 and 716 fabrics to warp and filling directions. The fabric length is 30 cm.

3.1.1.2. Ballistic structure pull-out result

Single yarn was pulled from front, middle and back faces of the 14 layered and one, two and four directional stitched structures, which are stitched by nylon 6.6. Single yarn pullout forces from the stitched line in stitched structure from both CT714 and CT716 are higher than those of the single yarn pullout forces from the unstitched line. The forces increase nonlineraly from one directional stitched to four directional stitched structure to the warp direction. When the pullout forces from single fabric and ballistic structure are compared to each other, it can be said that stitching increased the pullout forces considerably as it is seen in figure 6. The increased pullout forces in CT716 is higher than those of the CT714 due to the fabric density. The highest pullout forces in developed stitched ballistic structures for both type of fabrics are from four directional stitching. This means internal frictional forces generated between nylon 6.6 stitching and Twaron yarns in the process of pulling the Twaron yarn to the warp direction from front surface of the stitiched ballistic structure.

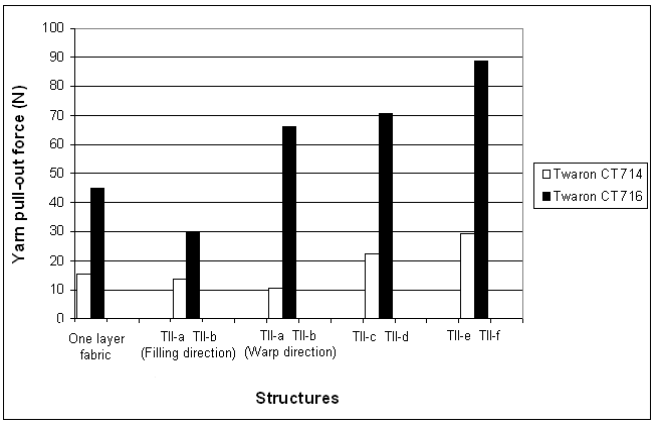

Figure 6. Single yarn pull-out force from single fabric and multilayered multistitched structures developed from Twaron® CT 714 and 716 fabrics. Yarn are pulled to warp directions for all strucutres except one structure indicated graph. Fabric and structure length are 30 cm. The yarn pulled region in the multilayered and multistitched structure is unstitched line.

3.2 Ballistic structure impact results

Ballistic impact results on the structures and impact failure on the structure for one particular threat type, IIIa, were analyzed.

Failure modes on the structure upon impact loading were analyzed and some of the distinct differences were found. Some of them for instance are seen in figure 7, 8 and 9. Under the IIIa threat type, impact loading on the unstitched structure from CT714, total and partial filament breakages and

crimp extension occurred in-plane of the fabric to the warp and filling directions. However, single or multiple yarns are pulled to the out-of-plane direction of the fabric layer in the structure and compressed to the other fabric layers as seen clearly in figure 7, (a, first and second). In the four directional stitched structure from CT714, nylon 6.6 and Kevlar® 129 stitching yarns are partially broken to the warp and bias directions and layers in the structure were dented based on projectile diameters, (b, third and fourth). Total and partially broken filaments are also observed in the dented areas.

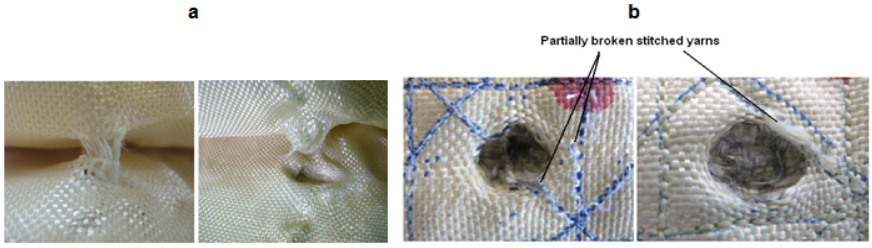

Figure 7. Effect of IIIa thread type seen in between layers on multilayered unstitched structure from Twaron CT® 714 fabric (a) first and second; effect of IIIa thread type seen in front surface on four directional stitched structure from Twaron CT® 714 fabric where nylon 6.6 fiber used for stitching (b) third; effect of IIIa thread type seen in front surface on four directional stitched structure from Twaron CT® 714 fabric where Kevlar® 129 fiber used for stitching (b) fourth.

A more detailed analysis was conducted on the back face of the one directional stitched structure from CT716. It is seen that many broken yarns are observed in the first layer of the structure. For instance, round nose projectile is interacted to 2-12 yarns in the fabric plane to the each warp and filling directions. This means that total yarns involed to absorbing the energy in the tip of the projectile 4 to 24. On the other hand, 2 unbroken yarns (1 warp and 1 filling) are caught by the projectile. In the second layer only eight yarns (4 warp and 4 filling) are caught by the projectile while other yarns are broken. In third layer, almost 24 yarns which are iteracted to the nose region of the projectile are catched and a few filament brekages were observed in each yarn in the impacted region. In the four layer the fabric is initially deformed under the projectile energy to the out-of-direction (transverse) of the structure and there is no obvious yarn brekages but minor crimp extension and pullout type deformation occured from in plane direction of the fabric to the out-of-plane direction of the structure.

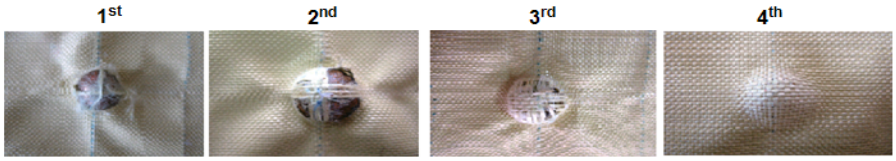

Figure 8. Effect of Ia thread type seen in between layers on multilayered one directional stitched structure from Twaron CT® 716 fabric where back of the first layer (first); back of the second layer (second); back of the third layer (third); back of the fourth layer (fourth). Shooting place is 5.

Another analysis is conducted on the front face of the two directional stitched structure from CT716. The structure is dented and the shape of the dent is based on projectile nose. Around the impacted region there are crimp extension and yarn pullout, which is clearly seen in the stitching line, and some yarn brekages are observed in the first layer of the structure. In the second layer again there is a few yarn brekages and crimp extension and yarn pullout around the impacting region. In third and fourth layers the dented shape becomes smaller, and around the area there is a lower degree of yarn movements. In the fifth layer there is no yarn or filament brekages nor are there yarn movements.

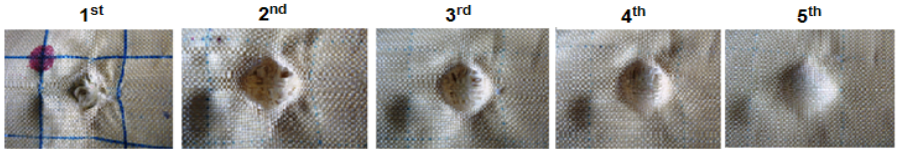

Figure 9. Effect of IIIa thread type seen in between layers on multilayered two directional stitched structure from Twaron CT® 716 fabric where front of the first layer (first); front of the second layer (second); front of the third layer (third); front of the fourth layer (fourth); front of the fifth layer (fifth). Shooting place is 3.

Each of the impacted structures was visually inspected and the damaged layer was identified. For the purpose of comparison, specific energy absorption capacities for each structure were calculated.

Additionally, conical depth and conical diameters were measured. Specific energy absorption based on damaged layer (SEADL) and structural densities (SEASD) were calculated by following relations:

SEADL = kinetic energy of the threat (joule)/damaged layer density (g/m^2) and,
SEASD = kinetic energy of the threat (joule)/structure density (g/m^2)

During shooting we did not get the exact projectile speed as determined for each threat type according to the NIJ standard due to the quality of the guns and gunpowder. Projectile speed of threat level IIIa varied between 390-397 m/s for structure from CT714 and 374-415 m/s for structure from CT716.

Specific energy absorption based on damaged layers is described for each structure. General tendency is that there is a significant difference between unstitch and stitched structures for SEADL. However, the differences between unstitched and stitched structure from CT716 is small whereas SEADL in stitched structure from CT714 is twofold compared to that of the unstitched structure from CT714. For instance, in the threat type IIIa, the best structures from CT714 is TII-g and TII-a followed by TII-e and TII-c, and the worst is TI-a. In the structure from CT716, the best is TII-d and TII-f followed by TII-h and TII-b, and the worst is TI-a. Specific energy absorption based on structure density is defined for each structure and presented in figure 10 and 11. General tendency is that there is no significant differences between unstitch and stitched structures from CT714 and 716 for SEASD. In this respect, stitching can be considered not to affect the energy absorption properties of the developed structures.

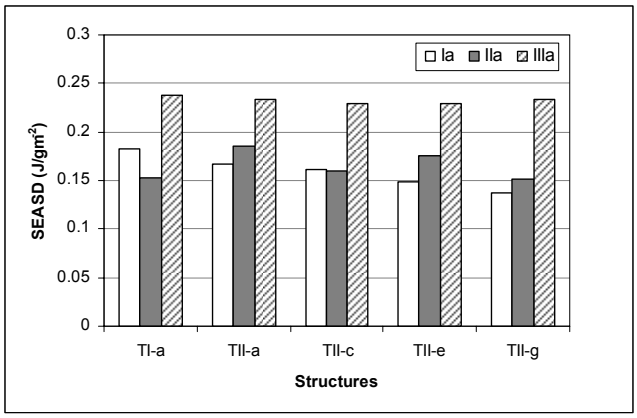

Figure 10. Specific energy absorption based on structural density of ballistic structures from Twaron CT® 714 fabrics for all threat types.

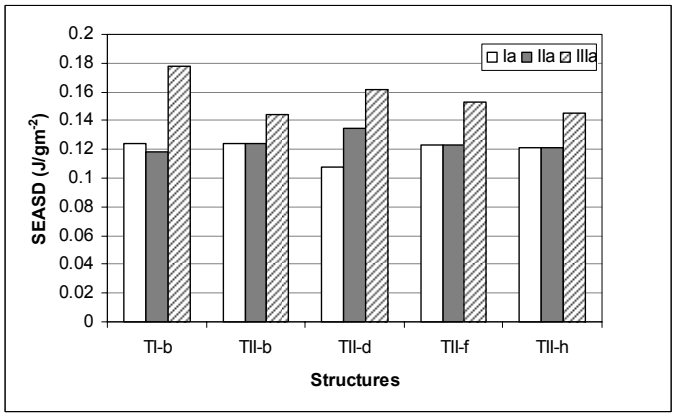

Figure 11. Specific energy absorption based on structural density of ballistic structures from Twaron CT® 716 fabrics for all threat types.

Conical depth (back face signature) of the each structure was drawn and presented in figure 12 and 13. Conical depth varies between 35 and 45 mm in the structure from CT714 whereas it is in between 30-40 mm in the structure from CT716. Almost all stitched structures have lowest conical depth compared to that of the unstitched structure from CT714 and 716. Also, the lowest conical depths were recorded at four directional structure having stitching yarn Kevlar®129 fiber compared to that of the structure having stitching yarn nylon 6.6 fiber. This indicates that multiaxially stitching with

Kevlar®129 makes the structure stiffer compared to that of the unstitched structure and somehow prevents large transverse deformation.

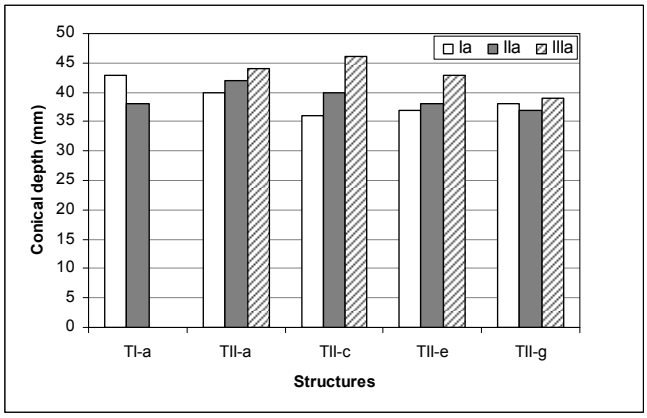

Figure 12. Conical depth of ballistic structures from Twaron CT® 714 fabric for all threat types.

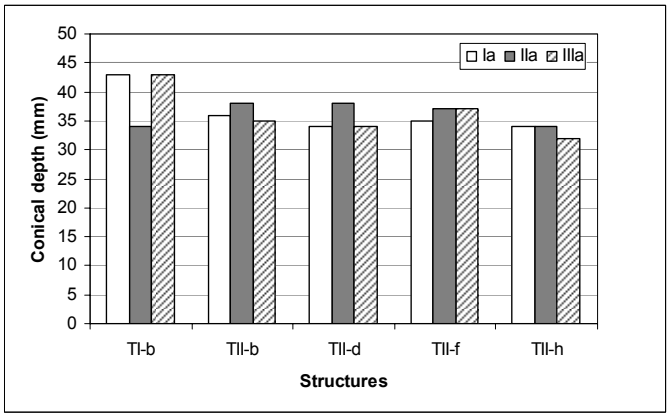

Figure 13. Conical depth of ballistic structures from Twaron CT® 716 fabric for all threat types.

3.3. General results

Under the round nose projectile impact loading with a speed around 300-400 m/s, all structures are compressed and bent based on sample dimensions. All structures are dented locally around the impact point and this causes the density of the structure to change.

Upon impact more yarn and filament breakages occurs in initial first layers. This is more obvious for the stitched structure.

If the impact load is under the yarn breaking strength, crimp extension and yarn pullout occur at each yarn sets to the warp and filling direction in the fabric plane. If the first layer of fabric is deformed to the out-of-plane direction of the structure, another layer in the structure shows similar deformation.

If the impacts load is above the yarn breaking strength, total and partial yarn and filament breakages occur before or after crimp extension and yarn pullout at each yarn sets to the warp and filling directions in the fabric plane. This phenomenon continues to the other layers at a lesser degree until the remaining energy in the projectile is absorbed.

If the specific energy absorption based on damaged layer is considered, structure with high fabric density shows favorable energy absorption properties compared to those of the structure with low fabric density. This is partly due to the number of the ends per fabric surface area and partly to the number of the crossing between warp and filling per fabric surface area. This causes high pullout forces which leads to high frictional forces and could play a role in the absorption of the impact energy.

It is proved that high density single fabric has high pullout force compared to that of the low density fabric. Multiple yarn pullout tests which simulate the real projectile-yarn interaction in the single fabric show very high nonlinearity compared to that of the single yarn pullout test in the same fabric.

In the four directional stitched structure, it is proved that stitching increases the frictional forces in-plane to the warp and filling directions. Under the impact loading stitch yarns absorb some of the energy to the out of the direction of the structure as a form of delaminating the fabric layers in the structure. Also, some of the energy are absorbed in plane as a form of complex friction between stitching and warp-filling crossing. On the other hand, it is found out that stitching yarn type have particular importance. If the specific energy absorption based on damaged layers are considered, four directional stitched structure shows more energy absorption properties along with low conical depth regardless of the fabric density. Stitching also makes the structure stiff and this affects the compression and bending behavior upon impact loading.

Future work should be concentrated on how much energy is absorbed as a form of friction and as a form of delaminating. Multihit performance of the multilayered and multidirectional stitched structure should be investigated as well. From the structural stand point, a single fabric with multidirectionally oriented yarns at in-plane should also be developed.

4. CONCLUSIONS

Multiaxially stitched ballistic structures have been developed and their ballistic performances were compared to those of the unstitched structures. High and low density fabrics were used to make the ballistic structures. Fabric pullout test was developed to understand the ballistic phenomena in stitched structures. Single and multiple yarn pullout were carried out on both single fabrics and only single yarn pullout made on stitched structures.

It is understood that high density fabric shows higher pullout forces compared to those of the low density fabric. Stitching increases pullout force in the structure compared to that of the single fabric.

All structures were impacted by one type projectile but varied speeds. It is revealed that specific energy absorption based on damaged layers is slightly better in the stitched structure compared to that of the unstitched structure. This is because stitching yarn and stitching frictional forces generated on each fabric layer. Therefore, total energy could be absorbed by stitching yarn itself to the out-of-plane direction of the structure and stitching frictional forces to the in-plane direction of the fabric layer.

Stitched structures have low conical depth compared to that of the unstitched structures. This is because stitching yarn makes the structure stiff and reducing the structural deformation to the out of plane direction. The best result is achieved in four directional stitched structures where stitching yarn is Kevlar® 129.

Future research should be analytically conducted on the role of stitching yarn in the energy absorption mechanism based on high modulus high extensional stitching yarns.

ACKNOWLEDGEMENTS

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DEVELOPMENT OF AN ENERGY GENERATING PHOTOVOLTAIC FIBRE

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ABSTRACT

Solar energy is an endless source of energy utilized in diverse areas including photovoltaic textiles as developed in recent years. Solar energy also has, no doubt, an important role in sustaining life on earth. The demand for solar cells using sun light is increasing due to photovoltaic energy generation is convenient, practical and clean. Photovoltaic technology will have some very unique advantages including flexibility when combined with textiles. In this regard, photovoltaic fibres will have many unique advantages such as flexibility, fineness, possibility to make yarns and fabrics generating electricity.

This study is focused on the development of a photovoltaic fibre by determining the structure and defining the appropriate materials. The fabrication processes of this flexible photovoltaic fibre and results of the photovoltaic characterization (short-circuit current density, open-circuit voltage, fill factor) are presented. The photovoltaic fibres were tested under simulated sunlight (100 mW/cm^2, AM1.5G) and a moderate performance in terms of power conversion efficiency was obtained. As a result of this study, it was shown that the fabrication procedures and structure of the photovoltaic fibre can be utilized for manufacturing of other photovoltaic textile fibres, at room temperature, easily.

Keywords: photovoltaic fibre, solar cell, textile, yarn

DISPOSABLE HYDROPHILIC ANTIMICROBIAL LAMINATED NONWOVEN BED SHEET

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ABSTRACT

In this study, the reduction of infection risk from patient to patient and the others during staying period in hospital using new designed "Disposable Hydrophilic-Antimicrobial Laminated Nonwoven Bed Sheet" is investigated. Because the traditional cotton bed sheets which are used in hospitals does not have any antimicrobial effect they are very suitable mediums for microbes to survive. In addition, due to their costs they are not disposable and have to be washed minimum 30 timesduring their use. If disposable hydrophilic-antimicrobial laminated nonwoven bed sheets were used, both antimicrobial protection and cost advantage would be obtained.

Disposable bed sheet is consist of three layers which are laminated to each other by hot-melt technique. Upper and lower layers are different weights of 100 % polypropylene produced by spunbond technology. Plasma technology has been used to make the surface of the spunbond polypropylene sheets hydrophilic. Additionally, thermalbond 100 % polypropylene sheets which have already hydrophilic surfaces by chemical finish are also used as upper layers for the sheets. As a core layer, different weights of 100 % viscose sheets which have high liquid absorption level have been used. All three layers have been laminated by hot melt technique using etylenevinylacetate interlayers between them. Antimicrobial effect has been achieved by the impregnation of silver and antibiotic based chemicals onto hydrophilic surface of upper layers. Quality control and performance tests of all these works have been performed according to ISO and BS norms.

Keywords: Nonwoven, Antimicrobial, Lamination, Bed Sheet

1. INTRODUCTION

Despite of improvements in service quality, infections on patients who stay at hospitals are still being observed worldwide and the risk of dead is being increased. Naturally, hospital personal is also effected by this situation. Hospital infections are important threats both for patients and environment (3).

It is known that only in United States of America, two million people per year are effected by infections via hospitals and ninety thousand people are dead. Hospital infections cost approximately 6.7 billion USD per year in USA. This is 1.7 billion USD in England. In Norway which has population of four million people only, this number is 132 million USD (7). In Turkey, it is calculated that hospital infections cost 1500 USD per patient. Staying period of the patients in hospitals because of infections varies from four day to thirtyfour day (6). Staying periods in hospitals for different countries are shown as in the below Table 1.1.

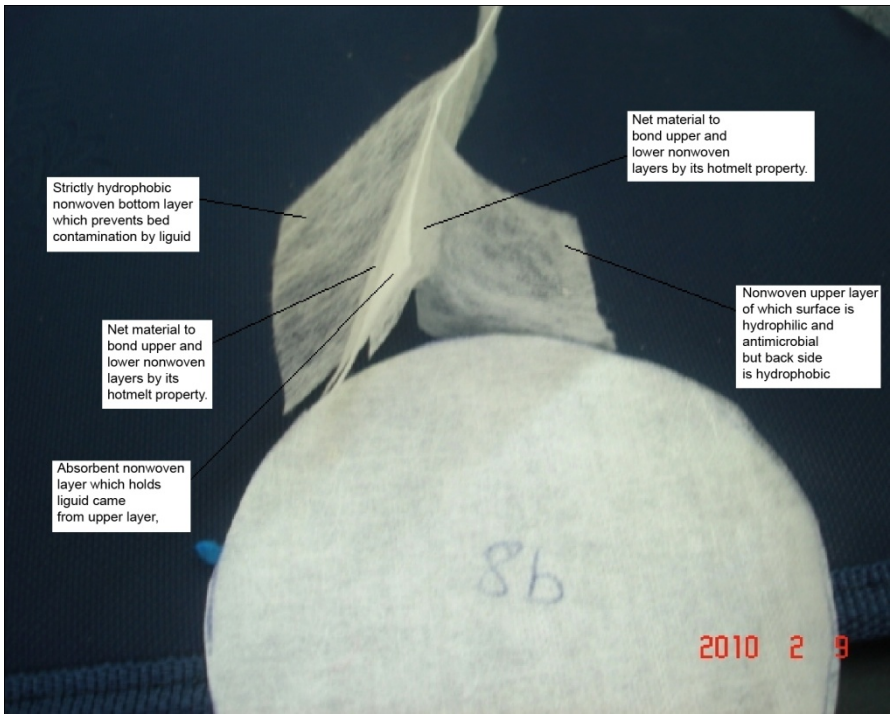
Table 1.1 Additional staying days because of hospital infections (6).

Study	Country	Additional stay (day)
1974 (Westwood)	ABD	22.0
1980 (Haley)	ABD	13.4
1991 (French)	Hong Kong	23.4
1993 (Diaz-Molina)	İspanya	4.3
1995 (Erbaydar)	Türkiye	10.6
1997 (Yalçın)	Türkiye	20.3
1997 (Leroyer)*	Fransa	5.2
1998 (Orrett)	Trinidad	33.5
1998 (Andersen)	Norveç	4.0
1999 (Navarette)*	Meksika	9.6
1999 (J Munoz)*	Meksika	7.4
2001 (Plowman)	İngiltere	11.0
2005 (Chen)	Tayvan	18.2

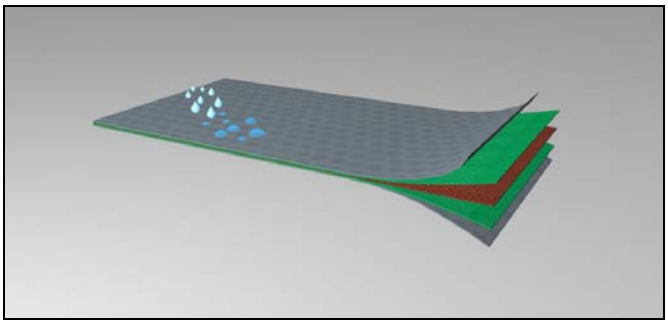
* Pediatri.

2. MATERIAL AND METHOD

The structure and features of the components of developed product are shown as in the below Scheme 2.1 and Scheme 2.2.



Scheme 2.1: Original sample.



Scheme 2.2: Appereance of laminated sheets

2.1 Material

2.1.1 Nonvowens

Nonwoven sheets used in this study and their functions are shown as in the below Table 2.1. Many multilayer combinations have been prepared by using below shown nonwoven types and all of them have been numbered. Then, all of them have been tested according to international ISO and BS norms

Table 2.1: Nonwoven sheets used in this study and their functions (6).

Nonwoven Type	Weight (g/ m^2)	Description and function
% 100 PP, Spunbond	15	As upper and bottom layer hydrophilic/ hydrophobic and antimicrobial/ microbial
% 100 PP, Spunbond	25	As upper and bottom layer hydrophilic/ hydrophobic and antimicrobial/ microbial
% 100 PP, Spunbond	35	As upper and bottom layer hydrophilic/ hydrophobic and antimicrobial/ microbial
% 100 PP, Thermalbond	18	Only as upper layer hydrophilic and antimicrobial
% 100 PP, Thermalbond	25	Only as upper layer hydrophilic and antimicrobial
% 100 CV	20	As middle layer high suction capacity
% 100 CV	30	As middle layer high suction capacity
% 100 CV	35	As middle layer high suction capacity
% 100 CV	50	As middle layer high suction capacity

2.1.2 Antimicrobial chemicals

Table 2.2: Antimicrobial Recipies and Application Conditions (2) (4).

	Nano Silver based recipe	**Polihegzametilenbiguanid based recipe**
ISys AG (g/ L)	2.0	--
Reputex 20 (g/ L)	--	20.0
Acetic acid (85%) (g/ L)	pH 5.0-5.5	pH 7.0-7.5
Impregnation Unit	KÜSTERS foulard	
Machine Speed (m/ dk)	20	
Sıkma basıcı (bar)	2.4	
Total Flotte (L)	50	
Flotte temperature (°C)	20-25	
Pick up (%)	40-45	

2.2 Method

2.2.1 Hydrophilization of upper PP nonwoven sheets by plasma method

Cold oxigen plasma method under atmospheric pressure has been used to modify the surfaces (5). Plasma conditions are shown as in the below Table 2.3.

Table 2.3: Plasma conditions (6).

Gas type	O_2
Pressure	Atmosferik
Voltage (V)	3500
Machine Speed (m/ s)	15

PP nonwoven sheets which will be used as upper layers have been passed three times through the machine under the same conditions for 20 seconds each (6).

2.2.2 Lamination (hotmelt technique)

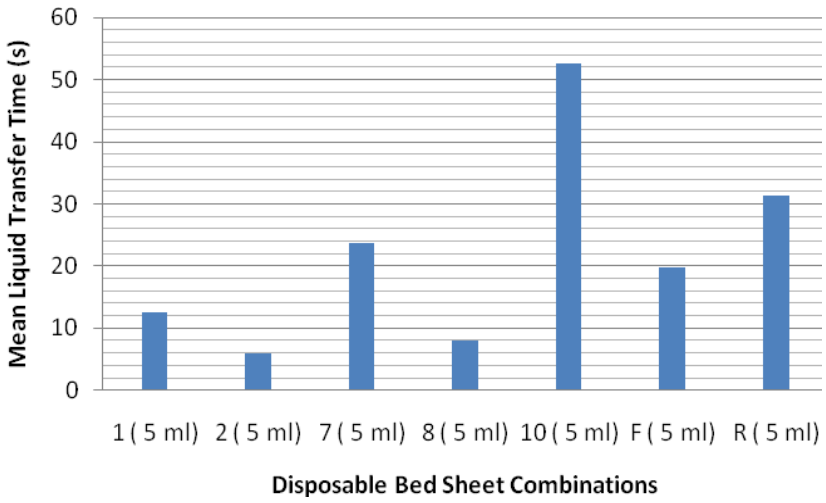
This process has been realized via a professional press. The nonwoven sheets have been replaced one on another according to combinations done before. Ethylenevinylacetate based hotmelt net has been replaced in each nonwoven pair sheets to bond them strictly. Then these prepared multilayer combinations have been pressed by hot press at 80°C.

3. OUTCOMES AND INTERPRETATIONS

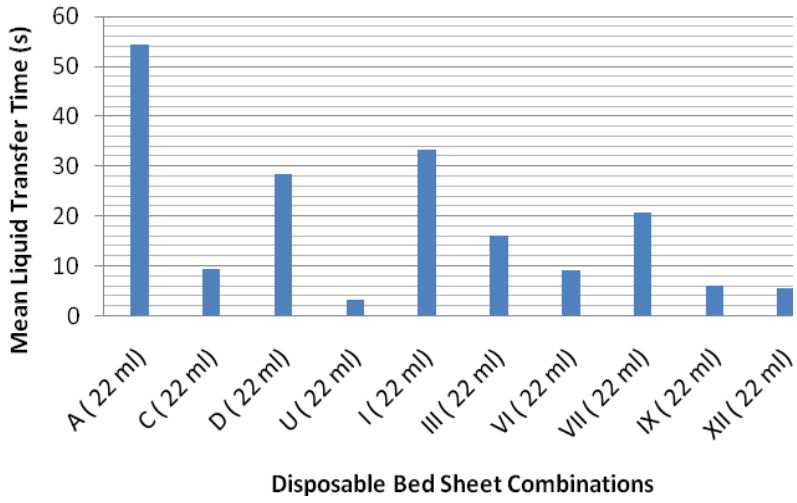
3.1 Applied tests and reference standarts in the study

Table 3.1: Applied tests and reference standarts in the study (1).

APPLIED TEST	REFERENCE STANDART
Weight measurement	TSE 251
Thickness measurement	TSE 4117 EN ISO 2589
Tensile strength and elongation	TSE EN ISO 13934-1
Tearing strength	TSE EN ISO 13937-2
Wetback	EDANA 151.3.02
Liquid transfer	EDANA 150.5.02
Air permeability	TSE 391 EN ISO 9237
Water vapour permeability	BS 7209
Antimicrobial efficiency	AATCC 100 (Stafilococcus Aureus)

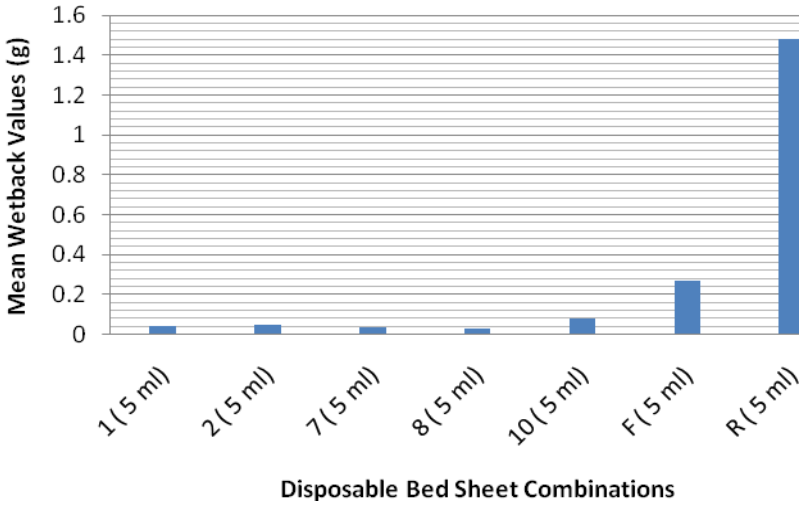


Scheme 3.1: Mean liquid transfer time values (5 ml test liquid).

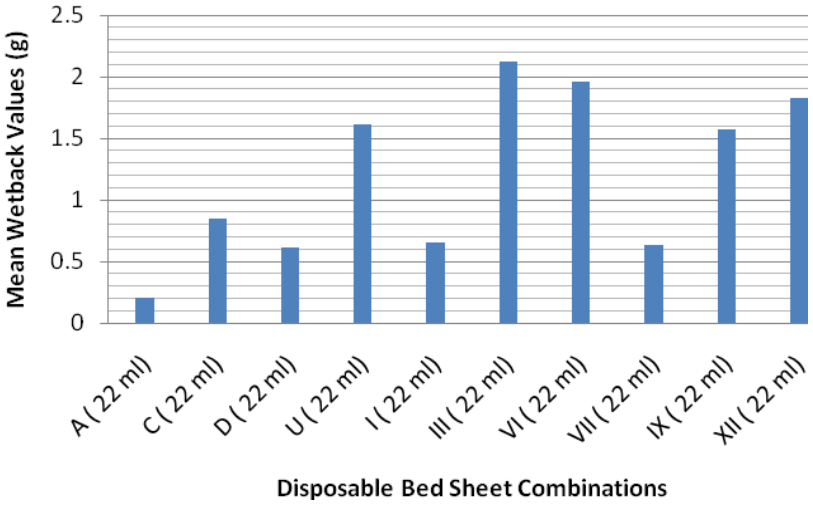


Scheme 3.2: Mean liquid transfer time values (22 ml test liquid).

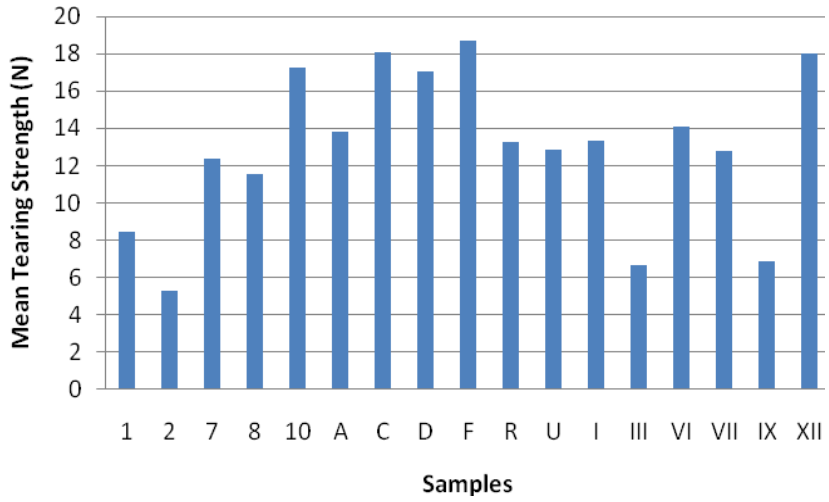
Regarding different multilayer nonwoven combinations which have lower than 60 s mean liquid tranfer values, five sample has been choosen because of having excellent wetback values (below 0.5 g): samples 1,2,7,8 and 10. As a result of this, other tests have been applied on these samples by omitting rest samples.



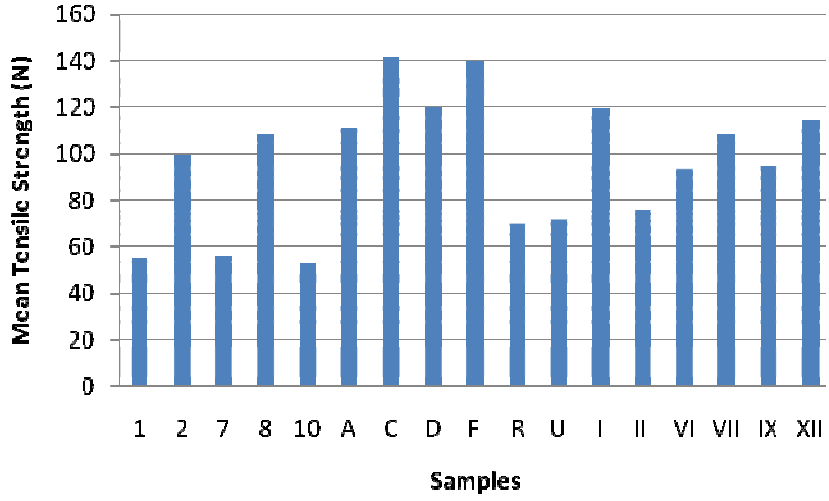
Scheme 3.3: Mean wetback values (5 ml test liquid).



Scheme 3.4: Mean wetback values (22 ml test liquid).

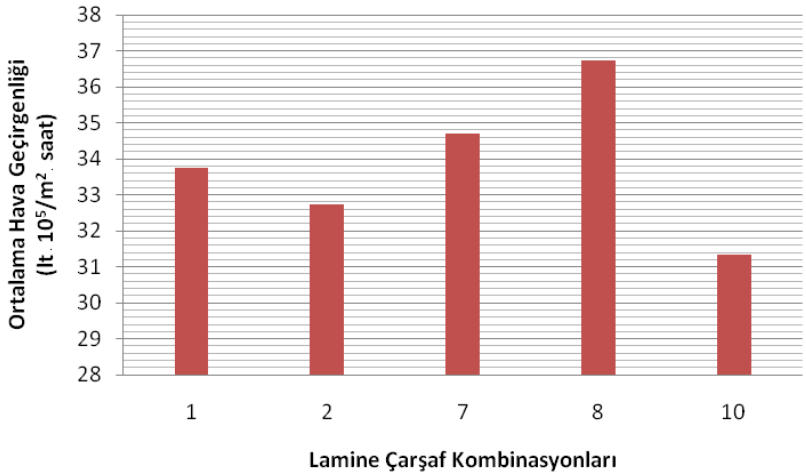


Scheme 3.5: Mean tearing strength values.

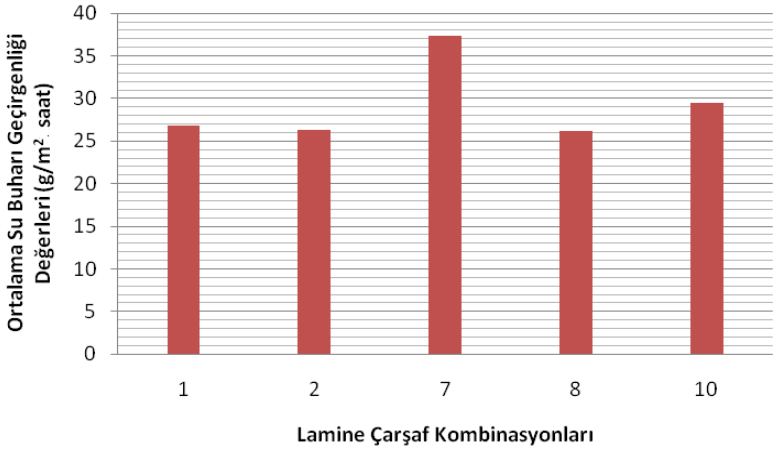


Scheme 3.6: Mean tensile strength values.

As we see in the Schemes 3.5 and 3.6 mean tear and tensile strength values of the samples 1,7 and 10 are moderate while samples 2 and 8 is better. Despite of this, it is not expected to have any problem because of having tearings in width direction and being disposable material.



Scheme 3.7: Mean air permeability values.



Scheme 3.8: Mean water vapour permeability values.

Air and water vapour permeability values of the samples 1,2,7,8 and 10 are very good. Naturally, it is expected that these disposable bed sheets will be comfortable for patients.

Table 3.2: Antimicrobial test results

	Bacteria reduction after 24 h (%)	
Antimicrobial chemical	Treated	Untreated
ISys AG (nanosilver)	99,9	0

Reputex 20 (Polihegzametilenbiguanid)	99,9	0

Antimicrobial tests have been done according to AATCC 100 standart by using Stafilococcus Aureus bacteria which is most common one in hospitals.

3.2 Cost analyze

Table 3.3: Comparison of classical and disposable bed sheets (1)

	Classical Hospital Bed Sheet	Disposable Hydrophilic Antimicrobial Laminated Nonwoven Bed Sheet (Samples 1/ 7/ 8)
Structure	100 % CO, 50 thread/ cm total density,	50-60% PP + 50-40% CV, nonwoven
Usage	30 times washing and reusing	Disposable
Initial Cost (TL) (180x220 cm)	7,7	2,31/ 2,39/ 2,77
Final Cost for 30 washing cycle (TL)	0,79	--

4. CONCLUSIONS

1. The best results belong to the sample 8. Then, sample 7 is coming. Moreover, the sample 1 is also usable despite of having lower tensile and tear strength values compare to samples 8 and 7.
2. When we look at successful samples again we see that the samples are consist of light weight nonwoven layers as shown below:
   a. Plasma and Polihegzametilenbiguanid applied PP upper layer 15 g/ m^2 + CV medium layer 20 g/ m^2 + Bottom Layer 15 g/ m^2 (Sample 1),
   b. Plasma and nanosilver applied PP upper layer 15 g/ m^2 + CV medium layer 20 g/ m^2 + Bottom Layer 15 g/ m^2 (Sample 7),
   c. Plasma and nanosilver applied PP upper layer 15 g/ m^2 + CV medium layer 35 g/ m^2 + Bottom Layer 15 g/ m^2 (Sample 8),

   We can say that costs of the disposable bed sheets will be lower because of being lightweight structure. Beside this, the disposable bed sheet will be more flexible and easy to use. Also, it is significant that all the successfull samples are plasma treated samples. In other words, chemically treated thermalbond hydrophilic samples were not good enough. Moreover, both polihegzametilenbiguanid and nanosilver based antimicrobial agents are effective.

3. When we investigate costs of successful disposable bed sheets we see that they are approximately three times cheaper than classical cotton made bed sheets regarding initial costs but after several washings classical bed sheet is getting cheaper. Considering thirty washing cycle the classical bed sheet is approximately three times cheaper. Despite of that, It can be thought that this cost difference can be ignored if we care about infection risk and hygiene.

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EFFECT OF AMBIENT PARAMETERS ON ELECTROSPUN POLYACRYLONITRILE (PAN) NANOFIBERS

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Abstract

In this study, the effect of environmental temperature and relative humidity on morphology of PAN electrospun nanofibers were investigated. It is observed that as the temperature increases, the fiber diameter increases. The fiber morphology becomes more regular. However, as the humidity increases the fiber morphology becomes worser and the fiber diameter decreases up to 30% relative humidity then starts to increase as the humidity value increases.

Keywords: Electrospinning, PAN, nanofiber, humidity, temperature.

1. Introduction

Electrospinning is a method where nanofibers are prepared from polymer solution utilizing an electrostatic field. The electric field is arranged between a nozzle and a collector and polymer solution is ejected from the nozzle toward the collector due to electric force. The polymer jet undergoes instabilities during electrospinning. Whipping instability, caused by electrostatic repulsion, is largely responsible for high stretching of the jet causing drastic reduction of its diameter. The morphology of nanostructures forming onto the collector varies from droplets (electrospray) to fibers (electrospinning) depending on the solution and process properties [1].

The morphology of electrospun nanofibres are dependent on a number of processing parameters that include:

(a) the intrinsic properties of the solution such as the type of polymer and solvent, polymer moleculaweight, viscosity (or concentration), elasticity, conductivity, and surface tension.

(b) the operational conditions such as the applied voltage, the distance between spinneret and collector (tip-target distance), and the feeding rate of the polymer solution ,the humidity and temperature of the surroundings [2-5]. Polyacrylonitrile (PAN) is the most extensively used polymer in electrospinning because of its excellent properties [6-8]. The effect of the electrospinning jet surrounding (temperature and relative humidity) is one area which is still poorly investigated [9-11]. Any interaction between the surrounding and the polymer solution may have an effect on the electrospun fiber morphology. Therefore, in this study the effect of environmental temperature and relative humidity on fiber diameter and morphology of PAN electrospun nanofibers were investigated.

2. Material and Method

2.1. Electrospinning Process

To conduct the experiment a solution was prepared by dissolving PAN polymer in dimethylformamide (DMF). The solution (10 wt% of PAN) was arranged by stirring magnetically for one hour at a temperature of 90 °C. The high voltage power supply used in the experiment can provide voltages between 0 to 50 kV. The other parameters as such flow rate, the distance between capillary and the collector, voltage were selected as 0.5 ml/hour, 100 mm, 35 kV respectively. The fibers were collected on the aluminum foil in the form of non-woven fabric. To examine the effect of relative humidity its value gradually increased from 25% to 50% with 5% intervals. During this experiment the temperature was held constant at 25 °C. Similarly, to analyze the effect of temperature, the environment temperature was increased 5 °C intervals from 15 °C to 35 °C. The relative humidity was adjusted to 35%.

2.2. Characterization

The morphological appearance of the electrospun PAN nanofiber mats and that of the individual fibers was investigated by a JEOL JSM-6390LV scanning electron microscope (SEM), operating at an acceleration voltage of 10 kV. The diameters of nanofibers were measured using Image-Pro Plus 6.0. 50 measurements were performed and average diameter of the nanofibers was calculated.

3. Result and Discussion

3.1 Effect of Humidity on PAN Nanofİber

As it is seen form Figure 1. when the humidity increases the fiber diameter decreases to a certain value then it increases and the fiber morphology becomes worse. Fibers become coarse, less regular and include more beads.

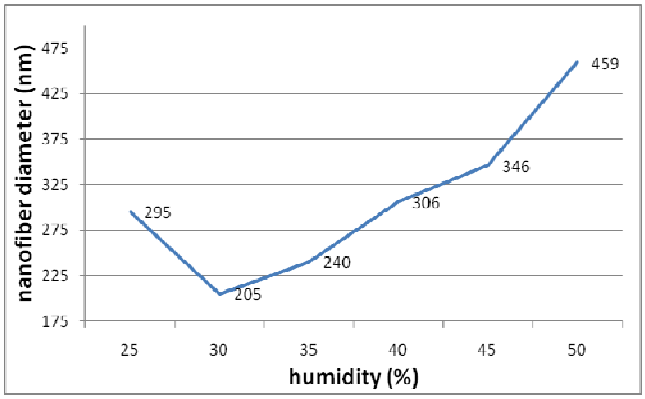

Figure 1. Effect of humidity on PAN nanofıber

However, the best results are obtained at 30% relative humidity.

3.2. Effect of Temperature on PAN Nanofiber

The experimental results show that increasing the temperature has a positive effect on the morphology of PAN nanofibers (more uniform diameter and less beads). However, the most uniform formation is obtained when the temperature is 25°C. As it is seen from ig.2 when the temperature increases the fiber diameter increases.

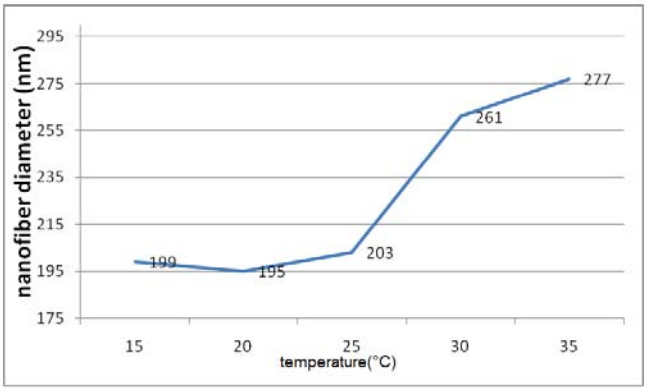

Figure 2. Effect of temperature on PAN nanofiber diameter

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EFFECT OF FRICTION ON FIBER DRAWING PROCESS

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Fiber drawing is an important step in the fiber manufacturing process, especially for technical fibers. In as-spun fibers polymer molecules have very low orientation and such fibers have low crystallinity resulting in low modulus and lower strength. Drawing, when appropriately distributed between different drawing zones, can induce significant molecular orientation and induce a higher degree of crystallinity, resulting in increased modulus and strength. Thus, drawing is an important manufacturing process to make strong fibers.

In a typical drawing process, fibers are passed through a number of rollers, each roller rotating faster than the previous roller, to induce draw. Friction between the fiber bundle and rollers plays a crucial role in fiber drawing process, as the tension induced in the fiber due to the feed roller and take-up roller is responsible for the draw induced in the fiber. Sometimes, localized heat sources are provided to facilitate drawing. We present theoretical models for a two-stage drawing process under various drawing conditions assuming the well established Coulomb friction and a new creep-friction models. Temperature gradients adds another complexity to the problem. It can be shown from theoretical considerations that draw cannot occur outside the rollers when fibers are not subjected to heat sources. Further, the distribution of the draw at various stages can be evaluated using these models. The formation of necks, or sudden draw-down, can be shown and analyzed with these models. Morphological aspects are not included in this work, but the forces and torques that causes drawing was investigated for various drawing conditions. The results will be presented along with parametric studies on the effect of various parameters on the drawing mechanism.

The effect of certain non-dimensional parameters will be highlighted. The case of local heating will add plasticity effects that cannot be readily accounted through simple formulation. Thus a numerical procedure must be incorporated. The complexities involved in the modeling of fibers with regions of unloading will also be introduced in this talk.

EFFECTS OF ALKALINE DYESTUFF ADDITION ON THE NEEDLE ELECTROSPINNING OF POLYACRYLONITRILE NANOFIBERS

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ABSTRACT

In recent years, depending on demands of fiber-based materials having superior quality, production of fibers with nano-scaled dimensions or nanostructured surfaces have gained more importance in worldwide market. Needle electrospinning is a well known nanofiber production method for it's simple set up and relatively lower cost. In this study, the effects of dyestuff addition on the needle electrospinning of polyacrylonitrile nanofibers were investigated. At first, 11 wt % PAN/DMF solutions have been prepared and one solution was colored with basic dyestuff, the other was not. After the polymer solutions were prepared, optimum process parameters such as voltage, feed rate and distance between the collectors for the spinning process were determined. During spinning, it was observed that production was more continuous with colourful solution. According to the results, basic dyestuff addition has an important effect on the viscosity of solution, thickness of nano web, fiber diameter, diameter uniformity and morphology. With addition of dyestuff, PAN/DMF solution viscosity and fiber diameter increased, however, fiber diameter and nano web thickness uniformity decreased and morphology get better (less-beads on string fibers occurs among the resultant fibers). Fiber diameter distribution of nano fibers was showed using histogram diagrams by SPSS statistical program. It was also determined about there is a significant difference between the uniformity coefficient results statistically.

Key Words: polymer, polyacrylonitrile**,** electrospinning, nanofibers

1. INTRODUCTION

In recent years, polymeric electrospun nanofibers are very attractive because of their various application areas such as filtration [1, 2], composites [3, 4], medical areas [5, 6], protective clothes etc. [7]. Electrospinning is a cheap and simple process, capable of producing fibers at nano scale from a variety of polymer/solvent systems. This method was patented first by Formhals in 1934 [8]. Electrospinning method contains high voltage supplier, needle, conductive electrodes and syringe for carrying polymer solution. Firstly high voltage is applied to the polymer solution and voltage difference will be formed between the needle tip and collector electrode. This voltage difference cause the deformation of droplet into a Taylor cone shape [9]. When the electrostatic force overcame the surface tension of polymer solution, jet of solution ejected from the needle tip. And then continuous nanofibers can collected on to the collector electrode.

In literature, there are many studies about electrospinning of polyacrylonitryle nanofibers [10, 11, 12]. However there has been very few work [13, 14] about the production of colourful nanofibers that's why we focused on this subject.

2. MATERIAL AND METHOD

In this study, polyacrylonitril (PAN) (M_w-150 000) was used as a polymer and N,N Dimetilformamide (DMF) (99,8 %) was used as a solvent. Two different solutions were prepared at 11 wt % concentration with dimethylformamide (DMF) solvent. The value of 11 wt % polymer concentration was preferred to consider of the previous studies from literature [10, 11, 12]. Both solutions were prepared at the same conditions except colored one of them adding alkaline dyestuff.

The receipt of dyestuff was given below;
Colour: Dark purplish-red
0.1591 % Yellow (Kemacrly Giollo Oro)
1.9656 % Red (Doracrly Rot)
0.2470 % Blue (Kemacrly Blue)

Then both solutions were stirred 45 hours to obtain homogeneous solution.
The viscosity of the polymer solutions and DMF were measured by using oswald viscosimeter from Chemical Department of Süleyman Demirel University. Times flow of solution and DMF were measured with oswald viscosimeter and spesific viscosity was calculated.

For this study, needle electrospinning method was used which was set up at Textile Engineering department of Süleyman Demirel University, supported by Tübitak project [15] (Figure 1).

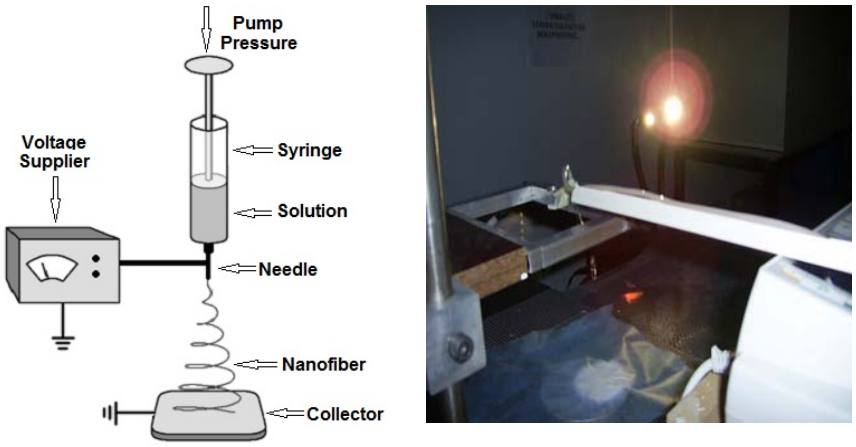


Figure 1. Basic set up of electrospinning (a) and electrospinning used for this study (b).

The solution was placed in a 10 ml syringe fitted with a metallic needle with an inner diameter of 0,7 mm. The syringe was fixed horizontally on the syringe pump. The high voltage power supply (Matsusada Precision Inc) was used. First of all we tried to find optimum process parameters such as voltage, distance between the electrodes etc. (Table 1).

Table 1. Process parameters of the needle electrospinning.

Voltage (kV)	Distance between the electrodes (cm)	Feed rate (ml/h)	Needle diameter (mm)	Electrical area (V/m)	Piston Pressure (kPa)
15	15	3	0.7	100.000	100

The experiments were carried out at room temperature in a vertical position.
The nanofibers were collected on the polypropylene (PP) spunbond nonwoven antistatic material.

The thickness of nanowebs were measured from different six areas by digital micrometer. Average of the results were calculated from these measurements.

The fiber morphology and diameter were determined using a scanning electron microscopy (SEM) (JSM 6060 JEOL) at 30 kV with 3.5 nm resolution. The average fiber diameter was calculated from the SEM photos using Lucia 32 G computer soft ware. From each sample, 100 fibers were used to calculate the average fiber diameter.

Then fiber uniformity was determined using the number and weight average calculations method which was used by Cengiz and Jirsak [16]. And this method has the same principle with molar mass distribution in chemistry science.

3. RESULTS AND DISCUSSION

3.1 Viscosity

After prepare the solutions, the passing time of flow solutions and solvent was determined using Oswald viscosimeter (Table 2).

Table 2. Passing time of the solutions.

Sample	Passing Time
Dimetylformamid (T_0)	2.38 seconds
Colourless PAN (T)	473 seconds
Colourful PAN (T)	1051.65 seconds

Then spesific viscosity values were calculated using the formula is given below;

Spesific viscosity= T / T_0

Table 3. Spesific viscosity of the solutions.

Sample	Spesific Viscosity
Colourless PAN (T)	198,74 seconds
Colourful PAN (T)	441,87 seconds

As it has seen from Table 3, the viscosity of colourful polymer solution is higher, because a second material was added and molecular weight of dyestuffs are very high so flow of dyestuff is decrease. As a result of interaction between the dyestuff and polymer macromolecules, molecular weight of the solution was increased. That was rised number of intermolecular bondings. Because of that flow resistance of polymer increased.

3.2 Thickness of Nanowebs

After produced the nano webs (Figure 2), thickness of webs were determined using digital micrometer.

a) Colourful nano web b) Colourless nano web

Figure 2. Produced nano webs.

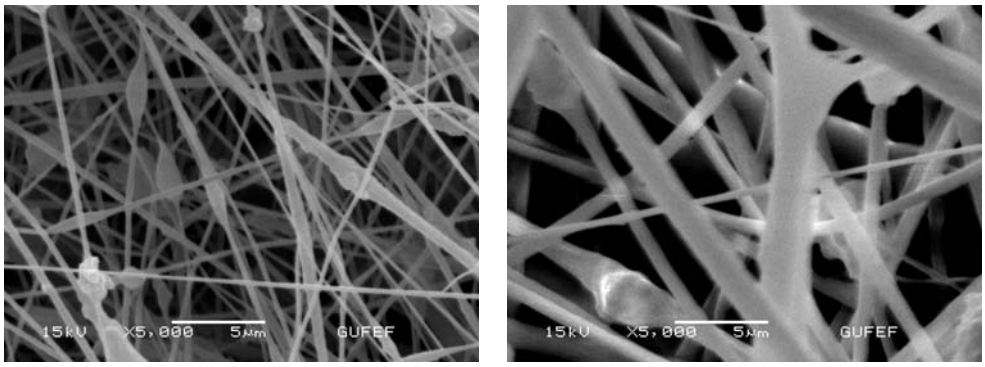
According to the measurements, nano web thickness increase with adding dyestuff to the solution but web density uniformity increase (Table 4).

Table 4. Thickness values of nano webs.

Measurement	Colourless PAN (mm)	Colourful PAN (mm)
	30 min.	30 min.
1	0.07	0.07
2	0.06	0.08
3	0.09	0.06
4	0.08	0.07
5	0.05	0.08
6	0.08	0.09
Average	0.072	0.075
SD	0.015	0.011
CV(%)	20.5	13.9

3.3 SEM Characterization

In Figure 3, there are SEM images of colourless and colourful PAN nanofibers. From these images, it can be seen that fiber diameter increases with dyestuff addition. Using Lucia program, average fiber diameter of colourless nano fibers is 247 nm and colourful nano fibers is 745 nm. Dyestuff molecules and PAN molecules were connected with eachother and so the structure of main molecules got bigger.



(a) (b)

Figue 3. SEM Images of nanofiber samples of PAN (5.000x) a) Colourless, b) Colurful.

Also we analyzed fiber diameter histograms as it is shown in Figure 4 and 5.

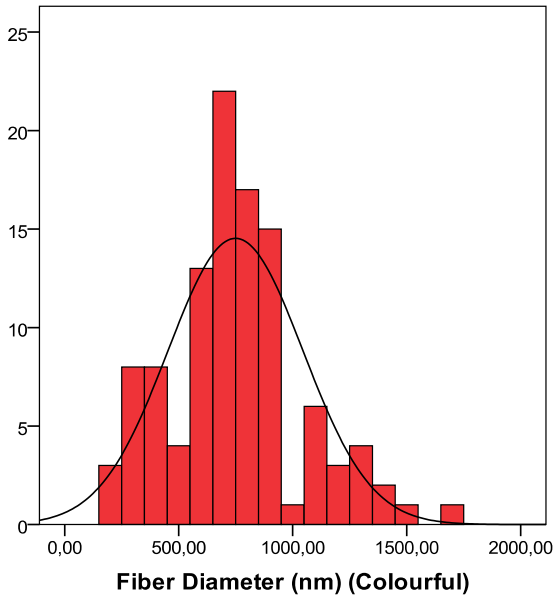


Figure 4. The fiber diameter distribution of colourful PAN.

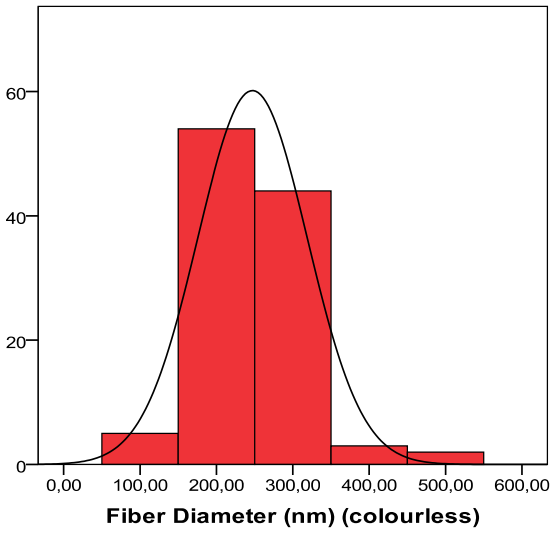
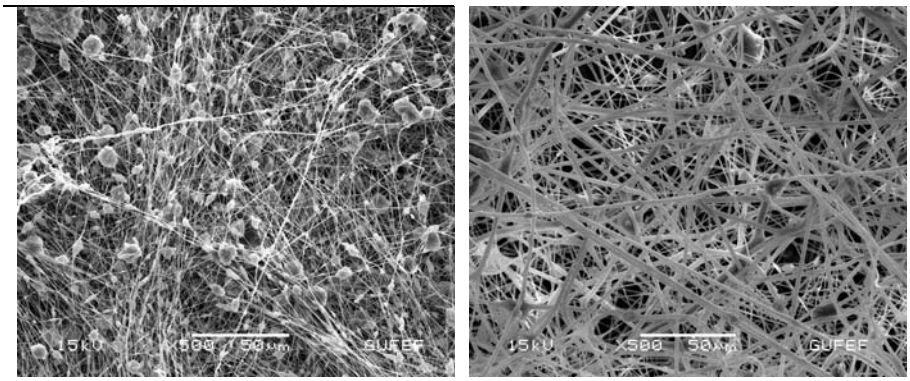


Figure 5. The fiber diameter distribution of colourless PAN.

Then fiber uniformity was determined using the number and weight average calculations. According to the results, number average and weight average of fiber diameter increase with dyesuff addition. When we analyzed uniformity coefficient of PAN nanofibers, colourful nano fibers is 1.162 and colourless is 1.083. It means that colourful nanofibers are more uniform than colourless fibers. It was also determined about there has been a significant difference between the uniformity coefficient results statistically.

500x magnification of SEM images give information about the fiber morphologies (Fig.6).



(a) (b)

Figure 6. SEM Images of nanofiber samples of PAN (500x) a) colourless, b) colourful.

It is very clear to see from Figure 6, colourless nanofibers have many beads but colourful has not.

4. Conclusion

This study was carried out to determine the effect of basic dyestuff addition to the polymer solution on the viscosity, spinning process, web density and fiber properties (diameter, uniformity etc.). At first solution viscosity, nano web thickness and fiber properties were determined. According to the results; solution viscosity and fiber diameter increase and fiber morphology is better (less-bead) with dyestuff addition. When we analyzed fiber diameter uniformity and nano web thickness, it was found that addition of dyestuff decreased these parameters. During spinning process, it was observed that colourful solution spinning is more continuous than colourless one. Consequently, dyestuff addition to the solution has an important role on the viscosity and fiber properties. For further studies; it is planning to perform this work in depth.

Acknowledgement

The authors would like to thank Mustafa Karaboyacı from İpliksan Company, Chemistry Department of Süleyman Demirel University, Biology and Chemistry Department of Gazi University for their supports during our study.

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EFFECTS OF PROCESS PARAMETERS ON MECHANICAL PROPERTIES OF COATED FABRICS

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The physical and mechanical properties of coated fabrics depend on the properties of base fabric, coating formulation, coating technique and process parameters during coating. By choosing the right fabric substrate and coating material and method, the fabric will exhibit desired mechanical properties.

The aim of this study is to examine the influence of coating process parameters on mechanical properties of fabrics. For this purpose, a systematically coated fabric production was performed by using two coating materials as polyurethane and polyurethane/silicone combination. Two cotton woven fabrics were used as base fabrics. Production parameters of two different coating techniques such as rotary screen coating and direct coating were varied in controlled conditions during coating processes giving twenty four test samples. Breaking strength and elongation, tear strength, bursting strength, bending rigidity, abrasion resistance tests were carried out and the results were evaluated to determine the effectiveness of the coating components.

Keywords: coating techniques, coated fabric, mechanical properties

1. Introduction

Coated fabrics have wide applications in fields such as medical substrates, protective clothing, sportive textiles, flexible membranes for civil structures, industrial fabrics and geotextiles, but nowadays, coated fabrics are widely used in protective and outerwear garments. The coated fabrics which are designed for garments against to foul-weather conditions like rain, wind and provide protection against loss of body heat are widely used today. For these functional garments there are two types of coated fabrics; impermeable coated fabrics and breathable fabrics are available [9]. Some functional features of coated fabrics stand out with their related end-uses but nevertheless fundamental mechanical and physical properties of fabrics are always critically important for their performances.

Coated fabrics behave during deformation much different from uncoated fabrics. To achieve reasonably good quality and to predict durability of such textile goods, it is essential to have enough understanding of their behaviour during wear. As a result, interest in this area of research has recently increased [1]. Some of these researches was studying the effects of membrane during lamination or coating material during coating processes [2, 3 and 5]. Cho et al. [6] tried to coat fabrics with shape-memory polyurethane and reported that the breaking strength and elongation were primarily depended on the PU hard-segment content in coating formula. Hu and Xu [7] studied effect of test method and tearing direction on tearing properties of PVC coated multi-axial warp knitted glass fabric and in their study, highest tearing strength was obtained in diagonal direction of the coated fabrics.

Some researches focused on the anisotropic behavior of coated fabrics. Masteikaite and Saceviciene [1] examined the influence of structural characteristics of coated fabrics and laminates on the tensile property and analyzed anisotropy of materials. Chen et al. [4] examined tensile performance of PVC coated woven fabrics under multiaxial loads and found out that tensile performance under bi- and multiaxial loads are much better than those under unaxial loads. Luo et al. [8] further examined tensile properties in seven in-plane directions (0^o, 15^o, 30^o, 45^o, 60^o, 75^o and 90^o with the weft direction) and the influence of initial crack length and crack propagation on tearing properties of PVC coated biaxial warp knitted polyester fabric. The highest breaking strength is obtained at warp direction whereas the lowest at 45^o along with the weft direction.

The aim of this study is to examine the effect of process parameters on mechanical properties of coated fabrics under systematically changing production conditions. In the study, the effect of coating on the base fabric's mechanics was investigated first, and then the effects of the coating parameters individually and their interactions were evaluated by variance analysis.

2. Materials and Methods

2.1. Materials

In this study, coated fabrics are produced under controlled production conditions by using two cotton base fabrics (Table 1) with systematically changing coating parameters. After coating, the coated fabrics were dried at 140°C and cured at the speed of 24 m/min for 45 seconds at 170°C and

twenty four test fabrics were handled. The production plan and test sample codes are given in Table 2.

Table1. The physical properties of base fabrics

Fabric code	Content	Weave	Yarn Setting (threads/cm)		Yarn linear density (tex)		Mass per unit area (g/m^2)
			Warp	Weft	Warp	Weft	
S0	100% cotton	Plain	51	29	14.8	14.8	122.0
K0	100% cotton	Plain	39	21	2x29.5	29.5	185.5

Table 2. The production plan of the test samples

Codes of test fabrics	Coating material	Coating technique	Production parameters
SPR1, SPR2, SPR3	PU	Rotary screen	Press: 2, 4, 6
SPB1, SPB2, SPB3	PU	Blade	Contact angle:20, 25, 30
SSR1, SSR2, SSR3	PU/silicone	Rotary screen	Press: 2, 4, 6
SSB1, SSB2, SSB3	PU/silicone	Blade	Contact angle:20, 25, 30
KPR1, KPR2, KPR3	PU	Rotary screen	Press: 2, 4, 6
KPB1, KPB2, KPB3	PU	Blade	Contact angle:20, 25, 30
KSR1, KSR2, KSR3	PU/silicone	Rotary screen	Press: 2, 4, 6
KSB1, KSB2, KSB3	PU/silicone	Blade	Contact angle:20, 25, 30

2.2. Methods

All test fabrics were conditioned in a standard atmosphere of 65±2% RH and 20±2°C. After this step breaking strength and elongation, tear strength, bursting strength, bending rigidity, abrasion tests were carried out and the results were evaluated by using variance analysis to determine the effect of the coating components.

All properties measured in the context of the study and related standards are given in Table3.

Table 3. The tests and related standards

Property	Related Standard
Mass per unit area	ASTM D 751-06
Thickness	ISO 5084
Air permeability	ISO 9237
Breaking strength and elongation	ASTM D 751-06
Tear strength	ASTM D 751-06
Bursting strength	ASTM D 751-06
Bending rigidity(Stiffness)	ASTM D 1388-96
Abrasion resistance	ISO 12947-3

Following steps were applied during experimental study:

1. The specimens of each sample were cut in square shape (7x7 cm^2) and the thickness of each sample was measured using James Heal RxB Cloth Thickness Tester under the 5g/cm^2 pressure. To evaluate the homogeneity, the fabric thickness and air permeability were measured on 10 different parts of each sample by using Textest 3300 Air Permeability Tester (test area=20 cm^2, test pressure=100Pa).

2. The breaking strength and elongation, tear strength and bursting strength were measured using Instron 4411 model tensile testing machine, the cross-head speed was kept constant at 300mm/min during all strength tests. Tensile strength was measured in three directions such as warp, weft and bias. Tensile strength specimen geometry in bias direction is shown in Figure 1.

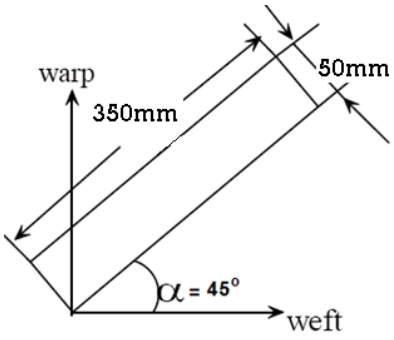

Figure 1. Tensile strength specimen geometry in bias direction.

3. The geometry of the test specimen used in the experiments is given in Figure 2 and the initial length between jaws was kept at 25mm and the tearing of the test specimen was calculated from the average of the five highest peak loads of resistance (not including the initial peak) registered during the separation of the tear according to ASTM D 751-06.

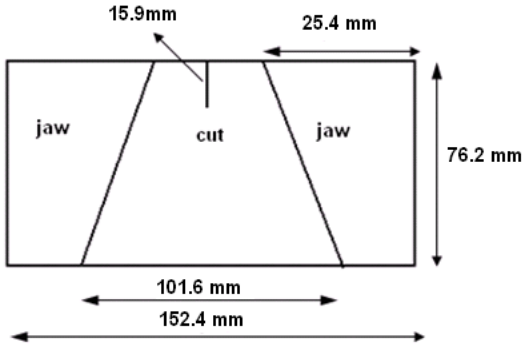

Figure 2. Tear strength specimen geometry (ASTM, 2006)

4. For bursting strength, force required for bursting that was perpendicular to the fabric surface was measured.

5. Bending length was measured according to the Cantilever method in three different directions (warp, weft and bias) and fabric rigidity was calculated from warp and weft bending rigidity.

6. The specimens were abraded to 20000 cycles under the pressure 9kPa and were weighed before test, after 10000 cycles and finally 20000 cycles. The weight loss in percentage were calculated.

3. Results and Discussion

Analysis of variance was applied for statistical evaluation to identify the differences between coating components (base fabric, coating material, coating technique and production parameters) for the mechanical properties examined in this study.

Before statistical evaluation of mechanical properties, fabric weight, fabric thickness and fabric air permeability are tested to evaluate the homogeneity of coating. With reference to results of variance analysis of these features, there is no statistically significant difference amongst repeats for 95% confidence level. After this procedure, breaking strength and elongation, tear strength, bursting strength, bending rigidity and abrasion tests were carried out and the results were evaluated to determine the effect of coating components.

3.1. Effect of Coating Parameters on Fabric Breaking Strength

When comparisons between base fabrics and coated fabrics are examined, it is determined that noticeable changes in breaking strength can be seen by coating in Figure 3. By restricting warp and weft yarn movement in fabric structure, coating causes fabric break as a whole and the yarns break at one time. After coating, generally decreases in base fabric K0 were observed when increments in base fabric S0 were the case. For both of two base fabrics, decreases in breaking elongation especially in warp direction were obtained and changes in breaking elongation in weft and bias (45^o) directions were similar after coating by changing parameters (Figure 4).

According to the variance analysis results, the effects of base fabric and coating material on breaking strength are statistically significant at 95% confidence level ($p<0.05$). Especially for PU/silicone coated fabrics decrease in breaking strength was observed, whereas increase for PU coated fabrics was obtained. When the effect of coating technique separately analyzed, the change of blade contact angle significantly affects breaking strength at 95% confidence level ($p<0.05$) although the change in press have not significant effect on breaking strength for fabrics produced by rotary screen coating technique ($p>0.05$).

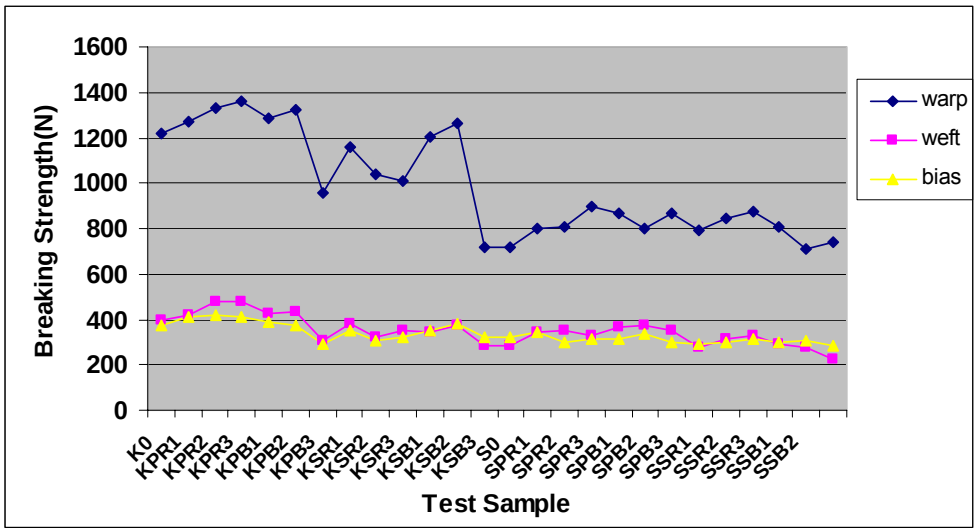

Figure 3. The breaking strength of base and coated fabrics

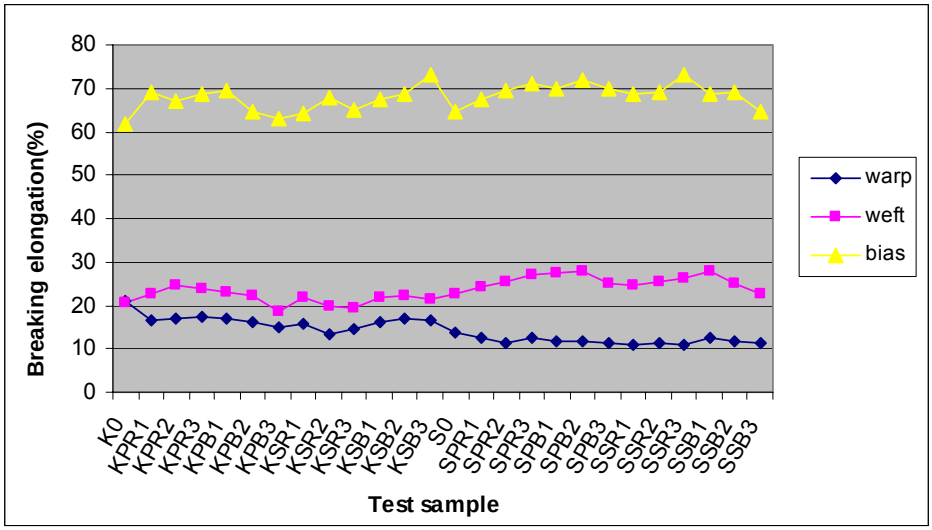

Figure 4. The breaking elongation of base and coated fabrics

3.2. Effect of Coating Parameters on Tear Strength

Coating has a very clear influence on tear strength of coated fabrics because coating material penetrates into the fabric structure and prevents the yarn's mobility in fabric structure and as a result, coating process makes the fabric more rigid and inflexible. Generally, this case causes decrease in tear strength of coated fabrics. In this study the base fabrics had plain weaves so the tear strength of fabrics were low at the beginning and also after coating decreases in tear strength were observed as seen in Figure 5. It is possible to say that coating technique and coating material were important when tear strength values were examined. The effect of production parameters of rotary screen coating depends on coating material and significantly affects tearing strength of polyurethane/silicone coated fabrics at 95% confidence level but not tearing strength of polyurethane coated fabrics ($p>0.05$). For direct coated fabrics, this case is just the opposite. According to the statistical analyses results, all coating parameters have significant effect on tear strength at 95% confidence level.

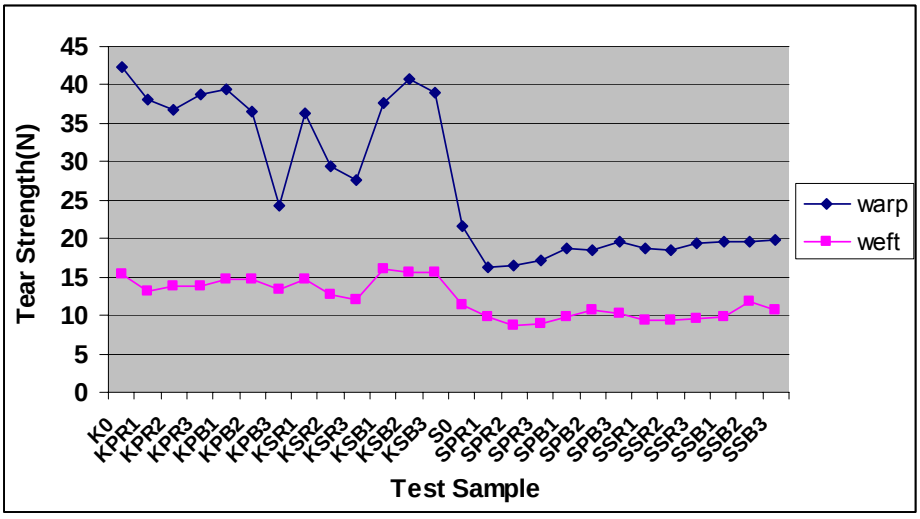

Figure 5. Tear strength of base and coated fabrics

3.3. Effect of Coating Parameters on Bursting Strength

When bursting strength values are examined, different changes for two base fabrics were observed. The results of variance analysis show that the effects of all coating parameters (base fabric, coating material, coating technique and production parameters) on bursting strength of coated fabrics are statistically significant at 95% confidence level but the effect of the interaction of all coating parameters are not ($p>0.05$). Coating improves the bursting strength of fabrics as seen in Figure 6; it reduces the flexibility of fabric and yarn's mobility, so under the applied force, the yarns in fabric structure suddenly break and bursting strength increase with the penetration of coating material into the base fabric.

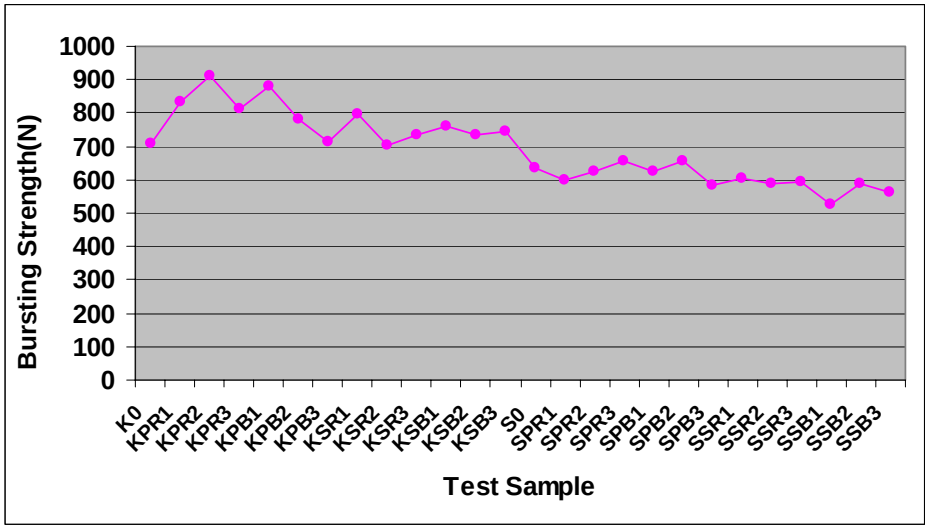

Figure 6.The bursting strength of base and coated fabrics

3.4. Effect of Coating Parameters on Bending Rigidity

As it is clearly seen in Figure 7, coating causes stiffness by penetration of the coating material and increments are determined for the bending rigidity of coated fabrics. In that case, it can be said that resin penetration is important and can be taken under control by making changes in coating technique and its parameters. When the press magnitude of rotary screen coating rises up, increments in bending rigidity for KPR3 and SPR3 samples were determined in the present study. For KPB3 and SPB3 samples, less blade contact angle causes decrease in bending rigidity according to resin penetration. According to the variance analysis results, the effects of all coating parameters (base fabric, coating material, coating technique and its production parameters) are statistically significant on bending rigidity of coated fabrics at 95% confidence level. Although the effects of these coating parameters are separately significant, the interaction of coating material and coating technique production parameters is not statistically significant ($p>0.05$).

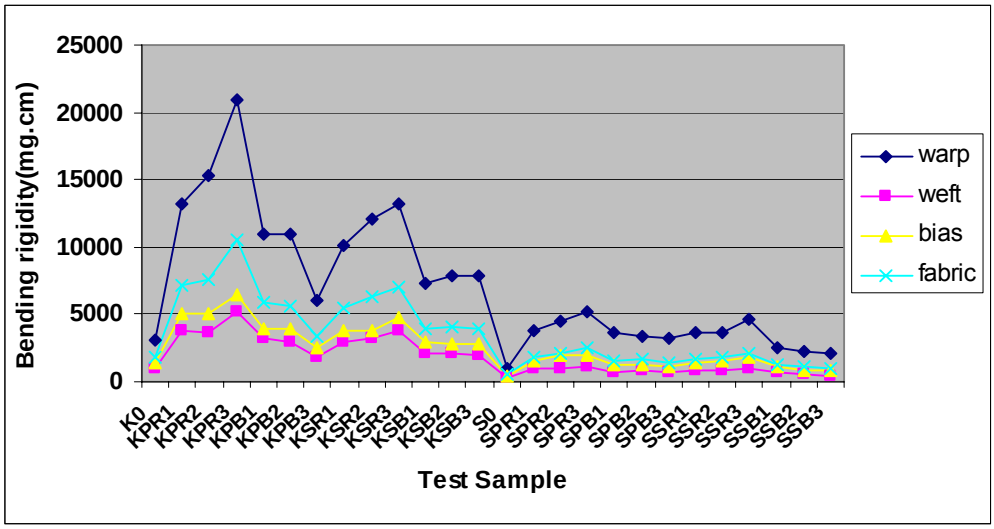

Figure 7. The bending rigidity of base and coated fabrics

3.5. Effect of Coating Parameters on Fabric Abrasion

After abrasion cycles, it was observed that coating enhanced the abrasion resistance of fabrics and prevents weight loss as it can be seen in Figure 8. If different abrasion cycles are compared, it is possible to say that 10.000 cycles didn't make a noticeable change in weight loss and in fabric appearance, but after 20.000 cycles brightness and smoothness was seen on the surface of coated fabrics. The results of variance analysis show that base fabric, coating material and technique have statistically significant effect on abrasion resistance after 20000 cycles abrading of coated fabrics. For 10000 cycles abraded coated fabrics, the effect of coating parameters on abrasion resistance are not statistically significant at 95% confidence level ($p>0.05$) except for base fabric.

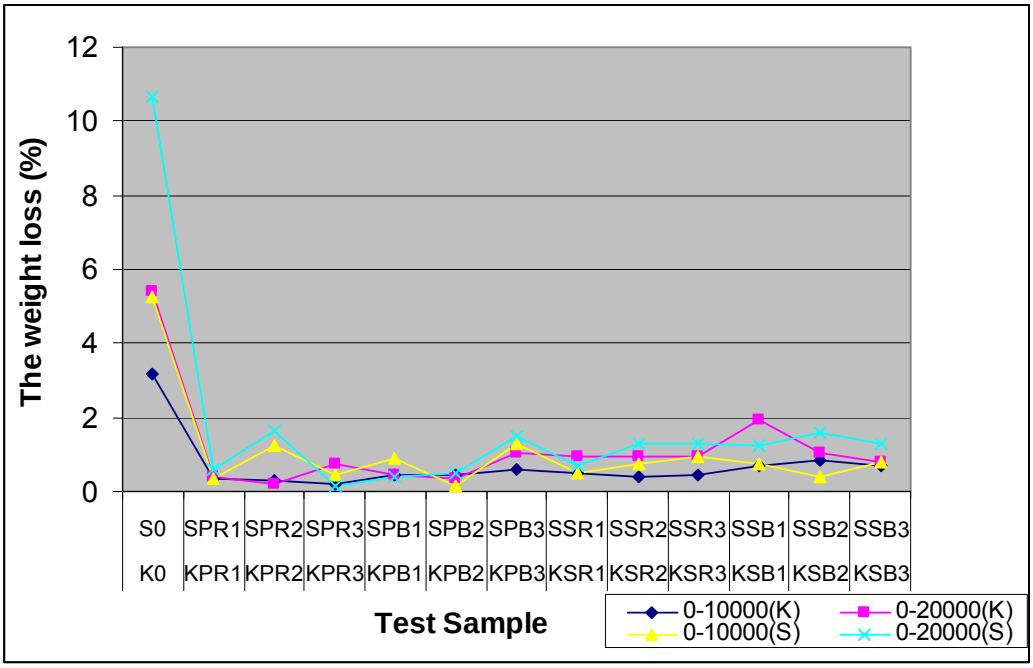

Figure 8. The abrasion resistance of base and coated fabrics

4. Conclusion

In this study, we have investigated the effect of coating parameters on mechanical properties of coated fabrics suitable for outerwear. For this purpose, a systematic production plan was applied. As a conclusion it is necessary to say the mechanical properties of coated fabrics are differently influenced by coating components. The breaking strength of almost all fabrics increases by coating application and the change in tensile properties is affected by base fabric, coating material, coating technique and coating process parameters. The breaking elongation reduced as a result of stiffening after coating. Tear strength, based on the ability of yarn movement, is affected by all coating material and dramatically decreased but the bursting strength is changed positively and negatively by coating. Coating that causes fabrics stiffer and more rigid structure, makes striking increases in bending rigidity of fabrics. With the change of coating technique and adjustments of process parameters, the penetration of coating resin can be taken under control. Finally, coating improves abrasion resistance of fabrics. After coating, the weight losses due to abrading becomes lesser rather than base fabrics, but the changes are slightly happens, brightness and smoothness are observed.

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ENHANCEMENT OF THE MECHANICAL AND VIBRATIONAL PROPERTIES OF GLASS/POLYESTER COMPOSITES VIA MATRIX MODIFICATION

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Abstract

Enhancement of the mechanical and vibrational properties of glass/polyester composites was aimed via matrix modification technique. To achieve this, unsaturated polyester was modified by incorporation of oligomeric siloxane in the concentration range of 1-3% by weight. Modified matrix composites reinforced with woven roving glass fabric were compared with untreated glass/polyester in terms of mechanical and interlaminar properties by conducting tensile, flexure, and short-beam shear tests. Scanning electron microscopy (SEM) was utilised to capture images of fractured composite surfaces. Furthermore, the effect of oligomeric siloxane incorporation on the vibrational properties of the composites was investigated by experimental modal testing. Evaluation of the mechanical test results revealed an improvement with increasing concentration of oligomeric siloxane in polyester. Tensile, flexural, and interlaminar shear strength (ILSS) values of the composite increased by 16, 15 and 75 %, respectively, with the incorporation of 3% oligomeric siloxane into polyester. These increases in ILSS as well as in tensile and flexural properties were considered to be an indication of better fiber/matrix interaction, which was also confirmed by SEM images. The natural frequencies of the composites also increased with increasing siloxane concentration.

Keywords: composites; matrix modification; polyester; glass fabrics; mechanical; vibrational.

ENZYMATIC MODIFICATION OF SYNTHETIC FIBRES

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Abstract

Synthetic fibres made of polyalkylene terephthalate are extensively used in the textile industry. The fibres show many advantageous properties such as excellent mechanical strength, low shrinking and high chemical resistance. However, their hydrophobic nature and crystallinity also results in undesirable textile characteristics that presently need to be improved by severe and difficult to control chemical and physical treatments to ameliorate their surface properties and performance characteristics.

Recently, the discovery of enzymes able to modify the surface of synthetic fibres has opened new prospects for the development of environmentally friendly targeted fibre functionalization processes. While several enzymes have been identified to partially hydrolyze polyester fibres, the challenge exists now to develop improved and tailor-made biocatalysts suitable for employment in industrial processes.

1. Introduction

The worldwide production of synthetic fibres is expected to reach 30 million tons in 2011. The majority of these fibres are made of polyethylene terephthalate (PET), a thermoplastic polymer composed of terephthalic acid and ethylene glycol.

Fabrics woven from PET thread or yarn are used extensively in apparel and home furnishings, and as cushioning and insulating material while industrial polyester fibres and yarns are used in tyre reinforcements, coated fabrics and plastic reinforcements.

The European textile industry, composed of mainly small and medium enterprises, is facing high price pressures for its products due to increasing costs for salaries and environmental constraints. This has resulted in an offshoring of textile production to low-income countries, especially in Asia. To increase competitiveness, the European industry is heavily relying on the development of environmentally friendly production processes and innovative products such as functional textiles with new user-specific properties. These novel textile products find a growing number of applications in technical and medical areas, for functional clothing and for the production of composite materials. A biofunctionalization of synthetic fibres is aiming at the production of textile materials with attractive new properties by employing environmentally friendly and energy-saving biotechnological methodologies.

2. PET fibre functionalization

PET is an extremely hydrophobic polymer that can occur in an amorphous and in a semi-crystalline form. PET fibres have many advantageous properties for applications in textiles: PET fabrics resist wrinkling, are easy to launder and dry quickly. They are resistant to stretching and shrinking, show high tensile strength, and are endurable and resistant against many chemicals. However, the hydrophobic character of the fibres results in a very low water absorption ability resulting in deficiencies in wearing comfort and oily stain removal. By increasing the hydrophilicity of the surface of the fibres, products with improved moisture take-up, breathability and dyeability can be obtained. Furthermore, the modified surfaces can be coated with

biological active compounds to obtain materials with new functional properties (Goddard and Hotchkiss 2007).

A modification PET fibres using aggressive wet chemical methods has the disadvantage of requiring large amounts of chemicals and energy and leads to fabric weight and strength losses of the material (Zeronian and Collins 1989). The surface hydrophilicity of PET textiles can also be modified using plasma treatments. While this is a dry method not requiring water or chemicals, it is difficult to operate continuously and the treatment has to be carefully controlled (Goddard and Hotchkiss 2007).

3. Enzymatic fibre surface modification

The use of biocatalysts represents an environmentally friendly, energy- and material-saving alternative for the surface functionalization of polyester fibres. Enzymatic desizing of textiles using amylases, the scouring of natural fibres with pectinases and cellulases, and softening of wool with proteases have already been successfully applied in the textile finishing industry (Araujo et al. 2008). Due to the high recalcitrance of synthetic aromatic polymers, an enzymatic modification of PET has previously not been considered as possible.

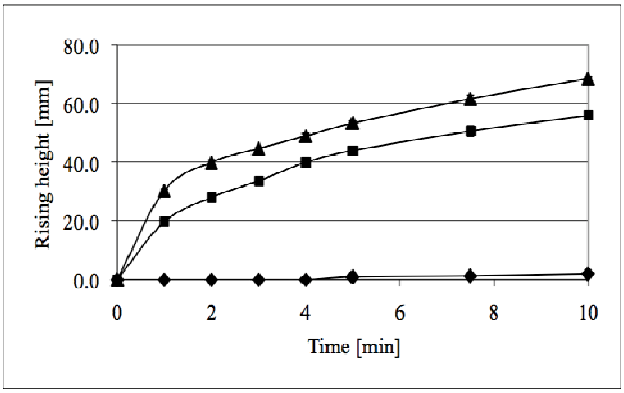

Fig. 1. Rising height of water in PET fabric swatches treated with a cutinase preparation from *T. fusca* ■; NaOH (2 M, 1 h), σ; untreated control, ◆. Enzyme treatment for 48 h resulted in increases in rising height of water comparable to a chemical treatment with NaOH (2M, 1h) (Alisch-Mark et al. 2006).

However, a number of enzymes able to attack PET and other synthetic polymers, most of them from microbial sources, have been identified recently (Gübitz and Cavaco-Paulo 2008). The most effective enzymes for the modification of PET are cutinases, enzymes able to hydrolyze cutin, a plant polyester (Purdy and Kolattukudy 1973).

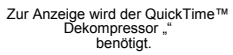

Fig. 2. Colour intensity increase measured by reflectance spectrophotometry of PET fabric dyed with a reactive dye following incubation with a cutinase for 0-170h (O´Neill and Cavaco-Paulo 2004).

The PET-hydrolyzing activity of cutinases from *Fusarium solani* f. sp. *pisi, Pseudomonas mendocina*, *Thermomyces (*formerly *Humicola) insolens* and *Thermobifida fusca* has been studied in detail (Vertommen et al. 2005, Ronkvist et al. 2009, Chen et al. 2010). The partial enzymatic hydrolysis of the PET fibres results in an increased surface hydrophilicity indicated by improved water absorption and decreased wetting times of the material (Yoon et al. 2002, Alisch-Mark et al. 2006, Liu et al. 2008, Eberl et al. 2009) (Fig. 1). The treated fabrics also show a reduced pilling (an undesired build-up of entangled fibres on the surface of PET fabrics) and a decreased oil stain retention (Yoon et al. 2002, McCloskey and Jump 2005).

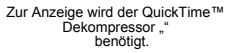

Fig. 3 Thermostability of cutinases from *T. fusca* Tfu_0882 (△), *T. fusca* Tfu_0883 (◇) compared to the cutinase from *F. solani* f. sp. *pisi* (□) at 60 °C (*A*) and 40 °C (*B*). (Chen at al. 2008).

The enzymatic hydrolysis of PET ester bonds creates hydroxyl and carboxylic acid groups on the fibre surface. These can be directly determined by measuring the increase in colour intensity by reflectance spectrophotometry following dyeing with a reactive dye (Fig. 2). The results obtained with different cutinases have further confirmed that a partial hydrolysis of the polyester surface occurs by treatment with the enzymes (O´Neill and Cavaco-Paulo 2004, Alisch-Mark et al. 2006, Eberl et al. 2009).

The extent of an enzymatic hydrolysis is strongly depending on the crystallinity of the PET polymer and on the reaction temperature. Cutinases able to hydrolyze PET at temperatures close to the glass transition temperature of amorphous PET have been described recently (Alisch et al. 2004, Svendsen et al. 2005, Chen et al. 2008) (Fig. 3). An enzymatic hydrolysis of PET has shown to be strongly enhanced when the treatment was performed above 65°C (Ronkvist et al. 2009).

The recent results obtained on the enzymatic modification of PET indicate that the presently used problematic chemical and physical processes for surface functionalization of PET fibres can be replaced by an environmentally friendly and mild biocatalytic process. The treatment times of PET fibres or fabrics with enzymes reported so far are however still too long for a viable industrial application. A prerequisite for a further development will be a successful upgrading to

the biofunctionalization process by identifying and designing new and highly active thermostable enzymes with improved PET-hydrolyzing properties.

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FILTRATION PERFORMANCES OF ELECTROSPUN PAN NANOFIBERS

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ABSTRACT

PAN (poly-acrlyo-nitrile) solutions in different concentrations and viscosities were prepared and electrospinned to produce nanofibers. SEM images of nanofibers were taken and effect of process parameters (viscosity, voltage and tip to collector distance) were observed. According to SEM images of diameter scales, at the point of maximum concentration (%15), minimum distance (10 cm) and maximum voltage (35kV), the maximum nanofiber diameter was 658 nm and the average nanofiber diameter was the highest results of all scales. Decreasing tip to collector distance shortened flying time of the polymer solution, so evaporation of solvent. As a result nanofiber could not dried and branched to produce thinner fiber diameters. Also results showed that increasing concentration caused to thicker nanofiber diameters. At %13 and %15 concentrations, the difference of nanofiber diameters was seen clearly. At the point of %15 concentration and 20 cm of tip to collector distance, the maximum nanofiber diameter was 530 nm, and same distance and %13 concentration the maximum nanofiber diameter was 399 nm. Besides, increasing voltage had impact on fiber uniformity causing higher deviations. Nanofibers in different concentrations such as %13 and %15 have different average nanofiber diameters. But the effect of distance could not seen clearly. Generally, the results showed that increasing distance caused to thinner fiber diameters. PAN nanofibers that could not break up and snapped, their cross section had a shape of 8. Besides, it was observed that they had cylindirical shape in the case of finishing separation. For example; in the case of the process parametres %13 concentration, 30 kV and 10cm distance, the images of cross section PAN nanofibers were taken and both shapes were observed. Besides, two dimensional and three dimensional SEM images were taken of PAN nanofibers that have different voltage, concentration and distances, so similarities were compared. We made some tests to determine the filtration performances of electrospun PAN nanofibers.

In this study, as a substrate material 20 g/m^2 PP (polypropylene) meltbown surfaces were used. According to SEM images of these fibers, meltblown fiber diameters were changed from 2 micron to 6 micron. Electrospun nanofibers were drawn onto PP meltblown surfaces, these surfaces were covered by PP meltbown materials, so nanofibers were sandwiched and protected against to abrasions and snaps. Filtration tests were done at constant pressure of 400 Pa for different weight of nanofiber layers. Double nanofiber layer surfaces have much more effective filtration efficiencies than single layer surfaces.

Keywords: Electrospinning, nanofiber, PAN, SEM, filtration

FUNCTIONAL POLYMERIC NANOFIBERS BY ELECTROSPINNING

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ABSTRACT

Electrospinning is a versatile and cost effective technique for producing nanofibers. This technique is very promising since it facilitates to produce multi-functional nanofibers from various polymers, polymer blends and composite solutions, etc. In this technique, a continuous filament is electrospun from polymer solution or polymer melt under a very high electrical field which resulted in the form of a web consisting of nanofibers. Nanofibers/nanowebs produced by electrospinning technique have several remarkable characteristics such as very large surface area to volume ratio, pore size within nano range, unique physical performance along with the design flexibility for chemical/physical functionalization. Here, we summarize our recent studies on the development of functional nanofibers by electrospinning technique and their potential applications in functional textiles, membranes/filters, biotechnology, etc.

Key Words: electrospinning, nanofiber, nanowebs, nanofiltration, functional textile

1. INTRODUCTION

Electrospinning is a versatile and cost-effective technique for producing nanofibers from a wide range of materials such as natural/synthetic polymers, sol-gels, ceramics, metal oxides and composites. In this technique, nanofibers are produced under a very high voltage from polymer solutions or polymer melts. Polymer/solvent types and electrospinning process parameters such as; applied voltage, feed rate, tip-to-collector distance determine the final structure of electrospun nanofibers. Electrospun nanofibers/nanowebs have unique properties such as very large surface area, nano-porous structure and design flexibility for specific functionalization, etc. Therefore, electrospun nanofibers/nanowebs show superiority to conventional textile materials which make them more attractive for many application areas such as filtration, biomedical, functional textile and energy, etc [1-5].
In our work, we have produced functional electropun nanofibers/nanowebs from many different kinds of natural/synthetic polymers and we investigated their potential applications in textiles, filtration, biomedical and packaging.

2. EXPERIMENTAL

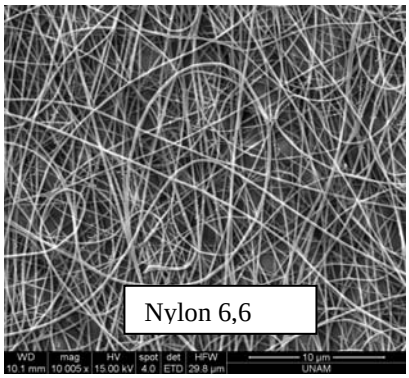
We have obtained functional nanofibers/nanowebs from various types of polymers by electrospinning technique. The polymers that we have electrospun into bead-free uniform nanofibers are as follows; Polyamide (Nylon 66), Polyacrylonitrile (PAN), polyethylene terephthalate (PET), Polyvinyl alcohol (PVA), Cellulose acetate (CA), Polycaprolactone (PCL), and Polyvinylidene fluoride (PVDF).

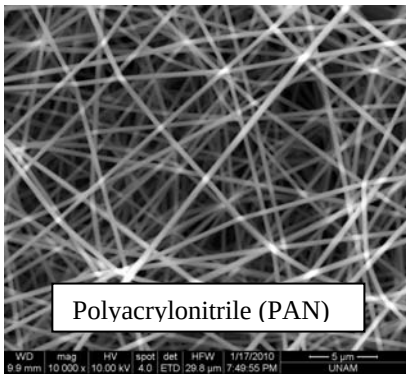
The electrospinning of these polymers were carried out using different solvent systems, varying the polymer concentrations and adjusting the electrospinning parameters such as applied voltage, tip to collector distance and solution feed rate in order to obtain bead-free uniform nanofibers. The

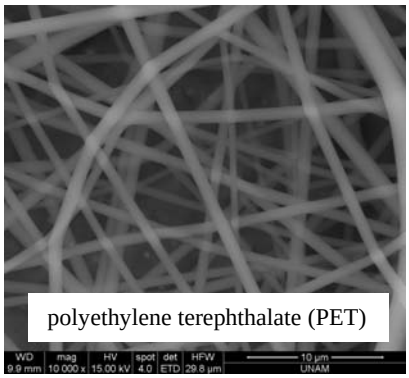
morphology of these nanofibers was studied by scanning electron microscopy (SEM), atomic force microscopy (AFM) and transmission electron microscopy (TEM). The physical and thermal characterizations of these nanofibers were carried out by X-ray diffraction (XRD), differential scanning calorimetry (DSC) and thermogravimetric analysis (TGA).

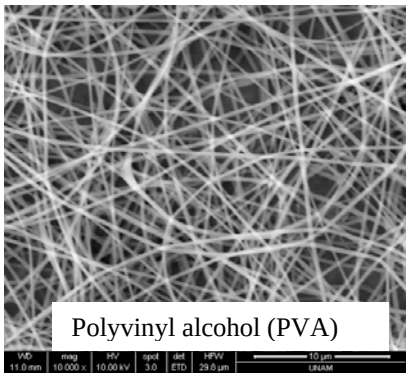
2. RESULTS AND DISCUSSION

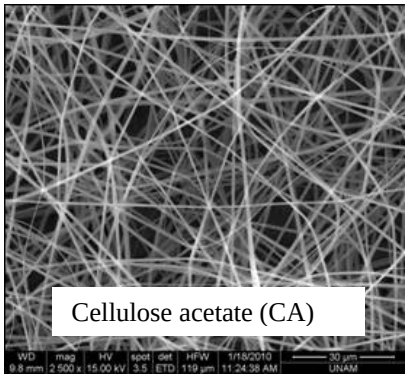
Electrospun nanofibers having various morphologies and dimensions were obtained from different solvent systems and polymer concentrations. For all the polymer systems beaded fiber structures were obtained at lower polymer concentrations but an increase in the polymer concentration to certain level yielded bead-free fibers, which indicates that a high viscosity is required to obtain uniform nanofibers. In addition it was also observed that type of solvent plays an important role on the final morphology of the nanofibers. Some of the SEM images of the uniform electrospun nanofibers that we have obtained are shown in figures below.

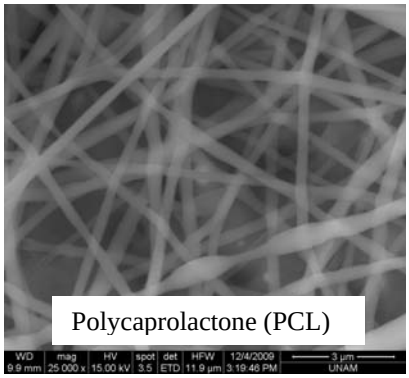


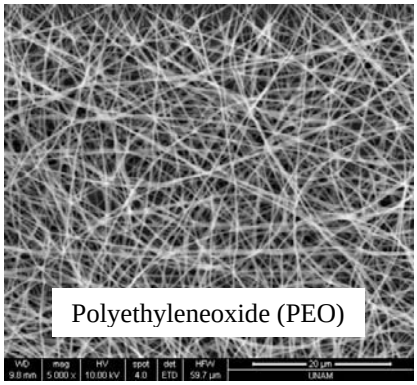


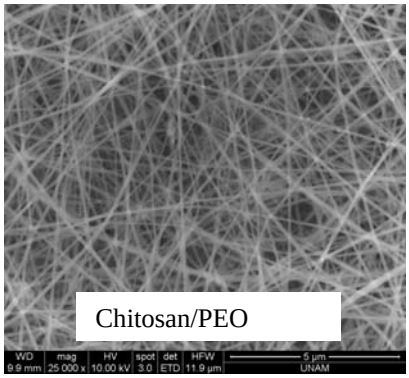












4. CONCLUSION

We have produced various polymeric nanofibers/nanowebs by the electrospinning technique. We have investigated morphology and physical and thermal properties of these functional nanofibers. Our goal is to develop multi-functional nanofibers/nanowebs for certain applications such as membranes/filters, textiles, biotechnology, packaging, composites, sensors, etc.

ACKNOWLEDGMENT

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FUNCTIONALIZATION OF POLYESTER FABRICS WITH Ag AND TiO_2 NANOPARTICLES

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ABSTRACT

This study discusses the possibility of engineering the multifunctional textile nanocomposite material based on the polyester (PES) fabric modified with colloidal Ag and TiO_2 nanoparticles (NPs). Namely, encouraging results on the effects of TiO_2 and Ag NPs separately applied to textile materials in our previous studies were the basis for an assumption that combined treatment with Ag and TiO_2 NPs may bring multifunctional textile nanocomposite materials with desirable UV protective and antimicrobial effects. The antimicrobial activity of differently modified PES fabrics was tested against Gram-negative bacterium *E. coli*, Gram-positive bacterium *S. aureus* and fungus *C. albicans*. The efficiency of UV blocking was evaluated by determining the UV protection factor (UPF) of PES fabrics. The effect of Ag NPs on the photoactivity of TiO_2 NPs deposited onto the PES fabrics was tested by degradation of methylene blue in aqueous solution under UV illumination. The total content of Ag and Ti in the PES fabrics was determined by atomic absorption spectroscopy. The morphology of PES fibers was followed by SEM.

The order of Ag and TiO_2 NPs loading affects the antimicrobial efficiency of PES fabrics. The fabrics provide maximum UV protection independently of the order of Ag and TiO_2 NPs loading. Ag NPs positively influenced the photodegradation activity of TiO_2 NPs and total photodegradation of methylene blue under UV illumination was achieved after 24 h.

Key Words: polyester fabric, Ag nanoparticles, TiO_2 nanoparticles, antibacterial efficiency, UPF

1. INTRODUCTION

Latest studies showed that metal and metal oxide nanoparticles (NPs) can be efficiently utilized for the finishing of textile materials [1]. Small amounts of NPs provide desirable effects without any change of the fiber bulk properties and deterioration of textile appearance. It is well known that Ag NPs can impart extraordinary antimicrobial properties [2-3] whereas potential applications of TiO_2 NPs are shifted more towards UV protection and self-cleaning effects [4-5].

Taking into account the photocatalytic efficiency of simultaneously applied TiO_2/Ag NPs [6-7] as well as encouraging effects of TiO_2 and Ag NPs separately applied to textile materials, it was assumed that combined treatment with Ag and TiO_2 NPs may bring multifunctional textile nanocomposite materials with desirable UV protective and antimicrobial effects. Therefore, this study was aimed to highlight the potentials of combined treatment of polyester (PES) fabrics with colloidal Ag and TiO_2 NPs. The influence of the order of Ag and TiO_2 NPs loading on antimicrobial, UV protective and photocatalytic properties of PES fabrics was examined.

2. EXPERIMENTAL

2.1. Synthesis of colloidal TiO_2 and Ag NPs

All the chemicals for the synthesis of TiO_2 colloid were analytical grade and applied as received without further purification (Aldrich, Fluka). Milli-Q deionized water was used as a solvent. The colloidal solution consisting of TiO_2 NPs was prepared in a manner analogous to the procedure

proposed by Rajh et al. [8]. The solution of $TiCl_4$ cooled down to -20 °C was added drop-wise to cooled water (at 4 °C) under vigorous stirring and then kept at this temperature for 30 min. The pH value of the solution was in a range 0-1, depending on $TiCl_4$ concentration. Slow growth of the particles was obtained by applying dialysis against water at 4 °C until the pH of the solution reached 3.5. The concentration of TiO_2 colloidal solution was determined from the concentration of the peroxide complex obtained after dissolving the particles in concentrated H_2SO_4 [9]. Subsequently, the colloid was thermally treated in reflux at 60 °C for 16 h.

$AgNO_3$ (Kemika) and $NaBH_4$ (Fluka) of p.a. grade were used without any further purification for the synthesis of colloid consisting of Ag NPs. 8.5 mg of $AgNO_3$ was dissolved in 250 mL of water purged by argon for 30 min [10-11]. Under vigorous stirring, reducing agent $NaBH_4$ (125 mg) was added to the solution and left for 1 h in argon atmosphere. The concentration of Ag colloidal solution was 50 ppm.

2.2. Sample preparation

Desized and bleached polyester (PES, 115 g m^{-2}) woven fabrics were cleaned as described elsewhere [12]. One gram of PES fabric was immersed in 65 mL of colloid of Ag NPs for 5 min and dried at room temperature. After 5 min of curing at 100 °C, the samples were rinsed twice (5 min) with deionized water and dried at room temperature. Afterwards, the fabric was immersed in 20 mL of 0.1 M TiO_2 colloid for 5 min and dried at room temperature. After 30 min of curing at 100 °C, the fabrics were rinsed twice (5 min) with deionized water and dried at room temperature. When the TiO_2 NPs were deposited on the PES fabrics prior to loading of Ag NPs, only the order of described procedures was switched.

2.3. Methods

Fiber morphology was followed by scanning electron microscope JEOL JSM 6460 LV. Gold layer was deposited on the samples before the analysis.

The total content of Ag and Ti in the PES fabrics was determined by a Perkin Elmer 403 atomic absorption spectrometer (AAS).

The antimicrobial efficiency of PES fabrics was quantitatively evaluated using a Gram-negative bacterium *Escherichia coli* ATCC 25922, Gram-positive bacterium *Staphylococcus aureus* ATCC 25923 and fungus *C. albicans* ATCC 24433. Microbial inoculum was prepared in the tripton soy broth (Torlak, Serbia), which was used as the growth medium for microbes while the physiological saline solution (pH 7.0) was used as the testing medium. Microbes were cultivated in 3 mL of tripton soy broth at 37 °C and left overnight (late exponential stage of growth). Afterwards, 70 mL of sterile physiological saline solution was added to sterile Erlenmeyer flask (300 mL), which was then inoculated with 0.7 mL of the microbial inoculum. The zero counts were made by removing 1 ml aliquots from the flask with inoculum, and making 1:10 and 1:100 dilutions in physiological saline solution. 0.1 mL of the 1:100 solution was placed onto a tripton soy agar (Torlak, Serbia) and after 24 h of incubation at 37 °C, the zero time counts (initial number of microbial colonies) of viable microbes were made.

One gram of sterile PES fabric cut into small pieces was put in the flask (70 mL of sterile physiological saline solution inoculated with 0.7 mL of the microbial inoculum) and shaken for 2 h. Two-hour counts were made in accordance with an above described procedure.

The percentage of microbe reduction (*R*, %) was calculated using the equation (1):

$$R = \frac{C_0 - C}{C_0} \cdot 100 \qquad (1)$$

where: C_0 (CFU – colony forming units) is the number of microbe colonies on the control fabric (untreated fabric without Ag and TiO_2 NPs) and C (CFU) is the number of microbe colonies on the fabric loaded with Ag and TiO_2 NPs.

Laundering durability of antimicrobial effects was evaluated after five washing cycles in Polycolor (Werner Mathis AG) laboratory beaker dyer at 45 rpm. The fabrics were washed in the bath containing 0.5% Felosan RG-N (Bezema) at liquor-to-fabric ratio of 40:1. After 30 min of washing at 40 °C, fabrics were rinsed once with warm water (40 °C) for 3 min and three times (3 min) with cold water. Afterwards, the fabrics were dried at 70 °C. The percentage of microbe reduction after five washing cycles was determined according to equation (1).

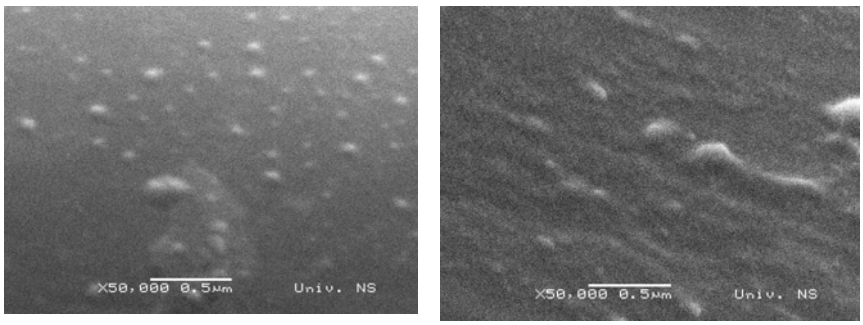
The UV transmission spectra of the PES fabrics were obtained by UV/VIS spectrophotometer Cary 100 Scan (Varian). The UV protection factor (UPF) value was automatically calculated on the basis of recorded data in accordance with Australia/New Zealand standard AS/NZS 4399:1996.

Photodegradation activity of the PES fabrics loaded with Ag and TiO_2 NPs was followed by decomposition of methylene blue (MB). 0.5 g of PES fabric was immersed in 25 mL of MB solution (10 mg L^{-1}, pH 5.8) and illuminated by ULTRA-VITALUX lamp, 300 W (Osram) for 2, 4, 6, 8 and 24 h. The MB concentration was determined by measuring absorption intensity at 664 nm using an UV/VIS spectrophotometer Cary 100 Scan (Varian).

3. RESULTS AND DISCUSSION

Combined modification of PES fabrics was carried out with colloidal Ag and TiO_2 NPs. Uniform, nearly spherical Ag NPs with an average diameter of approximately 10 nm, synthesized without using any stabilizer, and mostly single crystalline, anatase, faceted TiO_2 NPs with an average dimension of approximately 6 nm, were applied [12-13]. The morphology of PES fibers loaded with Ag NPs prior to deposition of TiO_2 NPs (PES+Ag+TiO_2) and PES fibers loaded with the same NPs in opposite order (PES+TiO_2+Ag) was analyzed by SEM (Figure 1). SEM images reveal considerable amount of well dispersed smaller and bigger assemblies of NPs on the surface of the PES fibers.

The presence of both NPs on the PES fibers was also confirmed by atomic absorption spectroscopy. The total Ag and TiO_2 contents in the PES fabrics are given in Table 1. The total TiO_2 content in the PES fabrics was calculated on the basis of measured Ti content. AAS analysis clearly demonstrated that the amounts of TiO_2 detected in the PES fabrics were three orders of magnitude higher compared to amounts of Ag, independently of the order of loadings. The results from Table 1 indicate that the order of NPs loading considerably affect the amount of deposited Ag and TiO_2 NPs on the PES fabrics. Ag content in the PES fabrics that were loaded with TiO_2 NPs prior to deposition of Ag NPs was approximately two times higher compared to PES fabrics that were treated in opposite way. This suggests that deposited TiO_2 NPs made the surface of the PES fibers more hydrophilic, facilitating the subsequent interaction with hydrophilic colloidal Ag NPs. On the other hand, TiO_2 content in the PES fabrics that were loaded with Ag NPs prior to deposition of TiO_2 NPs increased by approximately 25% in comparison with oppositely loaded PES fabrics. This could be due to higher affinity of TiO_2 NPs towards Ag NPs deposited onto the PES fabric compared to bare PES fiber surface.



(a) (b)

Figure 1. SEM images of: PES+TiO_2+Ag (a) and PES+Ag+TiO_2 (b) fibers

Table 1. Ag and TiO_2 contents in the PES fabrics

Sample	Ag content (μg/g)	TiO_2 content (mg/g)
PES+Ag+TiO_2	18.5	29.5
PES+TiO_2+Ag	39.4	21.7

Antimicrobial efficiency of modified PES fabrics was tested against Gram-negative bacterium *E. coli*, Gram-positive bacterium *S. aureus* and fungus *C. albicans* under daylight irradiation. The results in Table 2 show that the order of Ag and TiO_2 NPs loading had no influence on antimicrobial activity and maximum microbial reduction was provided in each case. The presence of TiO_2 NPs did not deteriorate the antimicrobial activity of Ag NPs since the equivalent antimicrobial effects were obtained

on the PES fabrics loaded only with Ag NPs from 50 ppm colloid [14]. Our previous study also revealed that even UV illuminated TiO_2 NPs could not impart satisfactory antibacterial properties to PES fabrics [13].

The effect of NPs loading order became more relevant after washing of PES fabrics (Table 3). The antimicrobial efficiency of the PES+Ag+TiO_2 fabrics significantly declined after five washing cycles whereas the PES+TiO_2+Ag fabric preserved the initial level of antimicrobial activity. Better laundering durability of the PES+TiO_2+Ag fabric is likely due to its higher Ag content (Table 1). It is interesting to note that the laundering durability of the PES+TiO_2+Ag fabrics was significantly higher compared to PES fabrics loaded only with Ag NPs from 50 ppm colloid [14].

Table 2. Antimicrobial efficiency of PES fabrics loaded with Ag and TiO_2 NPs

Sample	Microbe	Initial number of microbial colonies (CFU)	Number of microbial colonies (CFU)	R, %
Control PES	*E. Coli*	5.3×10^5	1.3×10^5	
PES+Ag+TiO_2			25	99.9
Control PES		8.0×10^5	1.2×10^5	
PES+TiO_2+Ag			<10	99.9
Control PES	*S. aureus*	5.4×10^5	2.0×10^5	
PES+Ag+TiO_2			<10	99.9
Control PES		4.4×10^5	1.1×10^5	
PES+TiO_2+Ag			<10	99.9
Control PES	*C. albicans*	2.0×10^5	2.1×10^5	
PES+Ag+TiO_2			<10	99.9
Control PES		2.0×10^5	1.7×10^4	
PES+TiO_2+Ag			<10	99.9

Table 3. Antimicrobial efficiency of PES fabrics loaded with Ag and TiO_2 NPs after five washing cycles

Sample	Microbe	Initial number of microbial colonies (CFU)	Number of microbial colonies (CFU)	R, %
Control PES	*E. coli*	8.0×10^5	2.0×10^5	
PES+Ag+TiO_2			1.2×10^5	40.0
Control PES		3.6×10^5	1.4×10^5	
PES+TiO_2+Ag			<10	99.9
Control PES	*S. aureus*	2.5×10^5	4.9×10^4	
PES+Ag+TiO_2			3.3×10^4	32.7
Control PES		2.7×10^5	9.8×10^4	
PES+TiO_2+Ag			<10	99.9
Control PES	*C. albicans*	3.1×10^5	3.2×10^5	
PES+Ag+TiO_2			1.1×10^5	65.6
Control PES		1.2×10^5	2.0×10^4	
PES+TiO_2+Ag			<10	99.9

The rate of UV protection was quantified and expressed via UPF values (Table 4). It is recommended that UPF rating of garments should be at least 40 to 50+. UPF value of 43 and related UPF rating of 40 categorize the PES fabric to fabrics with an excellent UV protection. The effect of Ag NPs

deposition on the UPF values of PES fabrics was negligible. The TiO_2 NPs deposition onto PES fabrics brought about the rise of UPF values to the level corresponding to UPF rating of 50+, which assigns the maximum UV protection. The loading of PES fabrics with TiO_2 and Ag NPs led to an increase in UPF values. This was particularly prominent on the PES+Ag+TiO_2 fabric (118.6) due to highest TiO_2 content detected in this sample (Table 1).

Table 4. UPF values of PES fabrics loaded with Ag and TiO_2 NPs

Sample	UPF value	UPF rating
PES	43.0	40
PES+Ag	48.4	45
PES+TiO_2	91.6	50+
PES+Ag+TiO_2	118.6	50+
PES+TiO_2+Ag	112.0	50+

UPF value of the PES+TiO_2 fabric decreased by 28 % after five washing cycles (66.2) and consequently UPF rating dropped down from 50+ to 50. In contrast, the PES+Ag+TiO_2 (113.4) and PES+TiO_2+Ag (90.4) fabrics exhibited excellent laundering durability.

Photodegradation activity of PES fabrics loaded with Ag and TiO_2 NPs under UV illumination was examined using the aqueous solution of dye methylene blue (MB). The photodegradation activity of TiO_2 NPs on the surface of the PES+TiO_2, PES+Ag+TiO_2 and PES+TiO_2+Ag fabrics was studied by following the changes of MB concentration (C/C_0) as a function of UV illumination time (Figure 2). Figure 2 indicates that the adsorption of MB on untreated PES fabric got saturated after 6 h and there was no additional decrease in MB concentration with time. The color of PES fabric turned from white to blue. Adsorbed dye did not degrade under the UV illumination implying that untreated PES fabric itself does not posses any photodegradation ability. The deposition of TiO_2 NPs onto the PES fabric remarkably enhanced the photodegradation of MB. However, it did not provide the complete photodegradation of MB neither in the solution nor on the fabric. The fabric remained blue-colored after 24 h of UV illumination and after rinsing in water its color was not changed.

The loading of PES fabrics with Ag and TiO_2 NPs induced complete photodegradation of MB after 24 h of illumination. No traces of blue color were observed either on the fabrics or in water after the rinsing of samples, indicating that the entire amount of MB photodegraded on their surface. Higher photodegradation activity of PES fabrics loaded with Ag and TiO_2 NPs compared to PES+TiO_2 fabric can be attributed to the presence of Ag NPs. It is well established that Ag NPs enhance photoactivity of TiO_2 NPs by lowering the recombination rate of its photo-excited charge carriers. Higher amount of Ag in the PES+TiO_2+Ag fabric obviously enhanced the efficiency despite the lower TiO_2 content compared to the PES+Ag+TiO_2 fabric. Additional reason for increased efficiency might lie in the fact that Ag NPs are exposed towards MB solution, providing the efficient transfer of TiO_2 charges that are involved in subsequent photodegradation of MB.

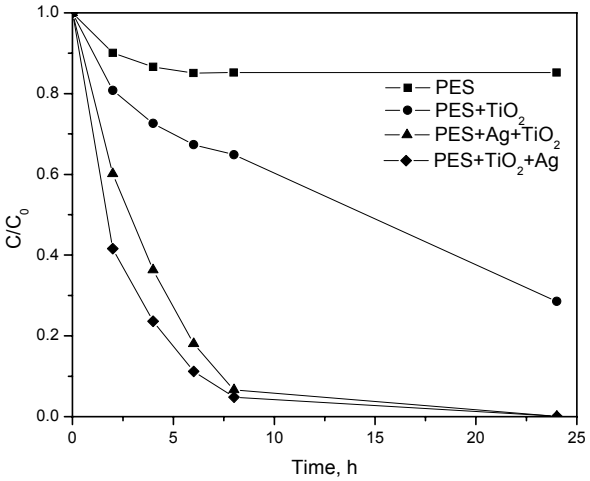


Figure 2. The dependence of C/C_0 versus time of UV illumination for differently modified PES fabrics

4. CONCLUSIONS

The results showed that PES fabrics modified with colloidal Ag and TiO_2 nanoparticles can simultaneously provide antimicrobial, UV protective and photocatalytic properties. It was found that all studied effects depend on the order of Ag and TiO_2 nanoparticle deposition. In order to preserve the initial level of antimicrobial efficiency after five washing cycles, it is recommended to treat the PES fabric with TiO_2 nanoparticles prior to loading of Ag nanoparticles. All fabrics loaded with Ag and TiO_2 nanoparticles exhibited considerably better photodegradation ability compared to PES fabric loaded with TiO_2 nanoparticles alone. Such behavior indicated the positive effect of Ag nanoparticle presence which likely lowered the recombination rate of TiO_2 photo-excited charge carriers.

ACKNOWLEDGMENTS

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INFLUENCE OF THE HORNIFICATION PROCESS OF CELLULOSIC FIBRES ON RESISTANCE OF CEMENTITIOUS COMPOSITES

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ABSTRACT

Besides ecological and sustainability considerations, natural fibres are cheaper and bring to cement or mortar cement matrixes resistance among other benefits. Nevertheless, the use of these cellulosic fibres in vegetable fibre reinforced cement composites (VFRC) is hampered by their low durability and poor adhesion, which in recent years has led to the replacement of these fibres by synthetic ones. The lack of durability of VFRC is mainly caused by the presence of calcium hydroxide on the matrix, which degrades the fibres, and by changes in the environmental moisture, which induce dimensional changes in the vegetable fibres.

It is well known that drying and rewetting cycles principally cause shrinkage of the natural fibres due to the formation of hydrogen bonds in cellulose. This irreversible effect is known as "hornification" and is quantified as the percentage reduction in water retention values (WRV). The reduction in the WRV of the hornificated fibres could have beneficial effects on VFRC. On one hand, the hornificated fibres will have higher dimensional stability, and thus higher fibre-matrix adherence is expected. On the other hand, as a consequence of the lower WRV of these hornificated fibres, a reduction in the formation of incrustations of calcium hydroxide on the surface and lumen of the fibres and consequently a reduction in the degradation of the cellulose in the cementitious matrix are expected.

In this study two types of cellulosic fibres -chemical pulp from softwood and cotton linters- previously subjected to hornification process have been used to prepare cement mortar composites with different composition. The resistance of these composites was tested after 28 days of cure treatment and after four wet-dry cycles. Results indicated that the previous treatment of fibres (hornification process) has beneficial effects on the resistance of the resulting cementitious composites.

Key Words: cellulosic fibres, hornification, cotton linters, mechanical properties, cementitious composites

1. INTRODUCTION

The use of vegetable fibers as reinforcement for brittle matrixes as cement mortar or concrete ones constitutes an interesting possibility that offers a lot of advantages with respect to the utilization of another fibers or reinforcements. Vegetable fibers are obtained from renewable sources and are biodegradable; it's to say, there are "eco-friendliness" materials. Besides ecological and sustainability considerations, natural fibres are cheaper and bring to cement or mortar cement matrixes resistance, improving the ductility, flexibility and crack resistance of the resultant material and low thermal conductivity among other benefits [1].

Despite all the advantages aforementioned, nowadays the industrial production of cement base composites reinforced with vegetable fibers is limited by the lack of durability of these materials [2-3]. That is why in the last decade the scientific community has been making a very important effort in order to improve the durability of the vegetable fiber reinforced cement mortar composites (VFRCMC).

The hornification is an irreversible effect that appears on the cellulosic fibers when they are subjected to drying and rewetting cycles. This effect, quantified as the percentage reduction in water retention values (WRV), principally causes shrinkage of the fibers due to the formation of hydrogen bonds in cellulose and don't modifies the resistance of the fibres [4-5]. Claramunt et al. [4] analyzed this effect on softwood pulps and fibers from cotton linters and proved that the hornification process causes an important decrease of the WRV of these fibers, mainly the softwood pulp ones. With respect to the morphology of the fibers, the hornification doesn't modify the length of the fibers but decrease significantly the thickness because of shrinkage in the direction of the fiber width.

The reduction in the WRV of the hornificated fibres could have beneficial effects on VFRCMC. On one hand, these fibres have higher dimensional stability, and thus higher fibre-matrix adherence is

expected. By the other hand, as a consequence of the lower WRV, a reduction in the formation of incrustations of calcium hydroxide on the surface and lumen of the fibers and so a reduction in the degradation of the cellulose in the cementitious matrix is expected.

The main objective of this study is to analyze the influence of the previous hornification process of the vegetable fibers on the resistance of cement mortar composites. Two types of cellulosic fibres - chemical pulp from softwood and cotton linters- with or without previous treatment of hornification, have been used to prepare different specimens of cement mortar composites. The resistance of these composites was tested after 28 days of cure treatment and after four wet-dry cycles of aging.

2. MATERIALS AND EXPERIMENTAL PROCEDURES

2.1. Materials

UNE-EN 197-1:2000 Type I cement was used in this research. The sand used was provided by the company Sibelco and was subjected to a grinding with a ball mill until a maximum particle size of 0,1 mm. Sika Viscocrete-3425 fluidizer, obtained from Sika S.A.U., was used at a maximum dosage rate of 40g/1000g of cement to aid workability.

Unbleached softwood Kraft pulp (Pinus insignis), supplied by Smurfit Kappa Nervión, S.A. (Spain) and Cotton linters provided by Celsur (Cotton South, S.L., Spain), were used as reinforcement at a wt. 4%.

2.2 Hornification process performed on the fibres

The process of the hornification of the fibres was performed by four drying and rewetting cycles. The sequence of the drying and rewetting cycles was as follows: 1) Drying in an oven with air recirculation at 60 ºC for 7 hours; 2) rewetting by soaking overnight; 3) disintegration of the wet pulp for 30,000 revolutions (ISO 5263-1:2004); and 4) Filtration of the pulp suspension through a Buchner funnel equipped with a wire screen (150 mesh). The first filtrate was recirculated during the pad formation with the objective of retaining pulp fines. At the end of the process the fibres were dried at 60ºC for 12 hours and stored in sealed bags until the preparation of the composite samples.

2.3. Fibre characterization

The WRV was determined by centrifugation according to ISO 23714:2007 (“Pulps. Determination of Water Retention Value”).

X-ray diffraction (XRD) was performed using a Siemens D-500 diffractometer with Cu Kα radiation (λ = 0.154 nm) operating at 40 kV and 30 mA. The crystalline-to-amorphous ratio of samples was determined using the empirical procedure first proposed by Segal et al. [6]. This method consists of estimating the crystallinity index for the Cellulose I (Cr.I.) according to the following equation:

$$Cr.I(\%) = \frac{I_{002} - I_{am}}{I_{002}} \times 100$$

where I002 is the maximum intensity (in arbitrary units) of the diffraction from the (002) plane at $2\theta = 22.6°$ and I_{am} is the intensity of the background scatter measured at $2\theta = 16°$.

Thermogravimetric analysis (TGA) was performed on a Mettler Toledo TGA/SDTA 851^e using Mettler Toledo Star SW 7.01 software. Samples weighing about 5.5 mg were heated in the temperature range from 25 to 600 ºC with a heating rate of 20 ºC/min under a nitrogen atmosphere (60 mL/min).

The fibres’ morphology was characterized using a Jeol-820 scanning electron microscope (SEM).

2.4 Composite preparation

Cement composites containing 4 wt. % of fibres were prepared with both the hornificated and unhornificated ones.

The composites were moulded in the size required for testing (40x20x160 mm) and compressed at 0,4 MPa during 24 h. All the specimens prepared were cured during 28 days (RH>95%, ambient pressure, 20ºC). Half of the specimens to test were aged with a process consisting in four wet-dry cycles.

2.4 Mechanical characterization of the composites

The mechanical characterization of the composites was performed with flexural tests under three-point bend configuration on an Incotecnic press equipped with a maximum load cell of 300 kN. These tests were performed following the UNE 196-1:2005 methodology.

3. RESULTS

3.1 Effect of hornification on the characteristics of the fibres

The phenomenon hornification was quantified as a percentage reduction in the WRV measured in the pulps and in the cotton linters after they were subjected to the drying and rewetting cycles. As shown in Table 1, overall, WRV decreases with the number of cycles, with this decrease being more significant in the softwood pulps. The explanation for this phenomenon is related to the higher percentage of hemicelluloses in softwood fibres than in the cotton linters (the hemicelluloses facilitate the accessibility of water).

The crystallinity index (Cr.I) obtained from X-ray diffractograms for the softwood pulps and the cotton linters and its variation with the drying and rewetting cycles are shown in Table 1. Overall, values of Cr.I. did not change significantly with the drying and rewetting cycles for the softwood pulps. Only a slight increase was found for the cotton linters. Nevertheless it must be taken into account that the experimental error in the calculation of Cr.I. with XRD technique is in the order of 5%.

Table 1. Variation of WRV values, crystallinity index and decomposition temperature obtained from TGA thermograms with the hornification process

		Water retention (%)	**Decomposition Temperature (ºC)**	**Crystallinity (%)**
Kraft pulp	Initial	126	350,4	56.8
	I	112	357,9	57.1
	II	102	371,2	57.8
	III	97	371,6	60.4
	IV	90	379,2	58.0
Cotton linters	Initial	--	380,9	78.5
	I	58	383,7	78.7
	II	54	381,8	82.0
	III	52	383,3	81.0
	IV	50	383,3	80.9

Figure 1 presents the overall thermogravimetric decomposition process of the softwood pulps and cotton linters. As shown, the thermal decomposition occurs in two main steps. The first, recorded below 110ºC, corresponds to the moisture evolution of the water absorbed. The second one, which occurs above 200 ºC until approximately 400 ºC, results mainly from the thermal decomposition of hemicelluloses and cellulose, and supposes the most significant weight loss percentage. As expected, the profiles of the fibres analysed are similar as a result of the material being cellulosic. The differences in the relative loss weight percentage

and in the decomposition temperatures are related to the differences in the chemical composition of the samples and to the values of the crystallinity index.

The TGA curves of the softwood pulp subjected to the drying and rewetting cycles and the initial sample are presented in Figure 2. As shown, as a consequence of the hornification process, the thermal decomposition is shifted to higher temperatures. Similar results were found in the cotton linters (see Table 1). This behaviour could be attributed to the formation of a more closely-packed crystalline structure.

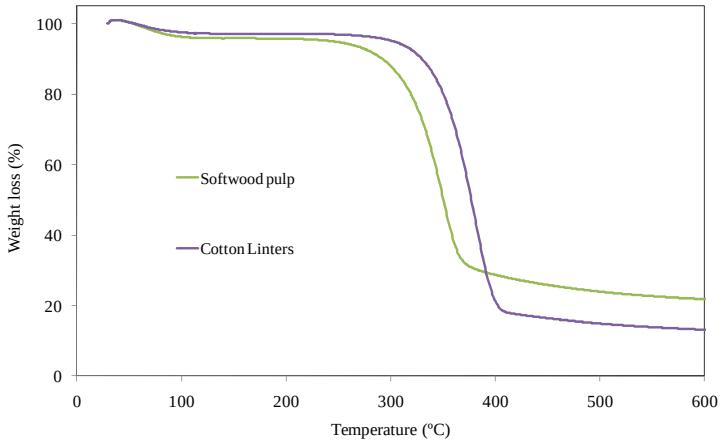

Figure 1: TGA thermograms of the softwood pulps and cotton linters.

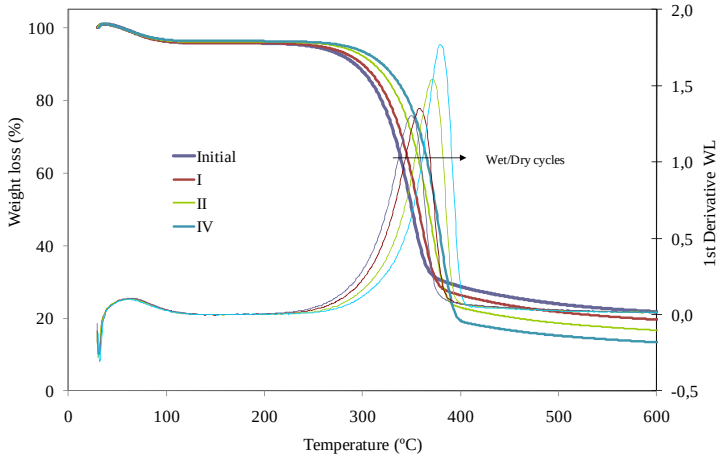

Figure 2: Variation in the TGA thermograms of the softwood pulps with the drying and rewetting cycles

The increase in the thermal stability of these natural fibres with drying and rewetting cycles could be a very interesting result in composite applications, not only in cementitious matrix but also for use in thermoplastic ones. Moreover, it is expected that the hornificated fibres will have higher values of stiffness and tensile strength as a consequence of the formation of a more close-packed crystalline.

SEM pictures of the initial and hornificated cotton linters show differences on the surface after hornification (Figure 3).

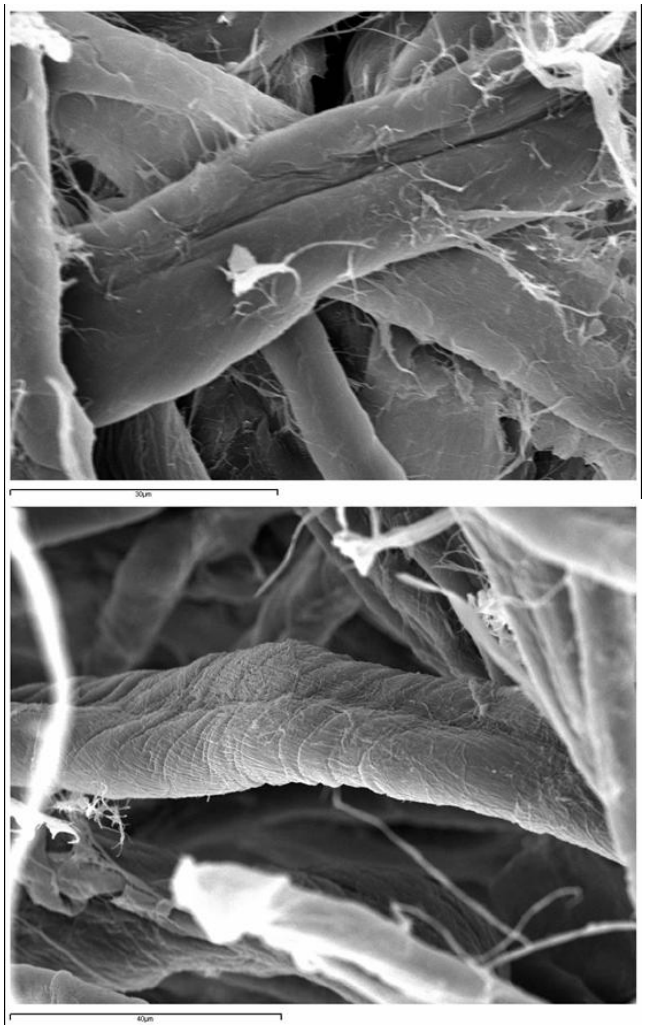

Figure 3: SEM micrographs of the unhornificated cotton linters (on the top) and of the hornificated cotton linters (on the bottom)

3.2 Effect of hornification on the mechanical behaviour of the composites

Figure 4 and Figure 5 show the typical load-deflection curves for the specimens analyzed under flexural tests. As could be seen, overall the composites prepared with the hornificated fibres have superior mechanical properties. The typical stress-strain behaviour for a cement mortar reinforced with fibres shows first a line with high slope and very linear stress-strain relationship. This behaviour corresponds basically to the work of the matrix and follows the Navier hypothesis. After to arrive to the maximum strength of the matrix, there is a fracture of the specimen, being this fracture more o less abrupt depending on the ductility of the material. Nevertheless if the mortar is reinforced with fibres, after the maximum strength point, there is a stress transfer from the matrix to the fibres which depends on the reinforcement capacity of the fibres and its adhesion to the matrix. As could be seen in these figures, although both, the composites with the Kraft pulp and the cotton linters, have similar maximum strength, the composites with the Kraft pulp fibres showed bigger curves than the composites with the cotton linters, probably due to the lower stiffness of the Kraft pulp fibres.

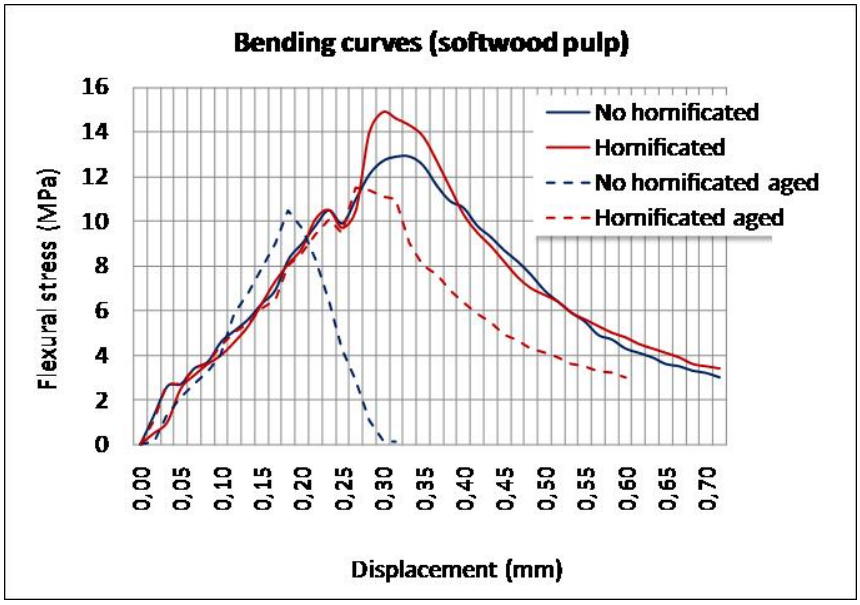

Figure 4. Typical flexural curves of the composites reinforced with the hornificated and untreated softwood pulp fibres.

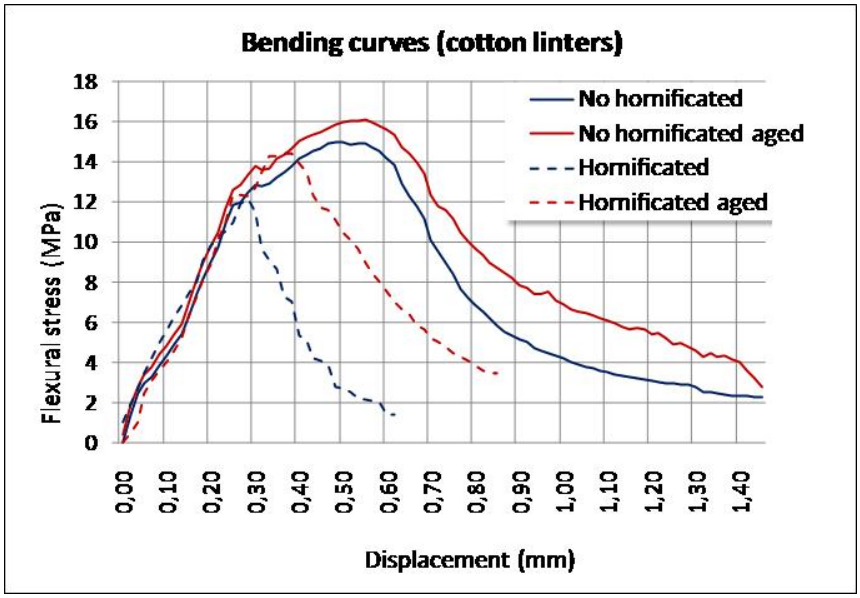

Figure 5. Typical flexural curves of the composites reinforced with the hornificated and untreated cotton linters.

4. CONCLUSIONS

The main conclusions of this paper are the following:

- WRV values decreased with the hornification process, with this effect being more significant in the softwood pulps. Cotton linters showed the lowest value for the percentage of hornification. This decrease in the WRV and the shrinkage of the fibres will improve their dimensional stability against environmental changes in cement mortar composites, reduce the water gradient in the fibre–matrix interface, and will probably decrease the crystallization of calcium hydroxide particles on the surface of the fibres.
- The hornificated fibres exhibited enhanced thermal properties, increasing the thermal degradation temperature with the number of drying and rewetting cycles.

- The flexural resistance increased in the composites prepared with the hornificated fibres. This behaviour was observed on both the unaged and aged composites.

ACKNOWLEDGMENTS

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INFLUENCE OF THE POLYAMIDE TYPE AND FIBRE DIAMETER ON THE WICKING HEIGHT IN NANOFIBROUS STRUCTURES

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ABSTRACT

Due to the high porosity of nanofibrous structures, it is difficult to measure the hydrofilicity of the material with contact angle measurements. Therefore, a new method to examine the wicking behaviour of the structures is developed. This method is used on several structures, which differ in fibre diameter and polyamide type. The structures with the thickest nanofibres have the highest wicking rates. For different polyamide types, the capillary forces establish the wicking behaviour in the initial phase. Further in the process, it is determined by the capillary forces and the water absorption capacity of the bulk phase

Key Words: nanofibrous structures, wicking behaviour, polyamides

1. INTRODUCTION

Nanofibres are obtained by using an electric field, applied between the nozzle tip of a polymer reservoir and the collector plate. The polymer solution is pumped at a constant flow rate through the hollow needle in the electric field. When the electrostatic forces overcome the surface tension of the solution, the droplet at the outlet of the needle will deform to a Taylor cone. From this moment a jet stream is drawn out of this Taylor cone. Due to the interaction of the charges, which are inherent to the solution, and the external electric field, this jet becomes unstable, and causes bending and splaying. As a result a nanofibrous nonwoven structure is deposited on the collector plate.

These nanofibrous structures could be used, for example, in biomedical applications [1], protective clothing, composites [2] and filtration [3]. For many of these applications, a good understanding of the liquid absorption and wettabillity of the structures is crucial. However, only a few studies about this subject are published. Jabal et Al. have investigated the hydrophilicity of Poly(vinylpyrrolidone)−Titania nanofibres by contact angle measurements [4]. Zhang et al did the same for cellulose nanofibres [5] and Chen et al. studied the hydrophilicity of thermoplastic polyurethane/collagen blends [6]. However, conclusions on hydrophilicity by contact angle measurements are based on adhesion principles but the water drop uptake behaviour of nanofibrous structures is more complex and determined by:

- The adhesion properties between the polymeric material and water
- The capillary forces due to small pore sizes
- The high porosity of the membranes allowing to soak a high amount of liquid.

As a consequence, contact angle measurements do not necessarily allow to draw conclusions on hydrophilicity of the material because it is unclear which effect is predominant over the other two.

Therefore the wicking method is proposed to get an idea of the hydrofilicity of the different polyamide nanofibrous structures. A specific norm for the measurement of the wicking phenomenon in nanofibrous structures does not exist, so as start point the norm for textile nonwovens, ISO 9073-6, is applied. Kong and Kang reported that the wicking height of polyamide 6 (PA 6) electrospun nanofibrous structures was a few times higher than that of the spunbund structure [7]. The range of the fibre diameter in the electrospun structures in the present research is 145 to 340 nm, which are diameters more than 5 times smaller than those of Kong and Kang. Besides PA 6 also other polyamides (PA 6.9, PA 4.6 and PA 6.6) are investigated.

2. MATERIALS AND METHODS

2.1. Preparation of the nanofibrous structures

All the nanofibrous structures are electrospun out of a 1:1 98-100 v% formic acid/99,8 v% acetic acid solution (both delivered by Sigma Aldrich). The used polyamides are PA 6 (Mw: 50.000 g mol^{-1}, Sigma Aldrich), PA 6.6 (Mw: 60.000 g mol^{-1}, Sigma Aldrich), PA 6.9 (Mw: 60.000 g mol^{-1}, Scientific polymer products) and PA 4.6 (Mw: 80.000 g mol^{-1}, Sigma Aldrich).

To obtain uniform structures a multi-nozzle electrospinning set-up is used [8]. By using a multi-nozzle set-up the nanofibrous structures produced are large enough so that all the wicking strips can be cut from one batch fabric. Table I gives the seven structures which are electrospun for this research. The tip to collector distance is held at 6 cm, the flow rate was 2 ml h^{-1}, and the voltage is set between 25 and 30 kV, in order to obtain steady state conditions [9].

Table I: Properties of the electrospun nanofibrous structures analysed in this work

Nonwoven	Material	D_{fibre} [nm]	Web density [g m^{-2}]
1	14 wt% PA 6	145 ± 16	51,44
2	16 wt% PA 6	160 ± 15	55,36
3	20 wt% PA 6	340 ± 28	50,49
4	14 wt% PA 6.6	143 ± 29	60,16
5	14 wt% PA 6.9	170 ± 25	42,43
6	14 wt% PA 4.6	203 ± 18	50,32

The morphology of the samples is examined by scanning electron microscopy (SEM) using a FEI QUANTA 200F system. Prior to the SEM-measurements, the nanofibrous structures were coated by a gold sputter coater (Balzers Union SCD 030). The average fibre diameter of each structure was determined out of 60 measurements, using the Cell^D software.

2.2. Wicking

Wicking is a spontaneous process whereby the fibre-air interface is replaced by a fibre-liquid interface. This wicking height is determined by the capillary force that overcomes gravity forces. Additionally, interfacial forces between the polymer material and the liquid also play a role.

In the early stages of the wicking phenomenon the behaviour can be described by the Washburn equation:

Where h is the height of the raising water, η and γ are respectively the viscosity and surface tension of the liquid, θ the advancing contact angle of the liquid on the surface, t is the time. r is an equivalent radius of the radius of the capillary porous structure, depending on the hydrodynamic radius and the mean static radius.

Because h^2-values must vary linearly with time, the Washburn equation can be written as $h^2 = D\ t$, where D is a capillary diffusion coefficient, related to the pore size and the properties of the liquid.

Before testing, the wicking strips (15 by 150 mm) were climatisated for 24 hours at a temperature of 296 K and a relative humidity of 50%. Next, the sample is clamped vertically to a horizontal support, parallel to a millimetre rod, which is placed 15 mm above the lower end of the sample. A water basin is raised by using a lab jack, till the liquid surface touches the measuring rod. At this moment the stop watch is started. The lower sample end is thus 15 mm below the liquid surface during the experiment. The height of the capillary rise is recorded at fixed moments. All wicking experiments were performed at 296 K and 50% relative humidity.

3. RESULTS AND DISCUSSION

3.1. Optimisation of the standard used wicking set-up

Although ISO 9073-6 describes how wicking should be determined for standard non-woven textile structures, it is not very useful for nanofibrous structures. Wicking height is detected through the uptake of a coloured liquid using a dye. Performing wicking tests with the coloured liquid and water at nanofibrous structures revealed that there is a significant difference for the wicking height between coloured and uncoloured liquids. In Figure 1 it is clearly visible that the wicking height, using a coloured liquid as described in the related ISO-norm, is significantly lower than the real height of the water in the nanofibrous structures. The underestimation is almost 30% of the real liquid height. The interaction between the dye-molecules, which are used in ISO 9073-6, and the fine nanofibres is highly resulting in adsorption of the dye at the nanofibre surface. Due to this lagging of the dye, the

dye front is not a good indicator of the liquid height. Therefore, pure demineralised water is used, and a strong lamp (Olympus KL 1500 LCD) is applied to follow the actual wicking height.

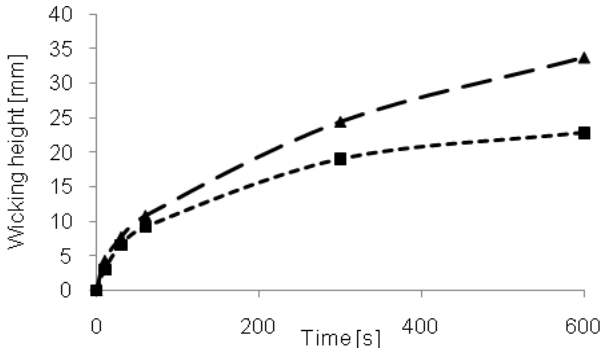

Figure 1: Wicking height of PA 6 nanofibrous structures using a dye (■) and without dye (▲)

3.2. Influence of the fibre diameter

PA 6 electrospun nanofibrous structures with a different fibre diameter were produced (see Table I) to investigate the influence of the diameter on the wicking rate and height. The three nanofibrous structures consist of the same material, are produced on the same apparatus, under the same processing conditions and possess the same weight. The only difference between the three structures is the fibre diameter. In Figure 2 the wicking height of nanofibrous structures with a diameter of 145, 160 and 340 nm is shown.

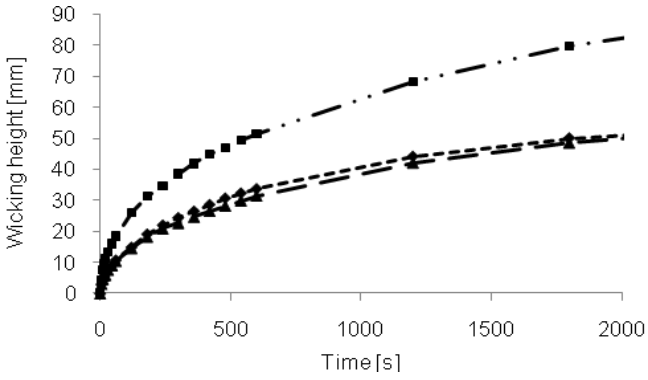

Figure 2: The influence of the fibre diameter on the wicking behaviour of PA6 nanofibrous structures with a diameter of 145 nm (▲), 160 nm (◆) and 340 nm (■).

It is clearly seen that the wicking height of the structures with a diameter of 340 nm is significantly higher than those of 145 of 160 nm. This is not only the case at equilibrium when the maximum wicking height is obtained but also in the initial stage of the process where the Washburn equation is valid. The data are plotted in Figure 4, and show a linear behaviour between h^2 and time. The slope of these linear curves corresponds to the capillary diffusion coefficients, which are given in Table II for all produced and investigated nanofibrous structures.

Table II: The capillary diffusion coefficients of the nanofibrous structures as numbered in Table I.

Nonwoven	D-value
1	1,8624
2	1,9139
3	5,7371
4	1,2021
5	2,0136
6	2,5171

These D-values are similar for the nanofibrous structures with an averagefibre diameter of 145 and 160 nm. This indicates that, taking the standard deviation on the diameter into account, there is no statistic difference between both nanofibrous structures. However, the D-value of the 340 nm structure is almost three times higher, indicating that the water uptake rate in this nanofibrous structure is 3 times higher than the one of the nanofibrous structures with a diameter of 145 and 160 nm.

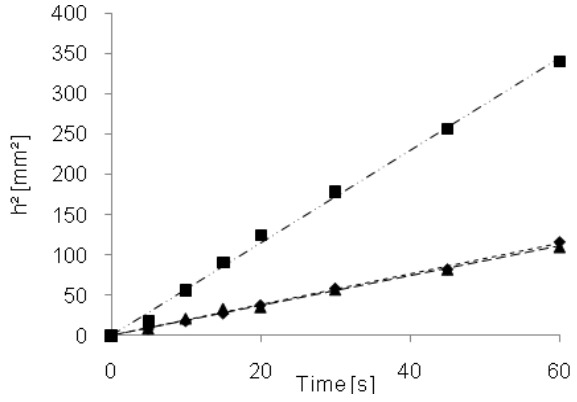

Figure 3: Square height of the capillary rise on PA6 nanofibrous structures with a fibre diameter of 145 nm (▲), 160 nm (◆) and 340 nm (■)

3.3. Influence of the polyamide type

Next the influence of the material properties was examined. Therefore four different types of polyamide nanofibrous nonwovens (PA 6, PA 6.6, PA 4.6 and PA 6.9) were produced. Figure 4 shows the wicking data obtained of a PA 6 and PA 6.6 nanofibrous structure with an average diameter of 145 nm, of PA 6.9 with an average diameter of 160 nm and of PA 4.6 with an average fibre diameter of 200 nm.

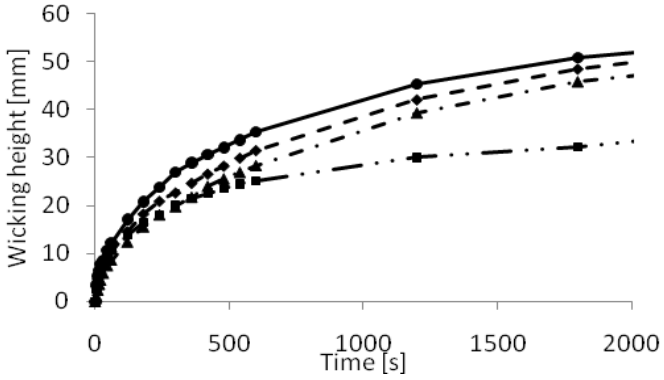

Figure 4: Wicking height of nanofibrous structures of PA 6 (●) and PA 6.6 (▲) with fibre diameter of 145 nm, PA 6.9 with fibre diameter of 165 nm (■) and PA 4.6 with a fibre diameter of 200 nm (◆).

It can be seen from the data that PA 4.6 possesses the highest wicking height at equilibrium, while the wicking height of PA 6.9 is approximately 20 mm less. This is in agreement with the water absorption capacity of the bulk material of these polyamides (1,5% for PA 6; 1,2 for PA 6.6; 0,48% for PA 6.9 and 2,3% for PA 4.6). Due to their higher water absorption capacity, PA 4.6 nanofibres, become more hydrophilic. Because of this increasing hydrofilicity the resistance for the liquid to rise to a higher level into the structure decreases. The water absorption capacity of PA 6.9 is lower, which means that the resistance for the rise of water is still present. At equilibrium, the properties of the material overshadow the capillary forces.

The capillary effect in the first minute is shown in Figure 5. Although PA 6.9 is more hydrophobic in the bulk faze, the wicking rate is higher than the rates of PA 6 and PA 6.6 in the first minute. The reason of this is the larger pores of the PA 6.9 membranes, due to the thicker fibres. Larger pores means less interface between liquid and fibres and thus less resistance for the liquid to rise to a higher level into the structure. This is in agreement with the Washburn equation. Moreover, PA 4.6 has the highest water absorption capacity and the largest pore sizes, so it is logical that the PA 4.6 curve has the highest gradient. Thus, during the first stages, the capillary force is the driving factor, after a while the material properties will be the dominant factor, as also seen in Table II.

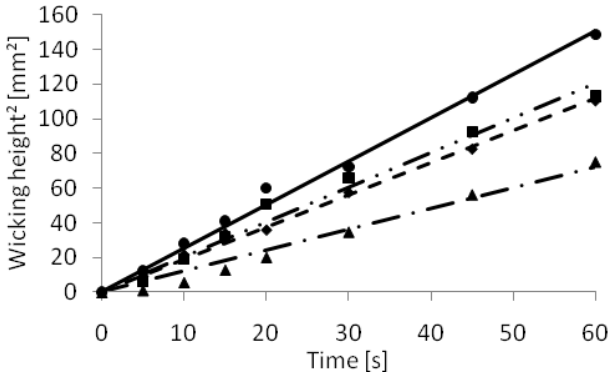

Figure 5: square height of the capillary rise in nanofibrous structures of PA 6 (●) and PA 6.6 (▲) with fibre diameter of 145 nm, PA 6.9 with fibre diameter of 165 nm (■) and PA 4.6 with a fibre diameter of 200 nm (◆).

4. CONCLUSION

A new method to examine the wicking behaviour is developed, in order to measure the real liquid height. The highest wicking rates were obtained by nanofibrous structures with the thickest nanofibres and with the largest pore sizes. The intrinsic water absorption of the bulk polymer has only a slight direct influence, but indirectly it contributes to the overall hydrophilicity of the fibre. During the initial phase of the wicking experiment the capillary forces, determined mainly by the fibre diameter, establish the wicking rate. Further in the process, height is determined by the capillary force and the hydrophilicity.

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INFLUENCE OF WOVEN FABRIC STRUCTURE ON THE ELECTROMAGNETIC SHIELDING EFFECTIVENESS OF ELECTRICAL CONDUCTIVE TEXTILE SURFACES

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ABSTRACT

Textile structures are one of the preferred surface structures used for electro conductive purposed material applications. Flexible and easy tailoring characteristics of textile surfaces are found quite appropriate for many different protective textile applications. One common application area for electro conductive textiles is electromagnetic shielding purposed use. Increasing use of electronic devices in our daily life grows the need for electromagnetic shielding material usage. Electromagnetic interference (EMI) problem is likely to become one of the major problem threatening our health and communication devices and technologies. To use the electro conductive textile surfaces as EMI shielding materials, it is important to understand the shielding possibilities of such materials from the view of textile structural parameters.

This paper presents a preliminary study of the development of electro conductive woven fabrics to be used in the electromagnetic shielding applications. Different structured yarns, containing copper, silver, and cotton (as weft yarn) and 100% cotton yarn (as warp yarn) are used to weave plain, twill, satin and basket structured electro conductive textile surfaces. Electromagnetic Shielding Effectiveness (EMSE) measurements of the fabric samples are completed via special designed measurement system-similar to the Mil-Std-285- in the frequency range of cellular phone communication frequency bands – between 860MHz-960MHz for 900MHz and 1750MHz -1850MHz for1800MHz- in Turkey. EMSE of the specimens are compared considering yarn components and fabric structure differences.

Keywords: electromagnetic shielding effectiveness, (EMSE), fabric structure, electro conductive textiles

1. INTRODUCTION

Electrically conductive textile product types have been widened during the last two decades. Electrically conductive textile products are combination of textiles with electrical conductive materials. Such interesting products are used for exhibitions of many new functions in many fields like comfort and well being, civil engineering, protection, medical and military applications. [1,2] Some well known application areas of electrically conductive metal sheet or wire mesh shielding materials are replaced by lightweight, flexible and non-expensive conductive textile surfaces. [3] One of the most common application areas of electrical conductive fabrics are shielding purposed surfaces from the harmful effects of radio frequency energy.

Researches about electrically conductive textiles producing methods are widening parallel to their increasing application areas. Related to electrical conductive textile products, extensively considered technical approach is use of electrical conductive filler materials in the traditional textile fabrics. Various conductive filler metals are used to make electrical conductive yarn structures. Beside yarn structural properties textile surface constructional parameters of ends/cm, picks/cm, wales/cm, course/cm, number of layers, cell dimensions, rate of electrical conducting component in the fabric are reported as influential factors on the EMSE of the shielding materials. [4-

14] Lin and Lou [5] was used PP/stainless steel commingled yarn to make laminates for the purpose of electromagnetic shielding materials. EMSE performance of laminated materials has found in the range of 30 to 60 dB and sufficient to be used as electromagnetic shielding materials. Ueng, Cheng, (2000, 2001, 2003, 2006) [8-10] had carried out a series of intensive works about EMSE of conductive textile surfaces and textile reinforced composite plates. Blend of stainless steel/polyester fibers ring, core spun, and open end friction spun yarn were used to make woven and knitted fabrics for electromagnetic shielding applications. EMSE measurement had been carried out using a coaxial transmission set-up, in the frequency range of 300kHz to 3GHz. These conductive fabrics were found maybe suitable for electromagnetic shielding of home electrical and electronic appliances. In another work they used stainless steel wire-copper/kevlar and rayon open-end friction core-spun yarn to make hybrid woven fabrics. The fabrics containing stainless steel wire/staple fibers or copper wire/stainless steel staple fibers are found technically useful material (EMSE. 40 dB) for shielding home electronics. EMSE of all specimen fabrics is found to be higher in the frequency range from 1800 to 2450 MHz. Perumalraj et al [11] has produced conductive textile surfaces using cotton/copper DREF 3 yarn. EMSE value of the produced conductive surfaces is measured in the frequency range of 20–18,000 MHz. They have found that increase in the number of conductive fabric layers, yarn fineness, warp density, weft density and cover factors provides increase in shielding effectiveness. With an increase in copper wire diameter, a decrease in shielding effectiveness is observed.Roh et al [12] introduced their study about electromagnetic interference (EMI) shielding purposed composite fabric. They have shown that the EMSE of the metal composite fabrics could be tailored by modifying the metal grid size and geometry.

Shielding is defined as confining radiated energy within a specific region or prevention of radiated energy from entering into a specific region. It is mostly processed in screened or shielded room, known as Faraday cage. Shielding room is a complete enclosure with hollow interior (which may be lined with absorbing materials to give an anechoic chamber) that has no gaps or holes. [15] Body of shielding room is built using plates or sandwich panels made of conductive materials. Shielding efficiency measurement is known as quite complicated measurement method. There are several methods to measure EMSE, described by standards of IEEE Std. 299 [16] ASTM D4935 [17,18] TS EN 50147-1, 2005, [19] MIL Std. 285 [20]. Principle of EMSE measurement is mostly performed in two steps. Shielding efficiency is enumerated from transmission between two antennas with setting of an open door and the close door of the enclosure. The shielding efficiency (SE) is a difference of these two values (in dB unit). There are different configuration of transmitting and receiving antenna, references, positions of antenna in the enclosure, positions of some object inside the enclosure and covering material of inner walls. [21] It is well known that enclosure is strongly influenced by resonances in the enclosure body. Current state of research development shows that there is lack of conventionally accepted standardized methods for measuring shielding effectiveness. [2,22,23]

Main objectives of this work are to introduce an EMSE measurement enclosure and explain the EMSE behaviors of produced electrically conductive fabric specimens. EMSE measurements are carried out in the frequency range of cellular phone communication dual bands (900MHz and 1800MHz) in Turkey. EMSE measurement unit is specially designed with appropriate devices and equipments of antenna couple, connection lines, connectors, signal generator and spectrum analyzer. Shielding efficiency of electrical conductive textile materials changes depending on the yarn type, woven fabric structure type, number of conductive surface layers, and frequency of radiation in the surrounding volume. In this work sixteen different specimen fabrics are tested in the -special designed- EMSE measurement chamber.

2.EXPERIMENTAL

2.1 EMSE Measurement Set

EMSE measurement set is a twin antenna (one transmitter and one receiver) used enclosure. (Figure 1). Aluminum box is divided into two rooms with an aluminum plate having 20cmx20cm opening for specimen placement. Whole measurement unit is grounded for electrical purposes.

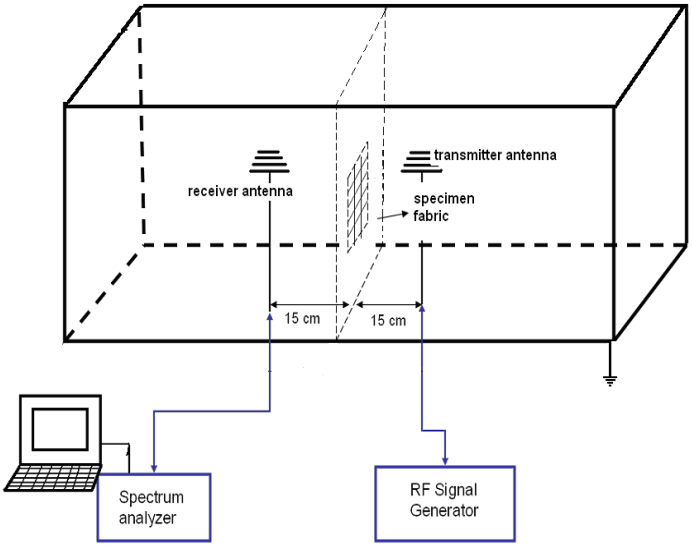

Figure 1 EMSE measurement set

Specimen fabric is placed in the specimen holder frame of the enclosure. Electromagnetic waves are generated by signal generator, and it is transmitted through the rod antenna to the other room of the enclosure. Signals from the signal generator are measured by the spectrum analyzer with receiver rod antenna placed in the other room. Attenuation of electromagnetic waves from the transmitter antenna to the receiver antenna through specimen surface gives the shielding performance of the related electromagnetic wave frequency. Miniwing GSM & S dual band antennas are used designed for the GSM dual bands of 900/1800 MHz and AMPS/PCS dual band of 800/1900 MHz. Appropriate positioning of rod antennas, enables the acquisition of relevant shielding-effectiveness data.

It should be mentioned that EMSE measurement system is not subject to any certification in this area. And results are accepted reliable and comparable in the frame of defined study, since all specimens are tested in the same test set up and geometry.

Shielding efficiency (SE) measurement is explained as screening effectiveness or insertion loss. Concerning electromagnetic screening property the basic characteristic of the conductive fabric is its attenuation. Attenuation of the electromagnetic energy is a result of the reflection, absorption and multi-reflection losses caused by a specific material inserted between the source and the receptor of the radiated electromagnetic energy. [11,18, 24]
In this work EMSE measurement was carried out at 860-960 MHz frequency range for 900 MHz, at 1750-1850 MHz frequency range for 1800 MHz frequency and with the step of 20MHz. SE value calculating as dB is shown following equation. [25]

SE (dB) =measured dB value without specimen – measured dB value with specimen

2.2. Electrically Conductive Textile Properties

Conductive yarn production is processed in a commercially available doubling and twisting machine. Cotton yarns are doubled and twisted with silver/cotton blended(10/90) staple yarn and copper wires. In the Table 1 conductive materials and their resistance data are introduced.

Using Ne20/2 cotton yarn and conductive yarn and wires four different characterized yarn types are spun. Yarn properties are given in the Table 2.

Table 1 Specific resistance of conductive materials

Conductive materials	Specific resistance, Ωm
Copper wire, 0,05 mm	$1{,}70.10^{-8}$
Copper wire, 0,1 mm	$1{,}70.10^{-8}$
Cotton/silver yarn, 90/10	$1{,}59.10^{-8}$

Table 2 Yarn technical parameters

code	Metal fiber content	Fiber types and content rate in weight, %			Yarn density (Nm)
		cotton	copper	silver	
1	50µ copper	89	11	-	7,06
2	100µ copper	62	38	-	5,05
3	50µ copper and staple silver	78	20	2	10,4
4	100µ copper and staple silver	50	48	2	6,81

Produced conductive yarns are used for weaving of plain, twill (1/3), satin and basket weave specimens. Specifications of specimens are summarized in the Table 3.

Tablo 3 Fabric technical parameters

	plain			1/3 Twill			Satin			Basket weave		
Weft yarn	Weft/cm	Warp/cm	Weight (g/m²)	Weft/cm	Warp/cm	Weight (g/m²)	Weft/cm	Warp/cm	Weight (g/m²)	Weft/cm	Warp/cm	Weight (g/m²)
1	13	13	245	12	14	244	12	14	274	13	14	245
2	13	13	334	13	14	339	13	14	310	13	14	359
3	13	13	187	13	14	179	14	14	215	13	14	195
4	13	12	265	13	13	254	12	14	288	13	14	285

2.3 Frequency Change

Experimental measurements were carried out in the frequency band of 860 MHz to 960 MHz for GSM frequency of 900 MHz and 1750 MHz to 1850 MHz for GSM frequency of 1800MHz to understand the EMSE behaviors of the specimen fabrics in the constant signal power of 20dBm. (dBm is an abbreviation for the power ratio in decibels-dB).

2.4 Number of specimen layers

To understand the effect of number of specimen layers on the EMSE of the conductive textile surfaces all sixteen different specimens are tested as single layer and double layers of 0° and 90° specimen placement.

3.RESULTS AND DISCUSSION

3.1. EMSE Measurement for Single Layer Specimens

Figure 2, Figure3, Figure 4 and Figure 5 show the EMSE of the plain, twill, basket weave and panama structured woven specimen surfaces. Warp yarns of the specimens are % 100 cotton yarn and weft yarns are conductive yarns that are introduced in the Table 2.

In general it is seen that twill and basket weave specimens are shown higher EMSE then plain and satin woven specimens.

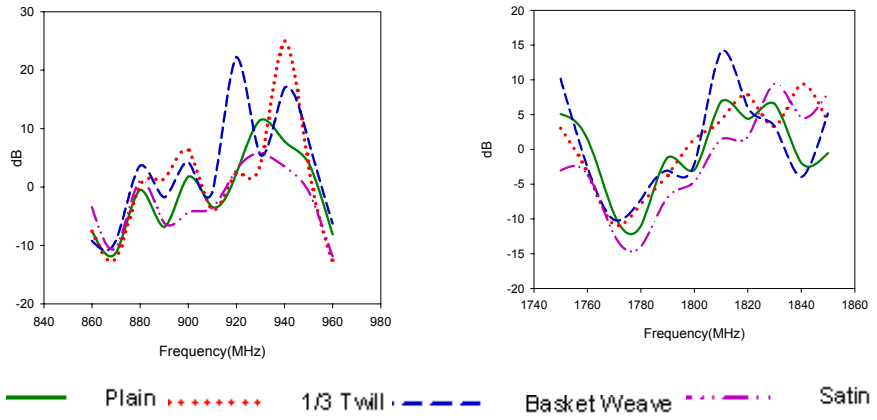

Figure 2 EMSE comparison of four different woven structures with yarn type 1 (50 µ copper –cotton yarn as weft yarn)

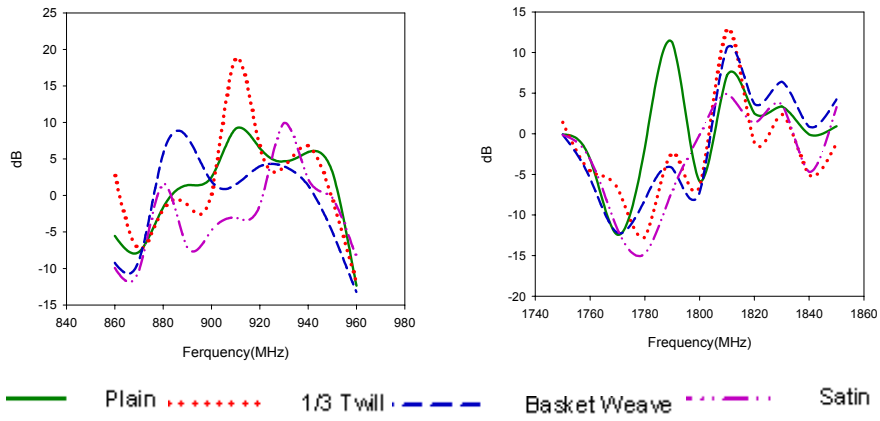

Figure 3 EMSE comparison of four different woven structures with yarn type 2 (100 µ copper –cotton yarn as weft yarn)

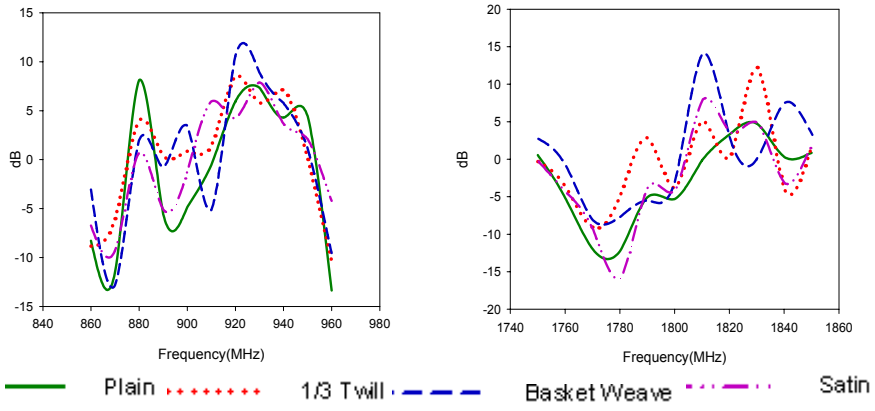

Figure 4 EMSE comparison of four different woven structures with yarn type 3 (50 µ copper/Ag cotton yarn as weft yarn)

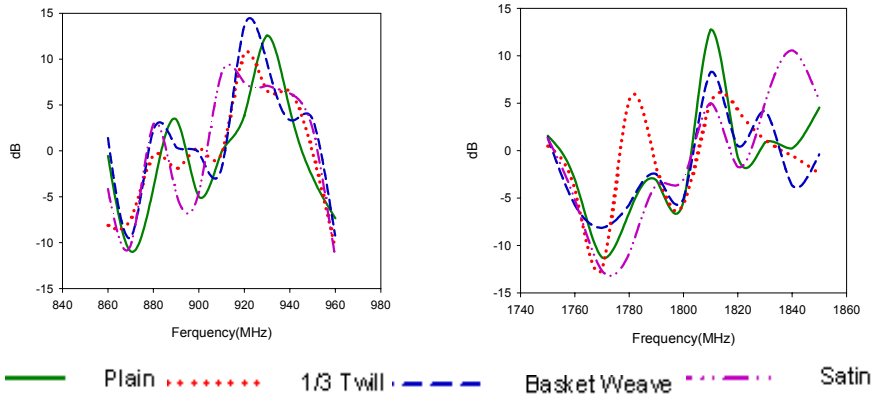

Figure 5 EMSE comparison of four different woven structures with yarn type 4 (100 µ copper/Ag cotton yarn as weft yarn)

Specimens that are woven using 50 µ copper wire consisting yarns, (Figure 2 and Figure 4) are shown higher EMSE then specimens that are woven using 100 µ copper wire consisting yarns.

Existence of low rate silver content in the yarn does not show any significant influences on the EMSE of woven surfaces.

The highest EMSE that is enriched among the defined single layer specimens is above 25 dB at 940 MHz. It belongs to the twill specimen that is woven with 50 µ copper consisting weft yarn. (Figure 2)

3.2. Influence of fabric layers on the EMSE

Double layered specimens show higher EMSE then the single layer specimens.

In Figure 6, single layered plain woven specimen has lower EMSE then the double layered specimen (over all) The highest EMSE is maintained at 940 MHz.

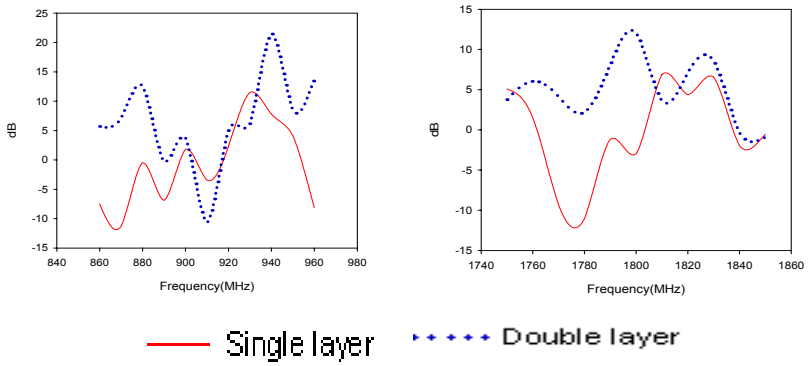

Figure 6 EMSE comparison of single and double layered specimens, plain woven fabric, weft yarn : 50 µ copper consisting yarn.

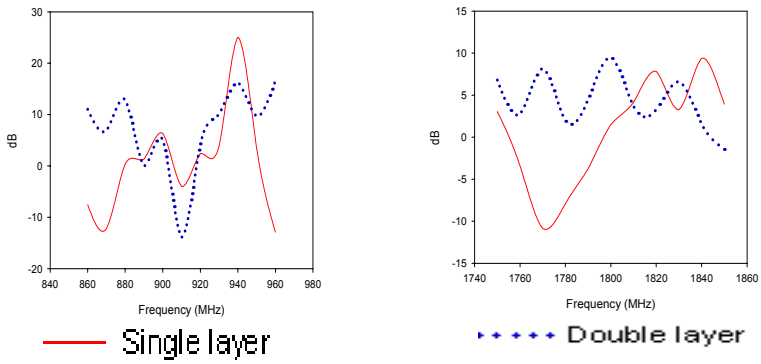

Figure 7 EMSE comparison of single and double layered specimens, 1/3 twill woven fabric, weft yarn : 50 µ copper consisting yarn.

In Figure 7, single layered 1/3 twill woven specimen has lower EMSE then the double layered specimen (over all) The highest EMSE is about 25 dB and it is maintained at 940 MHz.

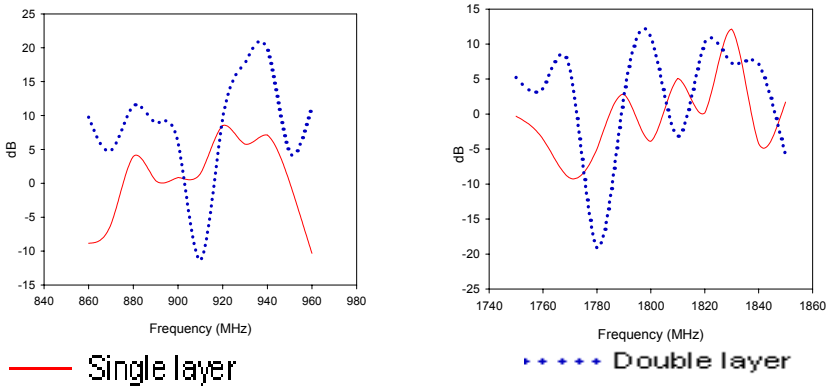

Figure 8 EMSE comparison of single and double layered specimens, 1/3 twill woven fabric, weft yarn : 50 µ copper/Ag consisting yarn.

In Figure 8, single layered 1/3 twill woven specimen has lower EMSE then the double layered specimen (over all) The highest EMSE is about 22 dB and it is maintained at 940 MHz.

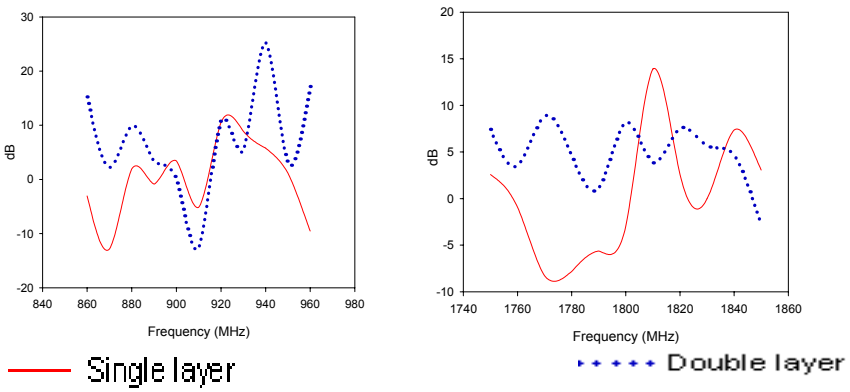

Figure 9 EMSE comparison of single and double layered specimens, satin woven fabric, weft yarn : 50 µ copper consisting yarn.

In Figure 9, single layered satin woven specimen has lower EMSE then the double layered specimen (over all) The highest EMSE is about 27 dB and it is maintained at 940 MHz.

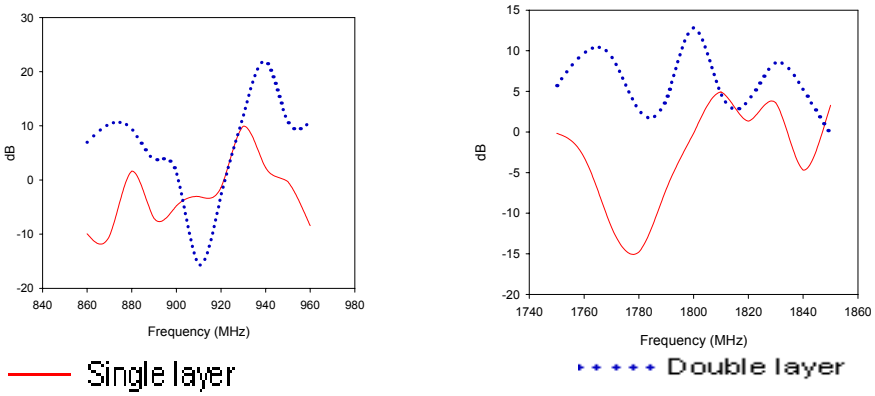

Figure 10 EMSE comparison of single and double layered specimens, satin woven fabric, weft yarn : 100 µ copper consisting yarn.

In Figure 10, single layered satin woven specimen has lower EMSE then the double layered specimen (over all) The highest EMSE is about 24 dB and it is maintained at 940 MHz.

4.CONCLUSION

EMSE of a conductive fabric specimens have seen changing depending on the conductive material thickness, woven fabric structure, number of fabric layers and frequency range.

-Fabrics consisting 50micron copper wire weft contending yarns has resulted giving better EMSE results then those of 100 micron copper wire contending specimens.

-Twill and basket weave fabric structures have shown better EMSE then plain and satin structured specimens.

-Double layered specimens have shown higher EMSE then single layer specimens.

-It is found that EMSE value for the frequency ranges of 860MHz -960MHz and 1750 MHz - 1850 MHz are not the same levelThe same specimen may show different EMSE at different frequency ranges.

-Designed EMSE measurement set is found giving reliable results in the frame of this work.

-Produced conductive textile surfaces has found giving higher EMSE when a different EMSE measurement method is used.

5.ACKNOWLEGMENT

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INTEGRATION OF SONAR SENSORS TO TEXTILE STRUCTURE

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ABSTRACT

During the past decades, several researchers have introduced devices that use sonar systems to detect and/or to determine the object location or to measure the distance to an object using reflected sound waves. In this study, a sonar system based on intelligent textiles approach for detection of objects, has been developed. In order to do this, ultrasonic sensor has been integrated to textile structures by using conductive yarns. Furthermore, an electronic circuit has been designed; PIC 16F877 microcontroller unit has been used to convert the measured signal to meaningful data and to assess the data. The algorithm enabling the objects detection has also been developed. Finally, smart textile structure integrated with ultrasonic sensor has been tested for detection of objects. Beam shape is presented related to identified object and compared with the actual one given in sensor's datasheet in order to test the efficiency of the proposed method of detection.

Key Words: intelligent textiles, ultrasonic sensor, object detection

1. INTRODUCTION

Sonar is a kind of device used for detecting, locating, determining objects or measuring the distance through the use of reflected sound waves. The frequencies used in sonar systems change from infrasonic to ultrasonic.

The term ultrasonic refers to frequencies above that of audible sounds, which humans could not hear and it nominally indicates anything over 20000Hz [1]. In the nature; bats, dolphins and some other species communicate and navigate in the range of 20-100 kHz [2].

In industrial applications, ultrasonic sensors are widely used for distance measurement, proximity detection, object localization, mobile robot guidance etc. [3, 4] and recently for the process control of liquids to measure the concentrations, levels and flows through the use of reflected sound waves. They are widely preferred in robotic applications because of their low price, high efficiency, and relatively simple structure [5-7].

In our study, ultrasonic sensor was chosen to detect the objects and to measure the distance to an object in the environment. This is the first time in the literature that ultrasonic sensor was integrated to textile structure and tested for detection of objects.

2. ULTRASONIC SIGNAL PROCESSING

2.1 Distance measurement by ultrasonic sensor

In sonar systems, electrical impulse is converted into sound waves and the sonar equipment as seen in figure 1 picks up the echoes of reflected sound waves. An ultrasonic sensor wave is a sound speed of about *c=344m/s* in 20C° air at sea level. Distance measurement in ultrasonic sensor is based on the "time of flight" principle (TOF) [8]. That means, the distance to an object is identified by the measurement of the time from transmission of a pulse to reception. In other words, the distance (L) to an object is calculated by Equation (1) (t: arrival time after reflection) [1].

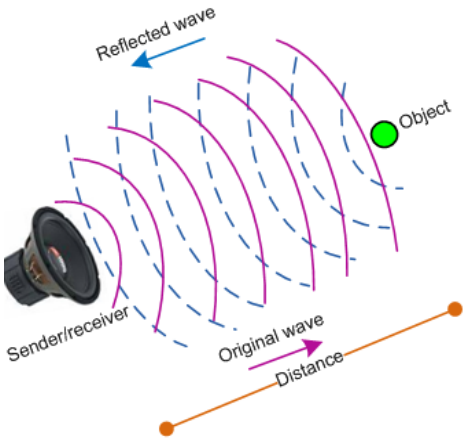

Figure 1: Principle of active sonar

$$L=c*t/2 \text{ (m)} \qquad (1)$$

2.2 Object Direction Measurement

There is a difficulty in measuring the azimuth of an object by using a single ultrasonic sensor. Figure 2 shows a drawing of the geometrical relationship in measuring azimuth of objects where they are vertically arranged at the same distance to sensor. Let us define O1, O2, O3 and O4 as objects and L1, L2, L3, and L4 as the distances measured respectively from the objects O1, O2, O3 and O4. The azimuth of objects can be expressed by using triangle rule as following:

For object 2: $$\theta_{12} = cos^{-1}\frac{L1}{L2} \qquad (2)$$

For object 3: $$\theta_{13} = cos^{-1}\frac{L1}{L3} \qquad (3)$$

Since object 4 is outside of the sensor's detection range, the azimuth value of this object cannot be determined by sensor.

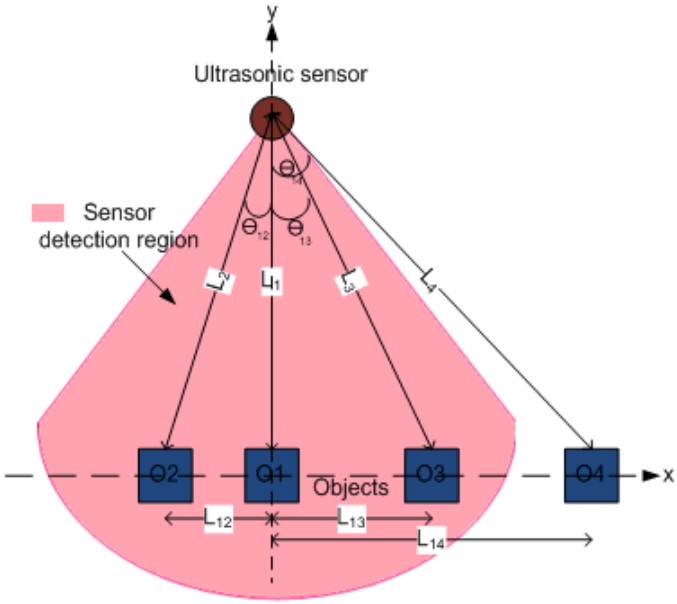

Figure 2. Geometrical relationship in measuring azimuth of objects by using ultrasonic sensor

3. EXPERIMENTS

3.1 Materials and Integration of Sensor Methodology

In this study, LV-MaxSonar ®-EZ3™ (MaxBotix) ultrasonic sensor was chosen due to its small dimensions and low power requirements, 2.5V to 5.5V supply with low (2mA) typical current draw [9]. Figure 3 shows the ultrasonic sensor with its circuit. This ultrasonic sensor enables us to detect objects or to measure the distance through the use of reflected sound waves and it gives information from 6 inches to 254 inches.

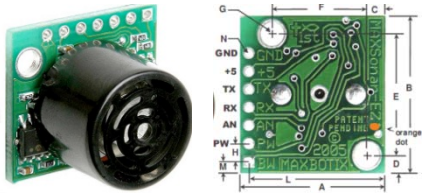

Figure 3. LV-MaxSonar ®-EZ3™ (MaxBotix) ultrasonic sensor [9]

To integrate the ultrasonic sensor into textile structure, 100% stainless steel yarn with a lineal resistance of <15ohm/m was used to form electric circuit in the woven fabric. Besides, to form non-conductive area in the woven fabric, polyester microfibers with a yarn count of 330dtex were used. To prevent the short circuits, fabric sample was designed as double-woven fabric and conductive yarns were hidden in the middle layer of structure as seen in figure 4.

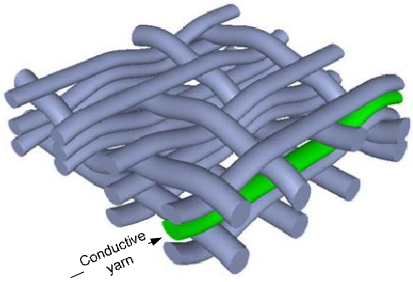

Figure 4. 3D representation of the double-woven cloth (TexGen software)

The position of conductive yarns in the woven fabric was decided in order to match with the Ground, Voltage (Vcc) and Analog Voltage Output (AN) of a given sensor device [Figure 5]. Furthermore, to construct electrical circuit and to connect sensor with fabric, loops were formed among conductive yarns and snap fasteners were sewn onto these loops [Figure 6].

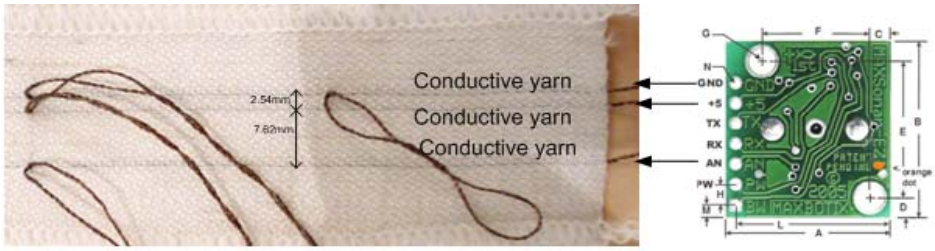

Figure 5. Sample overview: conductive yarns corresponding with sensor ground, Vcc and analog voltage output pins

3.2 Experimental Set up

Measurements were performed using TekoPIC Programming Experimental Set Kit as seen in Figure 6a. Our system includes power supply, ultrasonic sensor integrated to textile structure, microcontroller, and a LCD panel. To control the system 16F877 peripheral interface microcontroller was used. Its code was written in the PIC C language by using MPLAB®IDE software and then, to compile to assembler the HI-TECH C® Compiler was used. LCD screen was used to display the distance values to an object. The block diagram of system is shown in Figure 6.b As soon as the sensor is triggered, ultrasound will be transmitted and if any object is presented within working range, the ultrasound will

be reflected back. A counter using 40 KHz clock frequency measures the time taken by sensor from transmission of a pulse to reception. For continuous distance measurement, sensor is triggered at a regular time interval and accordingly, counter should be reset [10].

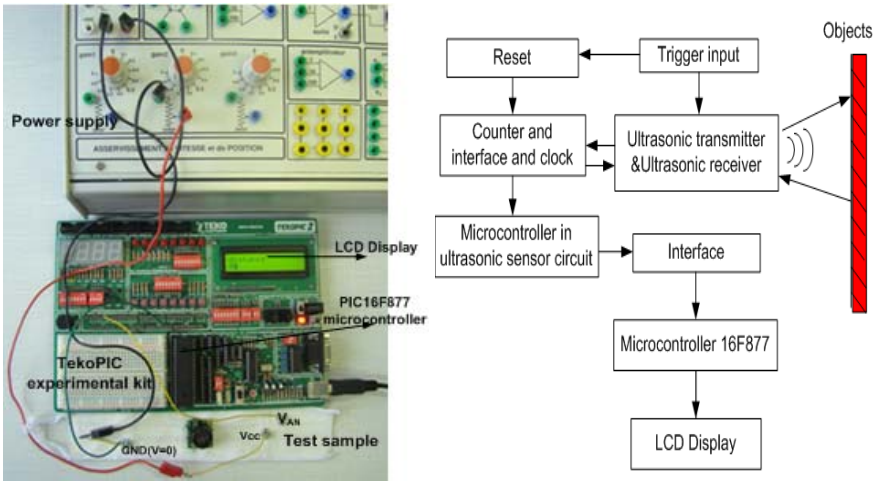

Figure 6. (a)Experiment set-up (b)Block diagram of system

Finally, by this control system, we have conducted a study to determine the working range of sensor between 50 cm and 2.5 meter.

4. RESULTS

To determine the beam pattern of given ultrasonic sensor, experiments were conducted as seen in figure 7, according to proposed experiment set-up above. First, consider the ultrasonic sensor is positioned at (0,0) and to detect the border of working range, object is positioned to a distance starting from (0, 50) to (x, 250) in cm. Measurements were repeated in every 5 cm starting from 50 cm to 250 cm of y-axis. Then, the actual position of object at the border of working range was compared with the one measured by the sensor. Table 1 shows the comparison of actual distance and measured distance to an object.

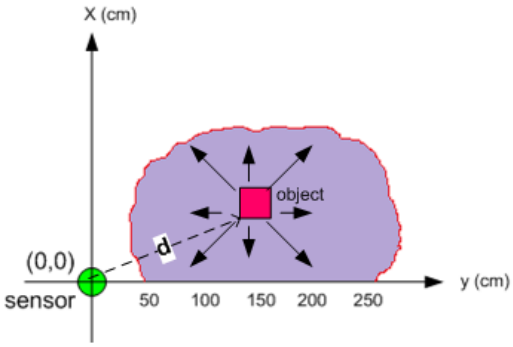

Figure 7. Experimental procedure to determine border of working range of sensor

Table 1. Results of experiments at the border of working range of sensor in one direction

Measurement no	Position of object (x,y)	Actual distance (d) (cm)	Measured distance (d) (cm)	|Error|	|Error| %
1	(19,50)	53,5	54	0,5	0,96
2	(20,55)	58,5	58	0,5	0,89
3	(22,60)	63,9	62	1,9	2,98
4	(23,65)	68,9	66	2,9	4,28
5	(24,70)	74,0	72	2,0	2,70
6	(26,75)	79,4	76	3,4	4,26
7	(25,80)	83,8	82	1,8	2,17
8	(26,85)	88,9	85	3,9	4,37
9	(27,90)	94,0	90	4,0	4,22
10	(27,95)	98,8	94	4,8	4,82
11	(28,100)	103,8	97	6,8	6,59
12	(29,105)	108,9	102	6,9	6,36
13	(30,110)	114,0	106	8,0	7,03
14	(31,115)	119,1	110	9,1	7,64
15	(31,120)	123,9	115	8,9	7,21
16	(30,125)	128,5	117	11,5	8,98
17	(29,130)	133,2	120	13,2	9,91
18	(30,135)	138,3	125	13,3	9,61
19	(32,140)	143,6	128	15,6	10,87
20	(33,145)	148,7	133	15,7	10,56
21	(36,150)	154,3	137	17,3	11,19
22	(37,155)	159,4	141	18,4	11,52
23	(38,160)	164,5	146	18,5	11,22
24	(37,165)	169,1	149	20,1	11,89
25	(41,170)	174,9	154	20,9	11,94
26	(33,175)	178,1	158	20,1	11,28
27	(35,180)	183,4	160	23,4	12,75
28	(37,185)	188,7	164	24,7	13,07
29	(40,190)	194,2	168	26,2	13,48
30	(40,195)	199,1	172	27,1	13,59
31	(34,200)	202,9	175	27,9	13,74
32	(37,205)	208,3	180	28,3	13,59
33	(38,210)	213,4	185	28,4	13,31
34	(38,215)	218,3	188	30,3	13,89
35	(35,220)	222,8	190	32,8	14,71
36	(34,225)	227,6	195	32,6	14,31
37	(36,230)	232,8	200	32,8	14,09
38	(38,235)	238,1	205	33,1	13,88
39	(41,240)	243,5	210	33,5	13,75
40	(42,245)	248,6	214	34,6	13,91
41	(40,250)	253,2	217	36,2	14,29

According to this table results, beam pattern of ultrasonic sensor integrated to textile structure was determined as seen in below figure 8a. Furthermore, determined beam pattern of sensor was compared with the sensor's beam pattern in its datasheet (see figure 8b). It is clear from the figure that the beam pattern that we determined in our study is similar to the sensor's beam pattern given in its datasheet [9].

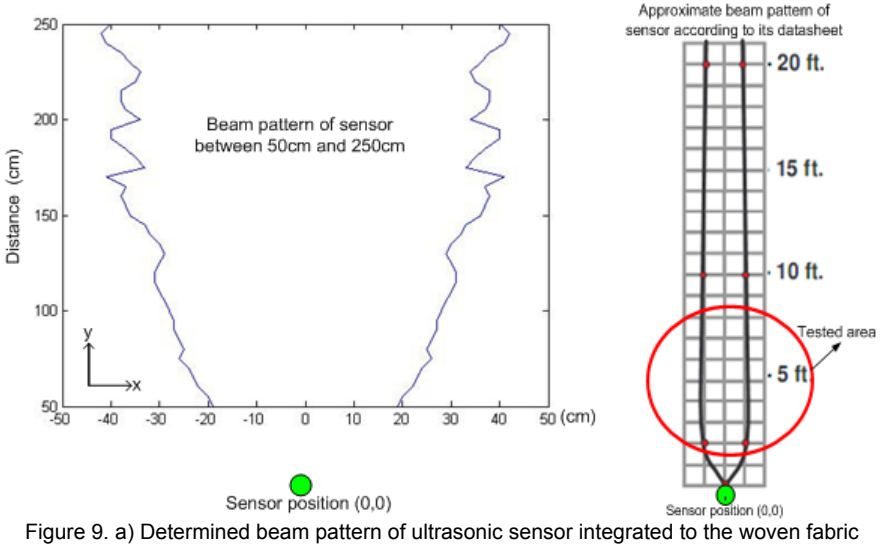

Figure 9. a) Determined beam pattern of ultrasonic sensor integrated to the woven fabric
b) Beam pattern of sensor according to its datasheet [9]

Furthermore, achieved results show that the error between actual distance and measured distance increases as the distance to an object increases. If the object is in the range of 50 and 100 cm, the

error will be 0-5 % and if the object is in the range of 200 to 250 cm, then the error will increase to 13-15 % (Figure 10).

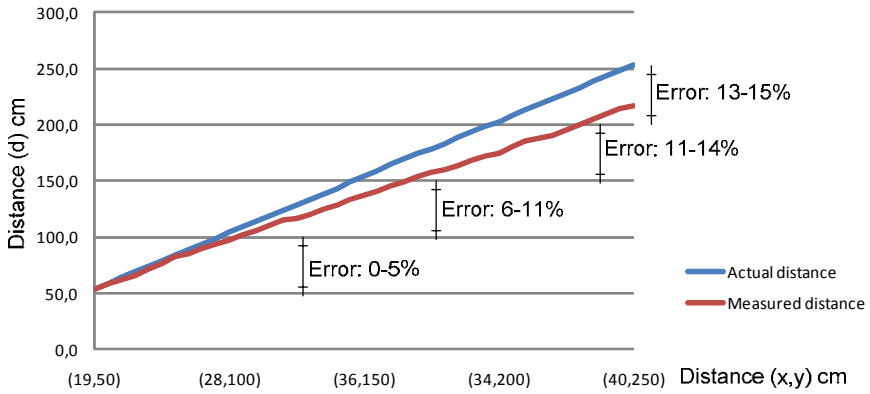

Figure 10. Error differentiation between actual and measured distance

4. CONCLUSION

In this study, for the first time in the literature ultrasonic sensor is successfully integrated to textile structure. To integrate the sensor, a double woven fabric was designed and to satisfy electrical connection in the fabric, 100% stainless steel yarn was used as a conductive yarn. Then to observe the working range of sensor, fabric was connected with a control system that includes: power supply, microcontroller and LCD panel. The beam pattern of sensor was determined by replacing the objects in front of the sensor in various positions.

The achieved results showed that the determined beam pattern matches with the actual one given in its datasheet. Therefore, it can be concluded that the integration of sensor was successful. Nevertheless, according to our results it should be noted that as the distance to an object increases measurement error increases. Thus to get right results, some coefficients could be added into programming language considering the errors due to the distance ranges.

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INVESTIGATION OF THE EFFECTS OF FILAMENT FINENESS ON THE PERFORMANCE PROPERTIES OF MICROFIBER KNITTED SPORTSWEAR FABRICS

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ABSTRACT

Due to increasing performance demands from textile products, synthetic fiber industry has seen very important developments. One of the most important developments in synthetic fiber industry is absolutely producing extremely fine fibers. These fine fibers which have a linear density above 1 dtex are called as microfibers. Microfibers provide light weight, softness, good drapeability, high water absorbency, quick dry and many distinguishing properties for different end uses such as apparel, sportswear and home furnishing. With respect to sportswear, knitted fabrics offer an important freedom of movement to the users differently from their woven counterparts. This comfort property served by knitted fabrics, is very important when choosing sportswear. So a combination of unrestricted movement of knitted fabrics and distinguishing properties of microfibers caused a market demand for knitted microfiber sportswear. In this study, the effects of filament fineness on performance properties of microfiber knitted fabrics were investigated. For this aim, microfilament polyester textured yarns of 110 dtex with 0,33 dtex, 0,57 dtex and 0,76 dtex filament finenesses and conventional polyester textured yarns of 110 dtex with 1,14 dtex and 3,05 dtex filament finenesses were knitted by a circular sample knitting machine. Then, bursting strength, air permeability, pilling resistance, abrasion resistance, and spirality properties of fabrics were tested. Consequently, it is seen that decreasing the filament fineness had an increasing effect on bursting strength and air permeability. Besides, the best pilling resistance was observed by 3,05 dtex filament fineness while for the other types a minor improvement was determined by finer filaments. With respect to abrasion resistance there was not a considerable difference between different filament finenesses. Angular spirality values did not influenced by filament fineness for microfilament polyester fabrics but for conventional polyester fabrics 3,05 dtex filament fabric had lower spirality even though all spirality values exceeded the acceptable levels of spirality.

Keywords: microfiber, knitted fabrics, sportswear, performance properties.

1. INTRODUCTION

Due to increasing performance demands from textile products, synthetic fiber industry has seen very important developments. One of the most important developments in synthetic fiber industry is absolutely producing extremely fine fibers. These fine fibers which have a linear density below 1 dtex are called as microfibers. Microfibers provide light weight, softness, good dreapability, high water absorbency, quick dry and many distinguishing properties for different end uses such as apparel, sportswear and home furnishing. With respect to sportswear, knitted fabrics offer an important freedom of movement to the user differently from their woven counterparts. This comfort property served by knitted fabrics, is very important when choosing sportswear. So a combination of unrestricted movement of knitted fabrics and distinguishing properties of microfibers caused a market demand for knitted microfiber sportswear.

Srinavasan and Ramakrishman [1] produced Ne 25/1 ring yarns from 0,8 denier viscose, 1,2 denier viscose and 1,5 denier cotton fibers. Then they produced single jersey knitted fabrics by these yarns and dyed the produced fabrics. They observed better dreapability, pilling resistance, bursting strength, dimensional stability and spirality but worse abrasion resistance water absorbency for microfiber viscose fabric than conventional viscose fabric. Karolia and Paradkar [2] studied on some fabric properties of microfiber polyester, conventional polyester and microfiber polyester/cotton blended knitted fabrics. Results of the study showed that microfiber polyester fabric had better strength, abrasion resistance and elastic recovery properties than other two types. Srinavasan et al. [3] investigated the performance properties of knitted fabrics produced from 1,2 denier and 0,8 denier polyester fiber yarns. According to performance tests microfiber polyester fabric had better dreapability and lower spirality than conventional polyester fabric. On the other hand, there was not a considerable

difference between samples with respect to bursting strength, abrasion resistance and pilling resistance values. Also microfiber polyester fabric had higher water transportability, water absorbency, water holding capacity and lower drying time than conventional polyester fabric. Jun et al. [4] studied on the performance properties of conventional polyester and microfiber polyester knitted soccer wear fabrics. As a result of this study fabric samples exhibited similar results for water vapor permeability, thermal conductivity and strength properties. Furthermore, conventional polyester fabric showed lower water absorbency, water transportability and higher drying time. Another study [5] was done to investigate the properties of microfiber viscose knitted fabric in comparison to conventional denier viscose knitted fabric. The study showed that, microfiber viscose knitted fabric had higher dreapability, water absorbency, water transportability, bursting strength and lower spirality.

In this study the effects of filament fineness of the performance properties of microfilament polyester knitted fabrics were investigated. For this aim, spirality, bursting strength, abrasion resistance, pilling resistance and air permeability properties of fabrics were tested.

2. MATERIALS AND METHODS

In this study, to investigate the effects of filament fineness on performance properties of microfiber knitted fabrics, microfilament polyester textured yarns of 110 dtex with 0,33 dtex, 0,57 dtex and 0,76 dtex filament finenesses and conventional polyester textured yarns of 110 dtex with 1,14 dtex and 3,05 dtex filament finenesses were used. Yarn tenacity and elongation were measured according to DIN EN ISO 2062, shrinkage was determined according to DIN EN 14621, crimp contraction, crimp module and crimp stability were determined according to DIN 53840-1. The physical properties of yarns are given in Table 1.

Table 1 . Physical properties of yarns

	110 dtex / 36 filaments	110 dtex / 96 filaments	110 dtex / 144 filaments	110 dtex / 192 filaments	110 dtex / 333 filaments
Yarn tenacity, cN/Tex	3,50	3,56	3,48	3,54	3,80
Yarn breaking elongation, %	30	27,65	23,52	22,34	24,84
Shrinkage , %	3	5,8	7,2	8	6,9
Crimp contraction, %	18	11,99	8,37	7,99	4,61
Crimp module, %	12	6,36	4,26	3,68	2,19
Crimp stability, %	81	81,90	77,93	75,83	70,03
Oil content, %	3	3	3,3	2,8	2,5
Intermingling frequency, points/meter	-	97	88	72	66
Intermingling retention (Stability at 3% elongation)	-	22	21	19	34

The sample yarns were then knitted by a sample, one feeder, 3,5 inch diameter circular knitting machine with 20±2 rev/min production speed. All yarn and fabric samples were conditioned according to ISO 139 before tests. Thickness of the knitted fabric samples were measured by Paramount thickness tester according to ISO 5084. Fabric weight values were measured according to TS EN 12127. Number of courses and number of wales were determined by a magnifying glass at 5 randomly selected regions of the sample fabrics. Fabric properties of samples are given in Table 2.

Table 2. Fabric properties of samples

Samples	Properties			
	Fabric Thickness (mm)	Fabric Weight (g/m²)	Number of wales per cm	Number of courses per cm
110 dtex / 36 filaments	0,43	80	11	13
110 dtex / 96 filaments	0,35	84	11	13
110 dtex / 144 filaments	0,35	81	11	16
110 dtex / 192 filaments	0,36	83	10	14
110 dtex / 333 filaments	0,30	86	13	13

Truburst bursting strength tester was used to determine bursting strength properties of fabric samples regarding ISO 13938-2 standard for pneumatic measurements. 50 cm² test area was used and an average of ten measurements was taken for each sample. Air permeability properties of fabrics were tested by SDL Atlas Digital air permeability tester according to ISO 9237. 20 cm² test area was used and 200 Pa air pressure was applied during the test. Twenty measurements were done for each sample fabric and an average of twenty measurements was taken for each sample. Martindale abrasion and pilling tester was used according to ISO 12945-2 for pilling resistance. Three specimens were tested for each sample fabric and woolen abradant fabric was used as the face fabric. The appearance of the specimens after 125, 500, 1000, 2000, 5000 and 7000 cycles of testing device were assessed according to ASTM pill grade photographic views. To determine the abrasion resistance of the fabrics, the fabric samples were tested according to ASTM D 4966-98 by a Martindale abrasion and pilling tester. The appearance of specimens was taken by a light microscope after 250, 1000 and 2000 cycles of Martindale test device. Spirality values of sample fabrics were determined after dry relaxation according to IWS 276 and five measurements were done for each fabric sample.

3. RESULTS

As a result of this experimental study, bursting strength, air permeability, pilling resistance, abrasion resistance and spirality test results of sample fabrics are given.

3.1. Bursting Strength

To determine bursting strength properties of fabric samples regarding ISO 13938-2 standard for pneumatic measurements, 50 cm² test area was used. An average of ten measurements was taken for each sample fabric and bursting strength test results are given in Figure 1.

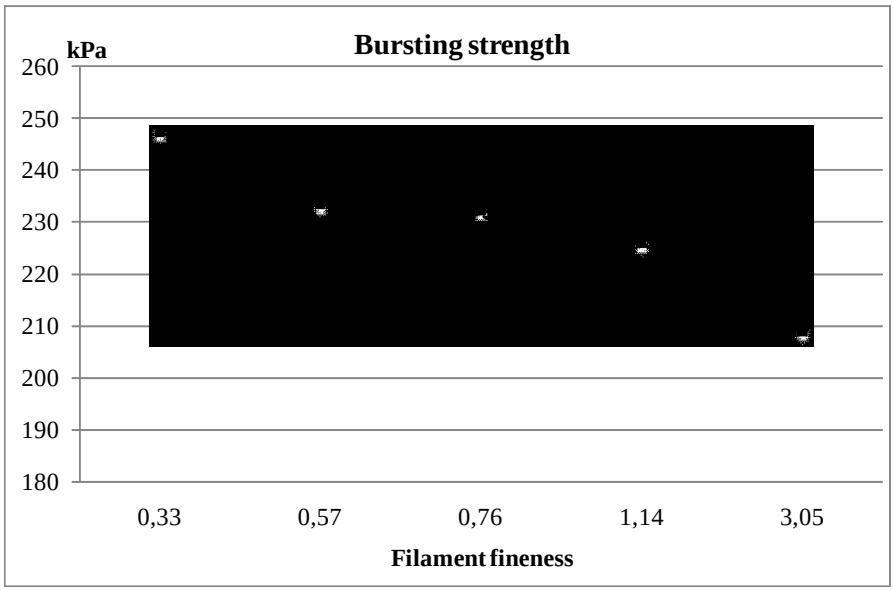


Figure 1. Bursting strength values of sample fabrics

It is clear from the results that decreasing the filament fineness provided higher bursting strength for sample fabrics observed in this study. This is a probable result of increased number of filaments in yarn cross section. Hence, bursting strength is directly effected by yarn strength and 0,33 dtex filament yarn has the highest tenacity. On the other hand, the lowest bursting strength value is belong to 3,05 dtex yarn but this yarn has similar tenacity value with 0,57, 0,76 and 1,14 dtex filament yarns. So, it can be said that even though the effect of filament fineness is not seen clearly, the effect of filament fineness on fabric bursting strength is clearer.

3.2. Air Permeability

Air permeability properties of fabrics were tested according to ISO 9237 by using 20 cm² test area at 200 Pa air pressure. Twenty measurements were done for each sample fabric and air permeability results of the fabrics are exhibited in Figure 2.

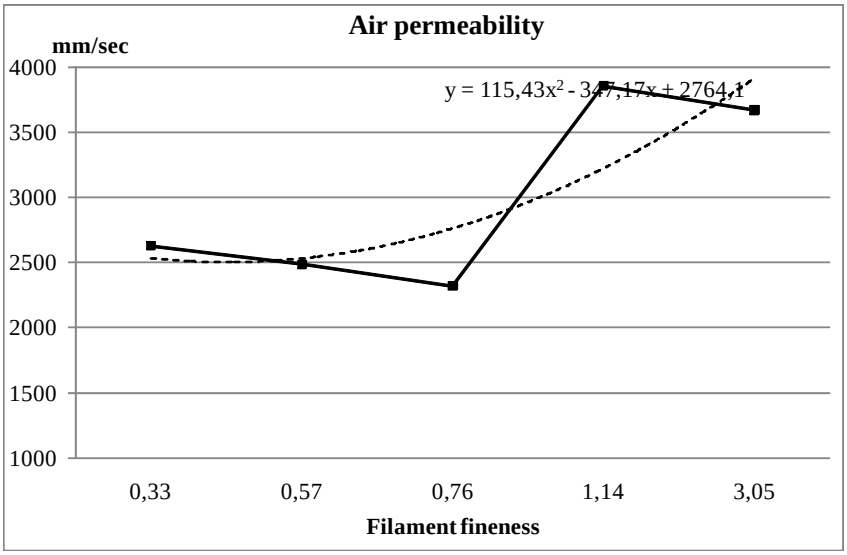


Figure 2. Air permeability values of sample fabrics

It is expected from the finest microfilament type to have the lowest air permeability value as a reason of smaller spaces between the filaments. But the highest air permeability value belongs to the finest microfilament type yarn. This is a result of the better dreapability of fabric which is a result of decreasing the filament fineness [1,3,5] that provides higher mobility of filaments permitting higher air permeability. A similar result was observed for conventional filament type fabrics. Because of the same reason 1,14 dtex filament fabric has higher air permeability than 3,05 dtex filament fabric. On the other hand microfilament polyester fabrics exhibited lower air permeability than conventional polyester fabrics.

3.3. Pilling Resistance

There are many test devices for observing pilling resistance of fabrics based on tumbling and abrade the specimen. Both tumbling and abrasion simulates different reasons of pilling. For example; to observe the pilling resistance of a fabric on underarm region, abrading principle is preferred. Martindale abrasion and pilling tester is used for both knitted and woven fabric types and in this study Martindale test device was used. Woolen abradant fabric was preferred as the face fabric and the appearance of the specimens after 125, 500, 1000, 2000, 5000 and 7000 cycles of testing device were assessed according to ASTM pill grade photographic views. According to ASTM pill grade photographic views the degrees of pilling are; 5-no pilling, 4-slight pilling, 3-moderate pilling, 2- severe pilling, 1-very severe pilling. Pilling resistance results of sample fabrics are given in Table 3.

Table 3. Pilling degrees of sample fabrics

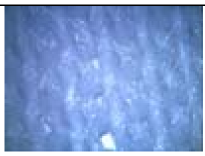
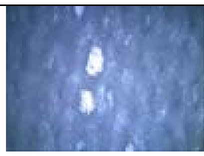
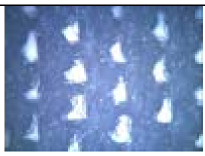
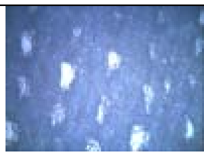
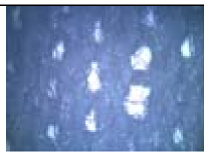
Cycles	0,33 dtex	0,57 dtex	0,76 dtex	1,14 dtex	3,05 dtex
125	4-5	4-5	4-5	4-5	4-5
500	2-3	2-3	3	3	4-5
1000	2	2-3	2-3	2-3	4
2000	1	1	1	2	3-4
5000	1	1	1	1	3
7000	1	1	1	1	3

It is seen form the table that 3,05 dtex filament type fabric had better pilling resistance than other types. Even for 7000 cycles, the appearance of this fabric type was acceptable. Among other fabric types except 3,05 dtex filament fabric, there were minor differences between samples. Nevertheless, according to the results shown in Table 3, it can be said that decreasing the filament fineness causes increasing levels of pilling.

3.4. Abrasion Resistance

As a result of abrasion test, microscopic examination is preferred to assess the abrasion resistance property of sample fabrics. Microscopic views of samples before abrasion test and after 250, 1000 and 2000 cycles of the test device taken by a light microscope are seen in Table 4.

Table 4. Microscopic views of samples after different abrasion cycles

	Before test	After 250 cycle	After 1000 cycle	After 2000 cycle
0,55 dtex				
0,57 dtex				
0,76 dtex				
1,14 dtex				
3,05 dtex				

Before abrasion test more porous structures were seen for conventional polyester fabrics than microfilament polyester fabrics and this porous structure is more obvious for 3,05 dtex filament yarn fabric than 1,14 dtex filament yarn fabric. On the other hand microfilament polyester fabrics had more compact structures. Surface modifications due to abrasive movements were observed until 2000 cycles of the test device according to microscopic examination. In this duration filament entanglements on the surface of the sample fabrics were observed. According to these observations, a significant difference was not determined for microfilament polyester fabrics. The entanglement of filaments caused nearly the same compact fabric structure for microfilament polyester fabrics. On the other hand, for conventional polyester fabrics similar entanglements with microfilament polyester fabrics were occurred. Due to this entanglement, the porous structure of 1,14 dtex filament yarn fabric was partially disappeared. But porous fabric structure of 3,05 dtex filament yarn fabric did not disappear. Consequently, with respect to the effect of filament fineness on abrasion resistance of knitted fabrics, a significant difference was not determined for different filament finenesses and abrasion cycles selected for this experimental study.

3.5. Spirality

Spirality values of sample fabrics were determined after dry relaxation according to IWS 276. Five measurements were done for each fabric sample and an average of these five measurements are given as angular spirality results of the sample fabrics are in Table 5.

Table 5. Spirality values of sample fabrics

Samples	Spirality angle, θ
0,33 dtex	32
0,57 dtes	32
0,76 dtex	32
1,14 dtex	38
3,05 dtex	22

With respect to spirality values, it is seen that microfilament fineness did not have any effect on spirality. Besides, spirality angle exceeds the acceptable levels of spirality with a wide manner. On the other hand, for conventional polyester fabrics coarser filament fineness caused lower spirality.

4. CONCLUSIONS

As a result of this experimental study following conclusions can be drawn;

- Both for microfilament and conventional polyester fabrics, bursting strength is increased by decreasing the filament fineness.

- Microfilament polyester fabrics exhibited lower air permeability than conventional polyester fabrics. Besides, finer microfilaments caused higher air permeability.

- With respect to pilling test results, decreasing the filament fineness had a minor deteriorating effect on pilling resistance. Also, conventional polyester fabrics had better pilling resistance than microfilament polyester fabrics.

- In order to inspect the effect of filament fineness on abrasion resistance of sample fabrics which are observed in the study, surface modifications due to abrasive movements were observed until 2000 cycles of the test device by microscopic examination. A significant difference was not determined for different filament finenesses and abrasion cycles selected for this experimental study.

- Spirality values did not influenced by changing the microfilament fineness. On the other hand, for conventional polyester fabrics, coarser filaments had a decreasing effect of spirality.

For further study, the effects of different filament cross-sections, different filament types such as acrylic and different blends with natural fibers on the performance properties of microfiber knitted sportswear fabrics may be investigated. Also, performance properties of microfiber woven sportswear fabrics may be another subject of study.

ACKNOWLEDGMENTS

We are grateful to Korteks for supplying the yarn samples used in the study.

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KNITTED FABRIC DESIGN WITH ENHANCED ACOUSTIC PROPERTIES

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Technical University of Istanbul, Faculty of Textile Technologies and Design

ABSTRACT

Reduction of interior noise in modern automobiles is an important issue in the automobile industry. Automotive interior noise causes driver fatigue, road accidents and thus reduces road safety. Very high density materials, such as steel, can insulate sound very effectively, but these rigid materials reflect most of the sound back to the environment, which causes sound pollution. In addition, these high density, rigid materials are also very heavy and costly, they can not be used efficiently for sound absorption in automotive industries. Textile materials however, have potential to reduce interior noise in an automobile due to their porous fibrous structures. Because they are both less expensive and lighter than steel like materials and additionally environment-friendly materials, they are mostly used in interior parts of automobiles. Nonwoven structures have also been used, but they have less aesthetic appearance and drapability compared with knitted structures. Knitted fabrics are mostly used for noise reduction in automotive industry due to their superior drapability properties. The aim of this study is to design and produce a knitted spacer fabric having relatively good acoustic behaviour and use this fabric to provide sound absorption in upholstery, headliners and other interior parts of automobile. Fabrics were knitted on a seven-gauge Shima Seiki flat bed knitting machine. The fabric has two layers which are interconnected through a series of tucks. Spacer fabrics show improvements in sound absorption compared to planar knitted fabrics. The acoustic behaviours like sound absorption coefficient of spacer fabrics are tested with impedance tube method. It is expected that this study plays also very important role especially for Turkey that has high traffic noise disturbing driver.

Key Words: Sound absorption, knitted spacer fabric, interior noise reduction, automotive industry

1. INTRODUCTION

Almost every textile has some potential for acoustic function. Textiles are used in many applications involving acoustics including acoustic panels for workstations, automotive insulation, upholstery in concert halls etc [1].

Acoustic behaviors of textile fabrics were also studied by some researchers before. Tilak Dias and his friends investigated sound absorption of thick knitted spacer fabrics knitted from covered elastomeric yarn in their study. The results of their study showed better noise absorption when there is a thicker air gap between the front and fabric layers of the spacer fabric and/or a thicker face layer [2]. In another study of Tilak Dias and his friends, they analyzed sound absorption of tuck spacer fabrics. Top and bottom layers were plain fabrics. These two layers were interconnected with a mesh of yarn oriented at an angle. They found that sound absorbency of these fabrics increased with both airflow resistivity and thickness. The porosity is inversely proportional to the airflow resistivity of the fabrics, therefore the sound absorbency of fabrics decreased with porosity. The fabric whose top and bottom layers knitted from textured polyester multifilament yarn had optimum sound absorbency [3]. In a study on sound absorption of plain knitted structures, fabric was knitted from 430dtex PE yarn and it was found that sound absorbency of fabrics was higher when they had low pore size, stitch size and high thickness [4]. In another study which determined sound absorption coefficients of fabrics with different structures knitted using 80/20 pet/nylon micro-fiber and % 100 pet conventional fibers, it was found

that sound absorbency of fabrics were directly proportional to fabric thickness at low frequencies. Micro-fiber fabrics absorbed all sound frequencies better than a conventional fabric because their fibers have a higher surface area than those of regular fiber fabrics, resulting in higher flow resistance [5]. The effects of basic weight, thickness and constructions of upholstery fabrics on acoustic properties of fabrics were analyzed and found that from all these parameters thickness had the highest effect on sound absorbency [6]. A study on acoustic behaviors of carpets obtained the result that pile structure, pile weight and pile height influence sound absorption coefficient of carpets [7].

Most of the research in the literature used two methods for measuring acoustical properties of fabric materials: the impedance tube method (ISO 10534-2) [8] and acoustic chamber method. The impedance tube method uses very small test samples (approximately 10cm diameter). On the contrary, large reverberation rooms and large test samples are used for the acoustic chamber method. In this study, two microphone impedance tube method was used to measure the absorption coefficients of spacer fabrics.

2. EXPERIMENTAL METHODS AND MATERIALS

2.1 Fabric samples

For designing of the spacer fabrics, SDS ONE Knit and Paint program was used. The spacer fabrics were developed and knitted on an E7-gauge Shima Seiki flat bed knitting machine. The front and back layers of the fabrics have been knitted with the cotton three plied yarn (Ne26/3). The cotton yarns were fed to knitting machine as four ply, whose final yarn count was Ne2.16. These two layers are then interconnected with polypropylene multifilament yarn (321.43denier). The raw material and yarn properties were kept the same for all the fabrics developed.

2.1.1 Yarn Properties

The properties of yarns used to knit spacer fabrics are shown in Table I.

Table I. Yarn Properties

	Yarn Type	**Yarn Count**	**Yarn Twist (rev/m)**		
			Single ply	**Double ply**	**Three ply**
For both layers of the knitted fabrics	100% Cotton	Ne 2.16 (Nm 3.67)	848.8	601.6	243.2
Interconnecting Yarn	100% Polypropylene multifilament	321.43 denier (Nm28)	-		

2.1.2 Fabric Properties

The details of the fabric structures developed are given in the figures below. As it may be seen from the figures, number of tucks was changed in fabrics I, II and III. Fabric I has one tuck per five loops, fabric II has one tuck per seven loops and fabric III has one tuck per eleven loops on front and back faces. Multifilament yarn connects two face layers in different number of points. The number of connection points was changed systematically and decreases from Fabric I to fabric III. In fabric I there

is one connection point per three loops, in fabric II one connection point per four loops and in fabric III one connection point per six loops. In fabric I.I, II.I and III.I mini-jacquard knit was used instead of plain knit. Fabric codes were arranged according to details of fabric structures. ".I" indicates mini-jacquard knit.

Figure 3. Structure of Fabric I

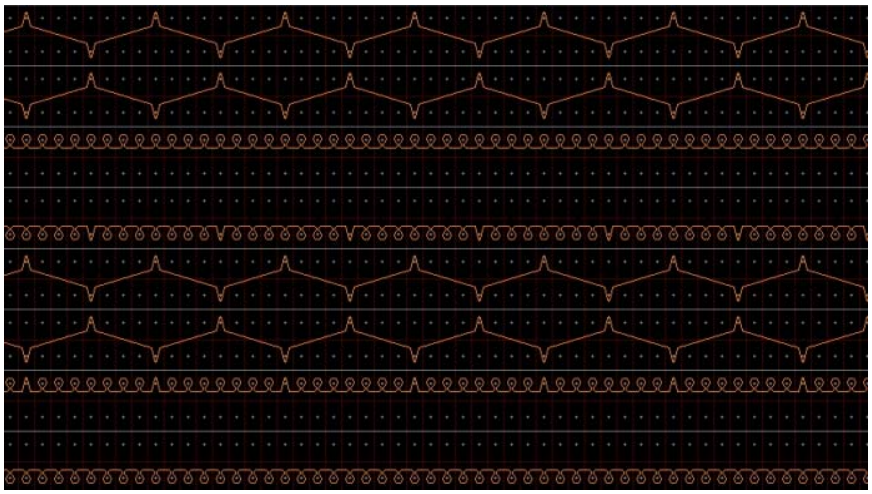

Figure 4. Structure of Fabric II

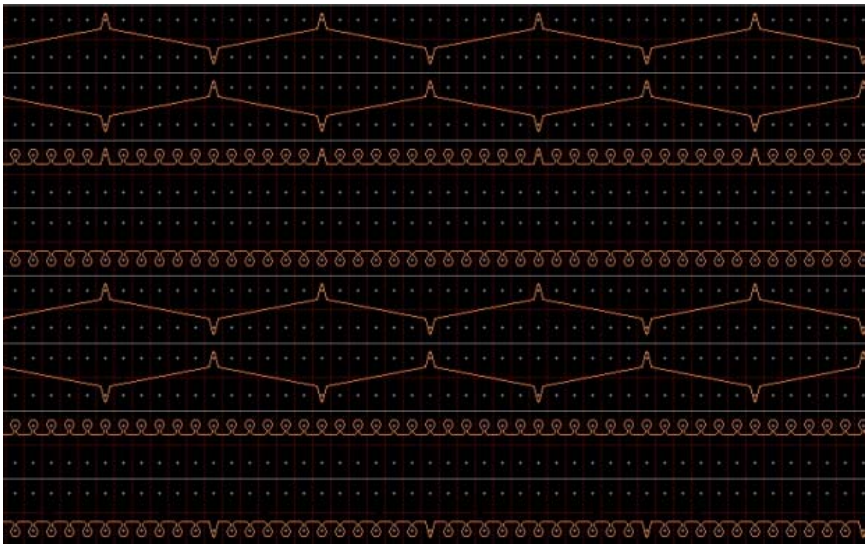

Figure 5. Structure of Fabric III

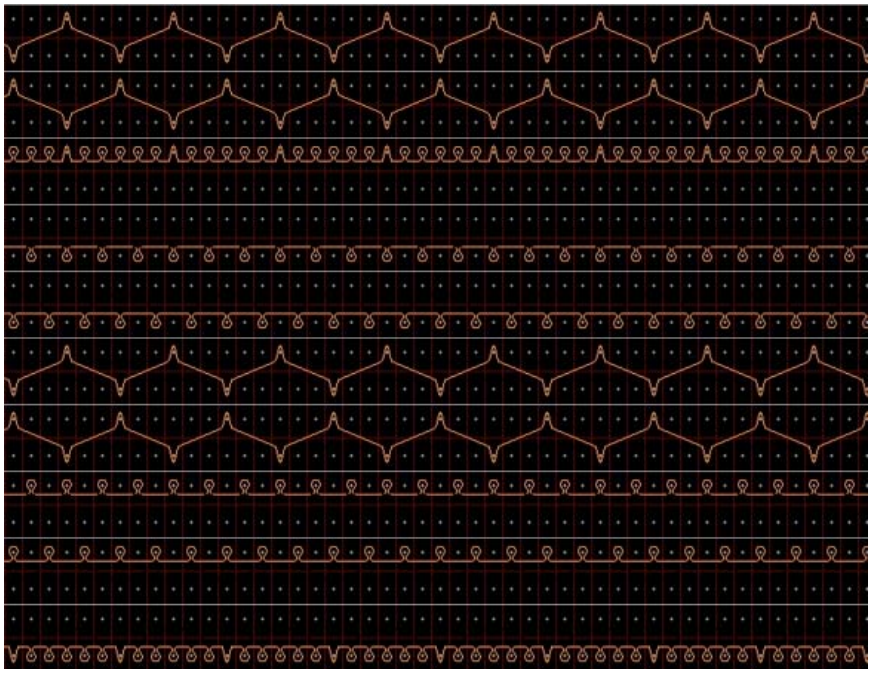

Figure 6. Structure of Fabric I.I

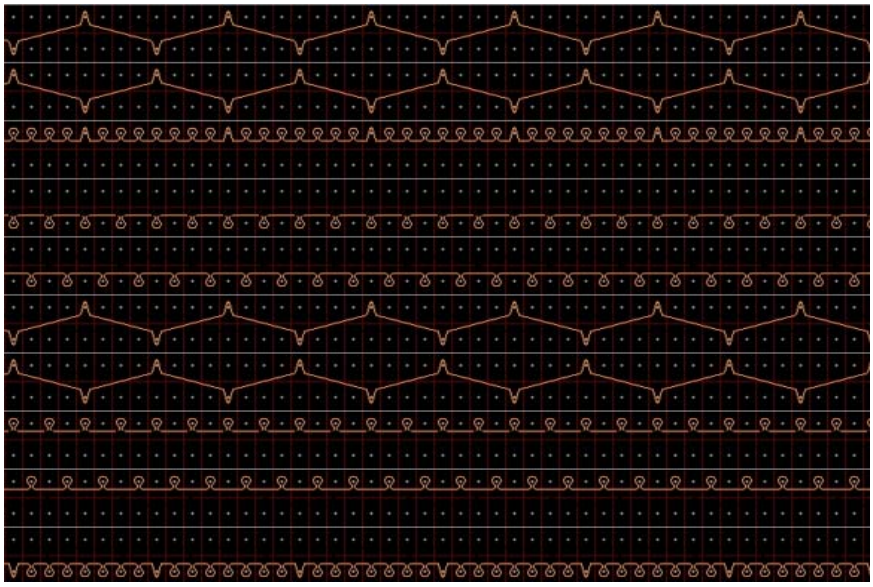

Figure 7. Structure of Fabric II.I

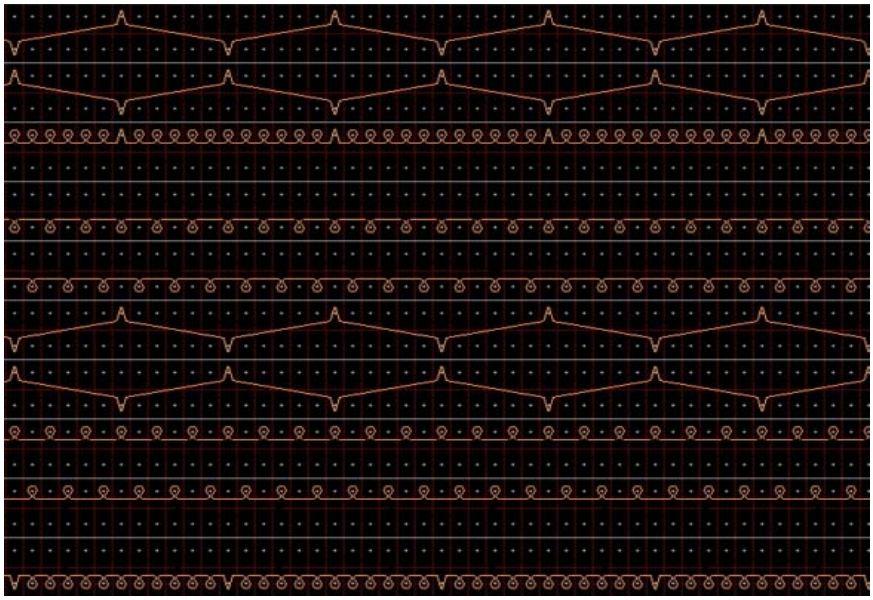

Figure 8. Structure of Fabric III.I

Table II shows the dimensional properties of the spacer fabrics.

Table II. Dimensional properties of knitted spacer fabrics

Fabric Code	Wale and Course density ($1/cm^2$)		Fabric Density (kg/m^3)	Fabric Thickness (mm)
	Front	Back		
I	20	20	284.085	4.43
II	20	20	282.636	4.40
III	20	20	280.066	4.50
I.I	20	20	272.637	5.08
II.I	20	20	283.176	5.10
III.I	20	20	281.788	5.20

2.2 Measurement of noise absorption coefficient

To validate the mathematical prediction of the NAC of spacer knitted fabrics a measurement of the NAC was done using a standard two-microphone tube provided by Bruel&Kjaer. Two-microphone impedance method is based on measuring sound pressure in an impedance tube at two flush-mounted microphone positions. It determines the acoustical characteristic quantities such as the absorption coefficient, reflection coefficient, surface impedance and surface admittance for small size objects exposed to plane waves at normal sound incidence, referring to the figure 1 [9].

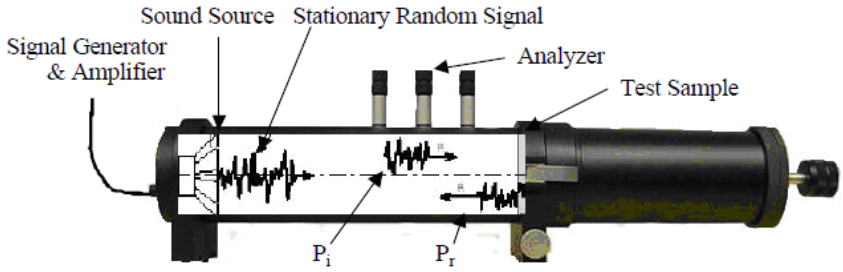

Figure 1. Conceptual Drawing of Two-Microphone Impedance Method

PULSE Material Testing is the complete and fully integrated system for acoustic measurements on small material samples in the 50 Hz to 6.4 kHz frequency range. The white noise signal required by the impedance tube is generated by software in PC, which is fed to the tube with a National Instruments data device. The A and B microphone signals are fed to the PC with this device. The sound absorption software in PC calculates the NAC from 50 Hz to 6.4 kHz. As per ISO 10534-2 standard, NAC measurements were done on three identical samples taken from different regions of the fabric under test and their average taken [10].

The system configuration of Material Testing is shown in figure 2 [11].

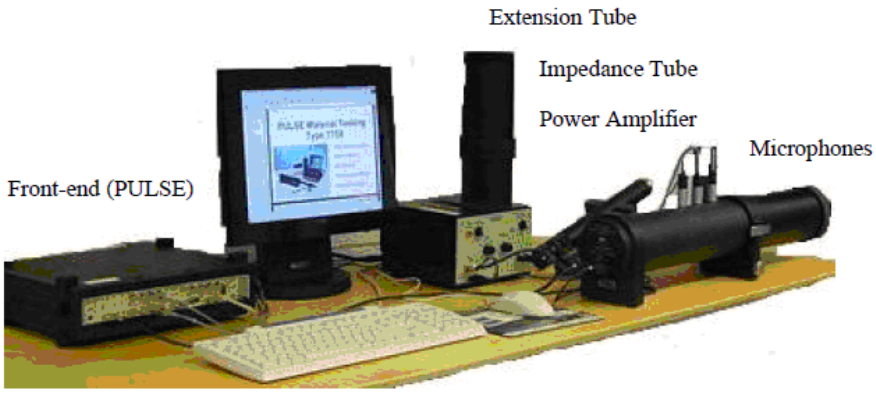

Figure 2. System Configuration of Acoustical Material Testing Using Two Microphone Method

2.3 Measurement of the total fabric thickness

The thicknesses of the fabrics as indicated in table II were measured with the use of a James H. Heal thickness tester. A 5 g/cm^2 pressure was used for this purpose.

2.4 Measurement of the fabric density

The weights of samples were measured in grams and the average was taken. The samples were cut in circular area of 100 cm^2. This value is then divided by 100 to obtain the mass per unit area (*M*) for the fabric in g/cm^2. This value and the measured thickness (t) of the fabric from table II are used to obtain the density of the fabric. The results are given in table II.

The density of the fabrics can be determined by the equation 1.

$$\rho_f = \frac{M}{t} \qquad (1)$$

3. RESULTS AND DISCUSSION

The results obtained are discussed below with the help of the relevant figures:

A comparative study of the sound absorption results of the fabrics I, II and III showed that Fabric III has the highest sound absorption coefficient value when compared with Fabric I and II (see fig. 9). In the knitting structure of Fabric III, the number of tucks is less and multifilament yarn connects two face layers in less number of points. Fabric III has a larger air gap in between two layers of the fabric, which in turn causes a smaller pore area and a larger pixel area corresponding to a smaller perforation area ratio than fabrics I and II. Density values of Fabrics I, II and III are very similar to each other. Therefore, effect of density on absorption behavior of fabrics can not be seen easily. With reference to Figure 10, sound absorption coefficient of fabrics increases with the decrease in the number of tucks in the stitch notation and the connection points of interconnecting yarn, because the total thickness of fabric increases. Figure 11, 12 and 13 on the other hand reveal the effect of technical back thickness on sound absorbency of fabric. Unlike the fabric types I, II and III in which plain knit utilized in the technical back, the thickness of the fabric increases when mini-jacquard knit (see fig. 11,12.13.) is employed in the technical back of the fabric. To analyse the effect of thickness on sound absorbency, the sound absorbencies of the fabrics I-I.I, II-II.I, III-III.I were compared. Sound absorption coefficient increases with thickness. Effect of face layer thickness on α is seen clearly at frequencies higher than 2 kHz.

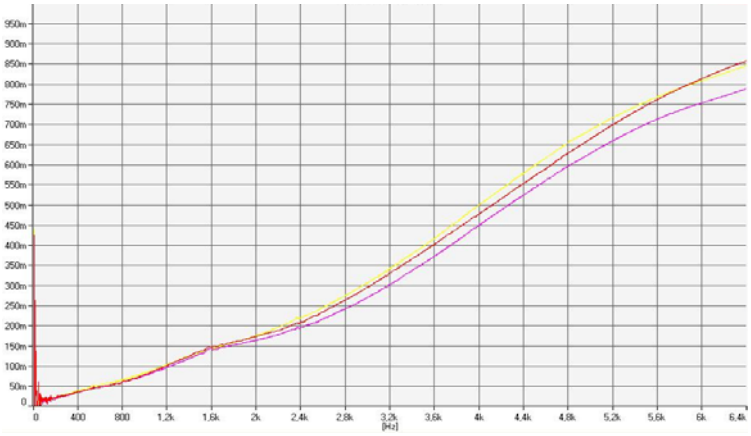

Figure 9. Comparison of absorption coefficients of Fabrics I, II and III (**I.II.III**)

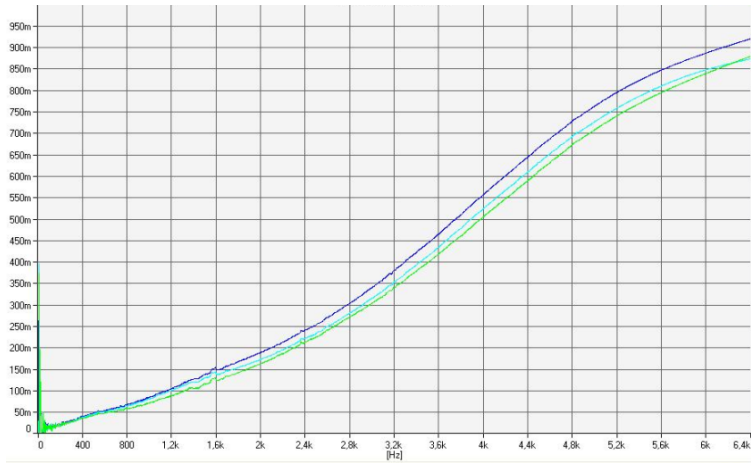

Figure 10. Comparison of absorption coefficients of Fabrics I.I, II.I and III.I (**I.I, II.I, III.I**)

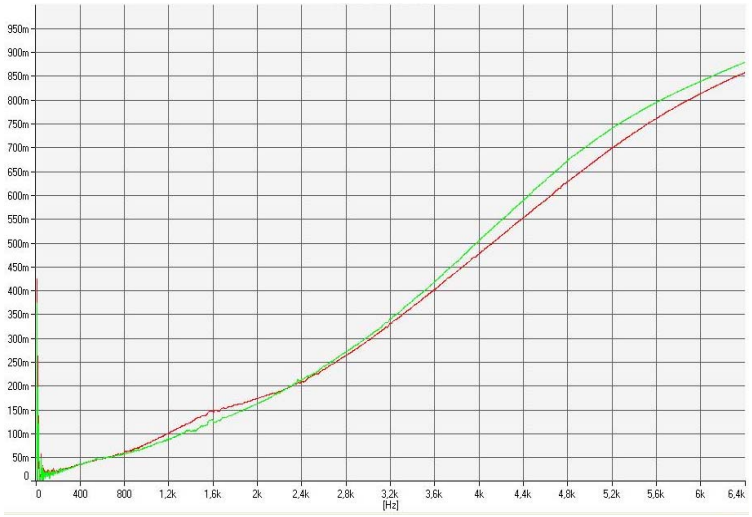

Figure 11. Comparison of absorption coefficients of Fabrics I and I.I (**I, I.I**)

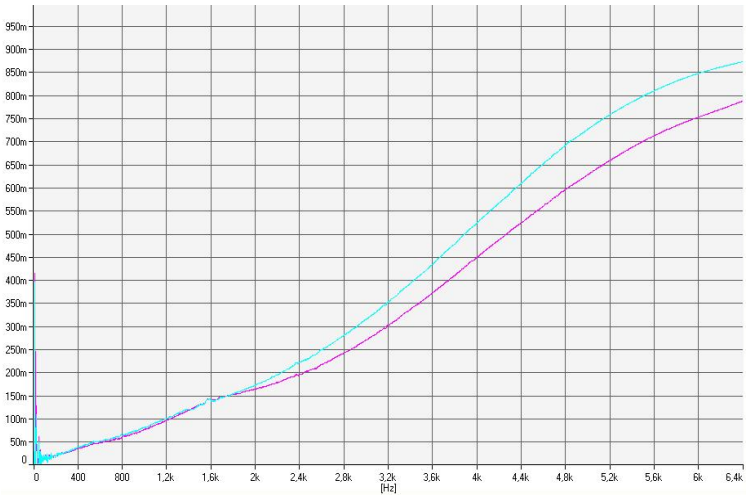

Figure 12. Comparison of absorption coefficients of Fabrics II and II.I (II, II.I)

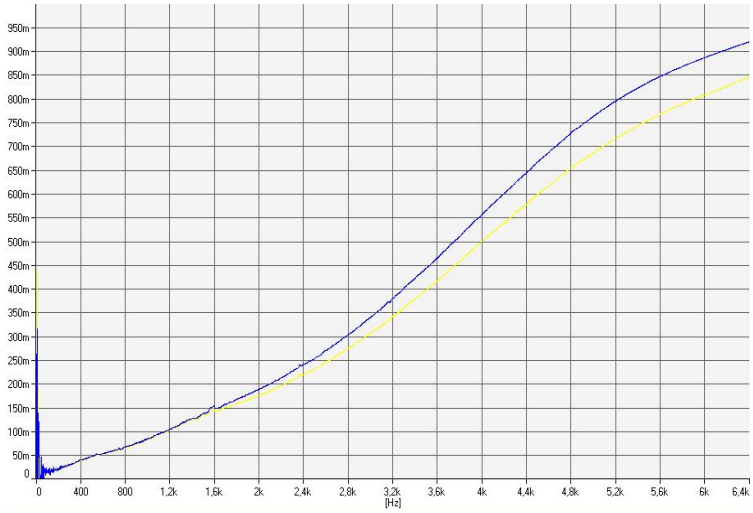

Figure 13. Comparison of absorption coefficients of Fabrics III and III.I (III, III.I)

4. CONCLUSION

Sound absorption of thick knitted spacer fabrics, which can be knitted from cotton plied yarns, was investigated in this study. Two-Microphone impedance tube method was used to analyse their sound absorption properties. The results show better noise absorption when there is a thicker air gap between the front and back fabric layers of the spacer fabric and/or a thicker face layer. This type of a knitted structure is a promising material for use in automobile interiors as headliner, parcel shelf and door panel liners.

The sound absorbency of the spacer fabrics developed is generally effective from 4000 Hz upwards when its noise absorption coefficient (NAC) is greater than 50%. Therefore, future work on these fabrics will be directed at the improvement of its sound absorbency in the region less than 4000 Hz.

ACKNOWLEDGEMENT

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MECHANICAL PROPERTIES OF BIOCOMPOSITES BASED ON THERMOPLASTIC STARCH AND CELLULOSIC FIBRES FROM AGRICULTURAL RESIDUES

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ABSTRACT

In the last years, the development of commercially viable "green products" based on natural resources for both matrices and reinforcements has attracted the interest of the industry and researchers. In this sense, composites made from biodegradable polymers and natural fibres are used in a growing range of products that include automotive use, building applications and packaging among others. Although natural fibres have been used in composites for many years, because of environmental reasons, nowadays there is a resurgence of interest in the use of these fibres as reinforcement for polymer composites. Using natural fibres to reinforce polymers has several advantages over synthetic ones: their renewable nature, low energy consumption in production, low cost, low density and high specific strength and modulus.

In this work, cellulosic fibres obtained from barley straw residues have been used to prepare thermoplastic starch composites.

Firstly, fibres with different percentages of lignin and α-cellulose were obtained from the barley straw using different chemical treatments. Cellulose, hemicelluloses and lignin contents of these fibres were determined by chemical analysis. The length, width and curl index were measured on a Kajaani Analyzer and the morphology was observed by Optical Microscopy.

Secondly, the effect of both the chemical treatment and the percentage of fibres on the mechanical reinforcement of the thermoplastic starch polymer were investigated with mechanical tests. To analyze the significance of the differences among the average values of the mechanical properties for the different contents of fibres on the starch matrix One Factor Analysis of Variance (ANOVA) was performed.

Key Words: cellulosic fibres, biocomposites, reinforcement, mechanical properties

1. INTRODUCTION

In the last years, increased attention has been paid to the use of natural polymers and natural fibres. The reasons of this include growing interest in reducing the environmental impact of polymers or composites due to awareness of eco-friendliness and the interest in increasing the use of renewable materials. [1]

Among natural fibres, cellulosic ones are the most used in polymer composites principally for their availability, same performance than other fillers for lower weight, low cost, fully and easy recyclability, reduced molding cycle time, non-abrasive to machinery, natural appearance, low thermal expansion coefficient, good sound abatement capability (thermal and acoustic insulation), easily coloured, high flexural and tensile modulus, high notched impact, lower processing energy requirements, etc. [2]. Among these cellulosic fibres, agricultural residues like cereal straws can be a valuable source of natural fibres because of its annual renewability. Like wood, cereal straws are primarily composed of cellulose, hemicelluloses and lignin. However, they also contain significant amounts of pectins, proteins and most importantly ashes. The typical composition of cereal straw fibres is 33-45.5% of cellulose; 21-28.5% of hemicelluloses, 10-21% of lignin and 3-7% of silica. In comparison with wood, straws contain less cellulose and lignin, but hemicellulose content is higher. Morphologically, straw fibres have an average length of 1.48 mm (between 0.68-3.12 mm); average diameter 13 μm (between 7-24 μm) and fibre length to diameter ratio 110:1. The advantages linked with the utilisation

of these fibres in composites include the use of one by-product of agriculture, low price (cheaper than wood), and that they can be cooked at low temperature. In addition, these fibres contain high amounts of silica, which could be beneficial in fire retardancy [3].

It is well known that renewable resources such as plants or bacteria, as well as non-renewable petroleum are sources of a variety of polymeric materials. Accordingly, biodegradable polymeric materials have been classified as natural or synthetic depending on their origin. Furthermore, biodegradable polymers themselves can be classified, depending on their origin, into agro polymers (starch or cellulose), microbial, chemically synthesized from agro based resource monomers (PLA) and chemically synthesized from conventionally synthesized monomers [2].

The most extensively studied biodegradable polymers are starch and poly(hydroxbutyrate)-PHB, particularly for composites, since the main sources for both are renewable resources. Starches are natural hydrophilic polymers processed by conventional methods, but exhibit poor melt processability and are highly water soluble, difficult to process and brittle. Hence, they need a plasticizer to make them suitable for engineering applications. Plasticizers such as water or glycols make starches flow and suitable for thermoplastic processing. Starch is biodegradable but very brittle and has poor mechanical properties. However, there are several ways to improve some properties of the starch, such as blending with other polymers or fillers [4-6]. In order to produce fully renewable and biodegradable composites, both the polymeric matrix and the reinforcement must be derived from renewable resources.

The main goal of the present work is to produce and characterize biocomposites fully renewable and biodegradable from wheat straw fibres and thermoplastic starch polymer. The mechanical properties of the composites have been evaluated to demonstrate the reinforcing potential of these fibres in biocomposite applications.

2. MATERIALS AND EXPERIMENTAL PROCEDURES

2.1. Materials

Thermoplastic starch was produced by using a co-rotating extruder.

Cellulose fibres in powder form were prepared from barley straw obtained from local sources.

2.2 Isolation of cellulose fibres

In order to isolate cellulose fibres with different percentages of lignin and α-cellulose, two kind of chemical treatments were performed on the barley straw (see Figure 1). Before these chemical treatments the barley straw (UF) was dried at 60ºC and cut into 3-5 cm length. The first treatment was performed cooking the cut barley straw in a sodium hydroxide solution (0.14 g of NaOH by 1g of dried barley straw) at 160ºC for 3h in a pulp digester. Anthraquinone was added as catalyser. The fibres obtained (ATF) were washed, filtered, dried and mechanically disintegrated with a mill.

The second treatment was performed in two steps: firstly the cut barley straw was soaked in a water solution at 165ºC for 2 hours in a pulp digester. Secondly, the hydrolysed fibres (PTF) were cooked in a sodium hydroxide solution under the same conditions followed on the first treatment aforementioned. The fibres obtained (PATF and PTF) were washed, filtered, dried and mechanically disintegrated with a mill.

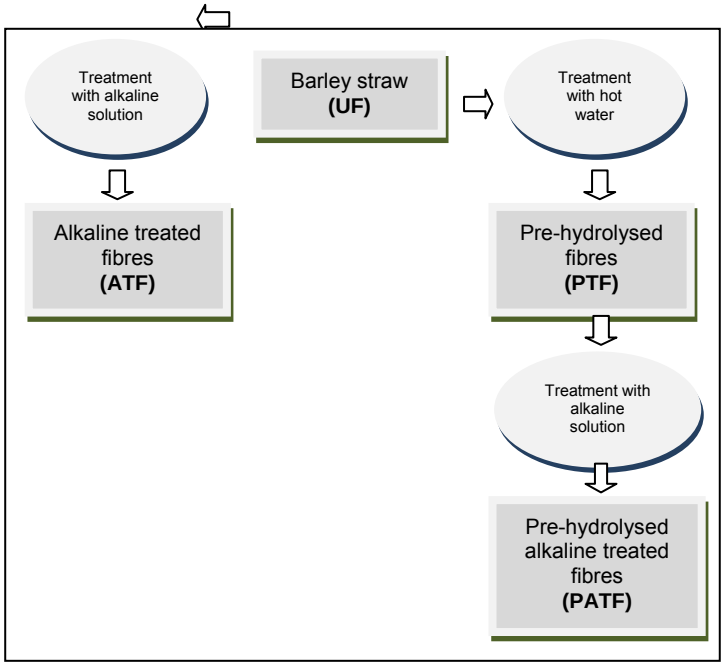

Figure 1: Scheme describing the procedures followed to isolate cellulose fibres from barley straw.

2.3. Fibre characterization

The composition in α-cellulose and hemicelluloses was analysed according the TAPPI standard T203 om-93.

The Lignin content was calculated as (Data Sheet D-6, Canadian Pulp and Paper Association):

$$Lignin(\%) = 0.147 \times K$$

where K is the Kappa number determined by the TAPPI test method (TAPPI 236 cm-85, 1994). K is defined as the volume in mL of 0.02 M potassium permanganate that is consumed by one gram of moisture-free pulp under specific conditions.

Viscosity was measured according to ISO 5351-1:2004 (TAPPI T 230, 1994) using cupriethylenediamine (CED) as a solvent and a Schott capillary viscometer.

The length, width and curl index were measured on a Kajaani FS300 Analyzer according to ISO 16065-1 (‘‘Pulps. Determination of Fibre Length by Automated Optical Analysis. Part 1. Polarized Light Method”). The measures were performed on more than 10,000 fibres.

The fibres’ morphology was characterized using an Optical Microscope.

2.4 Composite preparation

The thermoplastic starch was prepared by melt compounding in a co-rotating twin-screw extruder. Two mixtures were prepared: the first one (TPS) containing 68 wt.% of starch, 30 wt.% of glycerol and 2 wt.% of stearic acid and the second one (TPS-EVA) with 63 wt.% of starch, 5 wt.% of a ethylene vinyl acetate polymer (EVA), 30 wt.% of glycerol and 2 wt.% of stearic acid. A constant rotating screw speed of 120 rpm was used, assuring that the melt temperature measured at the die was never higher than 130 ºC. At the end, the extrudates were water-cooled and pelletised.

The pellets of TPS and TPS-EVA were blended with the treated fibres using a Brabender Plastograph. The temperature and rotation rate were 105ºC and 50 rpm respectively and the processing time was 8 min. The composition of the resulting composites is shown in Table 1.

Table 1. Reference materials composition

Mixtures with TPS	**Mixtures with TPS-EVA**
TPS	TPS-EVA
TPS-5%PATF	TPS-EVA-5%PATF
TPS-10%PATF	TPS-EVA-10%PATF
TPS-15%PATF	TPS-EVA-15%PATF
TPS-15%ATF	TPS-EVA-15%ATF
TPS-15%PTF	TPS-EVA-15%PTF

1 mm-thick square plaques were compression-moulded from the previously compounded composites using a hot-plate press Collin, applying a temperature of 105 ºC for 5 min and a maximum pressure of 100 bar. The plaques were cooled under pressure (100 bar) during 5 min using the cooling station of the press. Different specimens were machined from the plaques in order to characterize the prepared materials.

2.5 Mechanical characterization of the composites

The Young's modulus (E) and maximum tensile strength (σ_{max}) were measured on standard dumbbell test specimens obtained from compression-moulded plaques according to ASTM D638. The experiments were carried out at 23 ºC on an INSTRON 3366 dynamometer at deformation rates of 50 mm/min. The values reported in this work for each reference material are the average of five repeated experiments.

3. RESULTS

3.1 Physicochemical characterization of the isolated fibres

Table 2 shows the chemical composition of the treated fibres. As shown, the α-cellulose content on the fibres increased significantly by the chemical treatment, mainly on the PATF ones. Moreover, the lignin content was notably decreased as expected. This chemical compositional change in the barley straw fibres will result in a higher crystallinity degree and hence improved thermal and mechanical properties.

Table 2. Chemical composition and degree if polymerization of the isolated barley straw fibres

Isolated fibres	**α-cellulose (%)**	**Lignin (%)**	**Degree of polymerisation**
Untreated fibers(1)	33-44.5	10-21	---
ATF	85.1	3.11	1480
PATF	96.7	1.51	1289

(1)Theoretical average values [3]

Concerning the morphological characteristics of the treated fibres, as shown in Table 3, the average length and width of the fibres was around 0.4 mm and 15 μm respectively, being around 30:1 the fibre length to

diameter ratio. Lower values of length and width were found for the PATF as expected. The fibre curl index, defined as a gradual and continuous curvature of the fibres, was found similar for both treated fibres.

Table 3. Morphological characteristics of isolated fibres

Isolated fibres	Length mm	Width µm	Curl index (%)
ATF	0.48	15.6	20.2
PATF	0.39	14.9	26.6

Figure 2 (a) shows the general the morphology of the fibres. It can be seen that other non-fibrous components are mixed with the fibres (Figure 2 b). These non-fibrous components are typical in the pulps obtained from agricultural residues.

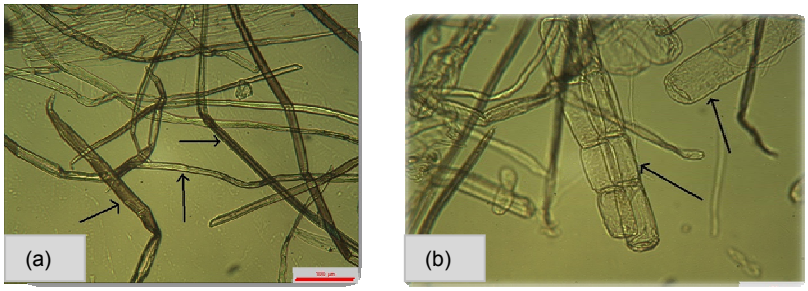

Figure 2: Microscopical images for the isolated fibres (PATF).

3.2 Mechanical properties of the composites

The results from the mechanical testing are shown in Table 4.

Table 4. Tensile modulus (E) and tensile strength (σ) of TPS and the composites

Sample	E (GPa)		σ (MPa)	
	Average	Standard deviation	Average	Standard deviation
TPS	403,3	44,6	8,58	0,33
TPS-5%PATF	960,2	62,8	12,58	0,37
TPS-10%PATF	1101,4	136,0	13,58	0,96
TPS-15%PATF	1789,6	145,2	16,14	0,92
TPS-15%ATF	1357,4	132,4	14,32	2,18
TPS-15%PTF	1909,5	177,1	20,65	1,47
TPS-EVA	627,5	53,6	9,24	0,53
TPS-EVA-5%PATF	657,4	80,7	10,54	1,07
TPS-EVA-10%PATF	1108,7	115,8	15,50	1,49
TPS-EVA-15%PATF	1549,0	208,6	15,63	2,27
TPS-EVA-15%ATF	1328,3	155,2	16,09	2,93
TPS-EVA-15%PTF	1410,2	55,4	12,39	0,95

In order to analyze the influence on the mechanical properties of the use of EVA in the matrix as well as the content of the PATF prepared fibres in the composite (variable X), a lineal model analysis has been carried out. The use of EVA in the matrix is a qualitative variable, which was introduced in the model by a categorical variable Q2. The categorical variable takes the value -1 for TPS and +1 for TPS+EVA.

Table 4. Tensile modulus (E) and tensile strength (σ) of TPS, TPS+EVA and the composites with different contents of PATF

Sample	Variables		Responses	
	Matrix (Q2)	Content of PATF (X)	E (GPa)	σ (MPa)
1	-1	0	403,3	8,58
2	-1	5	960,2	12,58
3	-1	10	1101,4	13,58
4	-1	15	1789,6	16,14
5	+1	0	627,5	9,24
6	+1	5	657,4	10,54
7	+1	10	1108,7	15,50
8	+1	15	1549,0	15,63

The initial model is as follows:

$$Y = \beta_0 + \beta_1 \cdot X + \beta_2 \cdot X^2 + \beta_3 \cdot Q_2 + \beta_4 \cdot Q_2 \cdot X + \beta_5 \cdot Q_2 \cdot X^2 + \varepsilon$$

And the obtained models for the responses are the following:

$$\textbf{Tensile modulus} = 460.9649 + 75.1568 \cdot X \qquad R^2 = 0,9077$$

$$\textbf{Tensile strength} = 9.13762 + 0.47814 \cdot X \qquad R^2 = 0,9124$$

Both statistical models for the response tensile modulus and for the tensile strength show that the use of EVA in the matrix is not significant. The concentration of the fibre in the composite is significant and has a lineal and direct relationship with the responses, the higher the fibre content, the better the mechanical properties. Hence, a significant increase in the tensile modulus with respect to that of the unfilled polymer can be observed on the composites. The maximum tensile strength increases also in the composites, indicating a very good interfacial adhesion between the matrix and the cellulosic fibres.

In order to analyze the significance of the differences among the average values of the differently prepared fibres a One Factor Analysis of Variance (ANOVA) was performed. In this analysis, two samples of each composite prepared with a content of 15% of the different fibres were analysed and compared with two samples of the matrix alone. The risk was fixed is 5% and the assumptions of normal distribution and homogeneous variance was checked by the analysis of the residuals.

Table 5. Tensile modulus (E) and tensile strength (σ) of the composites with different fibres

Sample	E (GPa)		σ (MPa)	
No fibre	403,3	627,5	8,58	9,24
15%PATF	1789,6	1549,0	16,14	15,63
15%ATF	1357,4	1328,3	14,32	16,09
15%PTF	1909,5	1410,2	20,65	12,39

For the tensile modulus, the significance level of the F statistic of the ANOVA is 0.0154, lower than the 0.05 value of the risk. Hence, the hypothesis of equal averages cannot be accepted. That means that there is at least one of the treatments that is significantly different than the others. With this situation, homogeneous groups can be found (Figure 3).

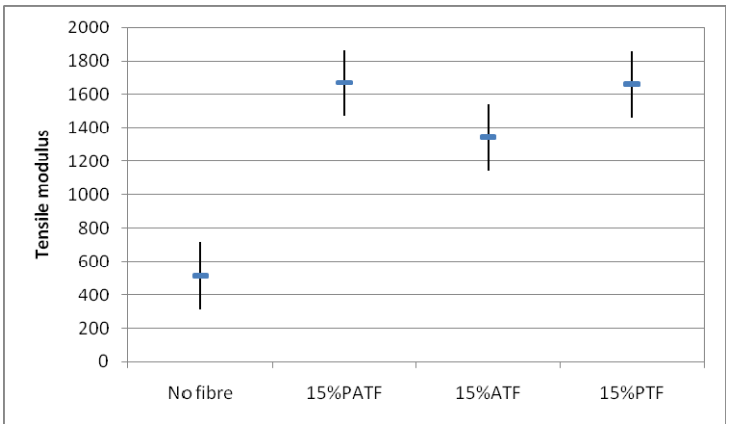

Figure 3: Homogeneous groups in the analysis of the fibres influence (tensile modulus).

The figure shows that a significant increase in the tensile modulus with respect to that of the unfilled polymer can be observed on the composites. However, there is not a significant difference between the results obtained with the different preparations.

For the tensile strength, the significance level of the F statistic of the ANOVA is 0.1764, higher than the 0.05 value of the risk. Hence, the hypothesis of equal averages is accepted. That means that there is not a significant increase in the tensile strength with respect to that of the unfilled polymer.

4. CONCLUSIONS

In this work, cellulose fibres were isolated from barley straw by chemical treatment. Experimental results showed that the content in cellulose increases after these treatments.

The tensile tests showed that composites had significant improvement in modulus and tensile strength compared to pure thermoplastic starch. Both statistical models for the response tensile modulus and for the tensile strength show that the use of EVA in the matrix is not significant. The concentration of the fibre in the composite is significant and has a lineal and direct relationship with the responses, the higher the fibre content, the better the mechanical properties.

Results showed that the barley straw fibre reinforced thermoplastic starch composites can find potential application in biocomposite production. Further characterization will be made in these materials in order to explore their applicability in packaging or other applications.

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MODELING THE TENSILE BEHAVIOUR OF NEEDLE PUNCHED NONWOVEN GEOTEXTILES

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ABSTRACT

Geotextiles, which are the members of geosynthetic group, are gaining more and more importance for complex technical textile applications in construction and environmental industries by virtue of their many advantages. Needle punched nonwovens, which are produced by the penetrating action of barbed needles, are amongst the most widely used geotextile materials. These types of geotextiles are felt like in appearance and are relatively thick. Various mechanical and hydraulic functions such as reinforcement, separation, protection, drainage and filtration are provided by fabrics in a geotextile-soil system. Hence, the mechanical characterization is very important in designing with geotextiles. The characteristics of nonwoven geotextiles depend upon the fiber properties (polymer type, fineness, tensile properties, orientation of fibers etc.) and manufacturing processes (method of bonding) and also on fabric weight, fabric thickness, finishing etc. Therefore several mechanisms occur such as breakage, elongation, shear, friction, bending, buckling during deformation of nonwovens. Moreover complexity of mechanical characterization of fabrics increases because of the interaction of these mechanisms. However researchers have considered mechanical behaviours of nonwoven fabrics under various kinds of loads and a number of theoretical approaches have been developed for years.

In this study, a theoretical model was proposed to predict the mechanical behaviours of needle punched heavy geotextiles in uniaxial tensile test. The model was constructed using theory of layered composite materials and finite element method. The properties of a lightly bonded reference fabric were used as initial data in theoretical calculations and a commercial available finite element program was chosen to carry out stress analysis. A comparison is made between theoretical calculations and experimental data to evaluate the deformation mechanism of geotextile fabrics in uniaxial tensile test. The results indicate that compatible results were predicted in terms of stress values and stress distribution of fabrics. The inconstant lateral contraction of nonwoven fabrics in tensile test is also successfully simulated by the model. However, in the case of elongations, the model could not predict the strains of heavy geotextiles accurately.

Keywords: Nonwoven, Geotextile, Composite Theory, Finite Element Method

1. INTRODUCTION

Geotextiles, which are the members of geosynthetic group, are gaining more and more importance for complex construction projects in engineering by virtue of their many advantages. Geotextiles are permeable textile structures such as nonwoven and woven fabrics. Needle punched nonwovens, which are produced by the penetrating action of barbed needles, are amongst the most widely used geotextile materials. These types of geotextiles are felt like in appearance and are relatively thick [1,2]. Needle punched nonwoven fabrics are characterized by high porosity, elongation and energy absorption properties which make them ideal for a wide range of geotextile applications [3].

Various mechanical and hydraulic functions such as reinforcement, separation, protection, drainage and filtration are provided by fabrics in a geotextile-soil system. Therefore mechanical characterization of the fabric is very important in designing with geotextiles. However several fiber and fabric parameters such as polymer and fiber type, orientation of fibers, fabric weight, fabric thickness and also method of bonding have influence on the mechanical behaviour of nonwoven fabrics. Moreover complexity of mechanical characterization of nonwoven fabric increases, because of the interaction of mechanisms like breakage, elongation, shear, bending and buckling during deformation. Nevertheless, several attempts were made to predict the mechanical behaviours of nonwovens under various kinds of loads. As a result of these studies a number of theoretical models were developed. In 1960 Backer and Peterson reported a fiber network theory for nonwoven fabrics based on fiber tensile properties and orientation of fibers [4]. The following theories generally consider the fiber network theory and improve it by using different and/or new analytical and experimental methods such as energy method, orthotropic symmetry theory, theory of composite materials, finite element method etc [5-13]. In most cases computer simulation and image analysis techniques were also used [14-19]. In the aforementioned studies, the properties of constituent fibers and structural arrangement of fibers in the web were commonly used to predict the mechanical properties of nonwoven fabrics. However

some specific mechanisms of deformation were ignored almost in each approach because of the complexity of problem. Moreover interactions of fibers are generally neglected in the previous studies considering the properties of constituent fibers, but in needle punched fabrics inter fiber friction plays a predominant role in deciding the mechanical behaviour of fabric as reported by Hearle and Sultan [8].

In this study, a theoretical model was proposed to predict the mechanical behaviour of needle punched heavy geotextiles in uniaxial tensile test. We assumed that this type of geotextiles as a laminated composite considering the previous studies [20-23]. The model was constructed using theory of layered composite materials and finite element method. The properties of a "lightly bonded reference fabric" were used as initial data in theoretical calculations instead of constituent fiber properties and a commercial available finite element program "ANSYS" was chosen to carry out stress analysis. The nonlinear stress strain behaviour of reference fabric was also considered in the model. The adequacy of the model was discussed by comparing theoretical and experimental results of geotextile samples in this study.

2. MATERIAL AND METHODS

2.1. Material

The five needle punched nonwoven geotextile fabrics, made from polypropylene staple fibers, were supplied by a commercial geotextile producer. Figure 1 illustrates the production process of sample fabrics in this study. The weights of reference and sample fabrics are 100gr/m^2, 200gr/m^2, 300gr/m^2, 500gr/m^2 and 800gr/m^2, respectively.

Figure 1. Flow Chart for the Production of Geotextile Fabrics

2.2. Experimental

At first the thickness of all samples was measured using a digital thickness gauge under 2kPa pressure according to TS EN ISO 9863-1 [23]. Then tensile behaviour of geotextile samples was examined both in the machine direction (MD) and in the cross machine direction (CD) on a computer controlled Shimadzu Autograph AG-IS Series universal testing machine. The wide-width tensile test was performed according to TS EN ISO 10319 to minimize the errors which can be caused by edge curling of specimens and to avoid the extreme strains in strip test [24]. The test length was kept as 100 mm and width as 200 mm and the fabrics were strained at a rate of 20 mm/min. The tensile behaviour of reference fabric was used as initial data in theoretical analysis to predict the mechanical properties of other samples. Therefore material constants of reference fabric such as poisson's ratio, shear modulus and elastic moduli were also obtained.

In the nonwoven production line all fibers in the card web are parallel to each other, but after lapping and punching, fibers in the layers of fabric are oriented at various directions following random or some known statistical distribution. Therefore the orientation of fibers in a layer of nonwoven fabric is another parameter that needs to be defined as initial data in the theoretical analysis. However it is very difficult to obtain fiber orientation distribution in heavy nonwovens such as needle punched geotextiles with experimental methods, because they consist of a large number of fiber layers [25]. In our approach, orientation angles of layers in heavy nonwovens were simply derived considering the orientation angles of reference fabric and the number of web layers in the heavier sample fabrics. For this purpose, at first fiber orientation distribution of reference fabric was measured under a projection microscope. Finally the orientation angle of layers in heavy samples was assigned to program considering both the number of web layers in fabrics and the fiber orientation distribution of reference fabric.

2.3. Model and Theoretical Formulations

The basic principles of our model for nonwovens are similar to the layer theory and finite element model proposed in earlier publications [20,21,26]. We assumed that nonwoven fabrics are made up of fiber layers similar to composite materials. Thus a layered nonwoven can be regarded as a laminate and each layer of fabric can be considered equivalent to a lamina. We also assumed that the nonwoven fabics are formed by layered finite elements, and fibers (layers) that make up the fabric are bound together at nodal points of the mesh of the finite element. As mentioned above nonwovens especially heavy ones consist of a number of layers (placed at an angle) as shown in Figure 2. The axes in the X-Y coordinate system represent the global axes, such that the uniaxial loading direction and traverse directions of fabrics coincide with the Y and X axes, respectively. The local axes for an individual layer (lamina) are given by the 1-2 coordinate system, such that all fibers in the layer are oriented along the 1 direction and the direction 2 is perpendicular to the fibers.

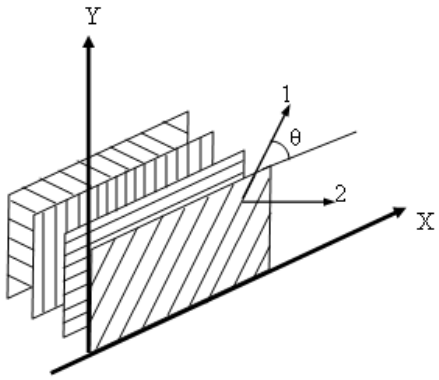

Figure 2 Layered Structure of Nonwoven Fabric

A unidirectional layer of fabric falls under orthotropic material category. If the layer is thin and does not carry any out of plane loads, one can assume plane stress conditions for the layer. The relationship of stress and strain for an orthotropic plane stress problem can be written as [27];

$$\begin{bmatrix}\sigma_1\\ \sigma_2\\ \tau_{12}\end{bmatrix}=\begin{bmatrix}Q_{11} & Q_{12} & 0\\ Q_{12} & Q_{22} & 0\\ 0 & 0 & Q_{66}\end{bmatrix}\begin{bmatrix}\varepsilon_1\\ \varepsilon_2\\ \gamma_{12}\end{bmatrix} \quad (1)$$

where $Q_{11}=\frac{E_1}{1-\upsilon_{12}\upsilon_{21}}$, $Q_{12}=\frac{\upsilon_{21}E_1}{1-\upsilon_{12}\upsilon_{21}}$, $Q_{22}=\frac{E_2}{1-\upsilon_{12}\upsilon_{21}}$, $Q_{66}=G_{12}$ and E_1 is the longitudinal Young's modulus, E_2 the traverse Young's modulus, v_{12} and v_{21} the major and the minor Poisson's ratios, G_{12} the in-plane shear modulus, $\sigma_1,\sigma_2,\tau_{12}$ the layer stresses in the 1-2 coordinate and $\varepsilon_1,\varepsilon_2,\gamma_{12}$ the layer strains in the 1-2 coordinate.

The global and local stresses in a layer are related to each other through the orientation angle of the layer. The relationship of stress and strain between the local and global system can be defined as [27];

$$\begin{bmatrix}\sigma_x\\ \sigma_y\\ \tau_{xy}\end{bmatrix}=\begin{bmatrix}Cos^2\theta & Sin^2\theta & -2Sin\theta Cos\theta\\ Sin^2\theta & Cos^2\theta & 2Sin\theta Cos\theta\\ Sin\theta Cos\theta & -Sin\theta Cos\theta & Cos^2\theta-Sin^2\theta\end{bmatrix}\begin{bmatrix}\sigma_1\\ \sigma_2\\ \tau_{12}\end{bmatrix} \quad (2)$$

and

$$\begin{bmatrix} \varepsilon_x \\ \varepsilon_y \\ \gamma_{xy} \end{bmatrix} = \begin{bmatrix} Cos^2\theta & Sin^2\theta & Sin\theta Cos\theta \\ Sin^2\theta & Cos^2\theta & -Sin\theta Cos\theta \\ Sin\theta Cos\theta & -Sin\theta Cos\theta & Cos^2\theta - Sin^2\theta \end{bmatrix} \begin{bmatrix} \varepsilon_1 \\ \varepsilon_2 \\ \gamma_{12} \end{bmatrix} \quad (3)$$

where, $\sigma_x, \sigma_y, \tau_{xy}$ are the layer stresses in the X-Y coordinate, $\varepsilon_x, \varepsilon_y, \gamma_{xy}$ the layer strains in the X-Y coordinate and θ the orientation angle of the layer.

By substituting Equations (2) and (3) into Equation (1) the stress- strain relationship of each layer in the global coordinate system can be expressed as;

$$\begin{bmatrix} \sigma_x \\ \sigma_y \\ \tau_{xy} \end{bmatrix} = \begin{bmatrix} \overline{Q_{11}} & \overline{Q_{12}} & \overline{Q_{16}} \\ \overline{Q_{12}} & \overline{Q_{22}} & \overline{Q_{26}} \\ \overline{Q_{16}} & \overline{Q_{26}} & \overline{Q_{66}} \end{bmatrix} \begin{bmatrix} \varepsilon_x \\ \varepsilon_y \\ \gamma_{xy} \end{bmatrix} \quad (4)$$

Where,

$$\overline{Q_{11}} = Q_{11}\cos^4\theta + 2(Q_{12} + 2Q_{66})\sin^2\theta\cos^2\theta + Q_{22}\sin^2\theta \quad (5)$$

$$\overline{Q_{12}} = (Q_{11} + Q_{22} - 4Q_{66})\sin^2\theta\cos^2\theta + Q_{12}(\cos^4\theta + \sin^4\theta) \quad (6)$$

$$\overline{Q_{22}} = Q_{11}\sin^2\theta + Q_{22}\cos^4\theta + 2(Q_{12} + 2Q_{66})\sin^2\theta\cos^2\theta \quad (7)$$

$$\overline{Q_{16}} = (Q_{11} - Q_{12} - 2Q_{66})\cos^3\theta\sin\theta - (Q_{22} - Q_{12} - 2Q_{66})\sin^3\theta\cos\theta \quad (8)$$

$$\overline{Q_{26}} = (Q_{11} - Q_{12} - 2Q_{66})\cos\theta\sin^3\theta - (Q_{22} - Q_{12} - 2Q_{66})\sin\theta\cos^3\theta \quad (9)$$

$$\overline{Q_{66}} = (Q_{11} + Q_{22} - 2Q_{12} - 2Q_{66})\sin^2\theta\cos^2\theta + Q_{66}(\cos^4\theta + \sin^4\theta) \quad (10)$$

If the stress of a material uniformly varies with strain, the Equation (4) is valid. However in some nonwovens namely needle punched ones, deformation is nonuniform in uniaxial test [1,26]. Figure 3 illustrates the nonuniform strain-stress curves of our reference fabric in MD and CD. The state of stresses and strains are not the same in different regions of curves due to various effects such as nonlinear stress strain behaviour of fibers, crimp of fibers and reorientation of staple fibers in the beginning of the test and shear effects.

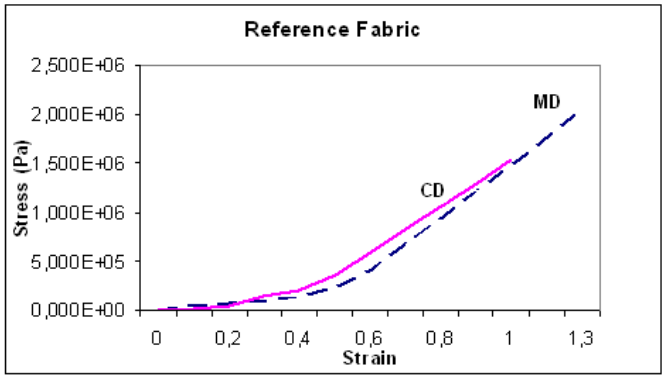

Figure 3 Stress-strain curves of reference fabric in the MD and CD

Therefore a nonuniform stress-strain behaviour was assumed for each layer and the stiffness matrix of layer divided into two parts. In the initial part stress varies nonlinearly with strain and in the second part stress varies linearly with strain. After reaching the maximum stress, the fibers and/or bonds start failing and the fabric stress drops to lower values, thus the theoretical calculations were not performed in these regions. The stress strain relationship of a lamina can thus be given as

$$\begin{bmatrix}\sigma_1\\ \sigma_2\\ \tau_{12}\end{bmatrix}=\begin{bmatrix}Q_{11}^{l} & 0 & 0\\ 0 & 0 & 0\\ 0 & 0 & 0\end{bmatrix}\begin{bmatrix}\varepsilon_1\\ \varepsilon_2\\ \gamma_{12}\end{bmatrix}+\begin{bmatrix}Q_{11} & Q_{12} & 0\\ Q_{12} & Q_{22} & 0\\ 0 & 0 & Q_{66}\end{bmatrix}\begin{bmatrix}\varepsilon_1\\ \varepsilon_2\\ \gamma_{12}\end{bmatrix} \quad (11)$$

The nonlinear part of the stiffness matrix contains only one stiffness term (Q_{11}^{l}), which relates the stress and strain components in the layer direction. The components of linear part of stiffness matrix are material constants which are denoted in Equation (1). If the strains are known at any point along the thickness of the laminate (fabric) the global stresses can be calculated for each layer by incorporating Equations (4) and (11). Then stresses in all layers can be integrated using theory of composite materials to give the overall mechanical behaviour of the layered nonwoven. Thus, fabric stresses in the X-Y direction for each finite element in the symbolic matrix form can be given by

$$[\sigma]^e=[D]^{e^l}[\varepsilon]^e+[D]^e[\varepsilon]^e \quad (12)$$

where $[D]^e$ and $[D]^{e^l}$ are the material constitutive matrices of the element in the linear part and nonlinear part, respectively. $[\sigma]^e=[\sigma_x\sigma_y\tau_{xy}]^T$ and $[\varepsilon]^e=[\varepsilon_x\varepsilon_y\gamma_{xy}]^T$

We incorporated the above finite element constitution relations into a commercial finite element program ANSYS to carry out stress analysis. Experimental data on the reference fabric tensile properties and web structure parameters are also supplied to program as input data. We have considered multi-linear stress strain assumption in the nonlinear initial part of stress strain curve of reference fabric. In the linear part, where the moduli are constant, we have considered orthotropic theory. In the multi-linear region fifteen respective stress-strain values of reference fabric and in the linear region material constants of reference fabric, which are given in Table 1, were used as initial data.

Table 1. Material Constants of a Layer in the Linear Part of Stress-Strain Curves

Property	Symbol	Value	
		MD	CD
Longitudinal Modulus	E_1	2.70 MPa	2.36 MPa
Traverse Modulus	E_2	2.36 MPa	2.70 MPa
In-plane shear modulus	G_{12}	0.91 MPa	0.88 MPa
Poison's ratio	υ_{12}	0.36	0.29

2.4. Geometry of the Finite Element Mesh

The needle punched nonwoven geotextiles were modeled considering wide-width tensile test. The initial geometry of fabric and the boundary conditions applied to the model are shown in Figure 4. Side AB and CD are constrained within the jaws. All translations and rotations are constrained on side AB. However, side CD is allowed to move only vertically. Both sides AD and BC are allowed to move freely in the traverse direction.

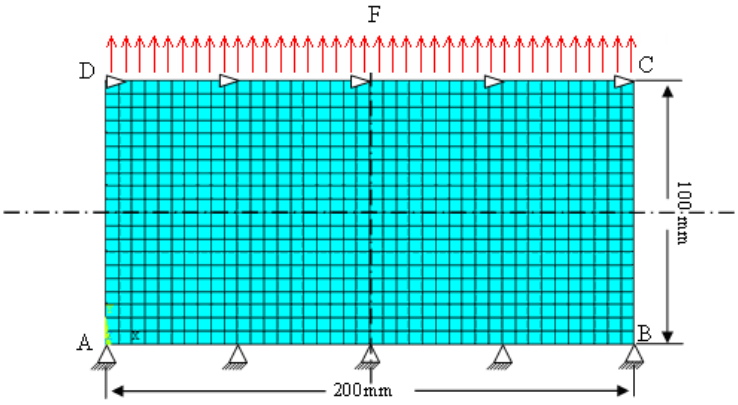

Figure 4 Initial Geometry of Fabric Model

"Structural Layered Composite" element was chosen to mesh the initial fabric model. This element type is suitable for the calculation of the behaviour of laminated structures with anisotropic nonlinearities [28]. Uniformly distributed tensile load (negative pressure) was applied to models. The magnitudes of applied loads are different for different fabric samples and are slightly less than their failure initiation loads. The real constants for layers and elements are given in Table 2. Fabric thickness measurement values are used to assign thickness value for each element.

Table 2 Real Constants for Elements and Layers

Fabrics	Fabric Weight (gr/m^2)	Total Number of Layers	Layer Thickness (mm)	Element Total Thickness (mm)
Reference	100	2	1.30	2.60
Heavier Samples	200	5	0.59	2.96
	300	8	0.44	3.56
	500	14	0.28	4.01
	800	22	0.23	5.20

3. RESULTS AND DISCUSSIONS

Stress analysis of geotextile samples was performed in both MD and CD using the constructed theoretical model. The distribution of computed stresses in the tensile directions can be seen in Figure 5.

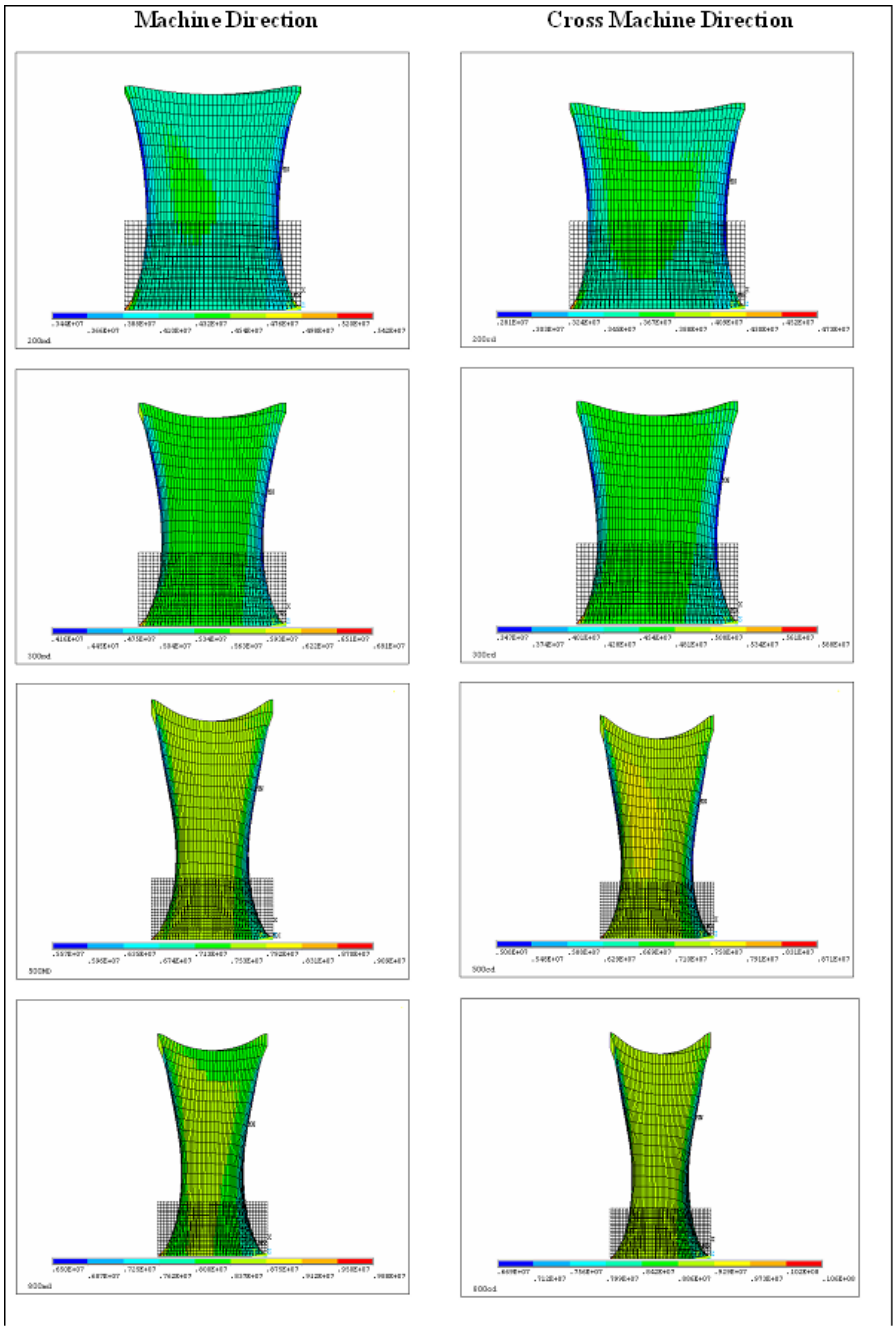

Figure 5 Distributions of Computed Stresses in Simulated Sample Fabrics

As seen in the plotted contours, the state of stresses is not the same throughout the models because of constraints, imperfectly symmetric distribution of fibers within the fabrics and traverse contraction during tensile deformation. Maximum stresses are calculated near the jaws as a result of constraints. Particularly stresses are much higher in the four corners than the other parts. Minimum stresses are obtained near the free edges. Besides critical stress distributions and concentrations are calculated around the center of the models. Consequently meaningful stress data can be obtained from the

stress distribution of computed models of needle punched nonwoven geotextile samples. The typical shape of the deformed fabric samples in the wide-width tensile tests can be seen in Figure 6.

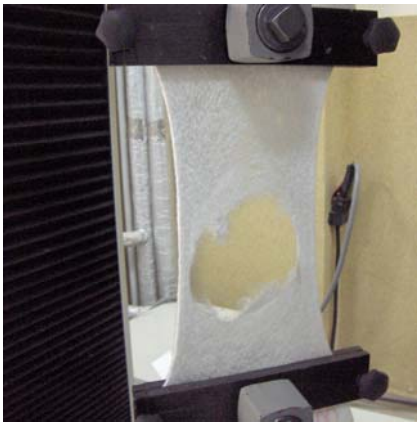

Figure 6 Deformation of fabric (500gr/m^2) in uniaxial tensile tests

The comparisons of Figure 5 and Figure 6 show that experimentally obtained and theoretically computed configurations of geotextile samples are similar in uniaxial tensile tests. There is not any lateral contraction at the jaws of computed figures; however contraction gradually increases to its maximum value at the center of the models. As given in Figure 6, very similar behaviours are observed during experiments due to the geometry of test. The inconstant lateral contraction of nonwoven fabrics in uniaxial tests is successfully simulated in the models. In the computed figures, critical stress concentrations were calculated around the center of models. On the other hand as seen in Figure 6, the experimental breaks usually occur around the center of specimens in uniaxial tensile tests. Therefore the element stresses in the center of models were considered for comparison. Theoretically and experimentally calculated parameters of reference and other fabric samples in the MD and CD are given in Table 3 and Table 4, respectively.

Table 3. Experimental and Calculated Stresses in Machine Direction

Fabric Weight (gr/m^2)	Experimental		Theoretical	
	Stress (MPa)	Max Displacement (mm)	Stress σ_x (MPa)	Max Displacement (mm)
100*	1.97	131.25	2.03	73.15
200	4.05	148.54	4.32	152.95
300	5.11	171.36	5.52	202.72
500	7.36	208.72	7.96	299.76
800	7.87	223.81	8.52	312.58

*Reference Fabric

Table 4. Experimental and Calculated Stresses in Cross Machine Direction

Fabric Weight (gr/m^2)	Experimental		Theoretical	
	Stress (MPa)	Max Displacement (mm)	Stress σ_x (MPa)	Max Displacement (mm)
100*	1.61	108.00	1.66	59.40
200	3.45	197.20	3.71	136.65
300	4.34	229.86	4.75	180.15
500	6.62	217.39	7.26	283.86
800	8.31	236.01	9.08	348.14

*Reference Fabric

As seen in the Table 3 and Table 4 predicted stresses in the center of plotted models are compatible with experimental ones and close to measured maximum stresses. Experimentally measured maximum stresses are predicted with almost 7-8 % average margin of error in the center of the models. In conclusion the agreement between the theoretical and experimental values is not poor in both MD and CD. However, in the case of elongations, the model could not predict the strains of heavy geotextiles in uniaxial tensile test accurately. As the fabrics become thicker, the difference between measured and computed displacements increases and higher displacements were predicted with respect to experimental measurements. In the model, the fibers that make up the fabric are assumed to be bound together only at nodal points of the mesh of finite elements, however in real fabrics bonded areas are not as homogeneous as in constructed model. Moreover reorientation of fibers was restricted because of the increasing number of bonded areas in heavy fabrics. As a nature of bonding process the weak bonded zones can also occur in real fabrics.

4. CONCLUSION

In this study a theoretical model is proposed to predict the mechanical properties of heavy nonwoven geotextiles using composite layer theory and finite element method. In the theoretical analysis the structural and tensile properties of a lightly bonded reference fabric is used as initial data. The nonlinear stress strain behaviour of reference fabric in uniaxial direction was also considered in the analysis. The comparisons of theoretical and experimental values indicate that meaningful stress data can be obtained from the stress distribution of computed models. The calculated stresses in the center of the model, where the experimental breaks are usually observed, are close to measured maximum stress. Moreover similar fabric configurations are observed in the experimental and computed results. In the case of elongations, predicted values are not very close to the experimental ones, because bonded areas in the real fabrics are not as homogeneous as constructed models. Consequently, the constructed model makes it possible to predict the stress distribution in heavy needle punched geotextiles form the properties of a light nonwoven. However, the elongation of heavy fabrics can not be predicted with adequate accuracy. Therefore further work is needed, which may consider the reorientation of fibers during deformation of heavy nonwovens exactly.

ACKNOWLEDGMENTS

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NANOSTRUCTURED SURFACE FUNCTIONALIZATION OF TEXTILES USING PLASMA TECHNOLOGY

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ABSTRACT

Plasma technology offers many interesting possibilities for the production of high value added textiles. A nanostructured surface functionalization can thus be achieved by a dry processing. This is shown here for the metallization of yarns, the permanent hydrophilization of fabrics, and for bioactive nanocomposite coatings. As illustrated through these examples, the successful implementation of plasma processes necessitates not only the thorough control of the plasma conditions, but also a consideration of the textile structural and chemical properties.

Key Words: plasma, sputtering, metallization, hydrophilization

1. INTRODUCTION

A shift toward highly functional and added-value textiles is now recognized as being essential to the sustainable growth of the textile and clothing industry in developed countries. The demand for tailored surface modifications for water repellence, long-term hydrophilicity, enhanced adhesion, anti-bacterial properties, etc, is therefore increasing. At the same time, the environmental restrictions concerning waste water produced by conventional textile finishing techniques are becoming more and more severe, generating higher running costs. In this context, plasma processing is seen as a very attractive alternative method to add new functionalities to textiles [1,2]. Plasma processing is a clean (dry) and sustainable technology that generates minimal amounts of waste. It is also characterized by much lower materials and energy consumption in comparison to wet-chemical based finishing methods, potentially resulting in markedly reduced running costs. Furthermore, plasma processing is very versatile since it can be used to impart a broad range of different properties, some of which being unattainable with conventional methods. It can also be applied to both individual yarns and fabrics. Because plasma processing results in a nano-scaled surface modification, it also has the advantage of preserving the bulk properties as well as the touch of textiles. In this contribution, we elaborate on two interesting examples of application, namely the metallization of polyester yarns and the hydrophilization of fabrics for wicking enhancement. These examples also show that in order to use plasma processes at their full potential it is important to take the properties of the treated textiles into account. More specifically, their surface chemistry (type of polymer, presence of oils) and structure can both have an important influence on the required plasma parameters.

2. METALLIZATION OF YARNS

The metallization of yarns and fabrics currently receives much interest for various textile-based applications, ranging from antistatic garments to textile-integrated electronics [3-5]. Applying the metallization at the yarn level has the advantage of yielding a more uniform coating and typically a better electrical conductivity (in contrast to the metallization of fabrics, where the contact points between the yarns usually remain uncoated). The metallized yarns can be integrated in textiles by weaving, knitting or embroidering. Low pressure plasma processes (sputtering) are very well suited for the metallization of polymers. Compared to existing wet-chemical based metallization processes (electroless plating), plasma methods offer a better control on the polymer/metal coating interface. Moreover, sputtering enables dense, smooth coatings grown of nano-sized grains (see Fig. 1) yielding already a good conductivity for a film thickness of 20-50 nm. Most yarns are covered by a substantial layer of oil and sizes which, if left on the surface before metallization, can act as a weak cohesion layer and lead to a delamination of the coating. Furthermore, the surface of many synthetic polymers is rather inert and do not adhere particularly strongly to metals. Plasmas can effectively address these two problems: prior to the coating, a plasma treatment can be used in-situ to etch away the layer of oil and to chemically modify ("activate") the polymer surface to enhance the adhesion. This pre-treatment step can be adapted depending on the type of polymer and on the quantity of residual oil on the surface of the yarn. With a suitable design of the plasma cleaning and sputtering system, an integrated air-to-air process has been developed at Empa which allows Ag-coating of polyester yarns at a speed of a few hundred meters per minute [6]. The coated yarns have a smooth and reflective surface (see Fig. 1), a relatively good conductivity (resistance ~ 10-20 Ω/cm) and are wash-fast. Since the thickness of the coating is in the nanoscale range (<100 nm), the yarns retain their flexibility and can be easily incorporated in fabrics. Although other metals could also be deposited with this process, silver has several advantages: is has a good conductivity, it is relatively inert and it has a high sputtering yield (which allows for a high production speed).

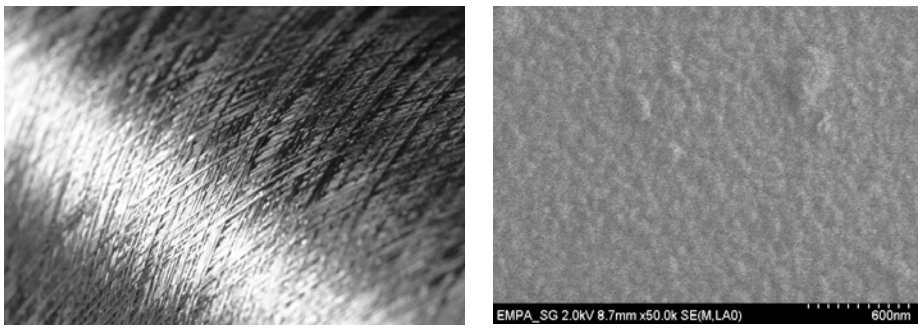

Figure 1. Ag-coated polyester yarn (left) and scanning electron micrograph on one filament showing the smooth and dense surface structure of the sputtered Ag film.

3. HYDROPHILIZATION OF FABRICS FOR WICKING ENHANCEMENT

Wicking or liquid transport in textiles mainly depends on the capillary action in the interstices between individual fibers [7,8]. This is an important property for moisture management garments, where a rapid transport of sweat is necessary. Plasma activation under low pressure can strongly enhance the wicking properties of a textile. This is achieved through an increase of the surface hydrophilicity inside the textile capillary structure. For that purpose, the diffusion of the active plasma species in the interstices between the filaments is obviously very important. This effect is strongly influenced by the plasma parameters: the use of lower gas pressure increases the mean free path of the active species generated in the plasma and generally allows a more efficient treatment of the inner fiber surfaces [9]. Treatments at higher pressures may also lead to a short term increase of the wicking. However, in this case the effect is rather limited to the outer textile surface, which results in a lower permanence of the improved wicking. The influence of the treatment pressure on the treatment stability is illustrated in Fig. 2 for a polyester multifilament fabric (radiofrequency Ar/O_2 plasma).

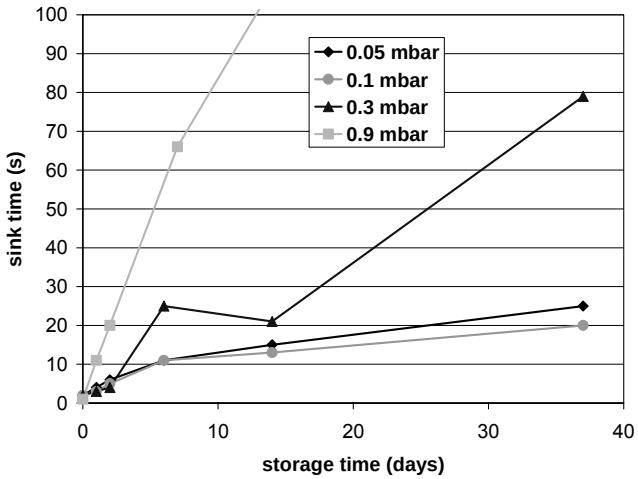

Figure 2. Evolution of the wicking properties with storage time in air (65% RH, 21°C) after the Ar/O_2 plasma treatment of a polyester multifilament fabric at different pressures. Sink time of untreated fabric: 600 s.

A scanning electron micrograph of the woven structure is shown in Fig. 3.

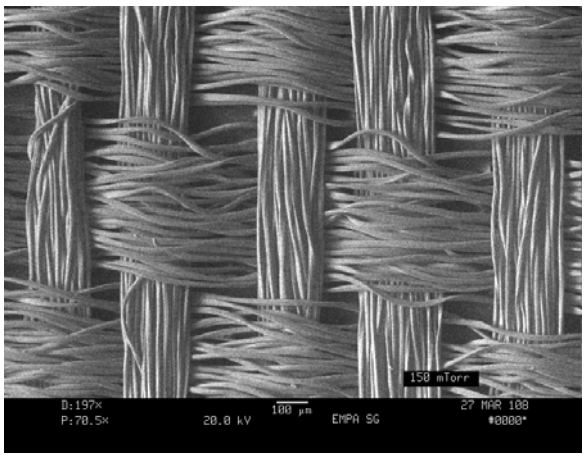

Figure 3. Scanning electron micrograph of a polyester multifilament fabric as used for the plasma hydrophilization.

The wicking properties of the treated fabrics were evaluated by measuring the time necessary for the complete absorption of a 10 µL water droplet by the fabric ("sink time"). As can be seen in Fig. 2, the treatments can drastically decrease the sink time value (600 s for the untreated fabric) through an improvement of the water transport. The graph also reveals that the stability of the hydrophilization considerably decreases upon increasing the pressure from 0.05 to 0.9 mbar (all other plasma parameters were constant). This effect is expected to be even more pronounced at atmospheric pressure. An optimal pressure range around 0.1 mbar is usually found for most textiles. As observed in Fig. 2, rather stable wicking properties can be obtained under these conditions.

Plasma polymerization processes, which consist in the deposition of functional thin polymer films [2], can also be used to increase the wettability of fabrics. In this case, the effect of the treatment can be much more permanent and wash fast than with plasma activation. By using appropriate combinations of gas mixtures and plasma parameters, plasma polymerization processes can actually impart a broad range of surface properties to fabrics [10]. Gas mixtures of hydrocarbons with oxygen or nitrogen containing reactive gases were found to result in nanoporous, cross-linked plasma polymers which combine high wettability and permanence [11,12].

4. BACTERICIDAL AND CYTOCOMPATIBLE NANOCOMPOSITE FILMS

While Ag-metallized yarns can also act as antibacterial surfaces depending on the morphology (roughness, voids) of the Ag coating, certain application require a controlled Ag ion release enabling bactericidal, yet cytocompatible surfaces, i.e. cell growth is supported. Therefore, the sputtering from a silver electrode was combined with plasma polymerization of hydrocarbon/reactive gas mixtures. Due to surface diffusion processes and aggregation of the metal atoms, Ag nanoparticles are formed in-situ during film growth (Fig. 4).

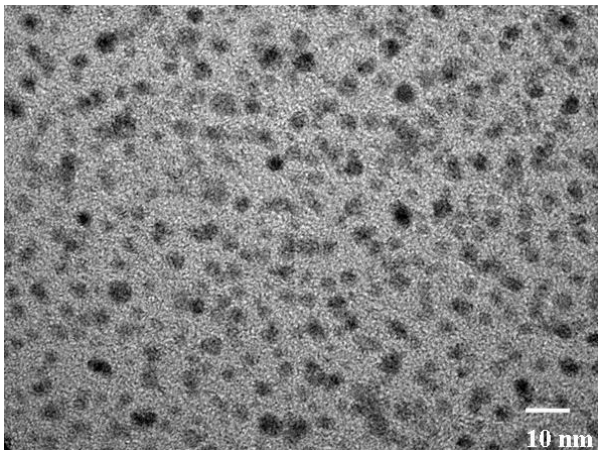

Figure 4. Transmission electron micrograph of a plasma nanocomposite coating. Small Ag nanoparticles are evenly distributed within a functional plasma polymer (a-C:H:O).

Both oxygen and nitrogen functional groups in the plasma polymer matrix were found to support cell growth, while water penetration is allowed yielding Ag ion release in aqueous environments [11,13]. Ag contents between 1 and 4 at% were found to enable both antibacterial and cytocompatible surfaces, whereas a higher Ag release suppressed cell proliferation. These coatings thus become interesting for textile implants.

5. CONCLUSIONS

Besides environmental advantages, plasma technology also enables unique high value added textile products. Examples of processes that were successfully transferred to the industry have been outlined here: the production of conductive and wash-fast yarns, and the permanent hydrophilization of fabrics. Furthermore, the potential of metal nanoparticle containing plasma polymers was discussed. In all cases plasma technology enables a nanostructured surface functionalization retaining the original textile properties.

ACKNOWLEDGMENTS

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PRE- AND POST-SPINNING CHARACTERIZATION OF POLYMER/CLAY NANOCOMPOSITES

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ABSTRACT

Polymer nanocomposite films based on poly(butylene succinate-co-butylene adipate) (PBSA) with various concentrations of organically modified montmorillonite were fabricated by the solvent casting technique. The films were cast from polymer with various concentrations of the added organoclay (0-15 %wt) in order to infer on the effect of clay loading on the hybrid material's properties. Fibrous mats of pure and nanocomposites PBSA were subsequently prepared by electrospinning. A comparison between the solution cast films and the corresponding fiber mats was introduced to monitor the differences from the two processes reflecting on the resulting structures and thermal properties. The characterization of the nanocomposite materials before (films) and after (fibers) electrospinning included investigation of their morphology by scanning electron microscopy (SEM) and X-ray diffraction (XRD), as well as examination of their thermal behavior by thermogravimetric analysis (TGA) and differential scanning calorimetry (DSC).

Key Words: PBSA, electrospinning, nanocomposite, SEM, XRD, TGA, DSC

1. INTRODUCTION

Recently, nanofiber manufacturing has become one of the key advancements in nanotechnology. For this reason, electrospinning has been widely used as an alternative technique in the fabrication of mats that consist of fibers with diameters ranging from few nanometers to few micrometers. Electrospinning is a markedly simple and cost effective process, which operates on the principle that the solution or the (polymer) melt is extracted under a high electric field. Once the voltage is sufficiently high, a charged jet is ejected following a complicated looping trajectory [1]. During its travel, the solvent evaporates within milliseconds and fibers are accumulated on the collector in a randomly oriented fashion forming the so-called "non-woven" mat. The final fibrous structure of the mat can be tailored by altering the material and process parameters involved, such as the concentration of the polymer solution, the applied voltage, the flow rate, the diameter, angle and distance of the spinneret in relation to the collector, the solution's viscosity and its conductivity and others. Furthermore, the combination of the mat's nanometric dimensionality with its high surface area, porosity, flexibility and mechanical integrity makes the electrospun fibrous mats suitable for several value-added applications in tissue engineering, wound dressing, clothing protection, nanoscale and biological adsorption and in filter and membrane technology [2].

2. MATERIALS AND METHODS

2.1. Materials

The biodegradable aliphatic polyester PBSA by the commercial name of Bionolle 3001 was supplied by Showa Highpolymer Co., Ltd (Tokyo, Japan). Bionolle 3001 is a copolyester of succinic acid (S), adipic acid (A), and 1,4 butanediol (B) with a composition ratio 40/10/50, respectively. The number average molecular weight (M_n) was 101300, as determined by gel permeation chromatography (GPC) and has an inherent viscosity of 1.15 dl/g. The nanofiller used was organically modified montmorillonite (Cloisite 25A) and was purchased by Southern Clay Products (Texas, USA). Dichloromethane (CH_2Cl_2) was obtained from Sigma-Aldrich. All materials were used without any further purification.

2.2. Preparation of Nanocomposite Films

A bulk preparation of nanocomposite materials was conducted according to the solution casting routine described in [3,4]. The films cast onto petri dishes were kept for 24 h in a dichloromethane atmosphere in order to achieve a slow solvent evaporation and were subsequently dried in vacuum at 40 ^{o}C for 24 h to eliminate any solvent traces left. The organoclay content of the produced films was ranged between 0-15 wt%.

2.3. Preparation of Nanocomposite Fibres

The schematic diagram of the electrospinning apparatus used in this study reported earlier [5]. The set up consists of a syringe pump for the injection of the polymer solution of 18 %w/v, an aluminium-covered pan used as a grounded substrate for the collection of the fibers and a high voltage supply set at 15 kV. All experiments described here were performed using a glass syringe of 1 mm (18G) needle diameter. The flow rate of the polymer solution was controlled by a syringe pump and was set at 0.5 ml/h. The needle is connected to a high voltage supply and the ground electrode is connected on the conductive surface of the aluminum plate. The distance between the needle and the collector's surface can be changed, but for the present work it was kept constant at 8 cm as the rest of the aforementioned electrospinning parameters after screening experiments previously carried out [5]. The organoclay content in the PBSA fibers was the only parameter that varied between 0-15 %wt. The temperature was controlled at 24 ^{o}C and ambient relative humidity was recorded for each experiment. After preparation, all the electrospun samples were placed in a vacuum oven for 24h.

2.4 Characterization

The fibrous structures were examined by scanning electron microscopy (SEM) (JEOL model JSM-840A) after coating them with graphite to avoid charging under the electron beam. Dimensional characterization of the mats morphology was implemented using an image analyzer with the appropriate software (Image J). Two samples were examined under the microscope and at least two representative areas from each sample were chosen to determine the average sizes.

The morphology of the nanohybrids was investigated by X-ray analysis (XRD) using a Rich. Seifert 3003 TT diffractometer with Ni-filtered CuKα radiation (λ=0.154 nm). The scanning range of interest varied from 2θ = 1.5^{o} to 10^{o} with a step of 0.01 and a measuring time of 15 s per step.
Thermogravimetric analysis (TGA) of PBSA nanocomposite films and the corresponding electrospun mats were performed on a Shimadzu TGA-50 Analyzer with a heating ramp of 10 ^{o}C/min up to 750 ^{o}C, both under flowing nitrogen (20 cm^{3}/min) and static air. Melting endotherms were also obtained with the aid of a Shimadzu DSC-50 differential scanning calorimeter (DSC). Temperature scans were carried out at a heating rate of 10 ^{o}C/min under a constant nitrogen flow of 20 cm^{3}/min.
The differences in surface morphology of the TGA residues were visualized by using the aforementioned SEM.

3. RESULTS AND DISCUSSION

3.1. Morhological characterization by SEM and XRD

In order to examine how different concentrations of the inorganic filler into the polymer influence the final fibrous structure, all the other electrospinning processing parameters were kept constant. The effect of the inorganic filler on the membrane morphology and the average fiber diameter was studied in the range of 0-15 wt % clay content. Representative images are presented in Figure 1 at two different magnifications.

The SEM images indicated that the final membrane structure was significantly affected by the presence of the inorganic material. In all cases, the introduction and increase of inorganic filler resulted in the formation of membranes with more uniform, beadless structures with continuous fibers and narrower diameter distributions. Total increment of the clay content from 0 to 15 wt % demonstrated an average fiber diameter decrease from 820 nm for pure PBSA to 405 nm for 15 %wt clay loading with narrower range of standard deviations (Figure 2). However, clay loading beyond 9 %wt had no major impact on the fibrous morphology.

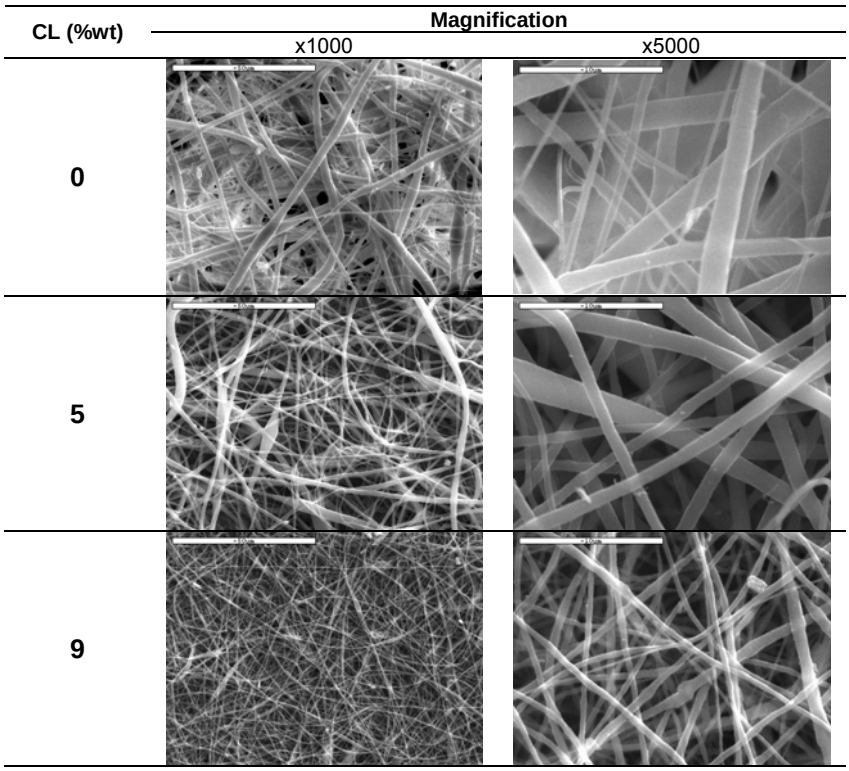

Figure 1. Indicative SEM photographs of pure PBSA and nanocomposites with 2 different clay contents; scale bar is 50 μm at magnification x1000 and 10 μm at x5000.

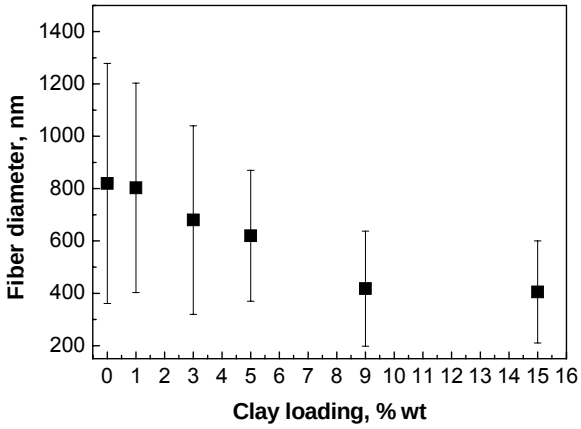

Figure 2. The average values of fiber diameters and standard deviations with regard to clay loading.

The XRD traces of all the materials are presented at Figure 3 for comparison reasons; the cast films are given in black and the electrospun mats in grey. The XRD pattern for the inorganic nanofiller (powder Cl25A) is also included in Figure 3 and displays a characteristic peak at $2\theta=4.51^{o}$ referred to a mean interlayer spacing $d_{(001)}$ = 1.96 nm of the silicate layers.

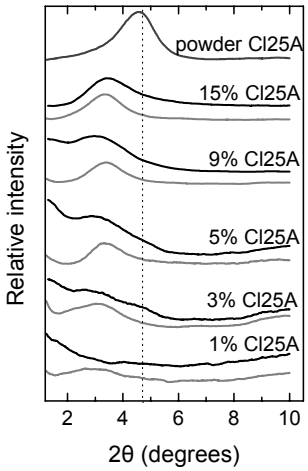

Figure 3. Comparison of XRD patterns between pre- and post-spinning of PBSA/Cl25A nanocomposites (in black and in grey, respectively). The diffractograph of the nanofiller powder is also given.

For the solvent cast films no diffraction peak is detected at low clay loadings indicating disordered or else "exfoliated" silicate layers with no periodic stacking. In fact, loadings more than 3 %wt are necessary in order to give traceable X-ray signal that would suggest intercalated nanocomposite formation. Increase of the clay content induces an increase of the intensity of the peaks suggesting a higher percent of ordered intercalated structure. This is because the number density of the intercalated clay particles in the polymer matrix increases, as the clay content arises, and many more X-rays are diffracted. The diffraction patterns of the composite films also reveal that the characteristic peak, referred to the $d_{(001)}$ spacing of the inorganic material, is shifted towards lower 2θ values and is broadened indicating that polymer chains have diffused into the silicate galleries expanding the clay structure. The same trends can be derived from the diffraction patterns of the electrospun mats only that here, even small amounts of clay are adequate of giving X-ray signal implying a percent of intercalated structure.

It appears that in both cast-films and fibrous mats, increase of the clay loading results to a less broad, more intense peak that is shifted to lower 2θ values (higher interlayer spacing). However, by comparing the XRD traces of the same material before and after spinning, the last remark is more obvious for the electrospun material, which in every case exhibits a more ordered intercalated morphology. This was also observed by Lee et al. [6], who performed XRD on PLLA/MMT cast films and fibers and cited that the MMT platelets at a relatively high concentration (i.e. higher than 3.58 vol% in their study) form an ordered structure during electrospinning seemingly due to the high elongation stresses for fiber formation and solvent evaporation.

3.3 Results of Thermal Analysis

Clay layers in low concentrations are considered advantageous for the thermal stability of polymer/clay nanocomposites because of their mass transport barrier action, which can retard thermal degradation [7,8]. In order to examine the thermal behavior of PBSA nanocomposite materials TG measurements were carried out both in inert and oxidant atmosphere. For the nanocomposite films the TG curves are given in Figure 4, while similar were those of the fiber mats. From Figure 4 it can be inferred that the higher the inorganic material content in the film, the faster the thermal degradation starts (see the magnified part of the curves). This may be ascribed to the surfactant in the organomodified clay, which is thermally instable and degraded in advance or could suffer decomposition following the Hofmann elimination reaction and its product would catalyze the degradation of PBSA [9]. The clay itself could also catalyze the degradation of polymer materials [9,10].

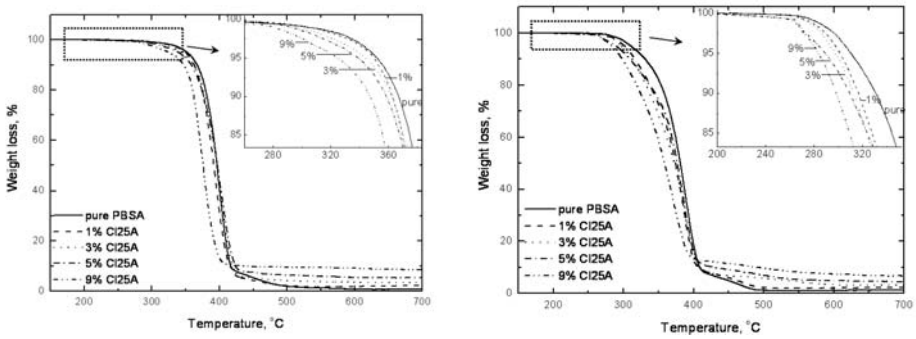

Figure 4. TG curves for PBSA nanocomposite films with various loadings of organomodified MMT in (a) inert and (b) oxidant atmosphere.

A much more clear view on the thermal degradation process of all the samples studied here can be given by the first derivative (DTG) of the TG curves, as presented in Figure 5. This figure shows that the decomposition peak for pure PBSA is located at 387 ^{o}C, while an improvement of thermal stability can be discerned only for the samples loaded with 3 %wt of clay (pre- and post-spinning). This result is similar with Ray et al. who examined the thermal stability for PBSA/clay nanocomposites prepared by the melt-mixing method [10]. The onset of degradation temperature of the neat PBSA and PBSA with 3% wt of an organically modified MMT is the same but systematically decreased upon further addition of clay [10]. The new peak here was located at 397 ^{o}C, which is a 10 ^{o}C difference compared to the neat polymer (Figure 5). This value of inorganic filler (3 %wt) may be a threshold above which aluminosilicates accelerate thermal degradation of the PBSA matrix.

Another striking observation from the DTG curves is that the curves from the electrospun materials with clay loading (CL) above 5 %wt gave a second peak at lower temperatures (below 350 ^{o}C) that was not observed at the cast films at all. We had reported in a previous work [11] that high concentrations of alkylammonium surfactants into the mineral led to a similar second peak at lower temperatures associated with the surfactant adsorbed on the external surfaces of the clay. This second peak here is probably due to the large surface to volume ratio of the fibrous materials that at higher clay loadings facilitated the occurrence of surfactant at external clay surfaces and hence some surfactant degradation in advance.

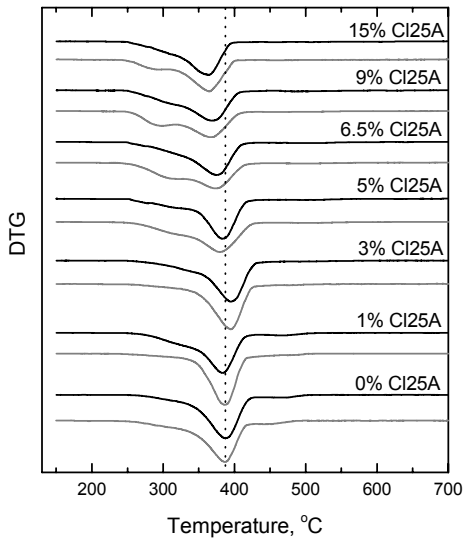

Figure 5. DTG curves for the cast nanocomposite films (black) and the as-spun fibers (grey) derived from the corresponding TG curves in air through a wide temperature range.

The solid char residue left from a polymer nanocomposite after pyrolysis can arise, firstly, in the condensed phase, by stripping off most or all noncarbonaceous material from the polymer, and secondly, by chain scission reaction in the condensed phase leading to the formation of volatile low molecular - weight compounds [7,8]. The chemical interaction of the polymer with clay layers at a low content is probably helping in retaining part of the polymer in residue. The remaining MMT char at the samples with 3 %wt clay could act as an insulator and mass transport barrier and, therefore, mitigate the escape of volatile products generated during polymer decomposition. This char is desired to reduce the flammability and increase the thermal stability of nanocomposites.

The burned surface of pure and nanocomposite films and fibrous mats were examined with the aid of SEM, which allows a relatively simplistic view of the complex changes that occur during pyrolysis. The samples were examined after heating treatment at 260 ^{o}C isothermally for 750 min, so that they would not reach a state of total incineration. Evidently, SEM photos for the pure materials (Figure 6) show polymer fragments or some organic retention reminiscent of the incomplete combustion. A perusal of the rest of the photos of Figure 6 depicts chars with relatively distinct differences in structure that derive from different decomposition in early stages.

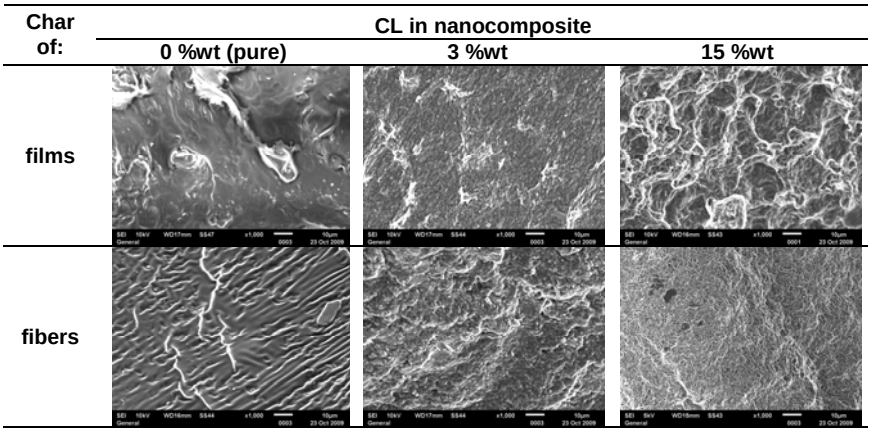

Figure 6. Char residues after heating isothermally for 750 min at 260 ^{o}C.

The surface of samples with CL 3 %wt is relatively smooth without too many surface irregularities as compared with that of higher CL. That is due to the fact that the residue retains the structure and part of the parent material as opposed to higher CL, where the extent of charring was higher and constituted by agglomerating of swollen inorganic material. The SEM micrographs of the films with CL 9 (not shown here) and 15 %wt exhibit an irregular swollen structure in which macropores were formed by swelling, and degassing during pyrolysis of the organic material in the early char burnout interval. On the contrary, that was not the case with the residues from the as spun samples, which had originally a porous structure, and hence, the decomposition of the organics and the released gaseous products could easily penetrate through the char leaving behind a loose structure of inorganic material apart from some areas where holes were observed (Figure 6).

In general, the resistance of generated char to thermal oxidation depends on its structure: the more compact the char structure, the more resistant is to heat and oxygen. Compared with the char from other samples, the char from the 3% sample displayed a more compact, consolidated structure with predominant matrix retention; this is probably the reason for the improved thermal resistance that nanocomposites with this CL exhibit.

Shanmuganathan et al. also reported entrapment of polymer fragments between the densely accumulated clay platelets by conducting FTIR studies [12].The char residue from Nylon 6/clay nanocomposite films revealed, apart from the peaks of Si-OH and Si-O stretching, two additional distinct peaks at 1630 cm^{-1} and 1520 cm^{-1} that could be assigned to amide I and amide II, respectively. This was an indication of possible unburnt polymer fragments or recession within the shielded char. Organically modified MMT platelets collapse to form a well integrated shield and this might have caused entrapment of polymer fragments and retention of unburnt chain fragments within the shielded char. However, cone calorimeter studies would be required to obtain more information and correlate char morphology and burning behaviour.

Figure 7 reports the DSC curves for all samples obtained with the solvent casting and the electrospinning process. No relevant changes were observed in samples obtained by either method, all of which present a peak centered at around 94 °C, where the melting temperature for PBSA is.

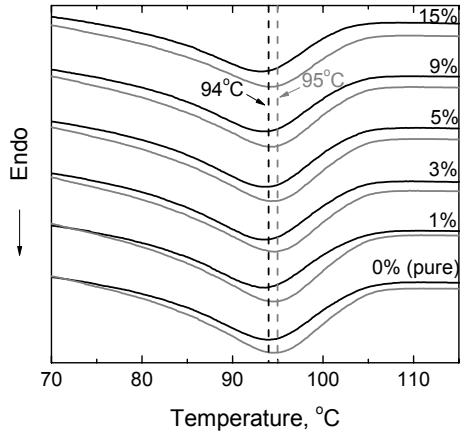

Figure 7. Melting endotherms of the pure and nanocomposite films (black) and fibrous membranes (grey).

4. CONCLUSIONS

A comparison between the solution cast films and the corresponding fiber mats was introduced to monitor the differences resulting from the two processes, as these differences are reflected upon the resulting structures. The characterized films were cast by polymer with various concentrations of the added clay (0-15 %wt). The nanofibrous membranes subsequently obtained (with fibers between 400 – 900 nm) revealed a more ordered structure of the clay platelets in the matrix and were less thermally stable at high clay loadings (>5 %wt) compared to the films due to their high surface to volume ratio. SEM images from the char residues indicated that nanofiller of 3 %wt may be a threshold value above which aluminosilicates accelerate thermal degradation of the polymer matrix. Finally, in spite the fact that introduction of the inorganic material above 3 %wt anticipates thermal degradation for both films and fibers, it had no impact on the melting behavior of the materials.

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PREDICTION OF POROSITY OF WOVEN FABRICS HAVING DIFFERENT WEAVES

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Abstract

Fabric's air, fluid and moisture permeability properties are important features and must be considered when designing products, as they affect the performance of fabrics. The main properties that affect the fabric permeability are the structural parameters of fabric, the properties of fluid flow through fabric and environmental factors. Due to the fact that the rate of fluid flow through a textile is a function of viscosity, density, pressure gradient and porosity, it is necessary to define fabric porosity by controlling the fabric structural parameters for a certain area of use. Flow mechanism through textiles is a complex physical event due to their non-uniform structure and structural deformations which occur during transfer. Pore shape, size and size distribution are influenced from fiber and yarn properties, fabric structural properties (e.g. density, fabric geometry, etc.) and finishing process. Prediction of porosity is difficult because of complexity of fabric structure, deformations and non-uniform structural properties.

In this study, it is aimed to calculate the porosity of woven fabrics with different weave types by using two-dimensional and three-dimensional pore models and to compare the relationship between porosity values and air permeability results. In addition, by using image analysis, which is more basic and objective method, fabric porosity is obtained and its relationship between the theoretical results and air permeability is studied. When examining the related literature, it is observed that image analysis is used especially in determining the porosity of non-woven and plain woven fabrics. It is expected that this study will contribute to knowledge about fabric porosity and permeability properties.

Key words: permeability, porosity, woven fabric, weave type

1. Introduction

Permeability is an expected performance property of fabric in different areas. The main properties affected the permeability of fabric are the structural parameters of fabric, the properties of fluid flow through fabric (e.g. viscosity, surface tension, density) and the environmental factors (e.g. temperature, humidity, pressure, etc.). Accordingly, in order to obtain a product with a desired end-use performance for a certain area, it is necessary to define and to control fabric structural properties affecting the permeability in these conditions.

Permeability is an experimental value defined as the fluid flow rate through unit fabric area. There is an important relation between fabric permeability expressed as a function of pressure differences across the fabric, and porosity defined as the ratio of voids' volume to the total volume. The flow mechanism through fabric is affected from porosity and the properties of pore structure such as, pore shape, pore size and pore size distribution. Pore structure must be defined while modeling the flow. The structural factors such as fabric type, weave type, yarn and raw material properties determine the fabric pore structure through which fluid pass, besides permeability properties of fabric. Due to complexity of fabric structure, non-uniform structural properties and deformations, modeling of pore structure and prediction of porosity are difficult. In this paper, it is aimed to investigate the relationship between fabric permeability properties and porosity by considering the change of fabric parameters such as weave type and weft setting. In the study, porosity, which is an important parameter in the flow mechanism, was obtained by two dimensional (2-d) and three dimensional (3-d) pore models and image analysis method. The porosity values of three methods were compared with each other and air permeability tests and results were discussed.

Since the properties of pore structure and porosity of fabric affect the properties of fabric such as wettability, moisture absorption, thermal insulation, and filtration, if the porosity can be estimated these properties can also be predicted. By Burleigh et al. (1949), the total porosity of fabric was denoted to consist of three components as intrafiber, interfiber and interyarn porosity and the total porosity available to fluid flow has been called the "effective porosity". Effective porosity is largely a function of interyarn and interfiber components. Total porosity between yarns and fibers was specified depending on structural properties such as fiber thickness, shape of fibre cross-section, weave type, settings, and yarn twist [1]. In woven fabrics, micro and interfiber pores play an important role in the technological processes like dying and pore between the weft and warp yarns are effective at practical problems [2]. In researches to simplify the complex fabric structure, generally fabrics were modeled as constructions formed by impermeable yarns. At these fabrics, interyarn pores determine the porosity. The shape and

size of this pores depends on structural parameters of fabric such as settings, yarn diameter, weave type and fabric thickness, etc. [3, 4, 5, 6,7].
By accepting yarns as flexible, inextensible and circular cylinders, Backer (1951) defined four pore types formed by different interlacing of warp and weft yarns, and the relationship between the minimum pore area and air permeability of loose and dense woven fabrics were studied by calculating minimum pore area for each interlacing. It was concluded that, in general interyarn porosity was effective at air permeability and the factors as flattening of yarn and yarn density did not affect air flow [5]. Goodings (1964) analyzed the air flow through pore with the approach of air flow through a cylinder having a certain diameter and length, and observed that pore shapes were varied according to yarn settings and packing degree [8]. Gooijer et al. (2003) developed 3-d pore cell models by utilizing from Backer's 2-d projection of pore units. The flow resistance was found as a function of fabric geometry by accepting the flow was perpendicular to the fabric plane [9]. However, the flow is a 3-d mechanism that occur in-plane and through-plane dimensions. For this reason, in further studies when porosity of the fabric was evaluating, total porosity of fabric has been tried to estimate by considering also the interfiber porosity [10]. Among these studies in recent years one of the most popular methods is CFD (Computational Fluid Dynamic) software, based on finite element method, in which to solve flow the structure is divided into smaller elements [7,11]. In addition, there are studies in which different flow equations were used for different regions –interfiber and interyarn- [12,13] or homogenization method was used to solve problems in two steps by computer analysis [14,15].
In addition to the experimental studies (with permeability test equipments) and the theoretical model studies of porosity, researchers also used optical methods to define porosity data which affect the permeability performance of fabric. It is possible to find an approximate value for porosity by measuring warp and weft yarns diameter (d_1, d_2) and spacings (p_1, p_2) with the help of surface image of fabric [16]. In recent years, by the development of digital imaging systems, image processing and analysis methods the material properties can be determined faster and in a simple way. Image analysis method was used in different textile problems such as determination of the cross sectional area of fibre, irregularities of fibre blends, trash rate of cotton fiber, maturity of cotton fibre, yarn diameter, twist, twist direction, fabric settings, fabric defects, estimation of wool damage, characterization of nonwoven, analysis of fabric pattern etc [17,18] . Image analysis method was used to find a conjectural data about fabric porosity and to evaluate the relationships with fabric parameters, particularly at nonwovens to define pore size distribution and pore shape, and at knitting and plain woven fabrics to predict interyarn porosity [19, 20, 21, 22, 23, 24, 25, 26]. Militky et al. (1999) found that the highest correlation exists between air permeability and light transmission results when examined correlation of porosity derived from ideal fabric geometry calculations, light transmission and air permeability of fabrics [19]. Çay et al. (2005) used image analysis method to estimate fabric porosity of a group of cotton plain fabrics with different settings and observed that there is a relationship between tightness index and brightness percentage. Due to the increase of the warp and weft number per unit area, the air permeability of the fabrics decreases [24]. Tapias et al. (2009) determined cover factor (CF) of fabric, having different yarn count, setting and raw material, by image analysis method. At the end of statistical analysis it was observed when the yarn count increased, CF was increased; raw material was affected CF value and weft setting was not caused a significant change at the CF value [26].
In this study, to predict the porosity of fabrics having different weave types the relationship between air permeability and porosity values obtained from three different methods, 2-d geometric pore model, 3-d geometric pore model and image analysis method were compared and results were discussed to determine the effective porosity value on the fluid flow mechanism.

2. Method

The flow mechanism which occurs through porous media is a function depending on fluid properties, environmental factors and the structural properties of media. It is necessary to define porosity parameters such as pore shape, size, and size distribution to predict fabric permeability features for a certain fluid and known environmental conditions. Different researchers described fluid flow behavior through fabric by using flow equations such as Darcy's law, Kozeny, Poiseuille equations, etc. In Darcy's law (Equation 1), which is the most common one of them, permeability of the fabric (B) is a function of fluid viscosity (μ), fabric thickness (t), fluid velocity (v) and pressure drop across the fabric (ΔP). The fabric permeability depends on porosity properties.

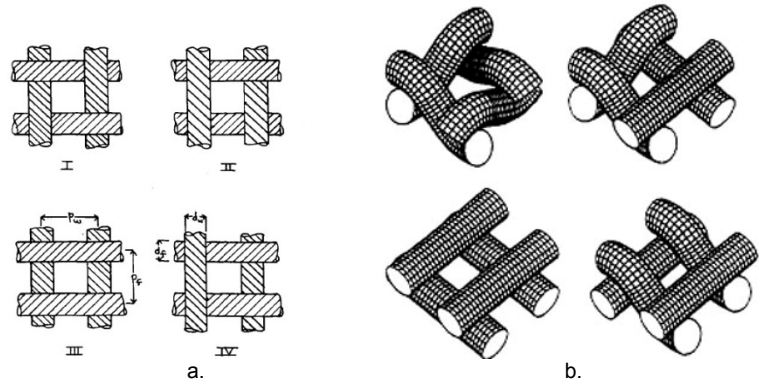
$$B = \frac{\mu \cdot t \cdot v}{\Delta P} \quad (1)$$

Porosity is calculated as 2-d by the ratio of projection area of openings to the total area (PA) or as 3-d by the ratio of pore volume to the total volume (PV). When calculating the porosity theoretically the most important error sources are structural deformations which occur during transfer and the non-uniform properties of structure such as yarn diameter (d), yarn spacings (p_1,p_2) etc. For this reason theoretically calculated data such as porosity and pore diameter are deviated from real values due to the assumptions. In their study, Xu ve Wang (2005) investigated the effect of interyarn and interfiber porosity on fabric permeability and denoted that in estimation of air permeability error result from three factors. These are the neglection of interfiber porosity, the assumption of cross section of interyarn pores as trumpet-like structure and uniform pore distribution [16]. Namely the relationship between fabric real and estimated permeability depends on simulating the fabric parameters with high accuracy and using suitable flow equations. In this study by using both 2-d and 3-d approaches, the areal and volumetric porosity (PA, PV) of fabric depending on structural parameters were calculated theoretically. In order to obtain fabric porosity by more basic and quick method, the validity of porosity value obtained by image analysis (PI) and PI relationship between calculated porosity values and air permeability test results were investigated.

2.1. Geometrical approach

Flow mechanism through fabric is a complex phenomena. The transition of fluid through the fabric is in-plane and through-plain directions. Especially in multiflament fabrics, the flow is affected from interfiber pores as well as interyarn pores, and capillary pressure helps the transfer of fluid. For this reason the flow mechanism taking place according to 2-d pore geometric model through the fabric does not show real conditions, but gives a basic approach. Consequently, to understand 3-d mechanism of fluid flow the pore model of fabric must be defined in 3-d space.

Woven fabrics consist of different interlacings of warp and weft yarns. In this study, the 2-d and 3-d models of four pore types, defined by Backer (1951), were formed and areal (2-d) and volumetric (3-d) porosity of all pore types were calculated.



a. b.

Figure 1. a. 2-d pore types (Backer, 1951), b. 3-d pore types (Gooijer et al., 2003)

A pore unit cell is formed by interlacing of two warp and two weft yarns (Figure 1). 2-d pore geometry was calculated by investigating the projection of this interlacing shape depending on structural parameters, d_1, d_2, p_1 and p_2. In this study, for each pore type 3-d pore unit cell was modeled by a rectangle prism fitting in the center lines of warp and weft yarns, and the dimensions of prism were t, p_1 and p_2. By assuming yarns as monofilament structure, in the prism covered volume of the yarns was calculated by using Pierce geometry. While yarns were assumed as impermeable structures, only interyarn pores were formed fabric porosity. According to this approach ratio of yarn volume to the prism volume gives packing rate and the ratio of pore volume to the total volume gives porosity (PV).

In this research, PA and PV values of cotton fabrics having three different weave types (plain, 2/1 twill and 3/1 twill) were calculated by taking into consideration the distribution of pore types in the weave type and the fabric structural properties (Table 1). Yarn diameter (d) was obtained from Ashenhurst theoretical model, as $d = 1/K\sqrt{N}$ [27].

Table 1. Structural properties of tested fabrics

Fabric No	Weave Type	Unit weight w (g/m^2)	Fabric Thickness t (cm)	Warp Count N_1 (Ne)	Weft Count N_2 (Ne)	Warp Setting S_1 (cm^{-1})	Weft Setting S_2 (cm^{-1})	Warp Crimp factor k_1	Weft Crimp factor k_2
K1	Plain	148	0.037	20	20	36	14	1.053	1.059
K2	Plain	163	0.037	20	20	36	18	1.057	1.076
K3	Plain	175	0.036	20	20	36	22	1.070	1.091
K4	2/1 Twill	158	0.038	20	20	36	18	1.036	1.067
K5	2/1 Twill	171	0.038	20	20	36	22	1.034	1.075
K6	2/1 Twill	186	0.039	20	20	36	26	1.076	1.099
K7	3/1 Twill	161	0.040	20	20	36	18	1.027	1.062
K8	3/1 Twill	186	0.041	20	20	36	22	1.022	1.142
K9	3/1 Twill	190	0.041	20	20	36	26	1.040	1.098

2.2. Image Analysis Method

In recent years, determining the porosity and the pore properties with image analysis method by using fabric's surface image is a common process especially for nonwovens and for knitted and plain woven fabrics. Using this method the complex three dimensional structure of fabric is examined from two dimensional images and to get information about pore. The advantage of image analysis method is the facility of learning information basically and rapidly about 2-d structural properties without complex processes. In this study the porosity of plain, 2/1 and 3/1 twill fabrics having different yarns interlacings were determined both calculating from 2-d and 3-d pore unit cells theoretically and applying image analysis method to fabric images captured from microscope.

a.

b.

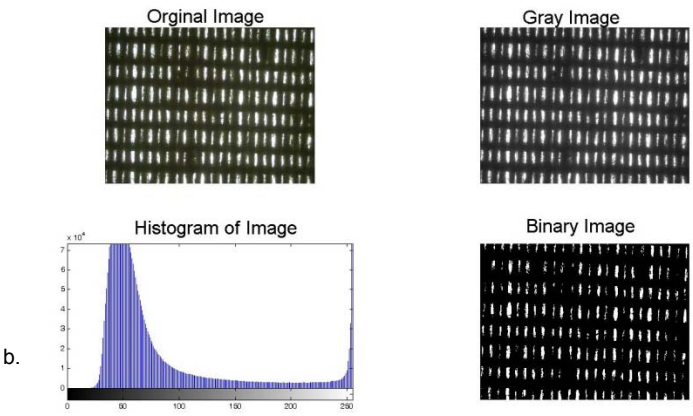


Figure 2. a. Image analysis system, b. Steps of image analysis

The image analysis system used in this study was consisted of a microscope (Olympus Bx41), a color CDD camera assembled to the microscope (Olympus C-4000), a PC as image analyzing device and software (Matlab) that provides all the necessary image processing and image analysis tools (Figure 2a). 24-bit color images of nine different fabrics, having three different weft settings for each weave types, were captured in JPG format, 2288 ×1712 pixels in size (80.7 × 60.4 cm linear field size). When capturing images from fabric samples, illumination was applied only bottom to clarify the positions of warps and wefts and to minimize the effect of fine hairs in images. Thanks to light transmission, pore regions are seen bright while the regions covered by yarns are dark. After capturing images second step is the determination of threshold value to achieve binary images and to calculate porosity. Therefore, first of all captured images were converted to 8 bpp, 256 gray level to reduce the image file size, to enhance the analyzing speed and so, to shorten the processing time. Then by using suitable threshold value in gray level image, pixels were classified into two groups: the dark pixels corresponding to the yarns converted to black, and the bright pixels corresponding to the pores converted to white. Porosity is calculated from the ratio of white pixels to whole pixels (Figure 2b). As mentioned by Tapias et al. (2009), the main problem to obtain porosity by image analysis is the misclassification of pixels that are close to yarn edges. Misclassification of pixels changes porosity largely, thus to choose suitable threshold procedure is important. In this study, the background image of fabric was captured without fabric sample and the mean value of background image's gray level was used as threshold value. Then in the fabric gray level images the pixels darker than the threshold value were converted to black while same or brighter ones were converted to white.

In image analysis method to reduce the noise of image because of on external and electrical causes, some image processing methods can be applied before the threshold process, such as filtration to minimize noise in image or histogram equalization process to increase image contrast for easier recognition or separation of specific regions. However, these image processing methods were resulted in bigger porosity values due to the elimination of hairiness and classifying the pixels near yarn edges as pore. With the aim of utilizing real fabric structure, it is decided that it is not needed to carry out an additional image processing operation.

3. Results and Discussion

In this study, it is aimed to investigate porosity and air permeability properties of weaves with different pore types. When evaluating porosity, primarily by considering 2-d and 3-d geometrical model of pores consisted of four different pore types' unit cells, porosity was calculated based on structural parameters. Besides that porosity was determined by image analysis method (PI) and the relationship of this value between calculated PA and PV values and air permeability results were discussed. The relationships of all parameters -weave type, weft setting, air permeability and porosity- with each other were examined by using statistical software (Minitab).

When examining the PA and PV values of pore unit cell, it was observed that the PA value of unit cells having same yarn diameter and setting were same, this means different yarn interlacing was not caused differences at porosity values of pore types in 2-d. But the air permeability of different weave types having same structural parameters is different. This can be explained by the differences of yarn geometry and PV value in different pore units. The yarn interlacing, namely yarn's geometry was affected permeability and porosity properties of fabric, owing to affecting both frictional properties and total yarn volume in the pore unit cell. If the yarn volume in the pore unit cell is greater than pore volume, then the pore unit has lower porosity. Calculating PV of four different pore unit cells having same fabric parameters, it was found that in the unit cell of type 1 yarn volume is the most- PV is least-, as opposed in type 3, in which yarns' interlaced anytime, yarn volume is least –PV is most. In 3-d pore unit cells model the relationship of porosity between pore types was type1< type2= type4< type3, respectively. This situation supports the results of Backer's study (1951), in which it is pointed out that plain weave, consisting of type1 pore unit cell with the greatest number of yarn interlacing, has the smallest minimum cross sectional area and offer most resistance to the passing of air comparing with the other weaves weaving with identical yarn count and setting. On the other hand long-float twills or sateens consisting with great number of type 3 with no interlacing have largest minimum cross sectional area, opening volume and show maximum permeability.

When examining the effect of different weft settings on air permeability and porosity, as shown in Figure 3, it is observed that at all weave types increasing of weft setting cause decrease at air permeability and porosity values (PA, PV, PI). The differences between settings were significant for %95 confidence level (Table 2).

In same settings, the air permeability value of plain fabric is less than 2/1 and 3/1 twill fabrics. Examining air permeability results, at all settings the differences between weave types were significant for %95 confidence level, (Table 3).

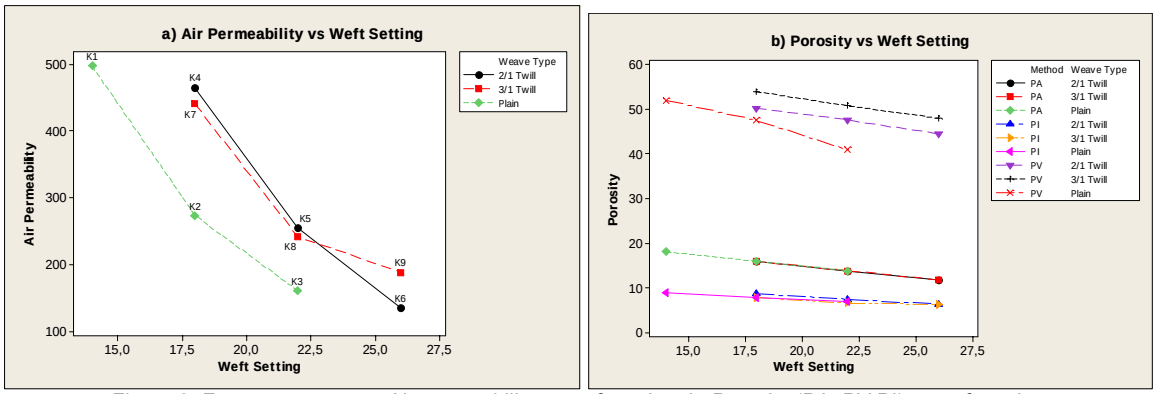


Figure 3. For weave types a. Air permeability vs weft setting, b. Porosity (PA, PV,PI) vs weft setting

Table 2. Relationship between Air permeability and weft setting a. Plain, b. 2/1 Twill, c. 3/1 Twill

```
 a)                    Individual 95% CIs For Mean Based on
                         Pooled StDev
Level   N    Mean  StDev  -----+---------+---------+---------+----
14     30  496,53  28,16                                    (*)
18     30  273,07  25,10              (*)
22     30  159,60  11,33  (*)
                          -----+---------+---------+---------+----
                             200       300       400       500

 b)                    Individual 95% CIs For Mean Based on
                         Pooled StDev
Level   N    Mean  StDev  -------+---------+---------+---------+--
18     30  464,77  23,52                                   (*)
22     30  255,07  12,94               (*)
26     30  135,47   6,49  (*)
                          -------+---------+---------+---------+--
                               200       300       400       500

c)  Individual 95% CIs For Mean Based on
                         Pooled StDev
Level   N    Mean  StDev  -----+---------+---------+---------+----
18     30  439,50  32,86                                     (-*)
22     30  240,80  29,74           (*-)
26     30  187,57  10,13  (-*)
                          -----+---------+---------+---------+----
                             210       280       350       420
```

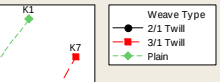
When PAs were examined, as the projection areas of all pore types were same, PA values were identical. But the air permeability of plain fabric was less than twills at same setting. This is because of the plain weave's pore type structure which has much yarn in 3-d weave unit due to having greatest number of yarn interlacing. The increasing of yarn quantity in weave unit caused both decreasing of PV and increasing of friction surface. The relationship between air permeability and PV is shown in Figure 4a. Between the fabrics having different weave types and identical structural parameters, 3/1 twill fabric composed from type1, type2 and type3 unit pore cells was obtained to have the maximum PV.

Table 3. Relationship between Air permeability and weave type at weft setting a. 18 cm^{-1}, b. 22 cm^{-1}, c. 26 cm^{-1}

a)

Individual 95% CIs For Mean Based on Pooled StDev

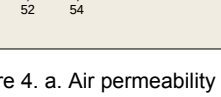
Level	N	Mean	StDev
2/1 Twill	30	464,77	23,52
3/1 Twill	30	439,50	32,86
Plain	30	273,07	25,10



b)

Individual 95% CIs For Mean Based on Pooled StDev

Level	N	Mean	StDev
2/1 Twill	30	255,07	12,94
3/1 Twill	30	240,80	29,74
Plain	30	159,60	11,33



c)

Individual 95% CIs For Mean Based on Pooled StDev

Level	N	Mean	StDev
2/1 Twill	30	135,47	6,49
3/1 Twill	30	187,57	10,13

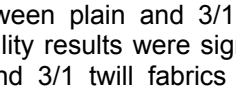


Figure 4. a. Air permeability vs PV, b. Air permeability vs PI

The differences between settings were significant for % 95 confidence levels for all weave types when examining porosity obtained from the image analysis (PI). When examining PI values of different weave types, it was obtained that at 18 cm^{-1} and 22 cm^{-1} weft settings difference was not significant for plain and 3/1 twill fabrics, unlike 2/1 twill fabric (Table 4). Here the crucial point is, although statistically the difference between plain and 3/1 twill fabric was not significant for PI value, the difference of their air permeability results were significant (Table 3). Likewise at 26 cm^{-1} weft setting the difference between 2/1 and 3/1 twill fabrics was not significant for PI, but significant for air permeability for % 95 confidence levels. This situation can be explained by the differences of PV value among different weaves. While permeability is a 3-d mechanism, PV takes an important role in permeability behavior.

Table 4. The relationship of weave types for PI value at weft settings a.18 cm^{-1}, b. 22 cm^{-1}, c. 26 cm^{-1}

a)

Level	N	Mean	StDev	Individual 95% CIs For Mean Based on Pooled StDev
Plain	5	7,7956	0,5012	(---------*---------)
2/1 Twill	5	8,6536	0,5526	(---------*---------)
3/1 Twill	5	7,7747	0,4231	(--------*---------)
				7,50 8,00 8,50 9,00

b)

Level	N	Mean	StDev	Individual 95% CIs For Mean Based on Pooled StDev
Plain	5	6,8896	0,7071	(----------*----------)
2/1 Twill	5	7,2204	0,5673	(----------*----------)
3/1 Twill	5	6,5959	0,8405	(----------*----------)
				6,00 6,60 7,20 7,80

c)

Level	N	Mean	StDev	Individual 95% CIs For Mean Based on Pooled StDev
2/1 Twill	5	6,3325	0,4018	(---------------*---------------)
3/1 Twill	5	6,2511	0,2282	(---------------*---------------)
				6,00 6,20 6,40 6,60

When the relationship between PA, PV, PI values and air permeability test results were investigated, correlation coefficient of PA and PI was obtained 0.935 which means there is an important relation between them. The correlation coefficient between air permeability and PA, PV and PI values were obtained 0.876, 0.800, and 0.902, respectively. This means statistically there is a considerably relation between air permeability and all porosity determination methods, especially with image analysis results.

4. Conclusion

PI was observed less than PA, since in 2d pore model the structure of fabric formed with monofilament yarns was modeled homogeneous in terms of yarn diameter, setting and fabric thickness. As two dimensional fabric images reflects fabric's non-uniform properties, the errors of 2-d theoretical model, caused from assumptions, considered to be reduced with this method. Therefore, when evaluating porosity in 2-d, image analysis approach was supposed to give more realistic results then theoretical 2-d geometrical model.

The correlation between air permeability and PI was obtained maximum when comparing with PA and PV. In this study, however, although statistically there was no difference in terms of PI between the fabrics having different weave type and identical setting, significant was obtained for air permeability. Differences between weave types formed by different pore units were significant for air permeability. The value which describes the differences between air permeability of woven fabrics and different weave types is PV, obtained from 3-d pore model. While the flow is a complex mechanism that occurs in three dimensions, volumetric porosity plays an important role in permeability. Three-dimensional yarn geometry affect porosity and the friction surface of fluid that passing through the fabric.

In this study, porosity of fabric having different weaves was evaluated with different methods. As a result, when examining the relation of image analysis method's porosity value (PI) with air permeability test results, it was found an automatic, objective and quick method for estimating the porosity of the fabric. Image analysis method provide to produce objective results by managing the image of 2-d fabric structure properties into digital data and obtaining statistical results from these data. But when the difference between the results of air permeability and weave types was taken into consideration, it was seen that PI was not adequate alone for evaluation. Consequently, the PV value obtained from 3-d pore geometry must be considered.

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PROBLEMS ASSOCIATED WITH THE MEASUREMENT OF THE MECHANICS OF WOVEN FABRICS

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As in aerospace, in automotive and in civil engineering, the stresses and strains of the constituent materials of these structures are precisely defined in order for making aeroplanes, cars and bridges, similarly textile fabrics in garments ought to be defined as engineering materials. For more than a hundred years efforts have been made to find properties and parameters that will characterise the behaviour in fabrics. It is generally accepted that tensile, shear and bending are three of the most fundamental modes of deformation that woven fabrics are subjected to, during manufacture and use. These properties also referred to as mechanics, since they are responsible for the mechanical behaviour of the fabric as is the case of garment drape for example. Despite these efforts however, textile fabric behaviour is still difficult to predict precisely. The nature of textile fabrics being non linear, not homogenous, diverse and limp, make them one of the most difficult engineering materials. Prediction needs models, which need precise measurement of these mechanical properties and this is the aim of this paper.

Measurement of textile fabrics falls in two categories; in low stress measurement to define structure and in the measurement of performance which is mainly it resistance to force and is destructive. Low stress deals with forces of very low magnitude in the range of 0 to 3N with most differences to be within 50 mN. These very low forces render high demands in the mechanical engineering design and the instrumentation of suitable apparatus. Frictional reactions of moving parts and their effect on measurement, clamping of fabrics and handling are problems that we have to deal with even today in measurement.

Methods of measurement, adaptation and development of instruments span from the industrial revolution, however the most important efforts to provide specific apparatus have been made by Lindberg in the early 60s, Kawabata in the 80's and Stylios the turn of the century. CSIRO have also tried around the 90's their simple version of instruments. The only commercially acceptable measurement system, which is still being used today is the KESF designed by Kawabata. The cost of this system was prohibitive to its expansion in industrial practice and alternatives such as the simplified FAST by CSIRO found limited use. Investigations continued to design better measurement systems with the view of making it more approachable to the industry and at the same time more precise as technology in mechanical, sensor and electronic engineering increases.

These efforts started in the early 90's resulted in designing and developing an automated fabric measurement system named FAMOUS and this paper investigates comparison of the measurement of the KESF and FAMOUS for a number of commercial fabrics. Interpretation of measured results is described and discussed.

PROCESSING AND PROPERTIES OF NANOCLAY REINFORCED POLYPROPYLENE MONOFILAMENTS

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ABSTRACT

This study focuses on combining traditional polymeric materials with nanoclays to engineer new composite monofilaments for nontraditional industries using extrusion process. Polypropylene/nanoclay composite monofilaments were produced using twin and single screw extruder, and the structure and properties of new monofilaments were characterized using scanning electron microscopy (SEM), X-Ray diffraction (XRD), Fourier transform infrared spectrometry (FTIR) thermal gravimetric analyzer (TGA), differential scanning calorimeter (DSC), and Instron universal testing machine.

Composite monofilaments were prepared at different weight percentage of nanoclay (1, 2, and 3%) and compatabilizer (10, 15, and 20%) contents with single screw extruder. Besides, twin screw extruder was used to produce composite monofilaments with different weight percentage (0.5, 1, and 1.5 %) and types of nanoclay (Cloisite 15A and 30B).

The results showed that the amount of the nanoclay and compatabilizer affected the formation and final properties of the new monofilaments. It was observed that tensile stress of composite monofilament decreased compared to pure polypropylene monofilament. Melting temperature and degree of crystallinity were not affected much; however, there was significant increase at decomposition temperature of composite polypropylene monofilaments.

Key Words: High performance fibers, processing, fiber, yarn, fabric formation, nanoclay, polypropylene, monofilament.

1. INTRODUCTION

Polymeric composite materials are reinforced with nanoparticles to obtain certain properties. Basically, the nanoparticles are dispersed in the polymer matrix at low amounts, most of the time less than 6% by weight [1].

Nano particle reinforced nanoparticles have been studied in recent years because of their superior strength, modulus, reduced gas permeability, improved solvent resistance and heat distortion temperature [2-4]. Polymeric properties can be improved even at low loading without negative effect on density, transparency and process ability [1]. The conditions for successful reinforcement and good properties are the homogeneous distribution and dispersion of the reinforcing components, high aspect ratio of the nanolevel fillers, and good adhesion between polymer matrix and fillers [5].

One of the most important nanofillers is layered silicates (nanoclays). Montmorillonite clay has two silicate tetrahedral layers sandwiching an inner octahedral layer which consist of either alumina or magnesia [6, 7]. The duty of the Na^+ is to counterbalance the Al or Mg for generation of the negative charge in platelet. Montmorillonite has many platelets (layers), and there are Van der Waals forces between these layers [8]. Montmorillonite is in powder form with a mean of about 8μm particle size, and in each particle of powder there are more than 3000 platelets [9]. The thickness of each layer is almost 1nm, and the length of these layers can vary from 300Å to several microns [10]. Therefore, it has high aspect ratio.

The polymer layered silicate nanocomposites are based on separation and dispersion of the clay platelets in polymer matrix, and this dispersion range goes from simple intercalation to complete exfoliation of the silicate layers [3, 11]. Clay layers are placed between the structure, and they exist as particles containing tactoids at immiscible nanostructures. Clays are more separated at intercalated systems, and penetration of the polymer chain may occur in the interlayer spacing. Clay layers are separated individually and better dispersions are achieved in exfoliated nanostructure compared to the other two systems [2, 7]. However, it is very difficult to obtain fully exfoliation due to poor affinity between nanofillers and polymer matrix [6, 12, 13].

Some of the polypropylene monofilament application areas are nets and fabrics for agricultural end uses, geotextiles, any kind of sun breakers, sun blinds, shade nets, wind walls, safety nets, swimming pool covers, reinforcements in various coated products (such as plastics, and papers), filtration, carpeting, packaging, concrete reinforcement, and medical sutures.

2. EXPERIMENTAL

2.1. Materials

Polypropylene copolymer 30 Melt 2 Izod Natural with melt flow index (MFI) of 30 g/10 min, and density of 0.91 g/cm^{3}was purchased from Premier Plastic Resins, Inc. (USA). Cloisite 15A and Cloisite 30B, which were already modified with a quaternary ammonium salt, was purchased from Southern Clay Products, Inc. Polybond 3200 (PP grafted with malefic anhydride; 1.0 weight % maleic anhydride level) was donated by Chemtura Corporation (USA). It has 115 g/10 min MFI, and 0.91 g/cm^3 density.

2.2. Preparation of PP/Nanoclay Composite Monofilaments

All PP/Nanoclay monofilaments were prepared with melt intercalation method through a twin and single screw extruders. Different amount of nanoclay and compatabilizer were used to form composite monofilaments. Tables 1 and 2 show the master batches and sample codes. Cloisite 15A and Cloisite 30B were dried in vacuum oven at 65 ºC for 12 hours prior the manufactoring. Pure polypropylene pellets, Cloisite 15A, and Polybond 3200 were mixed manually before processing of the monofilaments. Processing temperatures are given in Table 3. First, twin screw extrusion machine was used to make tape forms. Then these pellets were used in the single screw extruder to produce monofilaments.

Table 1. Sample Codes and Blends of Master Batches for Single Screw Extrusion

Sample Code	Clay Loading (%)	Compatabilizer Loading (%)
PP	-	-
P1-C10	1%	10%
P1-C15	1%	15%
P1-C20	1%	20%
P2-C10	2%	10%
P2-C15	2%	15%
P2-C20	2%	20%
P3-C10	3%	10%
P3-C15	3%	15%
P3-C20	3%	20%

Table 2. Sample codes and blends of master batches for twin screw extruders

Sample Code	%15A	%30B	% Compatabilizer
P-A-5	0.5	-	10
P-A-10	1.0	-	10
P-A-15	1.5	-	10
P-A	1.0	-	-
P-B	-	1.0	-
P-B-5	-	0.5	10
P-B-10	-	1.0	10
P-B-15	-	1.5	10

Table 3. Temperature Settings

Heating Zones	**Temperature (ºF)**
Barrel zone-1	400
Barrel zone-2	400
Barrel zone-3	400
Barrel zone-4	400
Die zone-1	425
Die zone-2	425
Die zone-3	425
Die zone-4	425
Die zone-5	425
Die zone-6	425

3. CHARACTERIZATION

The surface morphology of the pure and composite monofilaments was investigated by using Zeiss EVO 50VP scanning electron microscopy (SEM). Probe current was adjusted between 700-900 pA. All specimens were coated with gold before the experiment. Basic crystalline structures of pure and composite monofilaments were analyzed using Bruker APEX single crystal X-ray diffractometer. Sample collections were made between 2θ range of 5-40˚ with CuKα2 radiation at 40kv voltage, and 40 mA generators current. Scanning time was set to 750 seconds, and step size was 0.01˚. Melting behavior and degree of crystallinity measurements were made by using Perkin-Elmer DSC Q2000 instrument under nitrogen atmosphere. Sample sizes were between 5-10 mg. Samples were heated

from 50 to 250 ˚ C at 10˚C/min, and held there 2 minutes, then cooled to room temperature. The crystallinity of the samples was calculated according to the following formula:

$$Xc=\frac{\Delta H}{\Delta H^{0}_{pp}} \qquad (1)$$

QUOTE ΔH

PRODUCTION AND CHARACTERIZATION OF ACTIVATED CARBON ADDED TEXTILE NANOSTRUCTURES

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ABSTRACT

The development of polymer nanofibers attracts great interest due to the variety of application possibilities. Electrospinning is a versatile and relatively simple process to make nanofibers with fiber diameters in the range of about 10 nm to 10 μm from polymer solution through electrostatic force. The nanofibers produced by electrospinning are expected to have two main properties, a very high surface to volume ratio, and a relatively defect free structure at the molecular level. This first property makes electrospun nanomaterial suitable for activities requiring a high degree of physical contact, such as providing sites for chemical reactions, or the capture of small sized particulate material by physical entanglement-filtration. Nanofibers have the potential of numerous applications including high efficiency filter media, protective clothing material, drug release membrane, nanotube material, chemical catalytic apparatus, bio-transplant material, and hydrogen storage tank for fuel cell, etc. Activated carbon has also large number of pores and because of this is such an effective adsorbent material. These provide a large surface area relative to the size of the actual carbon particle and its visible exterior surface. Highly porous materials (like activated carbon, silica xerogel) have found important applications as adsorbents in the separation and purification of gas mixtures, can effectively remove particles and organics from water, etc, molecular sieves, filters, catalyts supports etc. In this study, it is aimed to combine these high surface area properties and obtain very good adsorption behavior against volatile organic compounds (VOCs) in the final product. For this purpose we will produced activated carbon doped (3%, 5%, 10%) polyacrylonitrile (PAN) fibers by electrospinning. Obtained activated carbon particles and nanostructures will characterized by BET analysis and SEM imaging.

Keywords: Adsorption, VOC, electrospinning, PAN

1. INTRODUCTION

Volatile organic compounds (VOCs) have high vapor pressure when they are under normal conditions. This property let them vaporize and liberate into the atmosphere. VOCs, of which common examples are BTX (benzene, toluene xylene), dichloromethane, and trichloroethylene, are mainly classified as aromatics, various chlorinated hydrocarbons, aldehydes and ketones, alcohols, organic acids, esters and aliphatics [Buburuzan et al., 2010, Das et al., 2004]. They are used in many industrial applications. If individual VOCs' or their mixtures' concentrations exceed a limit value, they might cause an indoor air pollution. Due to their harmfulness to human health and the environment, the stringent regulations are increased to control their concentration in effluents [Ramos et al., 2010; Elkilani et al., 2003]. Some of their hazardous effects are eye and throat irritation, damage to liver, damage to central nervous system and also carcinogenic effects. The most common health problems because of VOCs emission are asthma and SBS (sick building syndrome). Moreover, the emission of VOCs is considered as one of the reasons of the acidification of rain [Das et al., 2004; Yao et al., 2009; Lu & Wey, 2007].

There are mainly two types of techniques in order to reduce VOCs. The first type is the destructive techniques (thermal and catalytic oxidation, photochemical oxidation and biodegradation). The second one is recuperative techniques (adsorption, absorption, condensation and membrane separation). While the first type achieves this goal by eliminating undesirable compounds, the second one let them recove. The techniques other than adsorption are very effective if the concentration of the VOCs are relatively high (>1%), while the

adsorption method is more effective at low concentration levels. Its efficiency, capacity and applicability on a large scale make the adsorption method the most preferred [Buburuzan et al., 2010, Das et al., 2004; Salman & Hameed, 2010].

Activated carbon is the most effective and widely used adsorbent for separation, purification, catalysis and energy storage, since it has highly advanced surface properties like special enlarged surface area, large pore volume and surface chemistry [Salman & Hameed, 2010; Horikawa et al., 2010]. Activated carbon has many desirable properties. These are: (1) it can be used both in acidic or alkaline conditions; (2) it is durable to relatively high temperatures (650 °C); (3) its pore structure can be changed for different purposes; (4) its surface properties can be modified to become hydrophobic; (5) it can be recycled for metal by burning spent catalysts; and (6) it is cheap [Lu & Wey, 2007]. Moreover, many modifications have been applied on the activated carbon in order to improve its affinity for certain type of chemicals like with sulfur impregnated activated carbon, which has an improved affinity for Hg. Whether in powder or granular form, an active carbon particle's porous structure is like a network, which consists of interconnected macropores, mesopores and micropores. This type of structure makes them highly adsorbent for organic molecules, because of active carbon's high surface area. For example, only one gram commercial active carbon has a surface area of 1000 m^2. Activated carbon is especially good for removal of very low concentrations of volatile organic pollutants [9]. Since electrospun nanofibers have advanced surface to volume ratios, they are also good candidates to be adsorbent and filtering materials. Electrospinning, which is a simple fiber spinning technique from polymer solutions or melts using electrostatic forces, produces fibers, of which diameters are in the nanometer to micron range [Salman & Hameed, 2010; Samuels et al., 2010; Hou et al., 2010].

In the scope of our study, it is aimed to produce a protective mask that adsorbs VOCs. In the previous steps of this study we applied the combination of sol-gel and plasma techniques for gas defense. In the first part, we applied oxygen plasma treatment to polypropylene fabric before coating with sol-gel derived carbon xerogel. In the second part, acrylic acid plasma treatment was used to surface functionalization of polypropylene fabric and then it was impregnated by the activated carbon solution. After that the PP fabric was coated with silica sol. Finally, this fabric was treated with oxygen plasma to etch the silica layer on the active carbon [Cireli (Akşit) et al., 2006; Akşit et al., 2008].

In the current study, with the aim of production of the protective mask against VOC, activated carbon added polyacrylonitrile fibers were obtained by electrospinning method. Several PAN polymer solutions in dimethylformamide was prepared by adding activated carbon powder at different rates. Characterization of activated carbon added composite electrospun fibers was realized by SEM imaging.

2. MATERIALS AND METHODS

2.1 Polymer Solution Preparation:
Polyacrylonitrile (PAN) polymer was solved in dimethylformamide, which is a suitable solvent for electrospinning because of its sufficiently high conductivity. Activated carbon powder, Darco® G-60, -100 mesh, powder Cat:24,227-6(Sigma Aldrich) has been used as additive for PAN fibers to enhance adsorption. Concentration of polyacrylonitrile(PAN) / dimethylformamide (DMF) solution was fixed and 10% owf. The amount of added activated carbon powder was 3%, 5% and 10% with respect to polymer amount.

2.2 Electrospinning Procedure
Prepared polymer solutions were used to produce nanofibers with electrospinning technique. The spinning parameters were the same for all solutions. The distance from tip to collector was 10 cm, spinning voltage was 12 kV and the flow rate was 0,3 ml/h [Süslü, 2009; Qin & Xin, 2009].

2.3 Surface Morphology
The surface morphology of activated carbon doped electrospun PAN nanocomposite fibers was observed by scanning electron microscopy (SEM) (Philips / FEI XL-30S FEG) with magnification of 10000x and 50000x.

3. RESULTS AND DISCUSION

The SEM images of undoped, %3, %5 and %10 activated carbon doped polyacrylonitrile fibers can be shown in Figures 3.1, 3.2, 3.3 and 3.4.

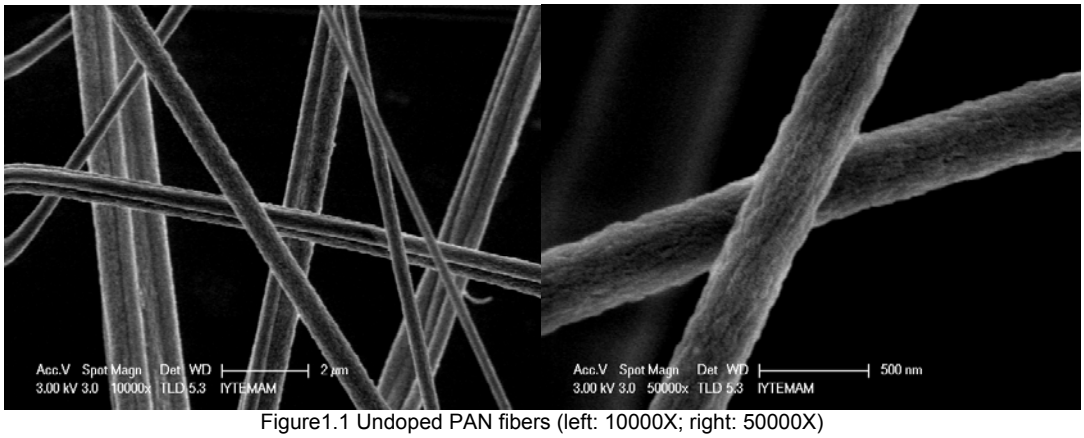

Figure1.1 Undoped PAN fibers (left: 10000X; right: 50000X)

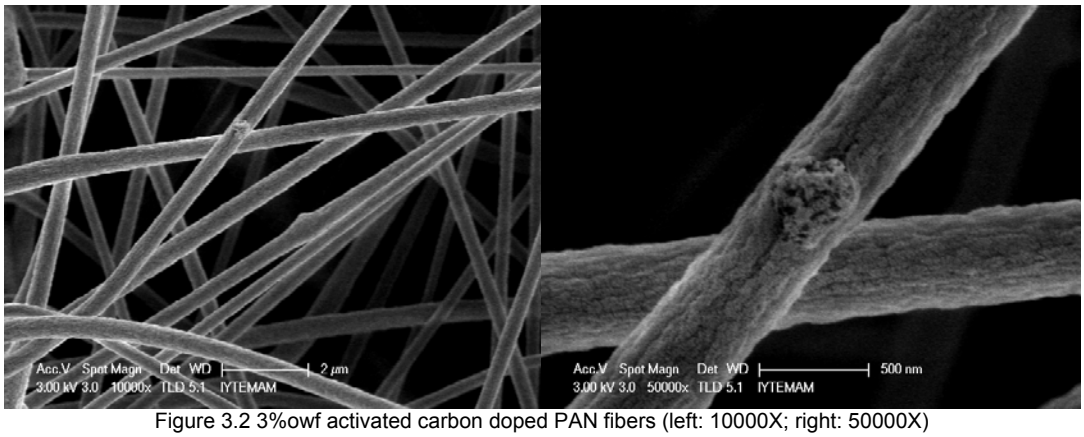

Figure 3.2 3%owf activated carbon doped PAN fibers (left: 10000X; right: 50000X)

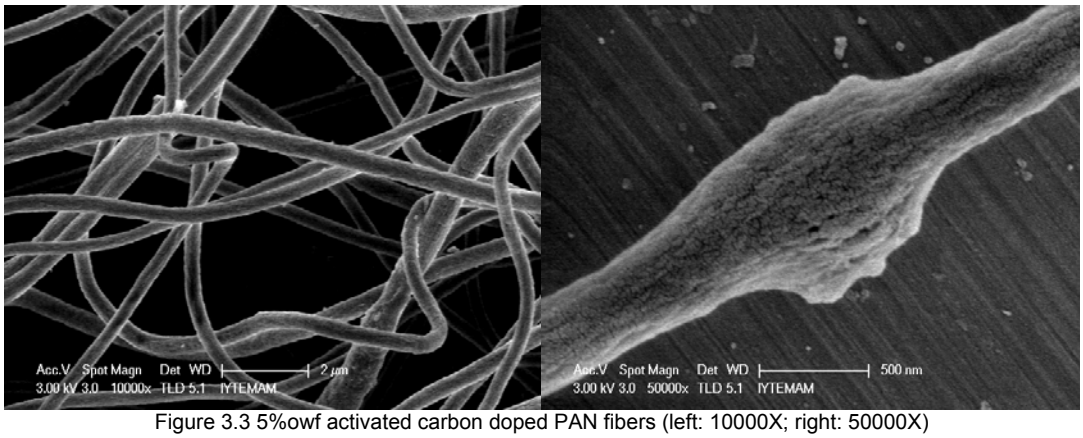

Figure 3.3 5%owf activated carbon doped PAN fibers (left: 10000X; right: 50000X)

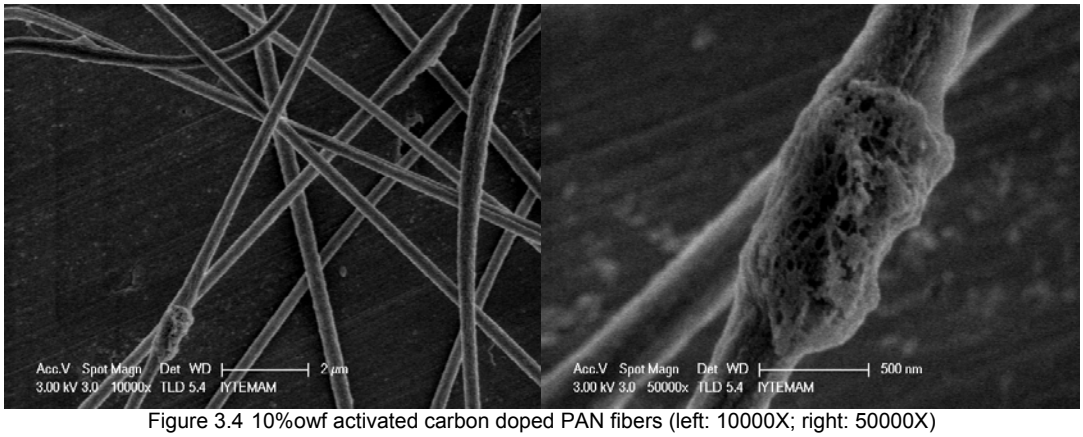

Figure 3.4 10%owf activated carbon doped PAN fibers (left: 10000X; right: 50000X)

It can be seen from the figures that doped fibers have accumulated regions. These accumulated regions are increased with increasing percentage of activated carbon. Therefore they may be resulted from the activated carbon particles in the fibers.

4 CONCLUSION

In this study, electrospun activated carbon doped polyacrylonitrile fibers were produced. Activated carbon particles were chosen because of their very good adsorption properties. According to fiber images, activated carbon particles can be seen in fibers as accumulated regions. The detailed investigation of these regions will be done by subsequent analysis. In addition, absorptive property of the nanofibers will be determined by BET analysis.

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RESEARCHES ON NEEDLEPUNCHED NONWOVENS FOR GEOTEXTILE APPLICATIONS

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ABSTRACT

The technical textiles by products and applications are the most fast changing sector of the global textile industry. The highest growth rates will be in geotextiles, but it remains a relatively small end-user of textiles compared with other application areas.
The paper is presenting the results of the researches regarding the influence of the fiber characteristic and the needlepunching parameters on the physically and tensional properties of the needlepunched nonwoven technical textiles, made from polyester fiber raw materials, used for geotextile applications. In this study, the effect of needlepunching process parameter named the punch density and the fibrous web characteristic induced by the fiber fineness has been investigated on dimensional (average surface weight) and mechanical (tensile strengths and elongation in the machine and cross-machine directions) properties of the needlepunched nonwoven geotextiles. The process parameter and fiber characteristic are then empirically related with the fabric properties using multiple regression technique.

Key words: nonwovens, needlepunching, geotextiles, regression technique

1. INTRODUCTION

The geosynthetical materials or „the engineering materials" are representing the materials, which are the results of advanced researches delivered as a „pack" including the „integrated solutions". The geosynthetics are including geotextiles, geonets, geocomposites, geomembranes, geocelulles, all used with great advantages in the soil works. Generally, the geosynthetics are a flate structure, obtained from polymeric materials and that are used together with rocks, stones and soils in the building field [1, 2, 3, 4].
The main geosynthetics's functions are the following: filtration, drenage, sealing, protection, separation, renforcement, erosion proof control and container.
As main types of raw materials for geosynthetics as geotextiles, are included the polyester with some desavantages, polypropylene because of high chemical resistance to the agressive environmental and good resistance to the high variation of temperature, polyethylene, bast fibers etc.
According with the ASTM D 4439-87 standard, the geotextiles are defined as "Any permeable textile used with foundation, soil, rock earth or any other geotechnical engineering-related material." [5].
The needlepunched nonwovens are the most used nonwovens for technical applications mainly for geotextiles. When standard fibers such as polyester fibers are used for needlepunched nonwoven geotextiles, then resistance characteristics should be increasing by variation either of the needlepunching parameter or either by choosing the right fineness of the fibers.
In this paper, from the main physical-mechanically characteristics of the polyester needlepunched nonwoven geotextiles are evaluated the average basic surface weight, expressed in g/m^2, the breaking force and the breaking elongation of the both MD and CD directions of trials.

2. EXPERIMENTS AND RESULTS

2.1. Technological process. Experimentally matrix and results

The raw materials adopted for obtaining the nonwoven geotextiles were the 100% polyester PET fibers of different fineness from 4 to 12 den and 64 mm length, and white colour.
The feeding-carding-lapping-needlepunching process to obtain nonwovens for geotextile applications has been accomplished in industrial scale.
The equipment types by steps were the Befama of Poland & Metalul Rosu of Romania for cross-lapping-needlepunching step.

Other parameters adopted during the processing of the raw materials according to task for obtaining geotextiles were the following: 20 g/m^2 the average surface weight for each fleece, 30 m/min the fleece delivery speed, 18 x 18 x 40 x 3 ½ RB Groz Beckert special needles type, 200 g/m^2 the surface weight for each fibrous web, 400 g/m^2 the nonwoven average surface weight, 2.2 m/min the fibrous web delivery speed, 2.25 m/min the nonwovens delivery speed, and 125% the laminating value from fibrous web to the nonwoven.
The independent variables adopted, as needlepunching process parameters and the fiber characteristics having influence on the functional characteristics for nonwoven geotextiles, have been the following:

- X_1, the needlepunching density, expressed in punches/cm^2;
- X_2, the fiber finesse from fibrous web, expressed in den.

Table 1 is presenting the field of variation of the needlepunching process parameters as codified and real values.

Table 1: The variation field of the needlepunching process parameter and fiber fineness

Codified values / Real value	-1.414	- 1	0	+ 1	+ 1.414
X_1, the needlepunching density [punches/cm^2]	20	38	80	122	140
X_2, the fiber finesse of the fibrous web [den]	4	6	8	10	12

The dependent variables, as nonwoven characteristics, to be studied and analyzed, have been the following [6, 7]:

- Y_W the average surface weight, expressed in g/m^2;
- Y_{FMD} and Y_{FCD} the breaking force to the MD machine direction and CD cross direction of trials, expressed in daN;
- Y_{EMD} and Y_{ECD} the breaking elongation to the MD machine direction and CD cross direction of trials, expressed in %.

Table 2 is presenting the experimentally matrix and data obtained for the considered dependent variables.

Table 2: The experimentally matrix and the nonwoven characteristic data

Exp.	X_1		X_2		Average surface weight [g/m^2]	Breaking force [daN]		Breaking elongation [%]	
	coded	real [punches/ cm^2]	coded	real [den]		MD	CD	MD	CD
1	-1	38	-1	6	364.60	35.11	64.45	121	105
2	1	122	-1	6	399.60	51.05	77.60	99	99
3	-1	38	1	10	389.25	55.10	66.50	107	109
4	1	122	1	10	374.25	67.30	80.40	100	105
5	-1.414	20	0	8	452.40	18.00	21.75	158	104
6	+1.414	140	0	8	463.90	74.35	85.50	107	112
7	0	80	-1.414	6	309.30	34.80	58.40	99	83
8	0	80	+1.414	12	404.50	62.50	98.80	119	111
9	0	80	0	8	408.60	45.95	74.20	127	124
10	0	80	0	8	408.50	46.20	75.00	128	123
11	0	80	0	8	408.30	46.15	77.00	127	124
12	0	80	0	8	407.90	45.80	74.10	126	125
13	0	80	0	8	408.10	45.50	74.30	127	124
coded - the codified value; real - the real value									

The experimental data have been processed by using the TEXPRO professional program software for the data statistical processing.
The experimentally matrix, in form of a central compound rotating program, is allowing to obtain of a statistical mathematical model as equation (1).

$$Y = b_0 + b_1X_1 + b_2X_2 + b_{11}X_1^2 + b_{22}X_2^2 + b_{12}X_1X_2 \quad (1)$$

The specimen testing have been done according to norms for geotextiles and nonwovens. The dimensions of the specimens were 100 mm x 100 mm for average surface weight and 250 mm x 50 mm for breaking force and breaking elongation characteristics.

2.2. Data evaluation

By evaluation of the resulted data given in Table 2, have been obtained five mathematical models, equation (2), equation (3), equation (4), equation (5) , equation (6) that are expressing the relationship between the characteristics, such as the average surface weight, and breaking force and elongation, and the needlepunching parameter and fiber fineness.

$$Y_W = 408.378 + 4.533\,X_1 + 16.739\,X_2 + 18.447\,X_1^2 - 32.162\,X_2^2 - 12.5\,X_1X_2 \quad (2)$$

$$Y_{FMD} = 45.931 + 13.477\,X_1 + 9.426\,X_2 + 1.3\,X_1^2 + 2.537\,X_2^2 - 0.935\,X_1X_2 \quad (3)$$

$$Y_{FCD} = 74.936 + 14.649\,X_1 + 7.747\,X_2 - 9.127\,X_1^2 + 3.356\,X_2^2 + 0.188\,X_1X_2 \quad (4)$$

$$Y_{EMD} = 127.029 - 12.639\,X_1 + 1.91\,X_2 - 0.775\,X_1^2 - 12.522\,X_2^2 + 3.75\,X_1X_2 \quad (5)$$

$$Y_{ECD} = 124.025 + 0.164\,X_1 + 6.199\,X_2 - 7.521\,X_1^2 - 13.019\,X_2^2 + 0.5X_1X_2 \quad (6)$$

Table 3 is giving the data including the Student statistic testing for the equation's coefficients that have been compared to the T_{tab} = 2.132 tabular value for α = 0.95 probability and μ = 4 free degrees, the resulted final equations after Student statistic testing as well other data relating the process optimization.
The final equations (7), (8), (9), (10) and (11) usefully have been for process optimization step.

Table 3: Statistical and optimization of the experimentally data

Y	Student Test Status, Final Equation and Needlepunching Optimization Results
Y_W – average surface weight	$Tb_0 = 3188.900 – b_0$ significant, $Tb_1 = 44.770 – b_1$ significant, $Tb_2 = 165.337 – b_2$ significant, $Tb_{11} = 169.882 – b_{11}$ significant, $Tb_{22} = -296.184 – b_{22}$ significant, $Tb_{12} = -87.304 – b_{12}$ significant $Y_W = 408.378 + 4.533 X_1 + 16.739 X_2 + 18.447 X_1^2 - 32.162 X_2^2 - 12.5 X_1X_2$ (7) - The coefficient of multiple correlation: 0.8908 - The coefficient of multiple determination: 0.7935 - Critic point: saddle of coordinates, $X_1 = -0.033$; $X_2 = 0.267$; $Y_w = 410.834$ g/m^2
Y_{FMD} – breaking force to MD machine direction	$Tb_0 = 361.430 – b_0$ significant, $Tb_1 = 134.146 – b_1$ significant, $Tb_2 = 93.821 – b_2$ significant, $Tb_{11} = 12.066 – b_{11}$ significant, $Tb_{22} = 23.547 – b_{22}$ significant, $Tb_{12} = -6.581 – b_{12}$ semnificativ $Y_{FMD} = 45.931 + 13.477 X_1 + 9.426 X_2 + 1.3 X_1^2 + 2.537 X_2^2 - 0.935 X_1X$ (8) - The coefficient of multiple correlation: 0.9243 - The coefficient of multiple determination: 0.8543 - Optimal point: minimum of coordinates, $X_1 = -6.265$; $X_2 = -3.012$; Y = 13.018 daN
Y_{FCD} – breaking force to CD cross direction	$Tb_0 = 137.875 – b_0$ significant, $Tb_1 = 34.093 – b_1$ significant, $Tb_2 = 18.030 – b_2$ significant, $Tb_{11} = -19.805 – b_{11}$ significant, $Tb_{22} = 7.283 – b_{22}$ significant $Tb_{12} = 0.309 – b_{12}$ insignificant $Y_{FCD} = 74.936 + 14.649 X_1 + 7.747 X_2 - 9.127 X_1^2 + 3.356 X_2^2$ (9) - The coefficient of multiple correlation: 0.872 - The coefficient of multiple determination: 0.7604 - Critic point: saddle of coordinates, $X_1 = 0.802$; $X_2 = -1.154$; $Y_w = 76.344$ daN
Y_{EMD} – breaking elongation to MD machine direction	$Tb_0 = 401.702 – b_0$ significant, $Tb_1 = -50.557 – b_1$ significant, $Tb_2 = 7.640 – b_2$ significant, $Tb_{11} = -2.892 – b_{11}$ significant, $Tb_{22} = -46.699 – b_{22}$ significant, $Tb_{12} = 10.607 – b_{12}$ semnificativ $Y_{EMD} = 127.029 - 12.639 X_1 + 1.91 X_2 - 0.775 X_1^2 - 12.522 X_2^2 + 3.75 X_1X_2$ (10) - The coefficient of multiple correlation: 0.8633 - The coefficient of multiple determination: 0.7448 - Critic point: maximum of coordinates, $X_1 = -12.485$; $X_2 = -1.793$; $Y_{EMD} = 73.442\%$
Y_{ECD} – breaking elongation to CD cross direction	$Tb_0 = 392.20 – b_0$ significant, $Tb_1 = 0.656 – b_1$ insignificant, $Tb_2 = 24.796 – b_2$ significant, $Tb_{11} = -28.048 – b_{11}$ significant, $Tb_{22} = -48.554 – b_{22}$ significant, $Tb_{12} = 1.414 – b_{12}$ insignificant $Y_{ECD} = 124.025 + 6.199 X_2 - 7.521 X_1^2 - 13.019 X_2^2$ (11) - The coefficient of multiple correlation: 0.9521 - The coefficient of multiple determination: 0.9065 - Critic point: maximum of coordinates, $X_1 = 0.000$; $X_2 = 0.238$; Y = 124.763%.

2.2. Data and results' interpretation

The veracity of the final equations, given in Table 3, also has been verified by the "A" value expressing the percentages deviations of the calculated values from measured values which are given in the Table 4. The deviation should be of ±10% value.

Table 4: The deviation data „A“, for needlepunched nonwoven characteristics

Exp.	A (%) by characteristic and equation				
	Y_W (g/m^2) Equation (7)	Y_{FMD} (daN) Equation (8)	Y_{FCD} (daN) Equation (9)	Y_{EMD} (%) Equation (10)	Y_{ECD} (%) Equation (11)
1	1.017	26.144	27.434	5.960	7.347
2	1.162	7.259	1.975	3.604	1.732
3	7.738	15.331	6.372	16.384	0.627
4	7.798	6.594	13.882	6.753	4.460
5	2.994	63.745	65.393	9.272	4.796
6	2.636	9.095	9.473	0.567	2.690
7	3.590	8.265	21.049	0.295	7.504
8	9.087	2.933	6.274	12.022	3.820
9	0.054	0.040	0.992	0.023	0.020
10	0.030	0.581	0.085	0.758	0.833
11	0.019	0.474	2.681	0.023	0.020
12	0.117	0.287	1.128	0.817	0.780
13	0.068	0.948	0.856	0.023	0.020

For the surface average weight characteristic, all data of the deviation “A” are less than +10%. Therefore by this point of view, the equation (2) is accurately expressing the fact that the average surface weight is influenced by the needlepunching density as well by the fiber fineness.
From the equation (7) can be observed the fact that the fiber’s finesse have greater influence than needlepunching density on the average surface weight value.
For the Y_{FMD} and the Y_{FCD} breaking force, expressed by the equations (8) and (9), the “A” deviations are surpassing the ±10% value mainly, very much for the experiment 5 and less for the experiment 1. This should be explained by the fact that, at these experiments, the needlepunching density is at the very low value, which means that the intimately interlacing between fibers are not yet fixed and then, during the resistance testing, the fibers are very easily moving some of them toward other fibers.
For the Y_{EMD} and the Y_{ECD} breaking elongation dependent variables, expressed by the equations (10) and (11), the deviation “A” is very low or only two data are surpassing the ±10% value, for the experiments 3 and 8 of the Y_{EMD} characteristic.
From the equation (8) and the equation (9) it is observing that the both independent variables have the same influence value either positively or negatively.
The 3D graphics, the contour curve graphics and the 2D graphics are plotted in the fig. 1, fig. 2, and fig. 3 for the average surface weight dependent variable, in the fig. 4, fig. 5, and fig. 8 for the breaking force on MD machine direction, in the fig. 6, fig. 7 and fig. 9 for the breaking force on CD cross direction, in the fig. 10, fig. 11 and fig. 14 for the breaking elongation on MD machine direction, and finally, in the fig. 12, fig. 13 and fig. 15 for the breaking elongation on MC machine direction.

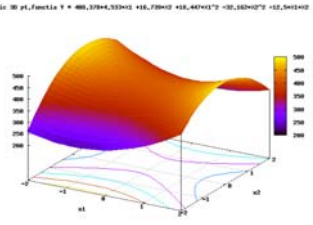

Figure 1: Effect of the needlepunching density and fiber finesse on Y_W average surface weight

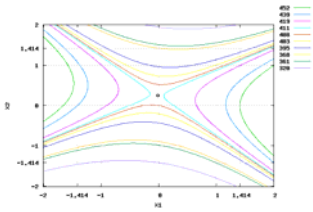

Figure 2: Effect of the needlepunching density and fiber finesse on Y_W average surface weight
The constant contour curves

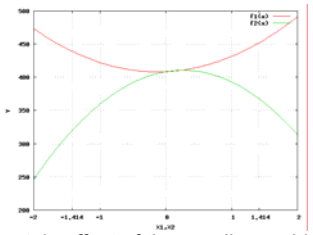

Figure 3: Separately effect of the needlepunching density and fiber finesse on average surface weight average Y_W.

The critical point for the average surface weight characteristic, is a saddle point, which has the codified coordinates of X_1 = -0.033 and X_2 = 0.267 at Y_w = 410.834 g/m^2 value is very close of center of the field of variation of the parameters.
The saddle point is also very accountable by technologically point of view.

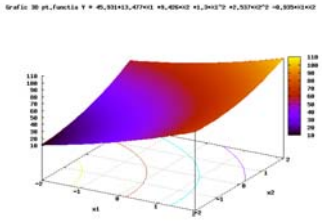

Figure 4: Effect of the needlepunching density and fiber finesse on Y_{FMD} breaking force

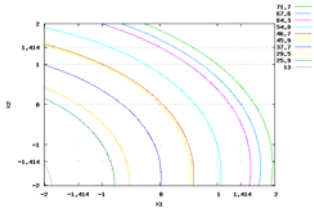

Figure 5: Effect of the needlepunching density and fiber finesse on Y_{FMD} breaking force. The constant contour curves

The critical point for the MD direction breaking force characteristic, as a minimum point, which has the codified coordinates of X_1 = -6.265 and X_2 = -3.012 for an Y_{FMD} = 13.018 daN breaking force value also is very accountable by technologically point of view. The very low parameter values are not accomplishing the strong links between fibers. The critical point is very far away from the center of the field of variation of the parameters.

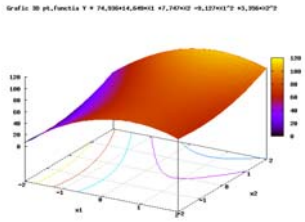

Figure 6: Effect of the needlepunching density and fiber finesse on Y_{FCD} breaking force

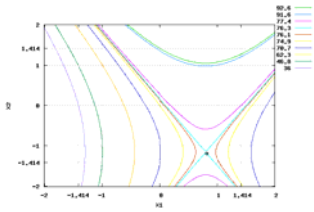

Figure 7: Effect of the needlepunching density and fiber finesse on Y_{FCD} breaking force. The constant contour curves

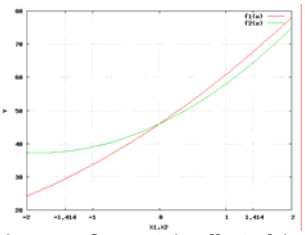

Figure 8: Separately effect of the needlepunching density and fiber finesse on Y_{FMD} breaking force.

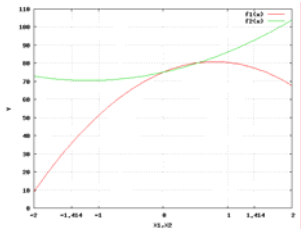

Figure 9: Separately effect of the needlepunching density and fiber finesse on Y_{FCD} breaking force.

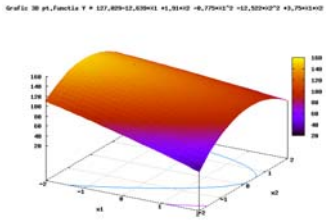

Figure 10: Effect of the needlepunching density and fiber finesse on Y_{EMD} breaking elongation

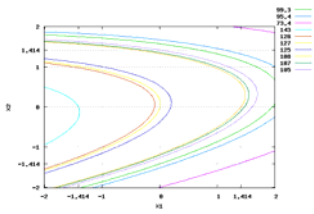

Figure 11: Effect of the needlepunching density and fiber finesse on Y_{EMD} breaking elongation. The constant contour

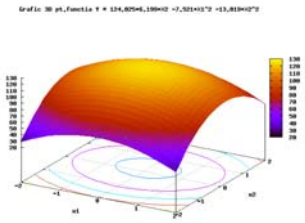

Figure 12: Effect of the needlepunching density and fiber finesse on Y_{ECD} breaking elongation

curves

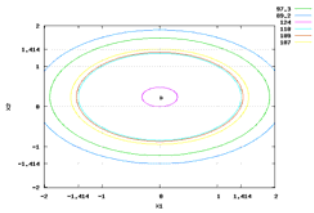

Figure 13: Effect of the needlepunching density and fiber finesse on Y_{ECD} breaking elongation. The constant contour curves

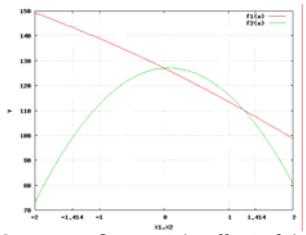

Figure 14: Separately effect of the needlepunching density and fiber finesse on Y_{EMD} breaking elongation.

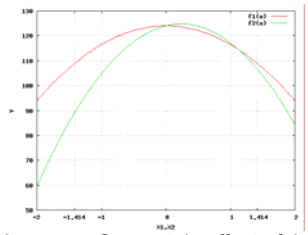

Figure 15: Separately effect of the needlepunching density and fiber finesse on Y_{ECD} breaking elongation.

The critical point for the breaking force characteristic on CD direction, as a saddle point, which has the codified coordinates of X_1 = 0.802 and X_2 = -1.154 for an Y_{FCD} = 76.344 daN real value, also is very accountable by technologically point of view. But, at the CD direction can be explained and interpreted by the fact that for cross direction it must co considerate the fibers' orientations into the fibrous web due the cross-lapping technologically step. The angle of lapping, in a value less than 15º, is resulting to a higher value of resistance for cross direction. If, for the MD direction are contributing to the nonwoven resistance mainly the links and bundle between fibers due, let say, to the needlepunching density parameter, then for CD direction are contributing, to the nonwoven resistance, also even the fibers' resistance as well the links due the needlepunching density.

3. CONCLUSIONS

The researches accomplished by using the polyester fibers of different fineness and of the some length in an experimentally matrix including the needlepunching density as independent variable are resulting to the following conclusions:

The fiber fineness and the needlepunching process parameter have influence on the physically-mechanically characteristics such as the average surface weight and the resistance and elongation to the rupture.

The average surface weight is determining the raw material consume and finnally the cost and price for the needlepunched nonwoven geotextiles, and certainly the soil work's value.

The tensional characteristics are the main requiremnts from geotextiles used for the allmost soil works of very heavy tasks.

The physically-mechanically characteristics of the needlepunched nonwoven geotextiles are influenced by a probability of 99.9% by needlepunching density and the fiber fineness.

The physically-mechanically characteristics are mainly influenced, between 76.04 % and 85.43 %, by the needlepunching density and the fiber fineness.

The average surface weight is influenced by 79.35 % of needlepunching density and the fiber fineness and by 20.65 % by other factors to be defined.

The breaking force on the MD machine direction is influenced by 85.43 % of needlepunching density and the fiber fineness, and by 14.57 % by other factors to be defined.

The breaking force on the CD cross direction is influenced by 76.04 % of needlepunching density and the fiber fineness, and by 23.96 % by other factors to be defined.

The breaking elongation on the MD machine direction is influenced by 74.48 % of needlepunching density and the fiber fineness, and by 25.52 % by other factors to be defined.

The breaking elongation on the CD machine direction is influenced by 90.65 % of needlepunching density and the fiber fineness, and by 9.35 % by other factors to be defined.
As other factors can be given the fleece uneveness, the fibrous web unevenes because of the some air motion during the cross-lapping process, the unveveness of the needlepunching density because of possible broken needles during the needlepunchin process, the irregularly motion of some equipment mechanical components, etc.
The assigning the interval of variation of the both independent variables on the base of the mathematical modelling method it must to be differently perform function of the conditions to that the needlepunched nonwoven geotextiles must to answer to the tasks according with the special requirements of the hydrotechnical works.
Because of the complex and complicated trials of the geotextiles during its exploatations, it must to determinate other functional and particularly characteristics such as hydraulically permeability, radially resistance, resistance to the harmefully environmental conditions, etc.

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SINGLE USE HYDROPHIL-ANTIMICROBIAL NONVOWEN LAMINATED MATTRESS

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ABSTRACT

In this study, the reduction of infection risk from patient to patient and the others during staying period in hospital using new designed "Disposable Hydrophilic-Antimicrobial Laminated Nonwoven Bed Sheet" is investigated. Because the traditional cotton bed sheets which are used in hospitals does not have any antimicrobial effect they are very suitable mediums for microbes to survive. In addition, due to their costs they are not disposable and have to be washed minimum 30 timesduring their use. If disposable hydrophilic-antimicrobial laminated nonwoven bed sheets were used, both antimicrobial protection and cost advantage would be obtained.

Disposable bed sheet is consist of three layers which are laminated to each other by hot-melt technique. Upper and lower layers are different weights of 100 % polypropylene produced by spunbond technology. Plasma technology has been used to make the surface of the spunbond polypropylene sheets hydrophilic. Additionally, thermalbond 100 % polypropylene sheets which have already hydrophilic surfaces by chemical finish are also used as upper layers for the sheets. As a core layer, different weights of 100 % viscose sheets which have high liquid absorption level have been used. All three layers have been laminated by hot melt technique using etylenevinylacetate interlayers between them. Antimicrobial effect has been achieved by the impregnation of silver and antibiotic based chemicals onto hydrophilic surface of upper layers. Quality control and performance tests of all these works have been performed according to ISO and BS norms.

Keywords: Nonwoven, Antimicrobial, Lamination, Bed Sheet

1. INTRODUCTION

Despite of improvements in service quality, infections on patients who stay at hospitals are still being observed worldwide and the risk of dead is being increased. Naturally, hospital personal is also effected by this situation. Hospital infections are important threats both for patients and environment (3).

It is known that only in United States of America, two million people per year are effected by infections via hospitals and ninety thousand people are dead. Hospital infections cost approximately 6.7 billion USD per year in USA. This is 1.7 billion USD in England. In Norway which has population of four million people only, this number is 132 million USD (7). In Turkey, it is calculated that hospital infections cost 1500 USD per patient. Staying period of the patients in hospitals because of infections varies from four day to thirtyfour day (6). Staying periods in hospitals for different countries are shown as in the below Table 1.1.

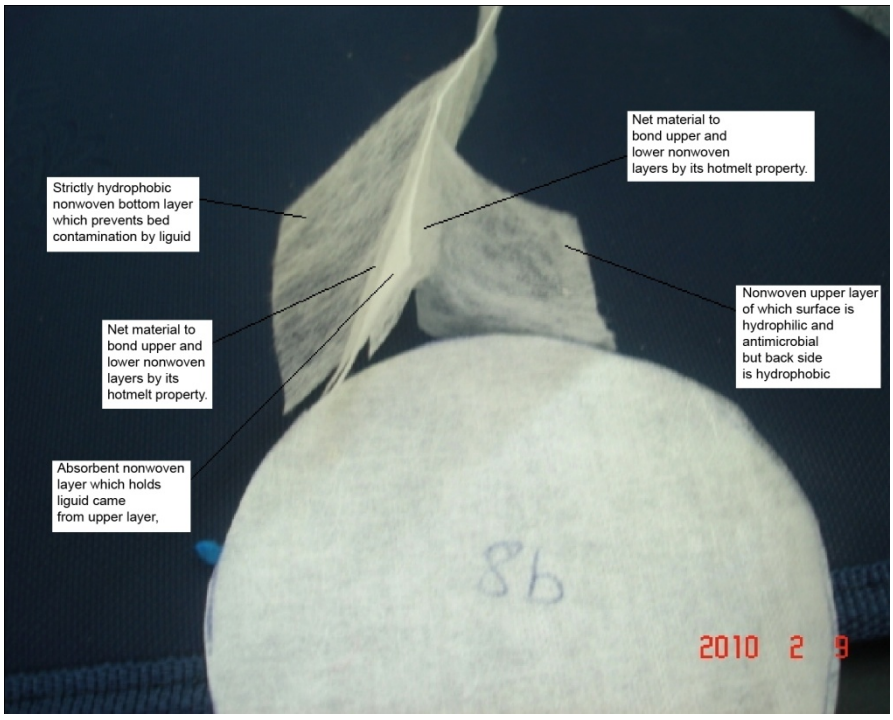
Table 1.1 Additional staying days because of hospital infections (6).

Study	Country	Additional stay (day)
1974 (Westwood)	ABD	22.0
1980 (Haley)	ABD	13.4
1991 (French)	Hong Kong	23.4
1993 (Diaz-Molina)	İspanya	4.3
1995 (Erbaydar)	Türkiye	10.6
1997 (Yalçın)	Türkiye	20.3
1997 (Leroyer)*	Fransa	5.2
1998 (Orrett)	Trinidad	33.5
1998 (Andersen)	Norveç	4.0
1999 (Navarette)*	Meksika	9.6
1999 (J Munoz)*	Meksika	7.4
2001 (Plowman)	İngiltere	11.0
2005 (Chen)	Tayvan	18.2

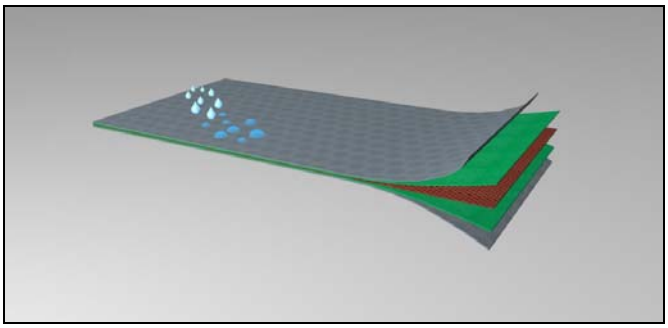
* Pediatri.

2. MATERIAL AND METHOD

The structure and features of the components of developed product are shown as in the below Scheme 2.1 and Scheme 2.2.



Scheme 2.1: Original sample.



Scheme 2.2: Appereance of laminated sheets

2.1 Material

2.1.1 Nonvowens

Nonwoven sheets used in this study and their functions are shown as in the below Table 2.1. Many multilayer combinations have been prepared by using below shown nonwoven types and all of them have been numbered. Then, all of them have been tested according to international ISO and BS norms

Table 2.1: Nonwoven sheets used in this study and their functions (6).

Nonwoven Type	Weight (g/ m^2)	Description and function
% 100 PP, Spunbond	15	As upper and bottom layer hydrophilic/ hydrophobic and antimicrobial/ microbial
% 100 PP, Spunbond	25	As upper and bottom layer hydrophilic/ hydrophobic and antimicrobial/ microbial
% 100 PP, Spunbond	35	As upper and bottom layer hydrophilic/ hydrophobic and antimicrobial/ microbial
% 100 PP, Thermalbond	18	Only as upper layer hydrophilic and antimicrobial
% 100 PP, Thermalbond	25	Only as upper layer hydrophilic and antimicrobial
% 100 CV	20	As middle layer high suction capacity
% 100 CV	30	As middle layer high suction capacity
% 100 CV	35	As middle layer high suction capacity
% 100 CV	50	As middle layer high suction capacity

2.1.2 Antimicrobial chemicals

Table 2.2: Antimicrobial Recipies and Application Conditions (2) (4).

	Nano Silver based recipe	**Polihegzametilenbiguanid based recipe**
ISys AG (g/ L)	2.0	--
Reputex 20 (g/ L)	--	20.0
Acetic acid (85%) (g/ L)	pH 5.0-5.5	pH 7.0-7.5
Impregnation Unit	KÜSTERS foulard	
Machine Speed (m/ dk)	20	
Sıkma basıcı (bar)	2.4	
Total Flotte (L)	50	
Flotte temperature (°C)	20-25	
Pick up (%)	40-45	

2.2 Method

2.2.1 Hydrophilization of upper PP nonwoven sheets by plasma method

Cold oxigen plasma method under atmospheric pressure has been used to modify the surfaces (5). Plasma conditions are shown as in the below Table 2.3.

Table 2.3: Plasma conditions (6).

Gas type	O_2
Pressure	Atmosferik
Voltage (V)	3500
Machine Speed (m/ s)	15

PP nonwoven sheets which will be used as upper layers have been passed three times through the machine under the same conditions for 20 seconds each (6).

2.2.2 Lamination (hotmelt technique)

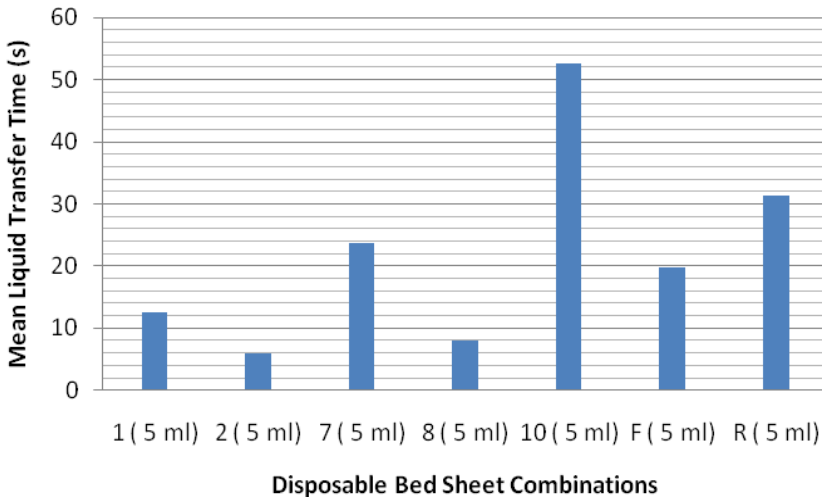
This process has been realized via a professional press. The nonwoven sheets have been replaced one on another according to combinations done before. Ethylenevinylacetate based hotmelt net has been replaced in each nonwoven pair sheets to bond them strictly. Then these prepared multilayer combinations have been pressed by hot press at 80°C.

3. OUTCOMES AND INTERPRETATIONS

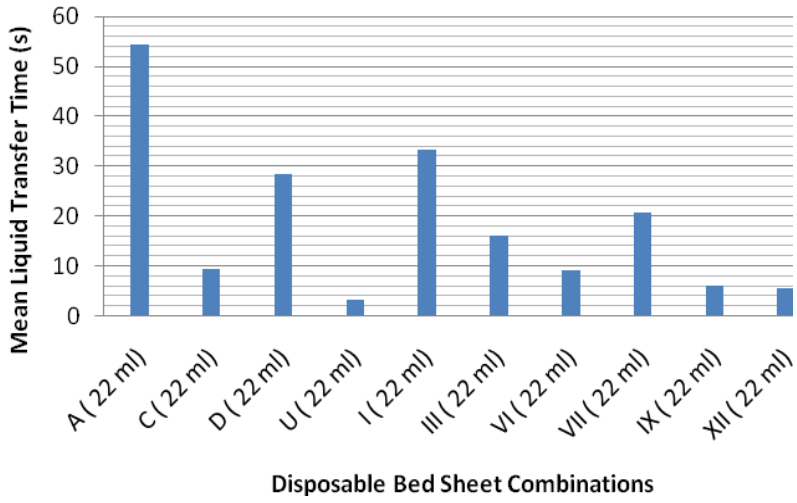
3.1 Applied tests and reference standarts in the study

Table 3.1: Applied tests and reference standarts in the study (1).

APPLIED TEST	REFERENCE STANDART
Weight measurement	TSE 251
Thickness measurement	TSE 4117 EN ISO 2589
Tensile strength and elongation	TSE EN ISO 13934-1
Tearing strength	TSE EN ISO 13937-2
Wetback	EDANA 151.3.02
Liquid transfer	EDANA 150.5.02
Air permeability	TSE 391 EN ISO 9237
Water vapour permeability	BS 7209
Antimicrobial efficiency	AATCC 100 (Stafilococcus Aureus)

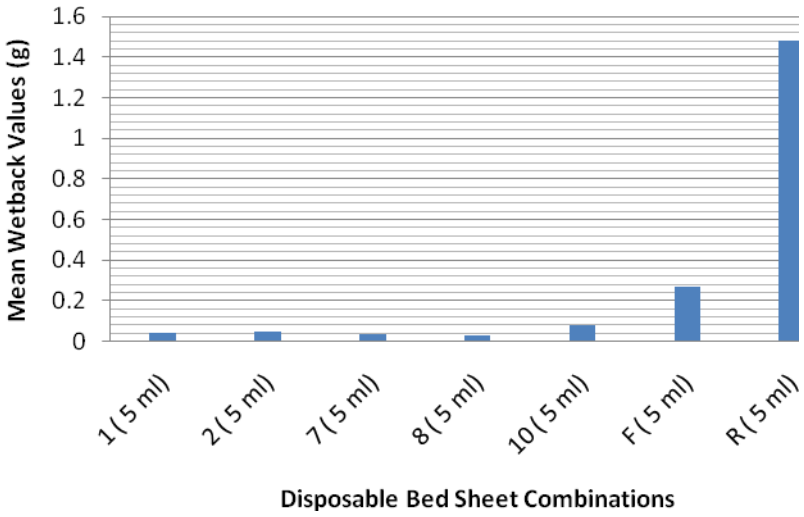


Scheme 3.1: Mean liquid transfer time values (5 ml test liquid).

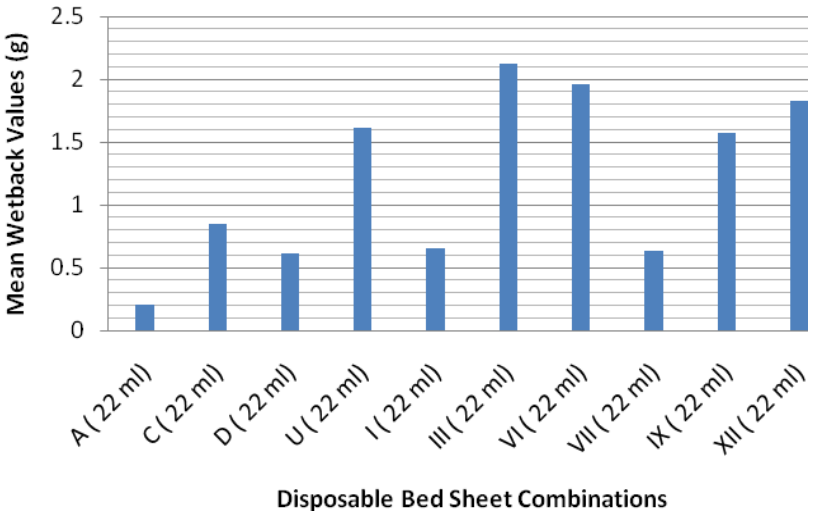


Scheme 3.2: Mean liquid transfer time values (22 ml test liquid).

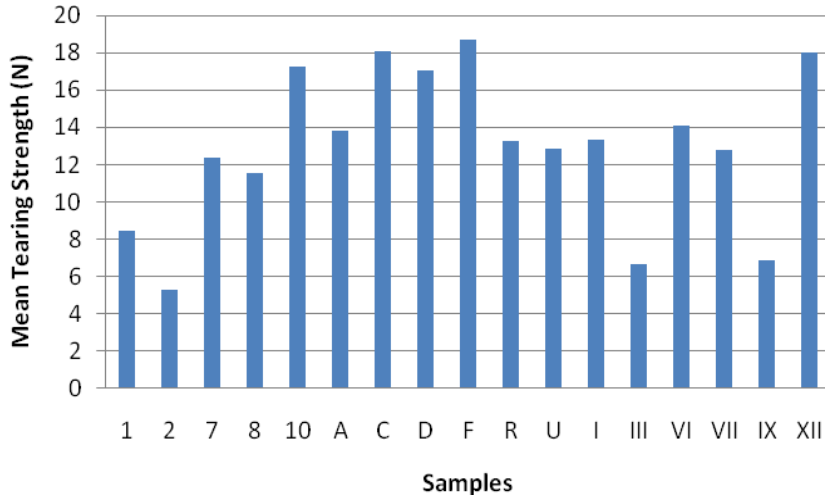
Regarding different multilayer nonwoven combinations which have lower than 60 s mean liquid tranfer values, five sample has been choosen because of having excellent wetback values (below 0.5 g): samples 1,2,7,8 and 10. As a result of this, other tests have been applied on these samples by omitting rest samples.



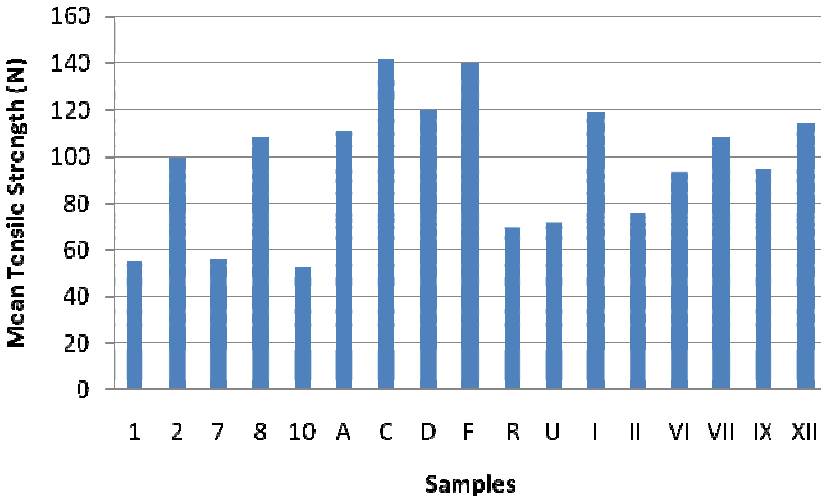
Scheme 3.3: Mean wetback values (5 ml test liquid).



Scheme 3.4: Mean wetback values (22 ml test liquid).

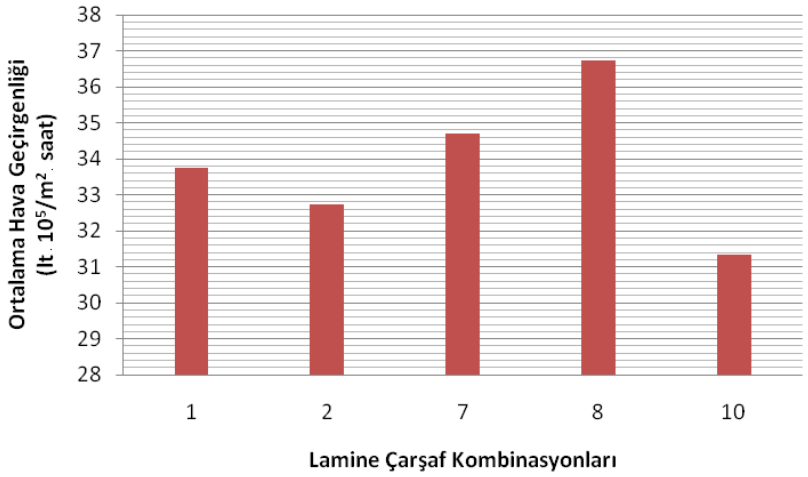


Scheme 3.5: Mean tearing strength values.

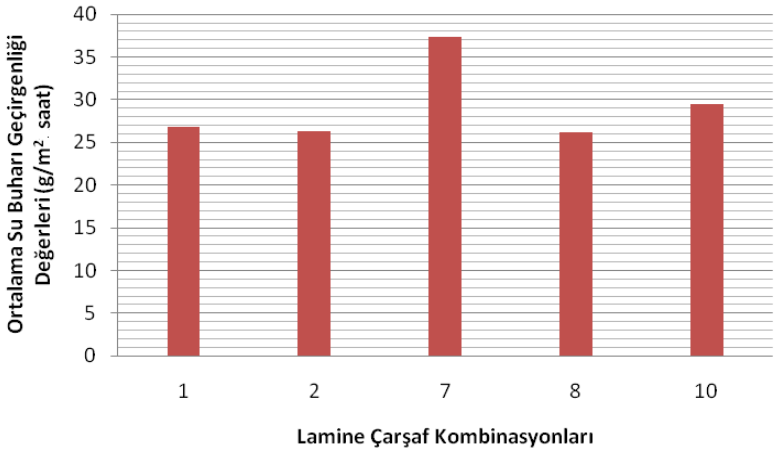


Scheme 3.6: Mean tensile strength values.

As we see in the Schemes 3.5 and 3.6 mean tear and tensile strength values of the samples 1,7 and 10 are moderate while samples 2 and 8 is better. Despite of this, it is not expected to have any problem because of having tearings in width direction and being disposable material.



Scheme 3.7: Mean air permeability values.



Scheme 3.8: Mean water vapour permeability values.

Air and water vapour permeability values of the samples 1,2,7,8 and 10 are very good. Naturally, it is expected that these disposable bed sheets will be comfortable for patients.

Table 3.2: Antimicrobial test results

	Bacteria reduction after 24 h (%)	
Antimicrobial chemical	Treated	Untreated
ISys AG (nanosilver)	99,9	0
Reputex 20 (Polihegzametilenbiguanid)	99,9	0

Antimicrobial tests have been done according to AATCC 100 standart by using Stafilococcus Aureus bacteria which is most common one in hospitals.

3.2 Cost analyze

Table 3.3: Comparison of classical and disposable bed sheets (1)

	Classical Hospital Bed Sheet	Disposable Hydrophilic Antimicrobial Laminated Nonwoven Bed Sheet (Samples 1/ 7/ 8)
Structure	100 % CO, 50 thread/ cm total density,	50-60% PP + 50-40% CV, nonwoven
Usage	30 times washing and reusing	Disposable
Initial Cost (TL) (180x220 cm)	7,7	2,31/ 2,39/ 2,77
Final Cost for 30 washing cycle (TL)	0,79	--

4. CONCLUSIONS

1. The best results belong to the sample 8. Then, sample 7 is coming. Moreover, the sample 1 is also usable despite of having lower tensile and tear strength values compare to samples 8 and 7.
2. When we look at successful samples again we see that the samples are consist of light weight nonwoven layers as shown below:
   a. Plasma and Polihegzametilenbiguanid applied PP upper layer 15 g/ m^2 + CV medium layer 20 g/ m^2 + Bottom Layer 15 g/ m^2 (Sample 1),
   b. Plasma and nanosilver applied PP upper layer 15 g/ m^2 + CV medium layer 20 g/ m^2 + Bottom Layer 15 g/ m^2 (Sample 7),
   c. Plasma and nanosilver applied PP upper layer 15 g/ m^2 + CV medium layer 35 g/ m^2 + Bottom Layer 15 g/ m^2 (Sample 8),

   We can say that costs of the disposable bed sheets will be lower because of being lightweight structure. Beside this, the disposable bed sheet will be more flexible and easy to use. Also, it is significant that all the successfull samples are plasma treated samples. In other words, chemically treated thermalbond hydrophilic samples were not good enough. Moreover, both polihegzametilenbiguanid and nanosilver based antimicrobial agents are effective.
3. When we investigate costs of successful disposable bed sheets we see that they are approximately three times cheaper than classical cotton made bed sheets regarding initial costs but after several washings classical bed sheet is getting cheaper. Considering thirty washing cycle the classical bed sheet is approximately three times cheaper. Despite of that, It can be thought that this cost difference can be ignored if we care about infection risk and hygiene.

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SPECTROSCOPIC AND MECHANICAL CHARACTERIZATION OF ELECTRICALLY CONDUCTIVE P(AN-co-BuA) COMPOSITE THIN FILMS

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Polyacrylonitrile (PAN) polymer and its various copolymers/terpolymers or composites have found great interest from researchers for the different application purposes. Acrylic fibers are produced from the copolymers of PAN by various ways of polymerization, they have good properties such as Acrylic is lightweight, soft, and warm, with a wool-like feel. It dyes very well and has excellent color-fastness.

In this study, P(AN-co-BuA) copolymers were synthesized from its monomers - Acrylonitrile (AN) and Butyl acrylate (BuA) - by free-radical polymerization method in different molar ratios of monomers. Synthesized copolymers were used to prepare solutions which were performed *via* Cerium (IV) initiated free-radical polymerization of pyrrole and N-phenyl pyrrole in copolymer matrix in DMF (Dimethylformamide) media. Thin films were produced by casting the resultant solutions on smooth glass surfaces, and applying a proper temperature under vacuum for a proper time period to remove excessive DMF. The presence of pyrrole and N-phenyl pyrrole in thin films is confirmed by FTIR-ATR studies. SEM analyses revealed the structural changes in microscopic scale. Dynamic Mechanical Analyses of thin films was appreciably improved relative to the results of PAN homopolymer used previous studies.

The results indicated that, with the increasing BuA content, the mechanical properties became better, and conductivity of thin films improved with the increasing pyrrole and N-phenyl pyrrole content. Mechanical properties and electrical conductivities were well balanced by properly changing the AN/BuA monomer ratios, and pyrrole and N-phenyl pyrrole content. The results are promising to approach better thin film properties for many different application areas of future.

Key Words: Acrylonitrile, Butyl acrylate, PAN copolymers, P(AN-co-BuA) copolymer, Free-radical polymerization, Pyrrole, N-phenyl pyrrole, Dimethylformamide, Composite thin films, Dynamic Mechanical Analysis, FTIR-ATR Spectroscopy, SEM analysis

STEADY STATE ELECTROSPUN POLYAMIDE NANOFIBRES FOR THE USE IN MBR

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Abstract

Electrospinning is the process to generate nanofibers. Some very specific application fields are targeted in the literature about electrospinning. One of these research fields is filtration. In this field, mainly air filtration is targeted. Recent studies showed the strong performance of nanofibrous material in liquid filtration.

For liquid (such as water) filtration the material needs to be flawless and pressure resistant. To cope with the first problem, we have developed a specific technology based on nozzle electrospinning. The key feature in our technology is the possibility to electrospin under steady state conditions. In each time period, the amount of polymer that is pumped out of the needle as a solution is the same as the amount of polymer that is deposited in the form of nanofibers. In the case of water filtration, a polyamide 6 nanofibrous nonwoven is created. The polyamide is chosen because of its high inherent strength. This high mechanical strength makes it possible for the material to withstand the pressure applied on the material during filtration.

At this moment, projects are running to investigate if the polyamide 6 nanofibrous structures give an added value in the field of water filtration. The first results show that nanofibres enhance the water flux values at the same pressure. Next to flux investigations, experiments concerning the use of the membranes in a membrane bioreactor (MBR) are performed. These experiments show that the nanofibrous material has the same filtration efficiency as commercial MBR membranes. It even surpasses that efficiency with an extra functionalisation.

Keywords

Electrospinning, steady state, membrane bioreactor, nanofibres

1.1 Steady state electrospinning

Electrospinning is an innovative process, capable of producing fibres with diameters typically one to two orders of magnitude lower than extrusion and conventional solution-spun fibres. A variety of polymers can be spun, each from a specific solution. In addition, the ability to produce highly porous nanofibrous membranes with structural integrity is also an attractive feature of electrospinning [1].

The key factor for successful nozzle electrospinning is achieving steady state conditions. Electrospinning is in steady state when the amount of polymer that is transported through the needle per unit of time equals the amount of polymer that is deposited as nanofibres on the collector per unit of time. This definition comprises two conditions. The first condition is that in time all the polymer that

is spun from the nozzle and collected at the target is converted into nanofibres, implying the absence of beads or drops in the structure. The second condition for steady state electrospinning is a stable, time invariant, Taylor cone. Steady state electrospinning allows for the long term stability needed for reproducibly producing samples of any desired size.

1.2 Steady state electrospinning of polyamide 6

Polyamide 6 is a well known polymer in the field of electrospinning. Most of the research so far uses formic acid as a solvent for electrospinning. We found that this solvent doesn't result in steady state electrospinning of polyamide 6. However, the solvent mixture formic acid / acetic acid does. Further on the steady state table of polyamide 6 with this mixture is presented.

The steady state table is made under a defined series of conditions. The process was investigated at a temperature of 20 °C and a relative humidity of 45 %. The tip-to-collector distance was 6 cm and the applied voltage on the needle 30 kV. The steady state table is table 1. For each composition for which steady state electrospinning could be reached, a single flow rate with an operating window of about 10 % results in steady state electrospinning. When the flow rate is higher than the flow rate in the table plus the operating window, drops of polyamide will be ejected out of the Taylor cone. When the flow rate is lower than the flow rate in the table minus the operating window, no Taylor cone will be observed any more during the experiment as the electrospinning will take place from within the needle.

Table 1: Steady state table of polyamide 6

	Volume fraction of acetic acid in the formic acid / acetic acid mixtures				
wt% PA6	25 v% AA	33v% AA	40 v% AA	45 v% AA	50 v% AA	55 v% AA
12						
13					1.5	
14			2	2.5	3	
15		2	2.5	3	4.5	
16		2.5	3	3.5	5	
17		2.5	3	3.5	5.5	
18		3	3.5	4	6.5	
19		3.5	4	4.5	7.5	
20		3.5	4	5	6.5	
21						

No steady state possible
PA 6 pellets do not dissolve completely
x Steady state flow rate for the above conditions (ml h^{-1})

The steady state table is the combined result of different parameters that play a role in the electrospinning process: the surface tension, the viscosity, the dielectric constant of the solvent mixture, the solidification process, and the solubility of the PA in the solvent mixture determine the borders of the steady state window.

It is noteworthy that the flow rates that generate a completely stable electrospinning process are many times higher than the ones discussed in literature. Steady state electrospinning is a fast, reliable and reproducible method for making nanofibrous nonwovens.

2.1 Clean Water Permeability

A first important feature is the clean water permeability (CWP) value of a membrane. This number is actually the amount of liters that goes through a membrane per hour per bar per square meter. It is therefore an important feature to compare the energy needs for a certain membrane. If a membrane has a high CWP value, it needs less energy (less pressure) to operate in the same flux.

The polyamide 6 nanofibrous material was tested and had a CWP value of 6300 ± 200 l (h bar m²)$^{-1}$. This is much higher than comparable commercial microfiltration membranes, that only have CWP values between 2000 and 3000.

2.2 Membrane Bio Reactor

A membrane bio reactor (MBR) is a setup used in the treatment of wastewater. It combines a microfiltration process with a suspended growth bioreactor. The wastewater is cleaned by the activated sludge, which is kept in the bioreactor by the membrane.

In this research a submerged MBR was built providing the right module to use a nanofibrous membrane, figure 1. The membrane module consisted of a central part and two side parts produced in PVC. The nanofibre membrane was pressed between the central part and the side part. A stainless steel grid was used as spacer on both sides of the membrane. The design parameters of the reactor are represented in table 2.

Figure 1: membrane module

Table 2: Design parameters of the MBR

Design parameter	Abbreviation	Unit	Value
Total reactor volume	V	l	50
Hydraulic residence time	HRT	d	0.5
Recycle ratio (return/feed)	R	-	3/1
Ratio aerobic/anoxic	V/V	-	2/1
Filtering surface	A	m^2	0.073

The reactor was constructed according to a pre-denitrification configuration. It was divided in two zones. The first zone was an anoxic zone, the second an aerobic zone. The forced aeration in the aerobic zone was realised by compressed air at 7 bar through a diffuser. Due to the hydrostatic pressure in the reactor and the underpressure on the effluent side the sludge/water mixture was pumped through the membrane. A level sensor was placed to avoid an overflow or running empty of the reactor if problems did occur. The reactor was inoculated with activated sludge from a municipal waste water treatment plant.

The return pump led the water to the anoxic zone where the denitrification took place. Due to the fouling on the membrane, trans membrane pressure (TMP) increased. At a set point of 0.4 bar backwashing was performed. The whole process was monitored and controlled with a Phoenix Contact Programmable Logic Controller. Online registration of TMP and flux allowed to evaluate the rate of fouling and the condition of the membrane.

2.3 Nanofibres in a Membrane Bio Reactor

During the test in the MBR, a polyamide nanofibrous nonwoven (50 g m^{-2}) was used with nanofibres with an average diameter of 150 ± 25 nm. The test continued for 3 months.

The online registration of TMP and flux gave an idea of the fouling on the membrane, figure 2.

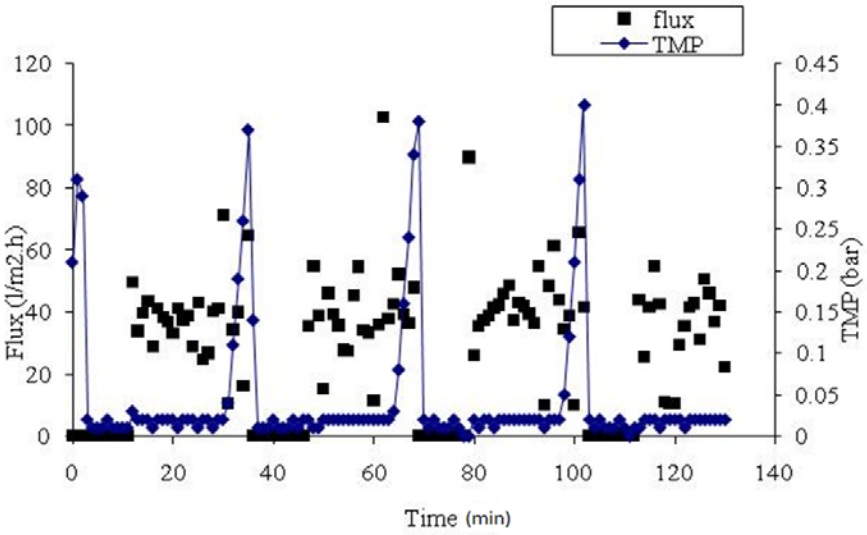

Figure 2: MBR results for TMP (bar) and flux (l m^{-2} h^{-1})

The curve shows the increase in trans membrane pressure till the set point (0.4 bar) and the activation of the backwashing mechanism till the TMP drops to 0 bar. The frequency of backwashing is one time in 30 minutes, which is in the same range as commercial flat sheet membranes as Kubota [2].

The flux is controlled at 30 l m^{-2} h^{-1}. A part from some exceptions, the flux was stable during the whole experiment.

An important issue in MBR is the fouling of the membrane. In the case of the nanofibrous membrane, there is a reversible and an irreversible fouling. The reversible fouling is removed by the backwashing. The irreversible fouling isn't removed by this, figure 3. This problem was solved by using a different MBR setup, namely a Biofilm MBR.

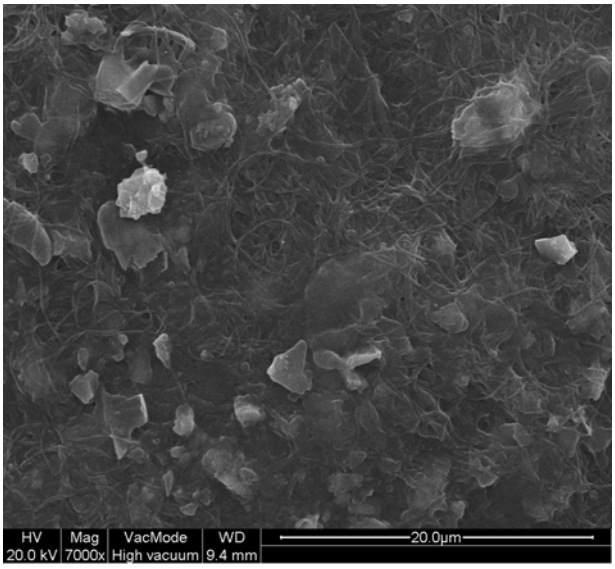

Figure 3: Irreversible fouling on the MBR membrane

Other important parameters that were monitored are the removal of turbidity, Chemical Oxygen Demand (COD), NH_4^+, Total Suspended Solids (TSS) and the total nitrogen. The results are illustrated in table 3.

Table 3: Removal of other parameters during the test

Parameter	Removal (%)
Turbidity	99.25
COD	94.73
NH_4^+	93.98
Total suspended solids	99.71
Total nitrogen	59.77

The results showed a very good removal of all parameters, except the total nitrogen. This was due to an unsatisfactory denitrification. Further tests will examine this problem.

3. Conclusion

A new solution system was discovered to electrospin polyamide 6 in steady state conditions. A steady state table was presented with which one can easily find the right conditions for stable, reproducible electrospinning.

Polyamide nanofibrous membranes were made for this research which had a defined set of parameters. The CWP value for these membranes was 6300 ± 200 l (h bar m²)$^{-1}$. Further on, very

promising results were already obtained in an MBR setup. Wastewater was successfully cleaned at an acceptable flux. There is however still a problem with the denitrification.

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SURFACE TOPOGRAPHY OF NANOCOMPOSITE FIBROUS ELECTROSPUN MATS USING AFM

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ABSTRACT

Fibrous mats of pure poly(butylene succinate-co-butylene adipate) (PBSA) and PBSA/clay nanocomposites were prepared by electrospinning. The produced electrospun mats were examined by SEM in order to ensure that the desired nanofibrous morphologies were obtained and to infer on the impact of the clay presence in the polymeric fibers. In parallel, the surface morphology of the mats was investigated by atomic force microscopy (AFM), which entailed two-dimensional (2D) and three-dimensional (3D) AFM images, the surface roughness, and the bearing ratio, which was introduced as an indication of clay dispersion in the polymer matrix. The increased surface roughness and the alternative phase among the fiber length are correlated to increased clay dispersion throughout the polymer matrix of the nanofiber.

Key Words: electrospinning, nanocomposite, AFM, SEM, surface, morphology

1. INTRODUCTION

Atomic force microscopy (AFM) or scanning probe microscopy (SPM) was invented by Quate and Gerber in 1986 [1] and since then it has been successfully used to investigate surfaces of polymers from the micrometer to the angstrom scale [1-2]. AFM is one of the foremost tools for imaging, measuring and manipulating matter at the nanoscale. This nanoscale characterization is uncommonly applied on electrospun non-woven nanofibers and until now it was usually used to analyze common fibers [3].

Scanning electron microscopy (SEM) gives access to the morphology of the mat such as the diameter of the fiber, while transmission electron microscopy (TEM) provides qualitative information on the inside of the sample. While these techniques have been widely used for the characterization of fibrous materials, atomic force microscopy (AFM) could provide conplementary information about the surface topography and especially the surface nanoroughness. Thanks to these observation tools, circular or flat filaments have been investigated with various surface topographies and nanoroughness, which can be linked to the spinning parameters [4] or the nature of the used polymer [5] and rarely to the nanofiller used (in the case of nanocomposite fibers).

2. MATERIALS & METHODS

2.1. Materials

The biodegradable aliphatic polyester PBSA by the commercial name of Bionolle 3001 was supplied by Showa Highpolymer Co., Ltd (Tokyo, Japan). Bionolle 3001 is a copolyester of succinic acid (S), adipic acid (A), and 1,4 butanediol (B) with a composition ratio 40/10/50, respectively. The number average molecular weight (M_n) was 101300, as determined by gel permeation chromatography (GPC) and has an inherent viscosity of 1.15 dl/g. The nanofiller used was organically modified montmorillonite (Cloisite 25A) and was purchased by Southern Clay Products (Texas, USA). Dichloromethane (CH_2Cl_2) was obtained from Sigma-Aldrich. All materials were used without any further purification.

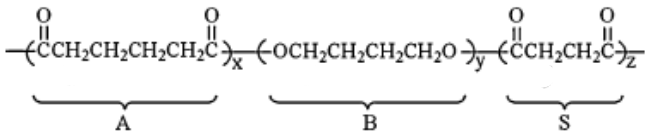

Figure 1. Chemical structure of poly(butylene succinate-co-butylene adipate) (PBSA):. A: adipate unit, B: 1,4 butanediol unit and S: succinate unit, where A/B/S = 10/50/40

2.2. Electrospinning

The electrospinning process is shown pictorially in Figure 2. The apparatus used in this study consists of a syringe pump for the injection of the polymer solution of 18 %w/v, an aluminium-covered pan used as a grounded substrate for the collection of the fibers and a high voltage supply set at 15 kV. All experiments described here were performed using a glass syringe of 1 mm (18G) needle diameter. The flow rate of the polymer solution was controlled by a syringe pump and was set at 0.5 ml/h. The needle is connected to a high voltage supply and the ground electrode is connected on the conductive surface of the aluminum plate. The distance between the needle and the collector's surface can be changed, but for the present work it was kept constant at 8 cm, as the rest of the aforementioned electrospinning parameters, because of screening experiments previously carried out [6]. The organoclay content in the PBSA fibers was the only parameter that varied between 0-9 %wt. The temperature was controlled at 24 ^{o}C and ambient relative humidity was recorded for each experiment. After preparation, all the electrospun samples were placed in a vacuum oven for 24h.

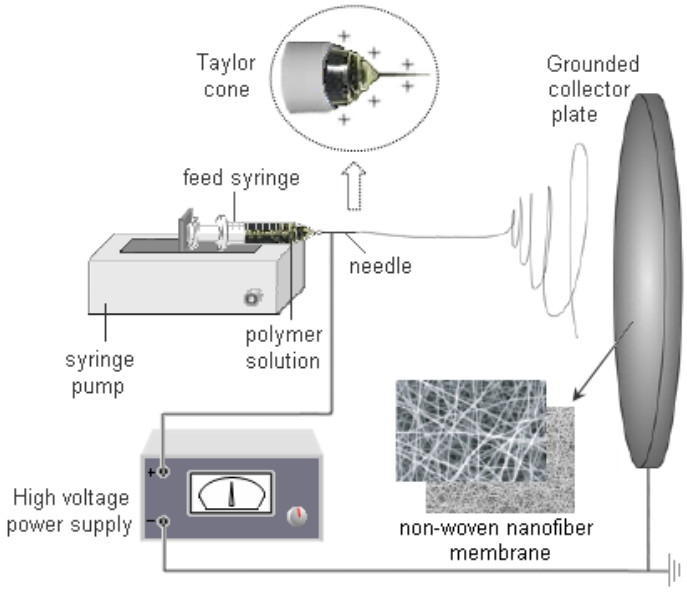

Figure 2. Schematic diagram of the electrospinning set-up used in this study.

2.3. Characterization Methods of the Nanofibres

The membrane structures were explored by Scanning Electron Microscopy (SEM) (JEOL, mod. JSM-840A) after coating all the surfaces with graphite to avoid charging under the electron beam. The image processing was performed using an image analyzer with the appropriate software (Image J). Two samples were examined under the microscope and at least two representative areas from each sample were chosen to determine the average sizes. The surface morphology of the fibers was investigated by Atomic Force Microscopy (AFM, CPII, Veeco Inc.). Scanning was carried out in intermittent-contact mode ('tapping mode').

3. RESULTS & DISCUSSION

3.1. Dimensional Characterization by SEM

Representative images of the pure and nanocomposite PBSA mats are presented in Figure 3 at two different magnifications and the average fiber diameters from image processing are given in the diagram of Figure 4 including their standard deviations. The SEM analysis revealed various morphologies depending on the presence of the inorganic material. In all cases, the introduction of inorganic filler resulted in the formation of membranes with a more pronounced fibrous structure. Particularly, increasing the clay loading (CL) from 0 to 5 wt % resulted in more uniform, beadless structures with continuous fibers and narrower diameter distributions. Further increment of the clay content from 5 to 9 wt % demonstrated increased uniformity and the average fiber diameter was further lowered (from 620 to 418 nm).

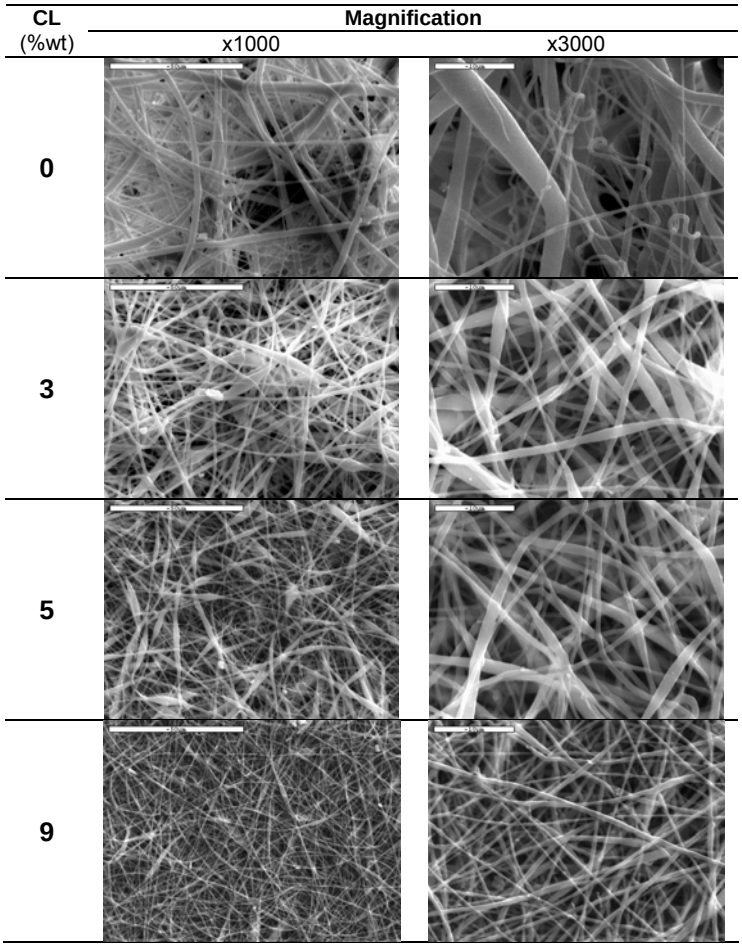

Figure 3. SEM photographs of PBSA nanocomposite with clay content ranging from 0 to 9 wt%; scale bar is 50 μm at magnification x1000 and 10 μm at x3000.

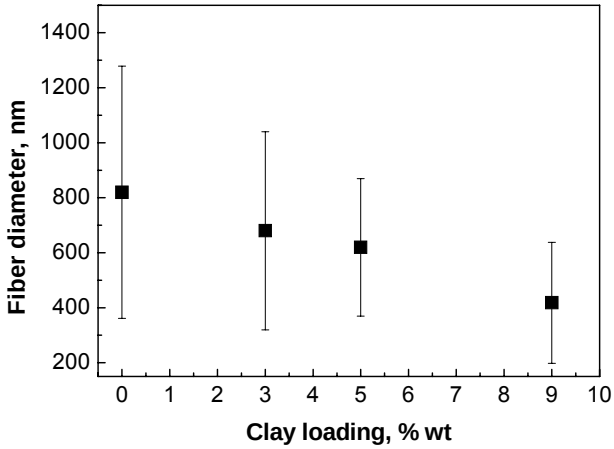

Figure 4. The average values of fiber diameters and standard deviations with regard to clay loading.

3.2. Investigation of the surface morphology by AFM

The nanodimensions of the fibers were further confirmed using AFM operated in intermittent-contact mode. In Figure 5, measurements of the cross-sections of the pure and nanocomposite PBSA fibers are presented. The results obtained show that the cross-sectional diameters of the fibers measured by AFM approximate the average fiber diameters values estimated by SEM and are within their standard deviations. Furthermore the AFM measurements are in agreement with the results of Figure 4; that is the decrease of the fibers' diameter as a function of the clay loading.

Figure 5 also presents the surface profile of the fibers as a function of the clay content. It is shown that the pure PBSA fibers have a relatively rougher surface, compared to the nanocomposite fibers. The addition of clay results in the formation of slightly smoother fibers. Finally, the surface roughness measurements performed on the surface of the nanocomposite fibers demonstrate that there is no significant effect of the clay content on the nanofibers' surface roughness.

In addition, AFM was used to further observe dinstinct phases within each sample. The study of the morphology on the surface of the fibers can provide with unique information regarding the superficial and half-burried clay platelets and probably their alighnment along the fiber axis. Generally, clay particles can be incorporated within the as-spun fibers and usually orient along the fiber axis; some of these are in intercalated or exfoliated structures and other may reside near the edge of the fibers [7]. Well oriented clay particles along the fiber axis that reside within the fiber in intercalated form can subsequently result in smoother fiber surface.

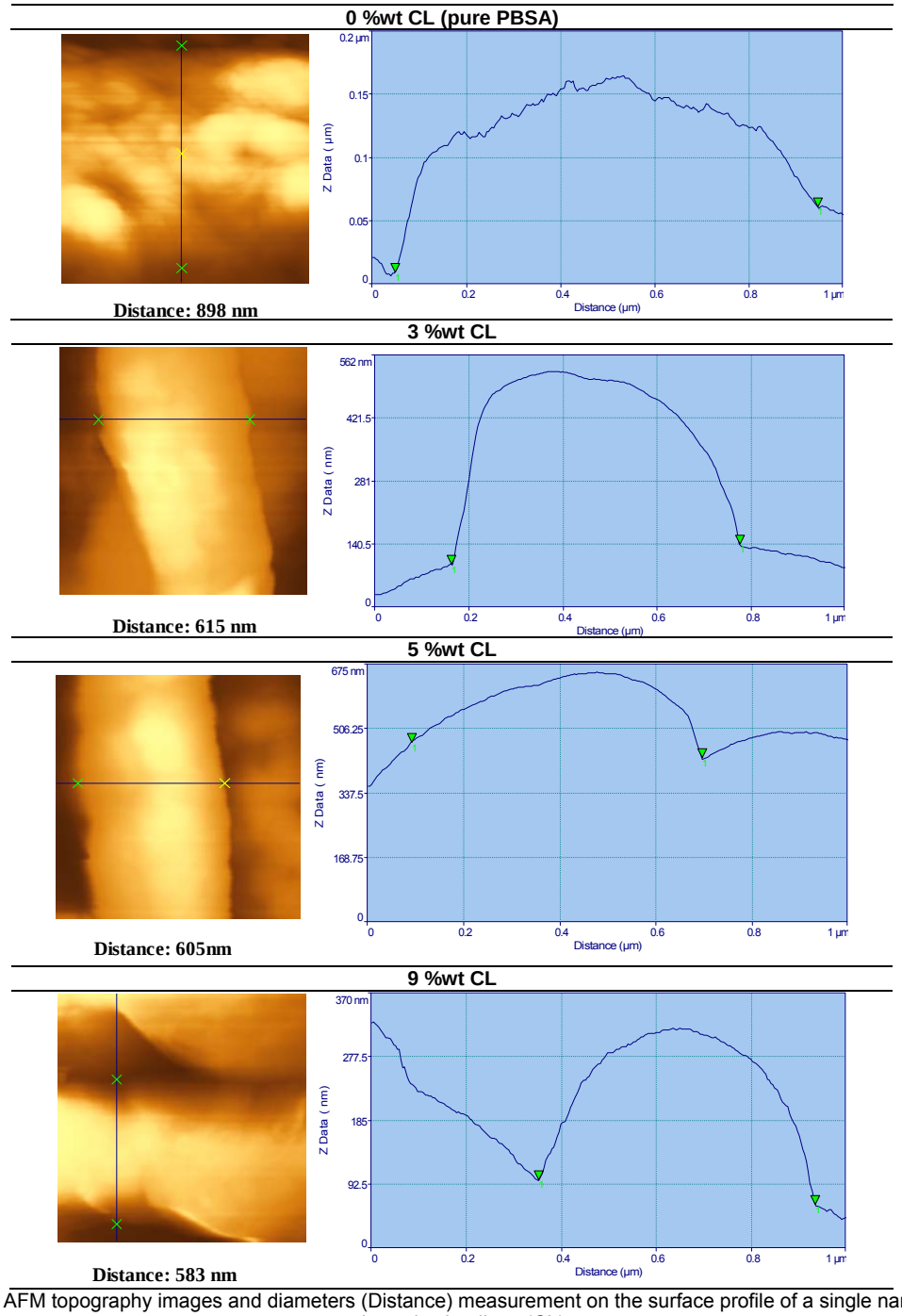

Figure 5. AFM topography images and diameters (Distance) measurement on the surface profile of a single nanofiber for various clay loadings (CL).

In the nanocomposite samples, the main components are the polymer matrix and clay tactoids or individual platelets depending on the extent of the nanoclay dispersion. On this basis, the dark regions in phase images of Figure 6 for pure PBSA are clearly linked with the bulk polymer. Consequently, the phase image in the case of the 3 %wt clay loading (CL) is indicative a different phase within the polymer represented with the ligher colors. The different phase is obviously a partially intercalated polymer/clay phase, where polymer chains have penetrated within the stacked layers.

At the sample with 9 %wt CL the PBSA/clay intercalated phase (light yellow) prevails as shown at Figure 6. Increase of polymer intercalation with increase of CL is also evidenced by the emergence of sharper peaks at low 2θ angles in the X-ray diffractograms (not shown here).

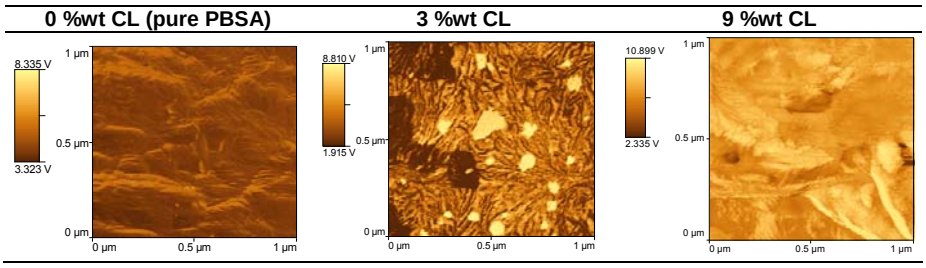

Figure 6. AFM phase images of pure PBSA, 3%wt CL and 9% wt CL.

More specifically, in an attempt to quantify the intercalated phase, a term referred as 'bearing ratio' is extracted from the AFM phase images (Figure 7). Bearing ratio is defined as the ratio of the bearing area (featured with green color) to the whole sample area. It represents the percentage of covered area that gives sign over the threshold value of 7V that was identified as the voltage value for the full coverage of the discrete light regions of the nanocomposite mat (Figure 6). The bearing area is actually assumed to be the PBSA/clay intercalated phase as opposed to the neat PBSA phase. This criterion of the voltage was further verified when a bearing ratio of 0.07% was obtained at the pure PBSA phase image (zero value is not pursued since a noise effect should be also considered). This way, an estimation method was established in order to infer on the extent of the polymer chain intercalation into the clay layers. Individual layers cannot be seen by AFM, unlike TEM (transmission electron microscopy) which could be used to corroborate these findings.

Interestingly, in Figure 6 the nanocomposite with 9 %wt of CL illustrates uniform green-level intensity in the bulk, indicating nanocomposite homogeneity. The seemingly intercalated phase, indicative of efficient clay dispersion, is present at a bearing ratio of 63.82 %.

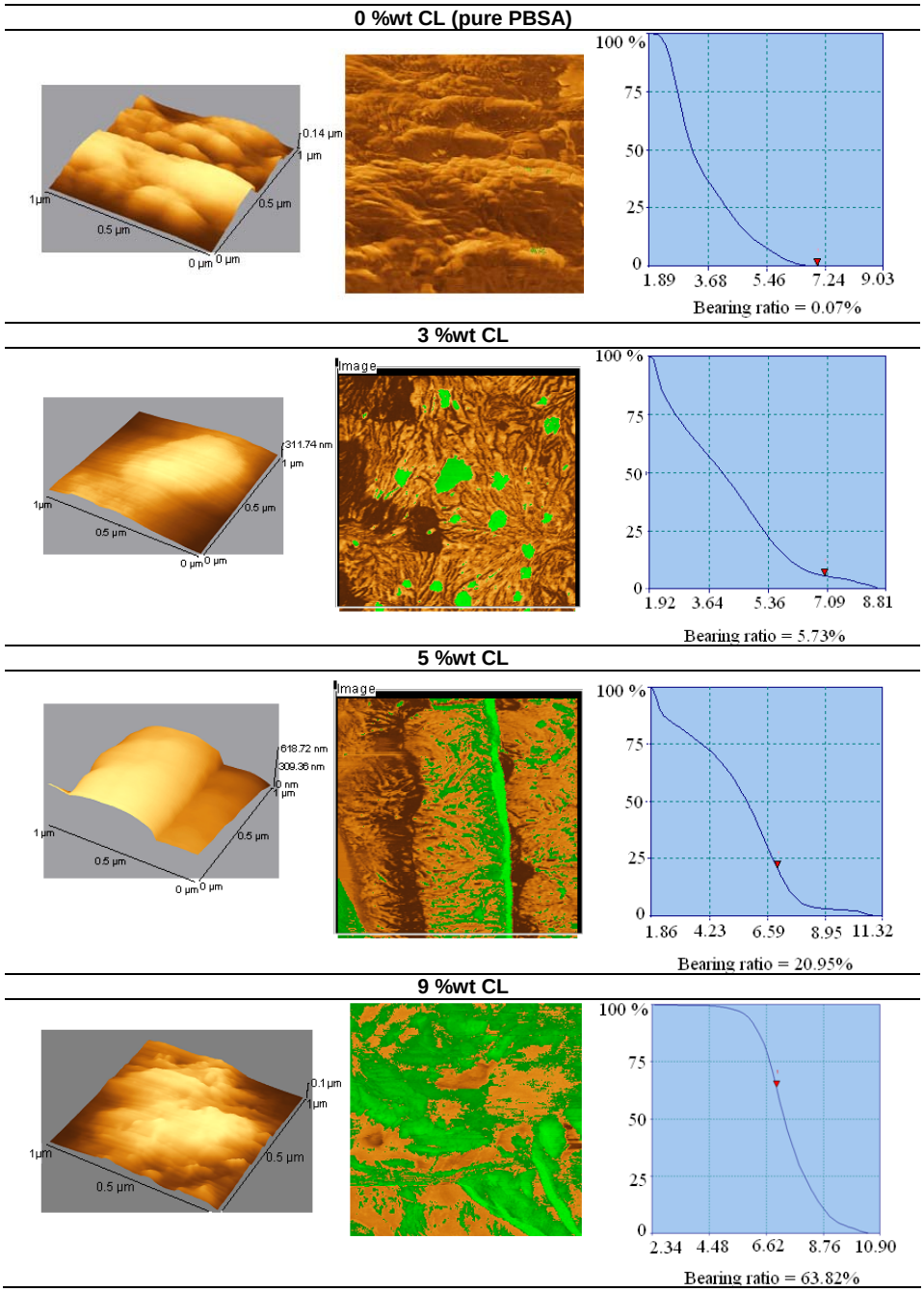

Figure 7. 3D AFM topography images and AFM phase images at the same scan area. The green area shows the PBSA/clay intercalated phase (bearing area).

The overall surface characterization carried out by AFM is summarized in Table 1.

Table 1. AFM estimated structural features of the nanofibrous samples with varying the clay content in the nanocomposite.

%wt CL	Dfiber (nm)	% Bearing ratio
0	898	0.07
3	615	5.73
5	605	20.95
9	583	99.47

4. CONCLUSIONS

In this work, fibrous mats of pure and nanocomposite PBSA were prepared by electrospinning and their morphology was examined by two microscopy techniques, SEM and AFM. The presence of the inorganic nanosized filler proved to have a major influence on the final fibrous structure of the electrospun mats according to SEM analysis. Introduction of small quantities of clay leads to more fine uniform fibrous structures with smaller fiber diameters. AFM-based surface features and clay content in the nanocomposite are also correlated. From the AFM images, it is established that as clay content increases, the PBSA/clay intercalated phase becomes more pronounced and dominates at 9 %wt indicative of efficient clay dispersion within the polymer matrix. Based on these results, AFM might well be used as a complementary tool for in-depth morphological characterization of the surface of polymer/clay nanofibrous mats.

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THE EFFECT OF NEEDLING INTENSITY ON THE BREAKING AND TEAR STRENGTH OF KNITTED FABRIC REINFORCED NEEDLE-PUNCHED FILTERS

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ABSTRACT

Filtration is a separation and purification process. The main goal of the filtration process is to improve the purification of filtered materials. Structure of textile materials make them suitable for filtration process. Commonly, filters without reinforcements or reinforced with woven fabrics were used in dry air filtration applications in cement, ceramic, and other similar factories. At the industrial filtration applications such as mentioned above, it is necessary to change the filters due to their mechanical failures. The aim of this study is to enhance the strength of filters in use. For this purpose, needle-punched nonwoven filters reinforced with knitted fabrics were designed and produced with different needling intensities. The breaking and tear strength of the filters were investigated and the variations of these physical properties were examined comparatively with respect to needling intensity and densities of the knitted reinforcement fabrics.

Key Words: needle-punched nonwovens, dry air filters, needling intensity, breaking strength, tear strength.

1. INTRODUCTION

Filtration is a common process that finds field of applications in automotive, paper, chemistry, food, and electronics industry. As awareness of environmental agencies and general public have rised for clean environment in the last few decades, researchers have tended to study on the topics including pollution [1]. Dry air dust filters considered in this study are specified as one of the pollution reduction tools [2].

Textiles attract much attention in filtration process because of the applicability of textile products to the filtration process. Especially substantial thickness of nonwovens makes them advantageous for using as depth filters [3]. Nonwoven fibrous materials are in the class of porous media [4]. Needle-punched nonwovens are assemblies of fibers mechanically bonded together in the form of webs. The needle-punched nonwovens exhibit higher strength when compared to thermally or chemically bonded nonwovens.

Recently, much attention has been paid to recycling of polymers. Reduction in consumption of resources on the world and reduction of waste are some of the advantages of recycling. Polyethylene terephthalate (PET) is an example of the polymers that are successfully recycled and commonly reused [5]. In this research, recycled polyester fibers were chosen as raw materials of the needle-punched nonwovens. It was emphasized to produce filter materials in the most harmless way to the environment.

There are lots of studies in the literature about the performances of filters such as air permeability, filtration efficiency and pressure drop. Modelling of fluid flow through woven filter fabrics were performed [6, 7, 8]. Studies include the enhancement of mechanical properties of filters are limited. The relationship between the performances and some structural characteristics such as packaging density, fiber diameter, porosities and pore sizes of filter fabrics were investigated [9, 10]. Liquid porosimetry was proposed as an efficient device for determination of pore sizes of nonwovens [10].

The physical properties of the needle-punched nonwovens can be changed by varying the needle penetration depth and needling intensity. Fiber damage due to the needling intensity was observed by Miao et al. [11]. The forces affecting to the individual needles were determined by a device on-line. And needle force parameters were found to be closely related by the performances of needle punched nonwovens [12].

The finishes of filters have gained importance in recent years. Calendering is a finishing process that smoothes fabric surface [3]. In bag filters, dust deposits on the filter surface and a dust cake is formed. These bag filters are cleaned at certain times. When the surface of the filter is smooth, the release of this cake becomes easier. Particulates tend to adhere on rough surfaces [13, 14].

Needled nonwovens used as bag filters in ceramic, cement and other similar factories. At the industrial filtration applications such as mentioned above, it is necessary to change the filters due to their mechanical failures. Filters that break under low loads are not preferred because of the short life times. The aim of this research is to enhance the breaking and tear strength values of filter fabrics. Needle-punched nonwovens with knitted reinforcement materials were designed for this purpose.

2. MATERIALS AND METHODS

2.1. Materials

In this study needle-punched nonwovens were designed using knitted reinforcement materials with varying densities, and the effect of needling intensity was investigated. The linear density and length of recycled polyester staple fibers used in the research were 3,3 dtex and 64 mm, respectively. Reinforcement materials were knitted using 2x25 tex acrylic yarn. 1x1 Rib structure was chosen because of its bulkiness. Densities of fabrics were given in Table 1. Filter fabric reinforced with "density 1" knitted fabric (the most dense) was named as "Type A", fabrics reinforced with "density 2" and "density 3" were named as "Type B" and "Type C", respectively.

Table 1. Properties of reinforcement materials

Reinforcement Material	Density		Basis Weight (g/sqm)
	Wale/cm	Course/cm	
1x1 rib Density 1	7	12	369.5
1x1 rib Density 2	7	11	353.3
1x1 rib Density 3	7	10	350.0

2.2 Methods

Needle-punching was performed on an Asselin France needle loom. The web was passed under a bed of needles 220 cm across and 40 cm wide in machine direction. The needle density on the bed was 1.875 needles/cm^2. The bed oscillated 374 cycles/min. The needle was Groz Beckert 15x18x36x3 1/2 R333 G 1002 model. 2, 3, 4, and 5 passages were applied to filter fabrics. In this manner the needling intensity effect on the characteristics of filter fabrics could be evaluated. Needling intensities of filter fabrics according to passages were given in Table 2. Filters were calendared through the 180 ^{o}C heated rollers.

Table 2. Needling intensity (punch/cm^2) with respect to the passages

Passages (Run)	Punch/cm^2
2	9.12
3	13.66
4	18.21
5	22.77

Breaking and tear strength of nonwoven fabrics were measured by U-Test electromechanical tensile tester with a load cell of 50 kN. Breaking and tear strength were determined according to the ISO 9073-3 and ISO 9073-4, respectively. The gauge length was 200 mm and the rate was set to 100 mm/min for the breaking test. And tear strength test was performed according to trapezoid tear method. 10 samples were tested for each property. Then, all data were analyzed with respect to the densities of knitted fabric reinforcements and needling intensities.

3. RESULTS AND DISCUSSION

The manufactured samples of filters were tested. Variation of breaking and tear strength of the filters were measured. Statistical analysis was performed in order to understand whether properties were significantly different according to the needling intensity and reinforcement types. The analysis of variances tests indicated that all measured properties of filter fabric were significantly different at the 5% significance test level. F values were given in Table 3.

Table 3. F values of properties tested according to needling intensity and fitler type

	Testing Properties	Breaking Strength in Machine Direction	Breaking Strength in Cross Direction	Tear Strength in Machine Direction	Tear Strength in Cross Direction
F value	Filter Type	5.118	49.251	7.831	3.529
	Needling Intensity	98.318	11.473	107.711	4.924
$F_{critical}$ = 3.075 (for filter type), $F_{critical}$ = 2.684 (for needling intensity)					

The measured physical properties of the filters according to the number of passages are given in Figures 1 through 4. Figure 1 shows the relationship between the breaking strength in machine direction and the needling intensity. As seen in the figure, the breaking strength in machine direction increases until a critical point, as the needling intensity increases. The basic principle of needling is to entangle the web with the aid of barbed needles. The web is formed of paralel fibers that is fed from nonwoven card. When the web is needled, a stable fabric form is created. The effect of needling intensity on the physical properties of needled nonwovens was tried to be evaluated by varying passages in this study. When fabrics passed through the needle loom 2 times, a little entanglement occurs between fibers. If needling intensity incresases, the entanglement increases too. This makes the physical bonds between the fibers each other and the reinforcement fabric stronger. But this situation continues in this manner until a critical point. For filter Type A and B, 3 passages give the highest breaking strength value and for Type C the maximum breaking strength value is obtained at 4 passages. Tear strength in machine direction shows the same tendency (Figure 3). Type C is the filter cloth reinforced with the loosest knitted fabric. An extra run may provide fabric structure to become tight and compact by the fibers getting good entangled. At 5 passages all of the filter types denote low strength values. This may be due to the fact that increasing needling intensity causes fiber breakage and fabric damage.

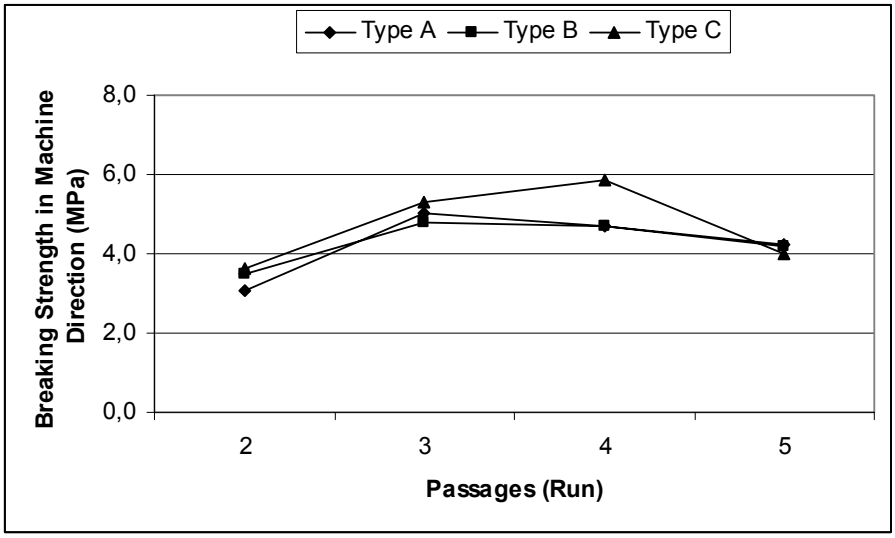

Figure 1. Variation of breaking strength in machine direction with passages

As seen in Figure 2, the breaking strength in cross direction is higher than the breaking strength in machine direction and the tear strength shows similar behaviour. This depends on the fiber orientation that was in the cross direction. The knitted reinforcement fabric was fed to the needle loom towards wale direction. The highest breaking strength values in cross direction were obtianed at 3 passages for all filter types.

Tear strength is the measure of the ability of materials to resist tearing. In breaking test, all specimen width resists to breaking load. However in tearing test, there is a rip. Not all width of the specimen but some of the fibers resist to the tearing. So tear strength values are lower than breaking strength

values. Variations of both breaking strength and tear strength were similar according to passages in this study.

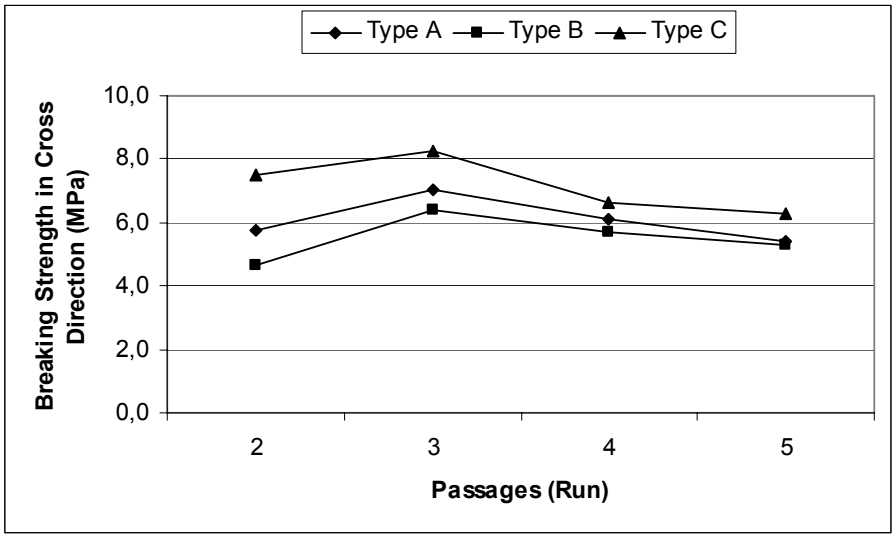

Figure 2. Variation of breaking strength in cross direction with passages

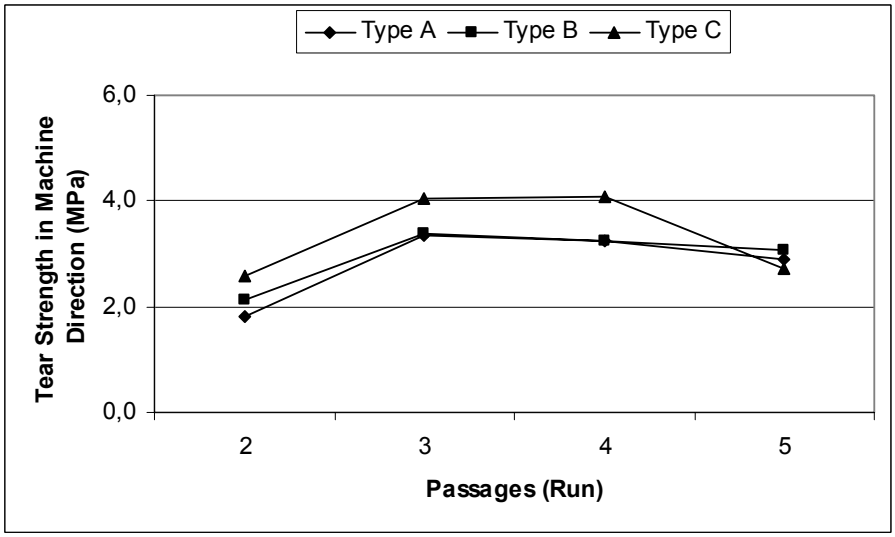

Figure 3. Variation of tear strength in machine direction with passages

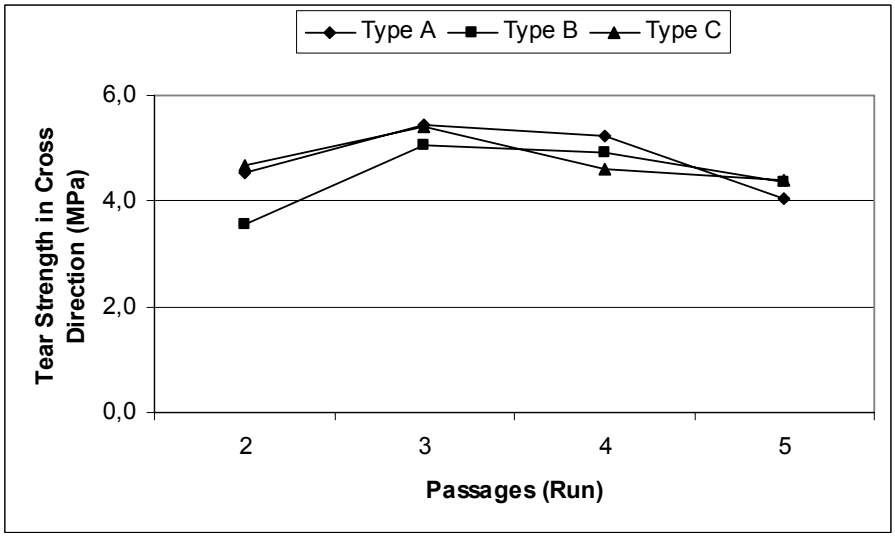

Figure 4. Variation of tear strength in cross direction with passages

Type C has the maximum strength values for both directions. This may be attributed to the looseness of the reinfocement fabric. Reinforcement material should meet the demands like supplying the fibers in the structure. Its damage should be minimum. The lowest density of the reinforcement materials, density 3, may be the optimum density for the conditions of the study.

4. CONCLUSIONS

The objective of this research was to evaluate effects of knitted reinforcement materials and needling intensity factor on the breaking and tear strength of filters. Optimum performance could be obtained by changing needling intensity during the manufacturing of the filter fabrics. Knitted fabric reinforced filters with a needling intensity of 13.66 punch/cm^2 (3 passages) seems to be the optimum filters in terms of breaking and tear strength. In fact, performances of filters are closely related with physical properties. So performances of these filter fabrics such as air permeability, pressure drop and filtration efficiency should be tested and then a general evaluation should be made. The filter reinforced with the loosest knitted fabric denoted the maximum strength values. But experiments may be expanded with denisities lower than tested ones. These are consireded as further works.

ACKNOWLEDGMENTS

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THE EFFECTS OF FABRIC LAMINATION ANGLE AND PLY NUMBER ON ELECTROMAGNETIC SHIELDING EFFECTIVENESS OF WEFT KNITTED FABRIC REINFORCED POLYPROPYLENE COMPOSITES

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ABSTRACT

In this study, it was aimed to investigate the effects of fabric lamination angle and fabric ply number on electromagnetic shielding effectiveness of weft knitted fabric reinforced polypropylene composites. Knitted fabric reinforced composites are composed of aramid yarn, polypropylene yarn and copper wire. Polypropylene is the matrix phase and the aramid yarn and copper wires are the reinforcement phase of the composite materials (Figure 1). It was achieved to form composites which have 1.5-3 mm of thickness and nearly 20-50 dB electromagnetic shielding values.

To produce the knitted fabrics, 7G semi-automatic flat knitting machine was used. The composites were formed by a laboratory type hot press. Electromagnetic shielding effectiveness (EMSE) of composites were tested by using ASTM D 4935 coaxial test fixture in 27-3000 MHz frequency band. Lamination angle and ply number parameters were examined related to EMSE of structures. For this study, three different structures, nameley plain knit, 1x1 rib and half cardigan were knitted. Then the composites were produced in 2 and 4 plies with two different lamination angles of 0º/90º/0º/90º and 0º/45º/0º/45º to determine the effect of fabric ply number and lamination angle on electromagnetic shielding performance of composites, respectively. Measurements showed that the fabric ply number and lamination angle does not affect the EMSE of knitted fabric reinforced composite materials, significantly.

On the other hand, the weft knitted reinforced composite structures were found to be suitable for electromagnetic applications with their high EMSE values. These knitted fabric reinforced polypropylene composites can also be used in other industrial applications such as civil engineering, aerospace etc, considering their physical properties such as strength and flexibility.

Key words: Composites, polypropylene, weft knitting, electromagnetic shielding.

1. INTRODUCTION

Conducting composites have much interest according to metals because of their light weight, hard corrosion, good processability etc [5,6,7,8].

In recent years, researchers and industrial companies worldwide have been showing increasing interest in conductive textile products and textile-based composite materials especially for applications in protecting from electromagnetic interference [9]. A few studies have been reported conductive knitted fabrics reinforced composites as electromagnetic shielding effectiveness and electrostatic discharge materials. In these studies, it has been indicated that knitted fabrics reinforced polymer composites are suitable for making complex shaped components and applications in EM shielding [5,8,10,11,12,13].

In some previous studies, it was reported that ply number and the lamination angle has an important role in determining the EMSE of knitted composites [13].

2. EXPERIMENTAL

2.1. Production of the Weft Knitted Fabrics

To produce the knitted fabrics; polypropylene, aramid yarn and copper wire are used. Polypropylene filaments of 300d/72f was chosen to form the matrix phase of the composites. Aramid yarn and copper

wire were selected to form the reinforcement phase of the composites. The twist of the conductive hybrid yarns was set at 150 twists per meter (tpm).

Conductive yarns were knitted by using a 7G manuel flat knitting machine. Three different weft structures, namely plain, 1x1 rib and half cardigan, were produced with the specifications given in Table 1.

Table 1. The weft knitted structures

KNITTED FABRIC SAMPLES				
Sample Number	Fabric Structure	Yarn	Course Density (loop/cm)	Wale Density (loop/cm)
F1	Plain Knitted Structure	Aramid/PP/ 0.15 mm Copper wire	7	4
F2	1X1 Rib Structure	Aramid/PP/ 0.15 mm Copper wire	4	2
F3	Half Cardigan Structure	Aramid/PP/ 0.15 mm Copper wire	2	3

The loop notations and pictures of three different fabrics are shown in Figure 1 and Figure 2, respectively.

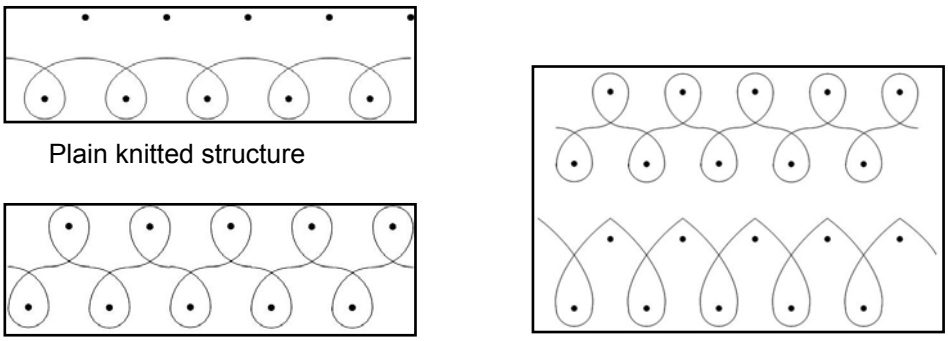

Figure 1. Loop notations of three different structures

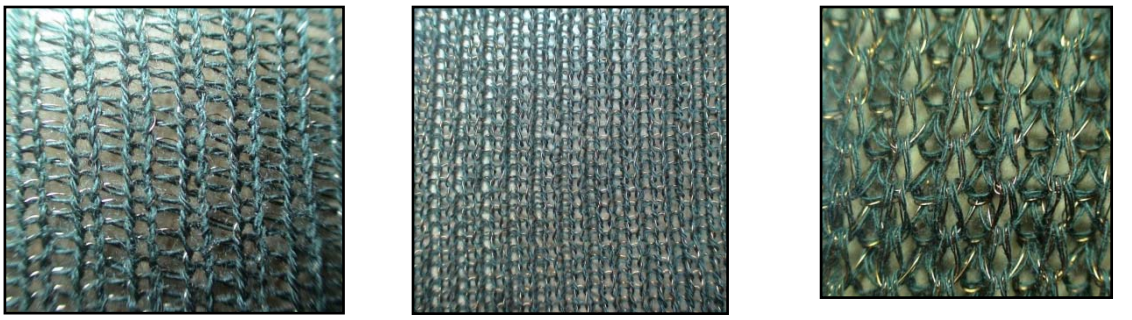

Figure 2. Fabric samples of three different structures

2.2. Production of Knitted Fabric Reinforced Composites

Production of composites was achieved by compression moulding technique [5,11]. Composite laminates were fabricated with four and two plies. Four ply composites were laminated with the lamination angles of, 0º/90º/0º/90º and 0º/45º/0º/45º and two plies composites were laminated with the lamination angles of 0º/90º. The properties of composite structures are summarized in Table 2.

The composite structures were produced by a laboratory hot pres under 10 kg/cm2 pressure at 230ºC temperature for 20-25 minutes. The composites have an elastic character and their surfaces are completely covered with polypropylene.

Table 2. The knitted fabric reinforced composites

KNITTED FABRIC REINFORCED COMPOSITE SAMPLES						
Sample	Yarn Combination	Fabric Structure	Ply Number	Lamination Angle	Course Density (loop/cm)	Wale Density (loop/cm)
C1	Aramid/PP/ 0.15 mm Copper wire	Plain Knited Structure	4	0º/90º/0º/90º	7	4
C2	Aramid/PP/ 0.15 mm Copper wire	Half Cardigan Structure	4	0º/90º/0º/90º	2	3
C3	Aramid/PP/ 0.15 mm Copper wire	1x1 Rib Structure	4	0º/90º/0º/90º	4	2
C4	Aramid/PP/ 0.15 mm Copper wire	Plain Knitted Structure	4	0º/45º/0º/45º	7	4
C5	Aramid/PP/ 0.15 mm Copper wire	Half Cardigan Structure	4	0º/45º/0º/45º	3	3
C6	Aramid/PP/ 0.15 mm Copper wire	1x1 Rib Structure	4	0º/45º/0º/45º	4	2
C7	Aramid/PP/ 0.15 mm Copper wire	Plain Knited Structure	2	0º/90º	7	4
C8	Aramid/PP/ 0.15 mm Copper wire	Half Cardigan Structure	2	0º/90º	3	3
C9	Aramid/PP/ 0.15 mm Copper wire	1x1 Rib Structure	2	0º/90º	4	2

2.3. EMSE Tests

A flanged coaxial test fixture relating to ASTM D 4935 test standarts was used for determining the EMSE of test samples as shown in Figure 3.

This test fixture does not rely on electrical contact with the sample. And for this reason it is regardes as more proper than other instruments for the shielding effectiveness measurements of surface insulated structures such as fabrics and fabric reinforced composites in literature [20-23].

Figure 3. Coaxial test fixture relating to ASTM D 4935

Both reference and load measurements are required for SE determination. For the reference measurement, a solid disk of diameter equal to the center conductor and an outer ring corresponding

to outer conductor flange dimensions, are made from the material to be tested. The incident power, Pref , measurement is made with this reference sample in place. Both the load and reference samples must be of equal thickness. To obtain the load or transmitted power measurement, a solid disk whose diaemeter is that of the flange is made from the test material. The transmitted power, Pload , is monitored with the solid sample fastened between the flanged cell halves. The SE is then calculated according to the equation 1 [20].

$$SE = 10 \log_{10}\left(\frac{P_{ref}}{P_{load}}\right) \quad (1)$$

P_{ref}: Incident electromagnetic power in W/m^2 .
P_{load}: Electromagnetic power transmitted through the plaque W/m^2 .

Number of samples was nine and the number of measurements for each sample was ten. The EMSE values of composite laminates shown in Table 3 are the mean values of ten measurement.

3. Results and Discussion

3.1. Observation of Knitted Fabric Reinforced Composites

Fig. 4 illustrates the micro structure of knitted fabric reinforced composites. Figure 5, illustrates a knitted fabric reinforced composite form, photographed by SEM (Scanning Electro Microscope). The composite structures were composed of a copper wire, aramid yarn and PP yarn. As seen in Fig.3 and Fig.4, the PP yarn is melted and covered the surface of the knitted fabric. This melted surface gave a composite form to the knitted fabric. So that, the composite form had flexibility that can be bend very easily. With this flexible property, the composite structures have been acquired a shape very easily. Good quality composites could be produced since copper wires and aramid fibers were tightly enclosed within the matrix PP.

It was much easier to press the composite laminates with two plies than with four plies. Besides that; the composites with two plies have more elasticity than with four plies.

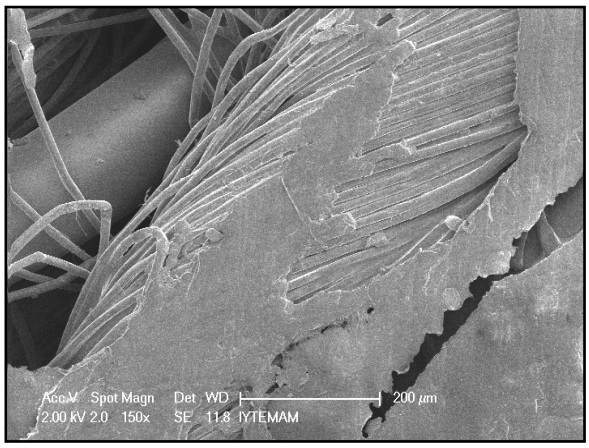

Fig.4. The micro structure of copper wire, aramid yarn and melted PP in knitted fabric composites

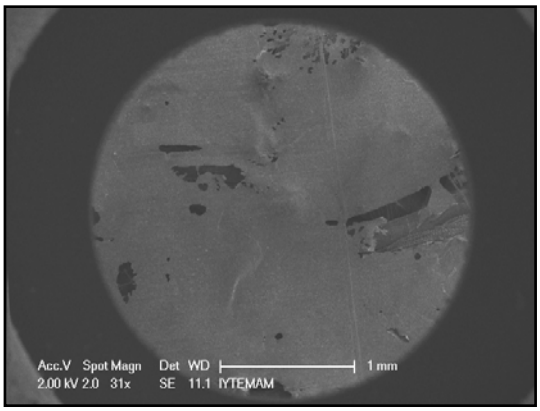

Fig.5. Microscopic surface photograph of the knitted fabric reinforced composites photographed by SEM

3.2. Electromagnetic Shielding Effectiveness of Composite Fabrics

The mean EMSE data of composites in some frequencies are presented in Table 3. As seen in Table 3 and in Figure. 6, all of the composites have high shielding values in the begining frequency of 27 MHz. The EMSE of all composites except C1, C4, C7 decreases gradually up to 250 MHz (C2, C3, C5, C6, C8, C9). While the EMSE of composites C2, C3, C5, C6, C8, C9 unchanged after the frequency of 250 MHz, the EMSE of composites C1, C4, C7 started to increase.

Fig.6 illustrates that C1, C4, C7 composites are the best three composites that have the best shielding values. As seen on Table.2; C1, C4 and C7 composites are formed from plain knitted fabric. Although C7 is formed with two plies of plain knit fabric, it has higher EMSE performance than four-ply formed composites. From that result, it is clear that the fabric structure has a very important role over the shielding performance of knitted fabric reinforced composites.

C1 composite, has the best shielding performance all over the other composites in all frequencies.

Table 3. EMSE values of composite laminates

Frequency (MHz)	C1 dB	C2 dB	C3 dB	C4 dB	C5 dB	C6 dB	C7 dB	C8 dB	C9 dB
27	65,10	35,15	59,15	61,53	56,27	56,80	27,26	36,03	34,05
30	53,92	34,41	53,32	53,22	56,30	56,87	26,98	35,27	33,94
60	53,28	35,49	49,35	51,87	53,35	67,03	27,70	35,03	33,61
100	45,15	48,61	37,89	45,29	52,20	43,27	28,84	36,62	35,44
120	38,61	47,54	35,86	45,38	44,45	40,77	29,95	34,02	45,50
150	53,53	33,83	26,97	25,47	39,53	42,98	29,22	33,66	32,92
180	35,22	26,15	24,44	36,22	37,19	42,18	27,95	29,40	26,47
250	35,39	13,60	20,15	54,20	41,35	28,03	19,76	12,54	11,33
300	34,43	16,53	23,06	48,63	28,17	18,66	23,61	12,83	10,16
350	31,60	11,88	10,72	25,69	22,90	12,88	7,69	21,40	17,62
450	42,75	13,58	35,38	39,53	26,88	20,44	20,68	18,90	16,32
600	35,28	21,15	22,12	41,22	20,89	19,29	38,50	17,82	15,20
750	33,69	14,36	16,42	29,15	20,53	15,82	32,18	16,62	13,33
900	31,14	15,87	14,11	25,55	18,40	13,23	31,81	14,07	12,44
1060	40,46	14,20	13,02	33,42	15,38	11,09	28,91	9,79	15,32
1250	40,57	10,17	10,83	27,91	9,87	6,07	23,72	9,44	6,62
1500	18,70	10,02	9,13	25,88	6,22	4,43	19,16	6,84	4,39
1800	27,82	11,16	10,50	31,06	16,72	6,39	23,31	7,26	6,75
2100	24,81	3,53	6,15	26,68	4,93	7,58	19,14	2,86	1,06
2500	22,11	4,03	3,59	24,83	8,46	13,27	21,26	4,16	5,21
3000	31,94	10,75	9,53	26,56	23,01	16,57	22,99	4,02	1,87

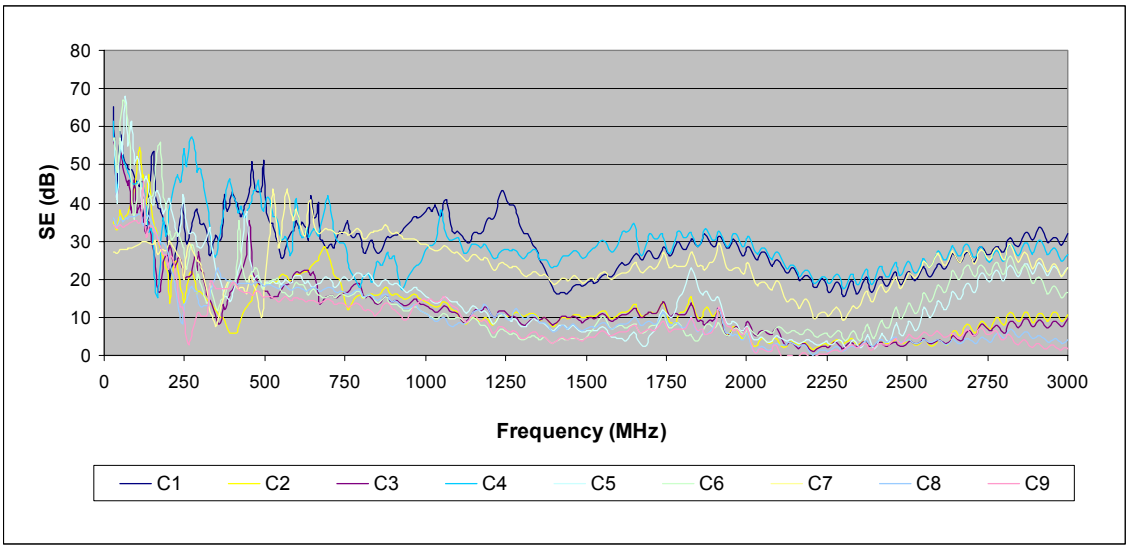

Fig.6. EMSE values of all composite laminates

3.3. The Effect of Ply Number on Electromagnetic Shielding Effectiveness of Composites

To investigate the effect of ply number on electromagnetic shielding effectiveness of knitted fabric reinforced composites; plain knitted fabric reinforced composites C1 and C7, half cardigan structure reinforced composites C2 and C8 and 1x1 rib knitted structure reinforced composites C3 and C9 are compared with each other. As seen on Table 2, C1, C2 and C3 composites are formed as four plies and C7, C8 and C9 are formed as two plies.

As seen in Fig.7, the most effective composite is C1 nearly in all frequencies. In addition to this, the most effective composites are C1 and C7 composites which are reinforced with plain knitted fabrics. Although C2 and C3 composites are produced as four plies, they are not more effective than composite C7.

Half cardigan and 1x1 rib structures have bigger holes than plain knitted structure because of their loop formations. So the results show that the fabric structure is more effective than the ply number on electromagnetic shielding effectiveness on knitted fabric reinforced composites.

Half cardigan structure reinforced composites formed of four plies (C2) and two plies (C8) have the same shielding values. 1x1 rib structure reinorced composites formed of four plies (C3) is a little more effective than two plies composite (C9) in some frequencies but generally they have the same shielding values.

As a result, we can say that electromagnetic shielding performance of composites does not increase parallel to the ply number.

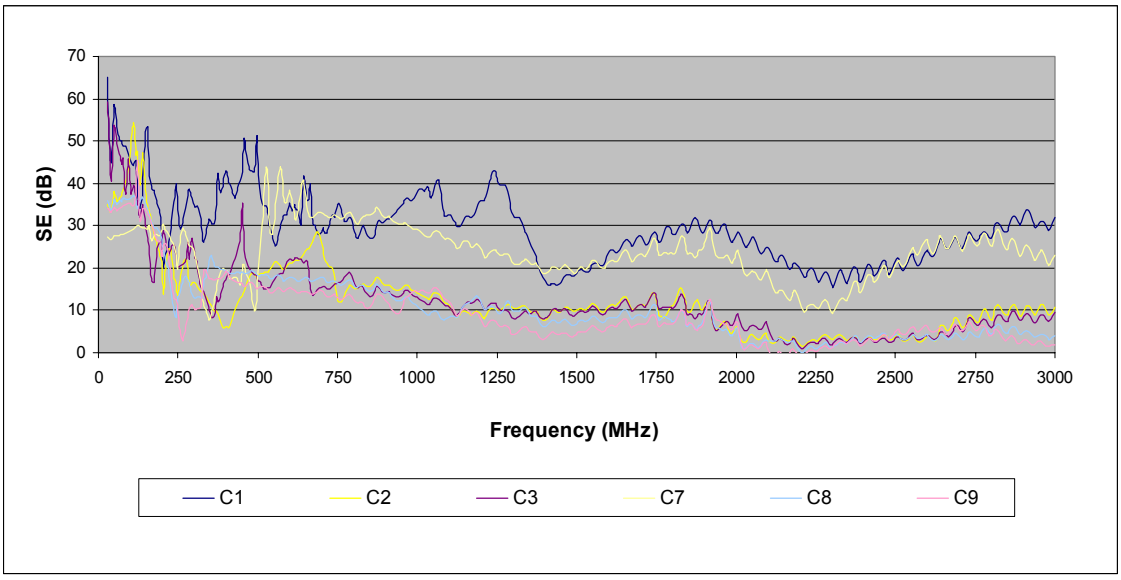

Fig.7. EMSE values of C1, C2, C3, C7, C8, C9 composite laminates

3.4. The Effect of Lamination Angle on Electromagnetic Shielding Effectiveness of Composites

To investigate the effect of lamination angle on electromagnetic shielding effectiveness of composites, plain knitted fabric reinforced composites C1 and C4, half cardigan structure reinforced composites C2 and C5 and 1x1 rib knitted structure reinforced composites C3 and C6 are compared with each other. As seen on Table 2, C1, C2 and C3 composites are formed as four plies with lamination angle 0º/90º/0º/90º and C4, C5 and C6 are formed as four plies with lamination angle 0º/45º/0º/45º.

As seen in Fig.8, composite C1 is slightly more effective than C4 composite only in some frequencies (750-1250 Mhz). But generally C1 and C4 composites have the same performance.

For half cardigan structures, C2 and C5 composites have the same performance up to 2500 Mhz but after 2500 Mhz C5 composite that has lamination angle 0º/45º/0º/45º is more effective than the composite C2 which has the lamination angle 0º/90º/0º/90º. The same result is observed for the 1x1 rib structures, too. C3 composite which has the lamination angle 0º/45º/0º/45º is more effective than the composite C6 which has the lamination angle 0º/90º/0º/90º after the frequency of 2500 Mhz. But before 2500 Mhz, the two composites have nearly the same performance.

Consequently, it can be said that the lamination angle is important for especially knitted fabric reinforced composites having bigger holes between the loops.

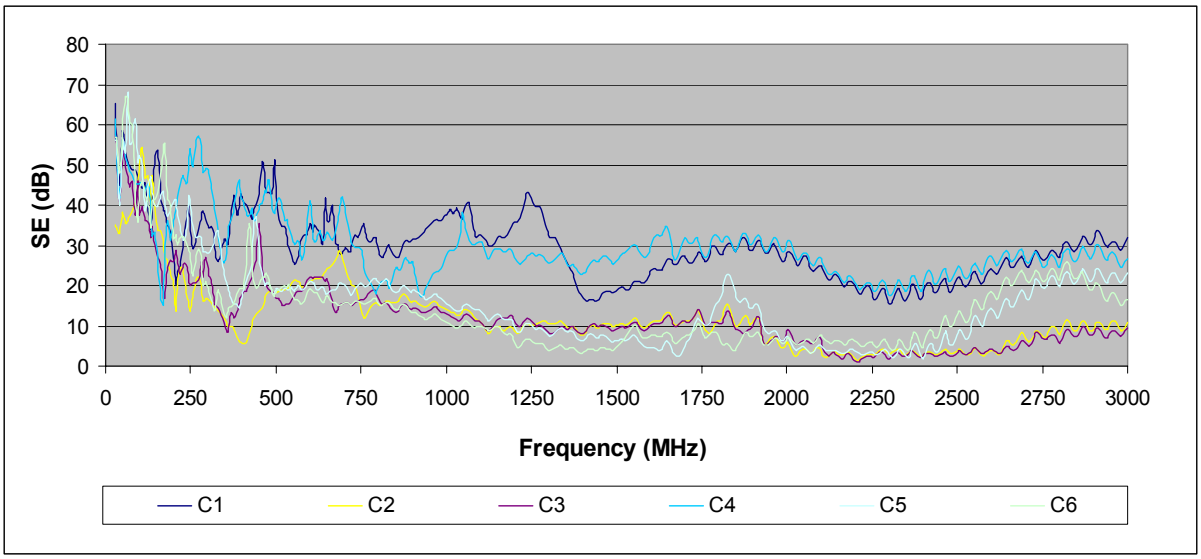

Fig.8. EMSE values of C1, C2, C3, C4, C5, C6 composite laminates.

4. CONCLUSION

In this study, we have seen that it was possible to form knitted fabric reinforced composites which have 1.5-3 mm of thickness and nearly 20-50 dB electromagnetic shielding values.

We have seen also, good quality composites could be produced since copper wires and aramid fibers were tightly enclosed within the matrix PP. The composite forms had flexibility that can be bend very easilyand with this flexible property, the composite structures have been acquired a shape very easily.

The study showed us that the electromagnetic shielding performance of composites does not increase parallel to the ply number and the lamination angle is important for especially knitted fabric reinforced composites having bigger holes between the loops.

On the other hand, the weft knitted reinforced composite structures were found to be suitable for electromagnetic applications with their high EMSE values. These knitted fabric reinforced polypropylene composites can also be used in other industrial applications such as civil engineering, aerospace etc, considering their physical properties such as strength and flexibility.

ACKNOWLEDGMENTS

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THE FORMATION AND MORPHOLOGY OF PVA FERRO GEL NANO FIBRE BLENDS BY THE ELECTRO SPINNING PROCESS

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ABSTRACT

Aqueous solutions of polyvinyl alcohol (PVA) with $FeCl_3$ were homogenously mixed; subsequently electrospun and its characteristics were studied as a function of voltage, tip-target distance and solution flow rate. Fibre mats of (PVA)/$FeCl_3$ composite thin fibres, in the diameter of 400–1400 nm were prepared by electrospinning. The results showed that the solution concentration significantly affects the morphology and diameters of the PVA/$FeCl_3$ fibers. Lower concentration solution tended to facilitate the formation of fibres with beads. With increasing solution concentration, the morphology was improved with smooth and uniform fibres and the increased fiber diameter at the nano range. Spinning voltage also had an important influence on the diameters of the nano fibres, while the collection distance affected some what the diameters of fibres. Nano fibres of lower diameter were formed with lower applied voltages. The morphology of the electrospun from PVA/$FeCl_3$ nano fibres and their magnetic power were observed and analyzed by scanning electron microscopy (SEM).The produced fibre potentially be used in fabrication of high-density magnetic recording, magnetic sensors, flexible magnets, and spintronic devices.

Keyword: Electrospinning, nanofibres, processing parameters, morphology.

1.1 Introduction.

Nano fibres have successfully been electrospun from different polymer systems such as organic polymers, high performance polymers, bio-polymers and polymer blends. The electrospinning process enables the formation of continuous nanofibres, composite fibres and align nano fibres [1-2].

The electrospinning was first explore in the 1930s by Formhals as a simple and versatile method of making fibres from polymer solution with diameters typically ranging from 50- 500 nanometers.[3].Current interests in nanostructured materials have stimulated renewed efforts in electrospinning.Nano fibre properties such as large area to volume ratio and high pore size make them suitable for adsorption of chemicals, military and civilian filtration application and aligned nano fibres in particular have potential applications in composite materials, in aerospace ,automotive, reinforcements, electrochemical sensing, bone and blood vessel engineering and tissue engineering[4-6].Melt spinning, solution spinning, and gel state spinning are the common method for polymer fibre production and these methods rely on mechanical forces to produce fibre by extruding a polymer melt or solution through a spinneret and subsequently drawing the resulting filaments as they solidify or coagulate. 5 to 500 micron diameter fibres can be produced by this method [7-8]. Electrospinning provides an interesting way to producing long polymer fibres with diameters in the range 10nm to a few microns. Nanofibre lengths depend on the time of electrospinning and can be a thousand of kilometers in a short period of time. Under room temperature, bending instabilities present in the polymer jets stream cause randomly oriented fibres with various diameters and structures during

the electrospinning process [4, 9].In electrospinning; a high electrostatic voltage is imposed on a drop of polymer solution held by its surface tension at the end of the capillary. The surface of the liquid is distorted into a conical shape called Taylor cone. Once the voltage exceeds a minimum value, the electrostatic forces overcome the solution surface tension and a stable liquid jet is ejected from the Taylor cone tip. A solvent evaporates as the jet travels through the air, leaving behind the ultrafine fibres collected on the grounded target. Bending instability play a part to produce random nonwoven electrospun fibre mats [10-11, 14].

PVA (poly vinyl alcohol) is a semi-crystalline, hydropholic polymer with good chemical and thermal stability, highly biocompatible, on-toxic and high water permeability [12-13]. The electrospinning of PVA solution and its potential applications in the preparation of ultrafine separation filters, biodegradable mats, etc have been reported by many researchers [23-24]. A number of grades of PVA are commercially available, which can be divided into two types: a fully hydrolyzed and partially hydrolyzed, PVA depending on the amount of acetate groups left in the backbone [14].PVA solutions can form physical gels from various types of solvents and these properties led the use of PVA in a wide range of applications in medical, cosmetic, food, packaging industries and pharmaceuticals [13]. In recent years, much attention has been focused on biomedical applications of PVA hydro gels including contact lenses, artificial organs and drug delivery systems [25].This is an important step towards R &D in controlled release of biomedical by means of manipulating the pore activities of the PVA by the $FeCl_3$ through magnetic field In this present work, we show structural results on electrospun PVA and FeCl3 blends. The solution flow rate, the effect of electric field and tip-target distance on the morphology of electrospun fibres were evaluated and analyzed.

1.2. Experimental

1.2.1 Materials

Poly (vinyl alcohol), 99-100% hydrolyzed approx 86000 g/mol M_w purchased from across organics, UK and FeCl3 purchased from sigma Aldrich UK.

1.2.2 Preparation of the solution (PVA/$FeCl_3$)

PVA solutions (polymer concentrations ranging from 5 to 8% (g/ml)) were prepared by mixing the appropriate amount of polymer and water (milli-Q grade) at 100 °C under conditions of vigorous stirring until the polymer was completely dissolved. Solutions were stored at 80 °C overnight and were then cooled to room temperature. PVA Ferro gels (polymer concentration 5% g/ml, 8%g/ml and Ferro fluid concentrations ranging from 0 to 8% g/ml) were prepared by mixing the appropriate amount of FeCl3 with aqueous PVA solutions. Homogenization was achieved at 90 °C under conditions of vigorous stirring. Samples were stored overnight at 80 °C and were then cooled to room temperature for 1 h, before being subjected to the electrospinning process.

1.2.3 Electrospinning setup

A Glassman MK35P2.0-22(New Jersey, USA) high voltage DC power supply was used to generate potential differences of between 5 KV to 18KV. One electrode of a high voltage was applied to a vertically (25-gauge) blunt-ended metal needle. The PVA Polymer solution was fed from a syringe (5-ml capacity, fisher Co, Leicestershire, UK) to a needle via Teflon® tubing and the flow rate was controlled using a digitally controlled, positive displacement syringe pump (Harvard Apparatus M22 PHD 2000, Edenbridge, Kent UK), The electrospinning schematic diagram Fig.1 .Various polymer solution concentration ranging from 5 to 8wt% were prepared by PVA with FeCl3 mixtures. Fibres were obtained using an earthed collection system, which consisted of a copper collector plate measuring 15cm × 15cm.The operating flow rates was 0.20mL/h to 0.30mL/h at applied voltage between 12KV, 15KV and 18KV. Collection distances used during this experiment are 8, 11, 14 cm.

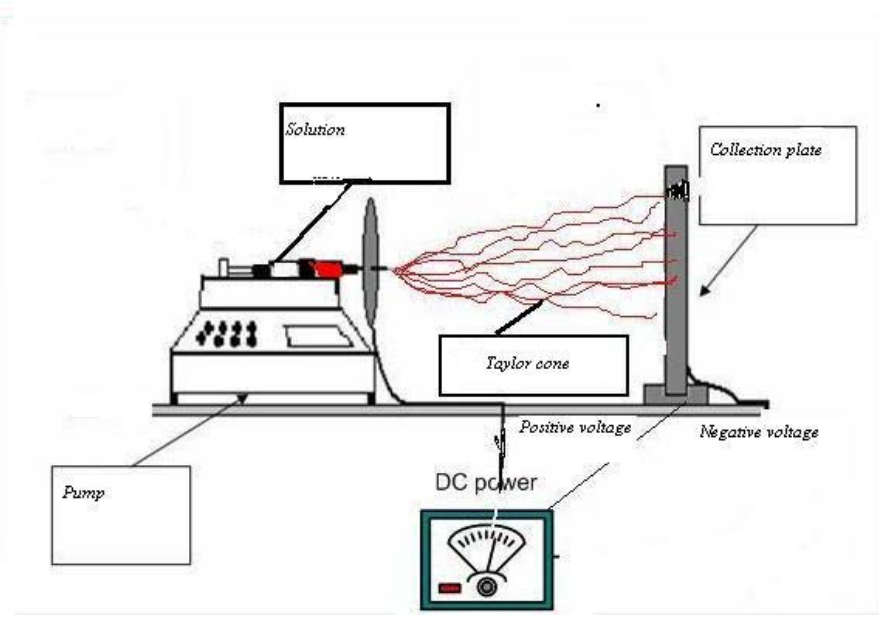


Fig .1. Schematic diagram of electrospinning process.

1.3 Characterization

The samples produced for random nano fibres were collected on aluminum stubs.

The morphology of the electrospun PVA/$Fecl_3$ fibres was observed with a Scanning Electron Microscope (SEM), Model Hitachi S-530, UK .To measure the diameter of the electrospun PVA/$FeCl_3$ was investigated by an image analyzer(Image pro express, Media Cybernetics Co,US) .

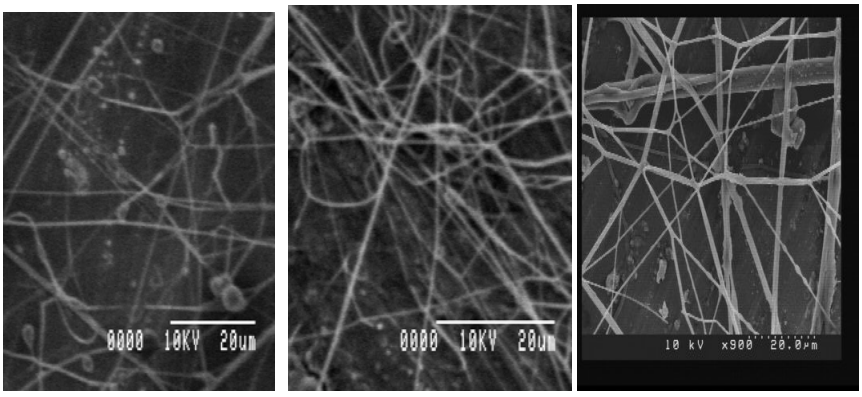
1.4. Results and Discussion

1.4.1 The effect of polymer concentration on the fibre morphology

The diameter and morphology of electrospun nanofibres dependent on the solution concentration, the applied electric field strength, the tip to collector distance etc. [15, 18, 19]. Among these parameters,

the concentration or the corresponding viscosity of the electrospun solution was one of the most effective variables to control the fibre morphology and diameter of the PVA Ferro gels, which is in agreement with the work of others[20].Solution concentration and viscosity are two closely correlated factors, increasing of solution concentration always result in increase of solution viscosity, and decrease of solution concentration always results in decrease of solution viscosity.

A series of samples with different PVA/$Fecl_3$ concentrations were electrospun, resulting in various fibre morphologies, as shown in Fig 2.At 6wt% polymer solution the average fibre diameters was 735 nm and beads were observed. Increasing the polymer concentration the morphology was changed from beaded fibre to uniform fibre structure and the fibre diameter was also increased between 789 and 987 nm. In electrospinning, the coiled macromolecules of the solution are transformed by the elongational flow of the jet into oriented entangled networks that persist with fibre solidification. Below this concentration(less than 6wt%) chain entanglements are insufficient to stabilize the jet driven by the surface tension caused the solution to form beads or beaded fibres.When the polymer solution increases at higher concentrations, viscoelastic forces which resist rapid changes in fibre shape result in uniform fibre formation. But if the solution concentration is too high, it would be impossible to electrospun because of their high viscosity. The changing of the fibre morphology can probably be attributed to a competition between surface tension and viscosity. It has been found that viscosity and surface tension are the most important factors that effect the morphology of the resultant fibres and Reneker et[10] all proved it his experiment when he and coworkers investigated the solution properties of poly(ethylene oxide) on the density of beads contained in the electrospun fibres.Vancso et al have also indicated their research that smooth fibres can be formed when viscoelastic forces prevent the formation of beads[21]. Uniform fibres obtain higher concentration and lower concentration give fibres with beads. If the concentration decreases the bigger beads are obtains and some spot might be formed.



a) b) c)

Figure.2 SEM micrographs of electrospun fibres from PVA/$FeCl_3$ solution with different solution concentration, Voltage 15KV, Tip to target distance 11cm, flow rate 0.25ml/h. PVA/Fecl3 concentration a) 5wt%, b) 8wt%, c) 10wt%

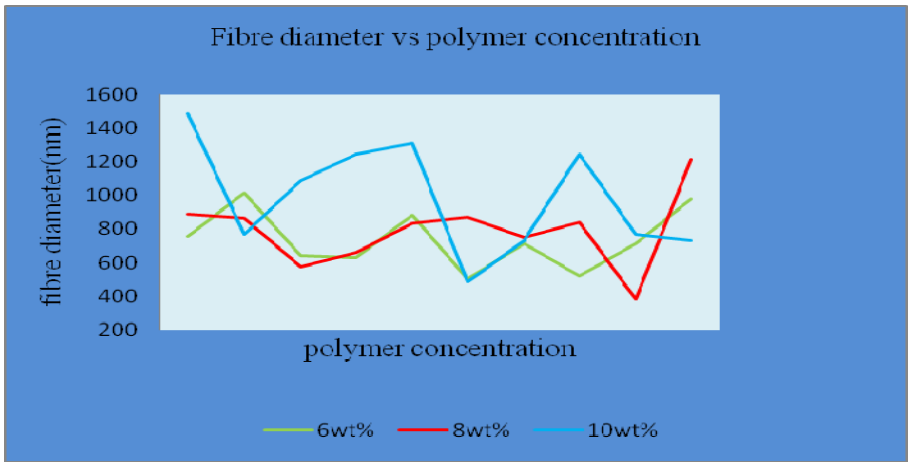


Figure 3 .The above graph describes the relationships between fiber diameter and the polymer concentration.

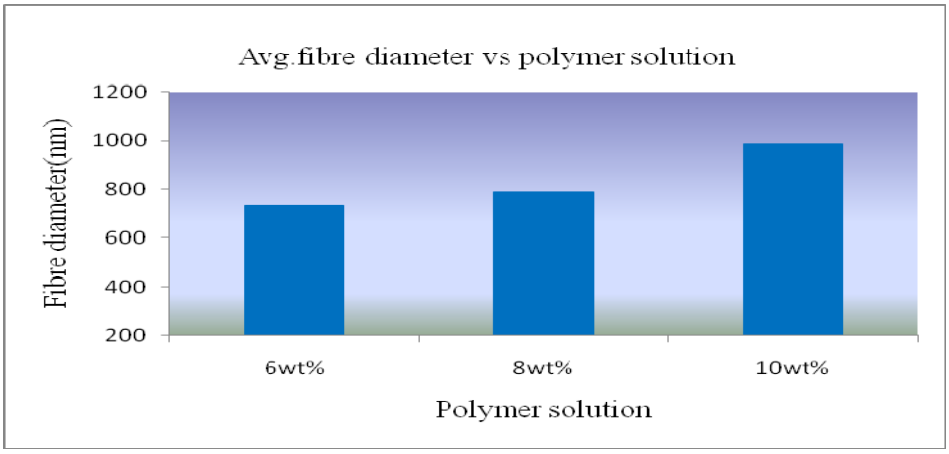
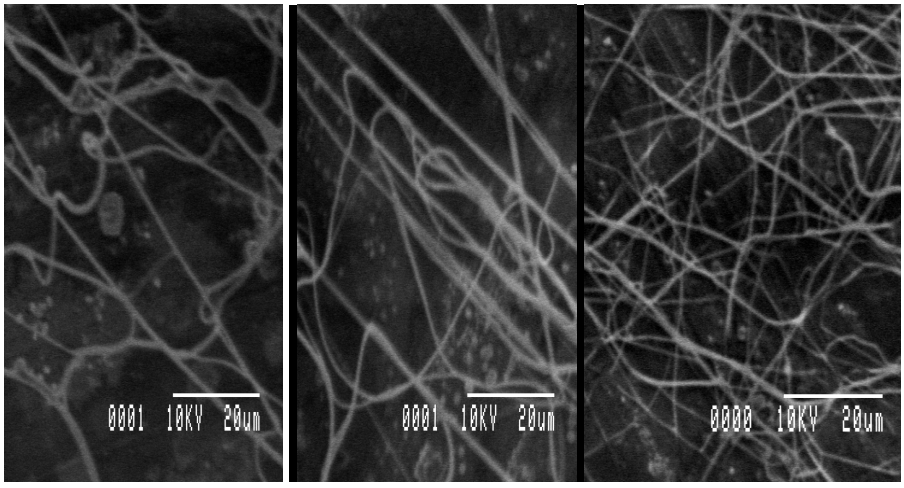


Figure 4. The above chart describe the relationship between the fibre diameter and polymer concentration

1.4.2 The effect of applied voltage on the fibre morphology

The voltage applied between the capillary and the metal target can be used to control the amount of fiber being formed. The number of droplets or fibers reaching the target is a function of the current flowing across the circuit. Hence the amount of fiber spun can be easily controlled by varying the voltage. At a lower voltage, typical value a droplet of solution remains suspended at the end of the syringe needle, and the fiber jet originates from the cone at the bottom of the droplet. The size of the droplet formed at the end of the capillary is large because the voltage is not high enough to transfer all the solution to the target. The nano fibers produced under this condition will typically have cylindrical morphology with few bead defects. The bead like structures are undesirable “by products” of the electrospinning process caused due to instability of the jet of the polymer solution [15]. A series of experiments were carried out by varying the applied voltage from 12 to 18 kV and tip to target distance at 15cm.When the applied voltage increases the fibre diameter slightly increases. .It has been reported that increasing the voltage will decrease the diameter of the fibers produced from the solution [16].However, upon further increasing of the voltage, some researchers found that the cone decreases and the fiber diameter begins to increase again. The smallest diameter fibers have been found to form

when a cone is present and the jet is being formed at the apex of the cone. [16,17]. The applied voltage may effect some factors such as the mass of polymer fed from the tip of the pendent, the elongation level of jet and the morphology of the jet(single or multiple jets)[22].A considerable amount of thin fibres with diameters below 850 nm were found when the applied voltage was above 12 kv.The average diameter of the fibre calculate 845nm to 855 nm . At lower voltage narrow distribution of fibres were observed.At higher voltages of 15kv to 18kv more fibres were obtained. Increasing the applied voltage will increases the electrostatic repulsive force on the fluid jet which favors the thinner fibre formation. The average fibres calculate 450nm t0 465 nm. The solution will be removed from the capillary tip more quickly as jet is ejected from Taylor cone and thus making larger diameter fibres. As figure 5 & 6 and 7 – shows the relationships between the fibre diameter and electric field with a constant concentration was 8wt% and the collection distances of 8cm. This figure shows that voltage played a part to produce uniform and its fiber diameter. It was observed that the diameter of the electrospun fibres was not dramatically changed with varied applied voltage. As the electric field strength increasee, the electrostically driven instability increases in magnitude that causes the jet to undergo higher amounts of whipping and plastic stretching that resulted in a decrease of the fibre diameter. It can be seen figure 5, That exceedingly uniform fibre obtain lower voltage and the average diameter was 800 nm to 900 nm.Higher voltage give more fibres but not uniformity like variation of the diameter of ultra fine fibre and its asymmetry distribution.. The diameter of ultra fibres was reduced by increasing the voltage. And above the graphs (fig-6)we can say that In general, increasing the applied voltage to a certain level would Change the shape of the pendant drop from which the jet originated so that a stable shape could not be achieved .Finally we can say that voltage affect has not got significant role to control the fibre morphology



a) 8wt% 12kv 8cm b) 8wt% 15kv 8cm c) 8wt% 18kv 8cm

Fig.5 PVA/$FeCl_3$ solution of 8wt% and collecting distance 8cm constant and different voltage a) 12kv,b)15kv,c)18Kv ,

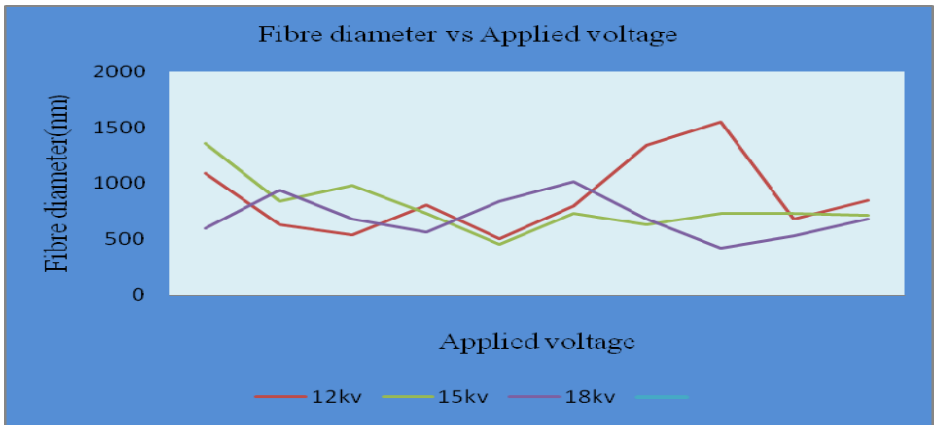


Figure 6. The above graph describes the relationship between fibre diameter and applied electric voltage.

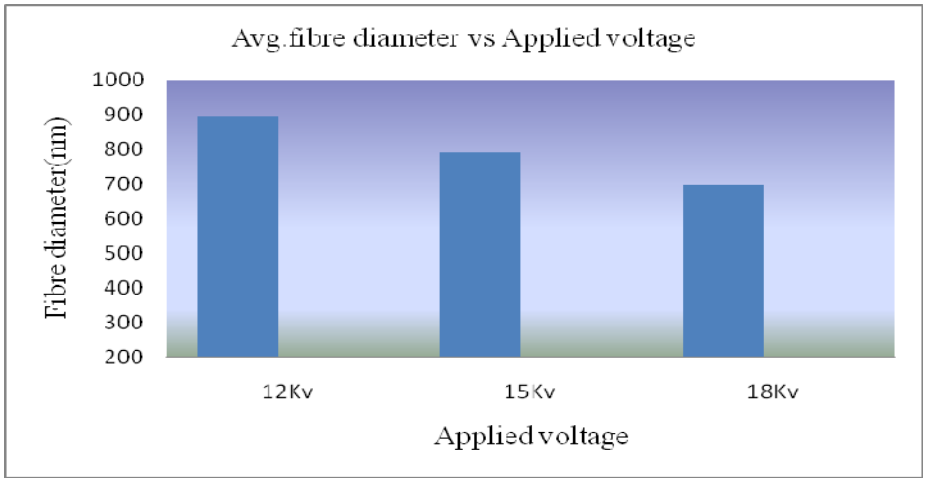
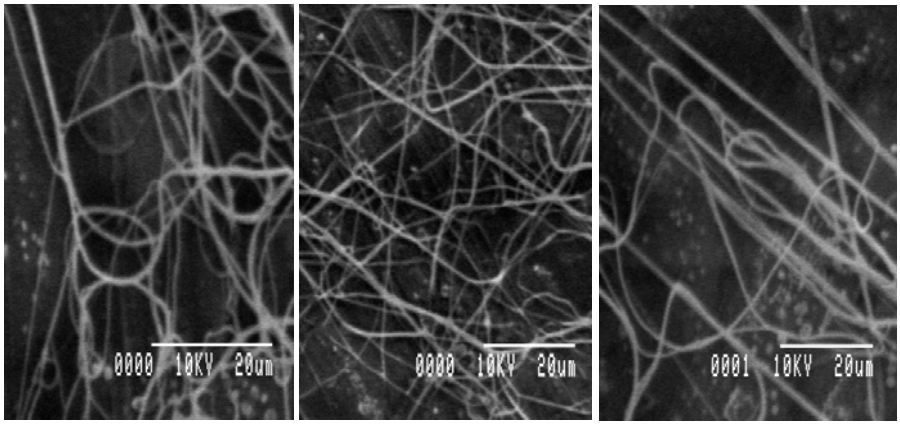


Figure 7.The above chart describes the relationship between average fibre diameter and applied voltage.

1.4.3 The effect of tip to collector distance on the fibre morphology

Tip to target distance is another process parameter for producing nano fibre by electrospun process. The most popular form of collected nanofibre is a nonwoven mat. The process enters an instability region and the fibers are distributed in a random formation .Tip to target distance actually make no significant effect on the electrospun fibre morphology of fully hydrolyzed PVA and this phenomenon is not yet fully understood and is currently being researched. In order to investigate the effect of the distance between the needle and the collector on the properties of resulting ultra fine fibres, the following spinning condition were fixed. The voltage was fixed 18KV and the concentration 8wt% and distance 8cm, 11cm, and 14cm.This result (figure 9) indicated that with varying size and thickness can be successfully produced. When the solution jets were elongated and solidified quickly they flowed out of the spinneret tip because of the high conductivity of fully hydrolyzed PVA and $FeCl_3$ used. At low separation distance between the capillary- end and the target, wet fibres was collected ,primarily due

to the presence of significant amount of residual solvent in the fibres. As the collection distance is increased, the time for the solvent to evaporate increased and as a result, dry solid fibres are collected at the target. With increasing the distance between the capillary-end and the target, the jet underwent a larger amount of electrically driven bending or whipping instability. Consequently, the amount of stretching or elongation of the jet increase resulting in the fibre diameter to decrease. The morphological structure can be slightly changed by changing the solution flow rate. When the flow rate is increased more than 0.25ml/hr, a few big beads were observed on the fibres. The solution flow rate also affects the electrospinning process. The electrospinning time when the flow rate exceeded a critical value, the delivery rate of the solution jet to the capillary tip exceede the rate at which the solution was removed from the tip by the electric forces and this provides unstable jets and big beads in fibres formation. As we can see the figure 8. The micrographs illustrate electrospinning of PVA Ferro gels at 8-14cm of tip target distance and at a flow rate of 0.25ml/hr and we can see the fig.9 and 10 then we easily identify with the effect of the tip to collector distance.



a) b) c)

Fig.8. PVA/$Fecl_3$ solution of 8wt% and collecting distance 8, 11,14cm, Voltage 18KV, flow rate, 0.25ml/hr. a) 8wt%, 18kv, 8cm, flow rate 0.25ml/hr, b) 8wt%, 18kv, 11cm (flow rate 0.25ml/hr) , c) 8wt%, 18kv, 14cm, flow rate 0.25ml/hr

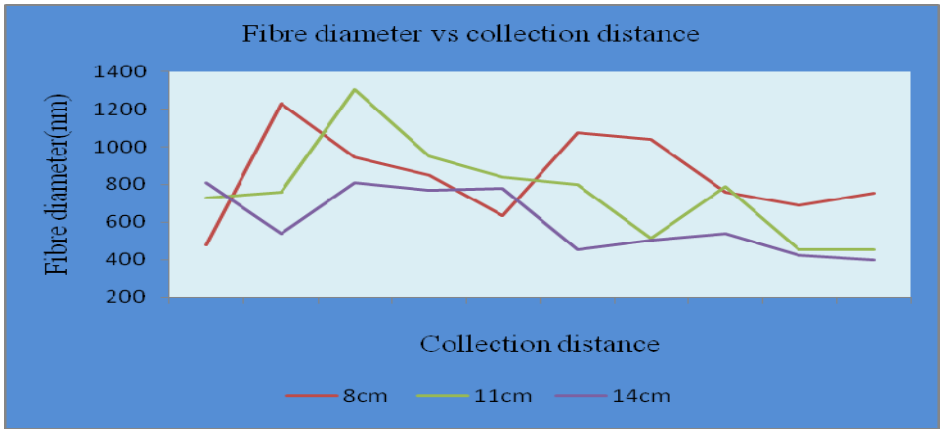


Figure 9. Above graph describe the relationships between fibre diameter and collecting distance

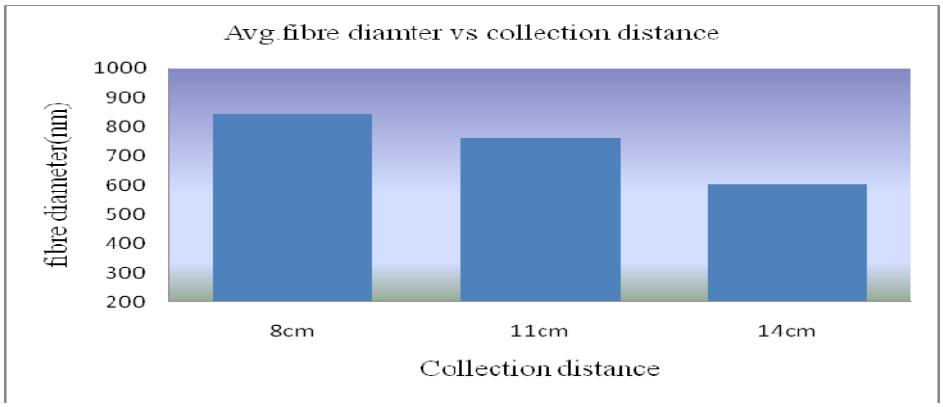


Figure. 10. The above chart relationship between the average fibre diameter and collection distance.

If we see the figure 9 and 10 then we can see that when the fibre collection distance 8cm then collected fibre diameter 480 nm to 1230 nm and average fibre diameter 845 nm. Increase the collection distance from 8cm to 11cm and 14 cm respectively the fibre diameter also decrease like 452 nm to 1076 nm and 425 nm to 815 nm. The average diameters also lower than shorter distance (8cm 845nm) 759 nm and 603nm.Finally we understand that the fibers with smaller diameters are obtained by allowing the jet

to cover more distance in the electric field. This also allows more time for the

evaporation of solvent from the fibers that can result in a decrease in the diameter. In this study, the tip-to-collector distance of 8 cm seems to result in uniform electrospun fibres.

1.5 Magnetic nano fibres

The above certain condition we got a blended fibre where the fiber contain magnetic power. The electrospun blend nanofibres have unique magnetic properties, with much enhanced coercivities relative to bulk materials. The outstanding features of this approach to get one-dimensional magnetic nanostructure are its simplicity, effectiveness, and ease of assembly. Therefore, electrospun magnetic nanofibres can potentially be used in fabrication of high-density magnetic recording, magnetic sensors, flexible magnets, and spintronic devices. It can be seen fig 11.

a) b) c)

Fig 11: PVA/$FeCl_3$ Blend nano fibres with magnet, it shows the magnetic power of the blended fiber. a) Blended fiber with magnet, b & c) Magnet attract the fibre.

1.6 .Conclusion

Electrospinning was used to fabricate nano fibres of PVA/$FeCl_3$ blends. The effect of processing parameters such as, the solution concentration, the voltage, the tip-target distance and flow rate on fibre and its morphology has been examined and magnetic fiber produced. The electrospinning of PVA/$FeCl_3$ solution was processed and fibers with diameter ranging from 600 nm to 1100 nm were obtained depending on the electrospinning conditions. The effects of the concentration, spinning voltage and collection distance between the tip to target on the morphological appearance and average diameter of the PVA/$FeCl_3$ fibre was also established investigated. It was concluded that the solution concentration significantly affected the morphology and diameter of the PVA/$FeCl_3$ nano fibers. Lower concentration tended to facilitate the formation of fibers with beads. As the solution concentration, the morphology was changed from beaded fibres to smooth and uniform nano fibre and with increasing fiber diameter. The spinning voltage had also an important influence on fibre diameter, while the collection distance had a lesser effect on the fiber diameter. Finer fibres with highly uniformity with the application of lower voltage. These produced magnetic nanofibers can potentially be used in fabrication of high-density magnetic recording, magnetic sensors, flexible magnets, and spintronic devices.

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THE ROAD TO A UNIQUE TEXTILE MATERIAL NANOFIBRES WITH A PH-SENSITIVE FUNCTION

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ABSTRACT

Colour changing textiles have recently gained much interest from the academic world. Although previously categorized as unwanted, colour changing textiles can be used in a broad field of applications since a colour change is a non-disturbing but clear signal which can perform a first warning function. This research focuses on halochromism or pH-sensitivity due to the importance of pH. These kind of materials can be applied in wound dressings, geotextiles, protective clothing etc. A halochromic wound dressing would for example be able to indicate the healing process of a wound since the pH-value varies during healing.

Thanks to their extremely fine fibres, nanofibrous structures show interesting characteristics such as small pore size, high porosity and high specific surface area, which turn them suitable for a whole range of applications. Incorporating pH-sensitive dyes into nanofibrous structures would lead to unique materials that combine the intrinsic properties of nanofibres with an extra sensor functionality.

As a start point, the feasibility of incorporating pH-indicator dyes in conventional textiles using standard dyeing processes was investigated. Next, the dyes were incorporated into a polyamide 6.6 nanofibrous structure by adding the dyes to the polymer solution before the start of the electrospinning process. The influence of this incorporation on the electrospinning process and the halochromic properties of the obtained structures were investigated.

Our results proved that it is possible to develop a pH-sensor using conventional textiles dyed by a standard dyeing process. Also the incorporation of the pH-indicator dyes into a nanofibrous structure was possible. Moreover, the process parameters and fibre diameters were not influenced by this addition and reproducibility could be obtained. Furthermore, the majority of the obtained textile structures showed a clear colour change with a change in acidity. This halochromic behaviour was however different from the behaviour of the dyes in solution due to dye-fibre interactions.

Key Words: halochromism, conventional textiles, nanofibrous structures, electrospinning

1. INTRODUCTION

Colour changing textiles have recently gained much interest from the academic world. Although previously categorized as unwanted, colour changing textiles can be used in a broad field of applications. The reason for this is that a colour change is a non-disturbing but clear signal which can perform a first warning function. [1]

A whole range of triggers can cause a colour change. The most known chameleon textiles have temperature and light as stimilus for the colour change and are designated as thermochromic and photochromic systems. [2] Despite of the whole range of possible applications, much less is known about halochromic systems. The degree of acidity is however an important parameter in daily live and a pH-sensitive sensor could therefore be very useful. [3]

Literature about halochromism is mainly focussed on the development of new halochromic dyes. [4, 5] The following step - the application of these dyes on a substrate material - is not yet studied in detail. This step is however essential if these newly developed dyes want to be used in practice. [6] The major aim in the current study is therefore applying pH-sensitive dyes on textile materials.

The newly developed halochromic dyes mentioned above are however not yet available on the market. On the other hand pH-indicator dyes, which are normally used to determine the pH of a solution, are easily available and also exhibit the desired halochromic properties.

Electrospinning from polymer solutions is a process which is able to produce nanofibrous nonwovens. It is based on the application of an electric field. This field is applied between the tip of a nozzle, through which the polymer solution is flowing, and a collector plate. Because of the applied voltage, the droplet at the tip of the nozzle deforms and a Taylor cone is formed. Next, a jet is drawn from this cone which elongates due to bending and splaying. The so-formed nanofibres are deposited on the collector plate. The obtained nanofibrous structure shows some unique characteristics such as an extremely high surface area, a high porosity and a small pore size. [7] These properties can be useful in a whole range of applications one of them being wound dressings since bacteria cannot reach the wound area while exchange of liquids and gases with the environment is still possible.

Incorporating pH-sensitive dyes into nanofibrous structures would lead to a unique material that combines the intrinsic properties of nanofibres with an extra sensor functionality. A great advantage is that the dyes can be added at the start of the production process and that thus the extra functionalisation step in the procedure can be avoided. However, before being able to incorporate the dyes into nano nonwovens, it is essential to investigate them in conventional textiles.

In this study pH-indicator dyes were applied on different textile materials. First, the incorporation was studied in conventional cotton and nylon. The functionalisation was realized by dyeing the fabrics using standard dyeing processes. Next, the dyes were added to a polyamide 6.6 solvent solution and electrospun. Finally, the halochromic behaviour of the produced structures was investigated.

2. MATERIALS AND METHODS

2.1. Materials

Cotton fabric was supplied by Utexbel (Ronse, Belgium), polyamide 6 and 6.6 fabrics were supplied by Concordia Textiles (Waregem, Belgium). The pH-indicator dyes, hydrochloric acid, acetic acid and sodium hydroxide were obtained from Sigma-Aldrich. Also the polyamide 6.6 pellets used for electrospinning were supplied by Sigma-Aldrich.

2.2 Methods

Conventional dyeings were performed in a Mathis Labomat BFA-8 dyeing machine using a direct dyeing process for cotton and a acid dyeing process for polyamide (Fig. 1). When dyeing cotton, sodium chloride was used to increase the exhaustion. The dyebaths for dyeing polyamide were set at pH 5 using acetic acid.

In the electrospinning process, the polymer solution was pumped from a 20 ml syringe into a 15.24 cm long needle with an inner diameter of 1.024 cm. A KD Scientific Syringe Pump Series 100 regulated the flow rate of the solution at 3.5 ml h^{-1}. The tip to collector distance was fixed at 6 cm. The voltage was adjusted using a Glassman High Voltage Series EH source. The morphology of the electrospun structures was examined using a Scanning Electron Microscope (FEI QUANTA 200 F). Prior to the SEM-measurements, the sample was coated with gold using a sputter coater (Balzers Union SCD 030).

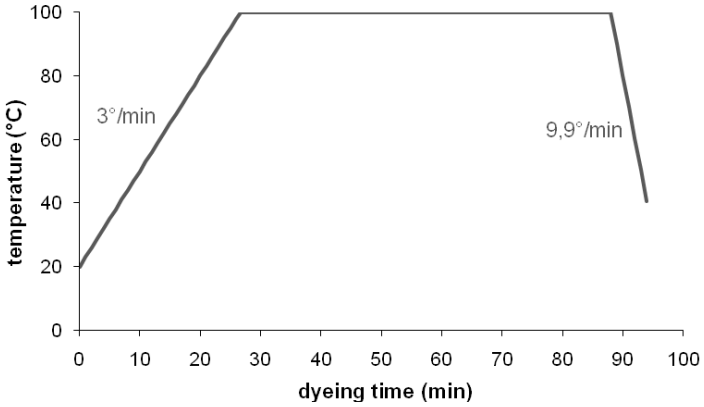

Figure 1. Temperature profile for dyeing conventional textiles

The pH-values were measured using a combined reference and glass electrode from Eutech Instruments. The UV-Vis spectra were recorded with a Perkin-Elmer spectrophotometer while Raman measurements were performed with a Perkin-Elmer Spectrum GX equipment.

3. RESULTS AND DISCUSSION

3.1 Conventional textiles

Cotton and nylon were dyed with a set of pH-indicator dyes. The results of this first screening are summarized in Table 1. It is clearly seen that certain pH-indicator dyes show good characteristics as dyes for cotton and/or polyamide. The results also indicate that the halochromic properties can disappear once the dyes are incorporated in a textile fabric by a dyeing process. On the other hand, enough pH-indicator textile systems remain their halochromic behaviour and thus are worth to study in more detail. The dye Brilliant Yellow was chosen to study more in depth.

Table 1. Screening of pH-indicator dyes on conventional textiles

	Cotton	***Polyamide 6***	***Polyamide 6.6***
Congo Red	X	X	X
Methyl Orange		X	X
Methyl Red			
Chlorophenol Red			
Bromocresol Purple		X	X
Alizarin		X	X
Nitrazine Yellow		X	X
Bromothymol Blue		X	X
Brilliant Yellow	X	X	X
Phenol Red			

X = good dyeing properties

= pH-sensitivity

Brilliant Yellow (Fig. 2) is anionic diazo dye and is used as a pH-indicator in solution in the neutral region. Its colour is changing from yellow to orange in the pH-range 6.5 - 8.0.

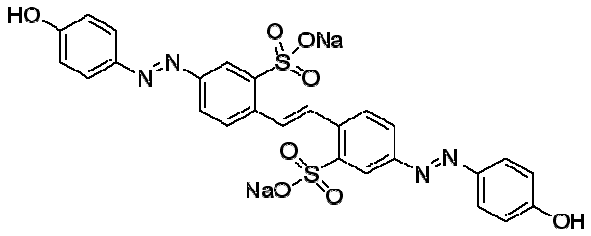

Figure 2. Molecular structure Brilliant Yellow

The preparatory experiments showed that Brilliant Yellow is able to dye cotton on a satisfactory level. Moreover also a clear colour change with a pH-variation was present. To characterize the halochromism of Briliant Yellow on cotton, the fabric was immersed in water baths with a specific pH. Next, the colour of the samples was measured with UV-Vis spectroscopy. The results of these measurements are presented in Fig. 3. From these data it was found that there is a difference in halochromism of the dye depending on the medium in which the dye is located since the pH-range of Brilliant Yellow on cotton is broader than the range of Brilliant Yellow in solution as can be seen in Fig. 4.

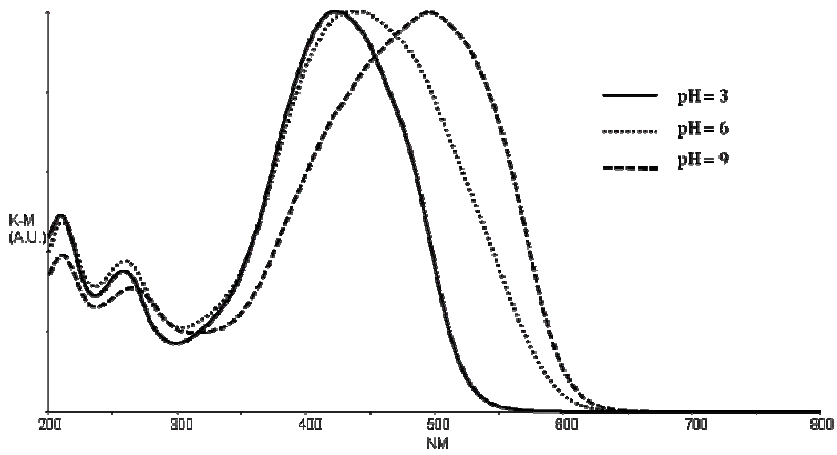

Figure 3. Normalized Kubelka-Munk spectra of Brilliant Yellow on cotton at pH 3, 6 and 9

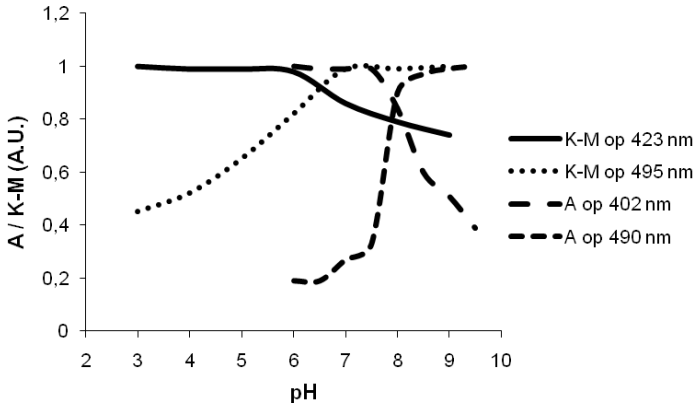

Figure 4. Normalized Kubelka-Munk (cotton) and normalized absorbance (solution) of Brilliant Yellow as a function of pH

3.2 Nanofibrous nonwovens

Various pH-indicator dyes were added to the polymer solution before the start of the electrospinning process. It was seen that the pH-indicator addition had no influence on the process since it still was possible to spin in steady state. Droplets were however noticed when poorly soluble dyes were used. Table 2 lists the average fibre diameter of polyamide 6.6 nonwovens with different amounts of Brilliant Yellow. It is seen that the diameter was not influenced by the dye addition.

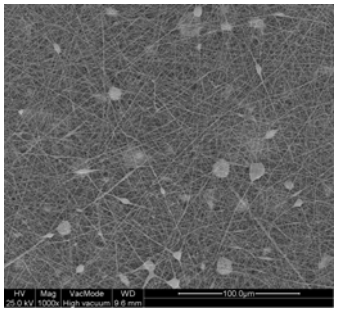

Figure 5. Droplets in an electrospun nonwoven

Table 2. Average fibre diameter of electrospun nonwovens with varying amount of Brilliant Yellow

Dye concentration (% omf)	Average fibre diameter (nm)	Standard deviation (nm)
0.08	177	23
0.16	180	18
0.32	166	24
0.54	178	27
1.35	183	20

The obtained samples showed pH-sensitive properties as illustrated in Figure 6 in which the halochromism of Brilliant Yellow incorporated in a nanofibrous structure is presented. It should be noted that polyamide 6.6 dyed with Brilliant Yellow by a standard dyeing process showed a visually negligible colour change while an electrospun polyamide 6.6 nonwoven varied clearly in colour.

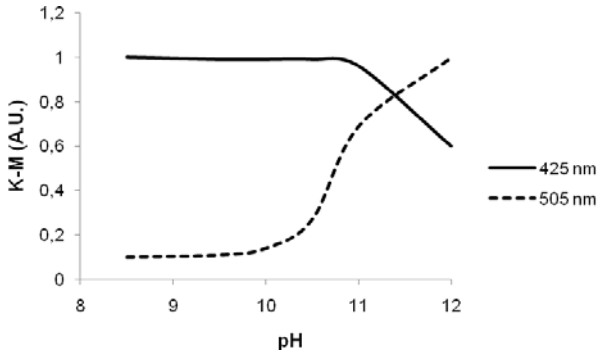

Figure 6. Normalized Kubelka-Munk of BY in a polyamide 6.6 nonwoven

4. CONCLUSIONS

Our results proved that it is possible to develop a pH-sensor using conventional textiles dyed by a standard dyeing process. Also the incorporation of the pH-indicator dyes into a nanofibrous structure was possible. Moreover, the process parameters and fibre diameters were not influenced by the dye addition and reproducibility could be obtained. Furthermore, the majority of the obtained textile structures showed a clear colour change with a change in acidity. This halochromic behaviour was however different from the behaviour of the dyes in solution due to dye-fibre interactions.

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THERMOREGULATION AND PHYSIOLOGICAL PERFORMANCE OF PERSONAL PROTECTIVE CLOTHING

A. GSTETTNER

Lenzing AG

Lenzing FR® is an inherently flame resistant **CELLULOSIC** fiber based on Modal technology.

Modal fibers are the advanced generation of Viscose fibers, with high tenacity in wet and dry conditions, as well as improved color fastness and durability. Modal fibers are also well recognized on the market as being the ultimate in softness and skin friendliness.

Lenzing FR® is recognized as both a high performance flame resistant fibre and as a blending fibre, that can improve performance, especially in terms of comfort. Protective clothing made of Lenzing FR® is inherently flame resistant, which results in permanent protection for the lifetime of the garment. Lenzing FR® feels immediately cool, even after severe flame and heat exposure."

Combining comfort

Lenzing FR® protective clothing offers superior protection, but it provides also comfort and flexibility. Its body climate control properties minimize the risk of heat stress and heat stroke, whilst its inbuilt natural moisture management effectively suppresses the growth of bacteria responsible for bad odour. Certified to ÖKOTEX Class 1, Lenzing FR® fabrics are also known for feeling exceptionally soft and gentle on the skin.

We should accept nothing less for our skin. "As our skin is the most important 2m² in our life, we need to take good care of it. It's not necessarily the actual fire, metal splash, or electric arc, which is harmful to our skin, but rather, the heat created. To be protected we need to wear protective clothing - and the protective clothing should be comfortable to wear. This combination of ultimate protection and comfort is a constant research priority for Lenzing".

Keywords: personal protection, heat stress, physiological performance, protective clothing,

USE OF NONWOVENS IN ROOFING INDUSTRY AND DEVELOPMENT OF A CARRIER NONWOVEN FOR BITUMINOUS ROOFING MEMBRANES.

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ABSTRACT

Nonwovens are one of the most developing and promising sector in the global textile industry. Construction industry is one of the major markets for durable nonwovens. The use of nonwovens in the construction industry is growing rapidly. In this study the use of nonwovens in roofing industry has been studied. An introduction to the use of nonwovens in roofing and tile underlayments, shingles, waterproofing applications and bituminous membranes are made.
The study also includes the introduction of a project aimed to develop a carrier for bituminous membranes. A polyester spunbond nonwoven fabric can be used as a carrier for production of bituminous insulation material production.

Nonwoven fabrics made of polyester needs a certain dimensional stability because the process of applying bituminous involves in coating under high temperature of about 200C. A combination of melamine and binder chemicals is used to give dimensional stability. Melamine is described as being harmful if swallowed, inhaled or absorbed through the skin. Chronic exposure may cause cancer or reproductive damage. It is eye, skin and respiratory irritant. Trials and test will be made to develop a spunbond nonwoven carrier in cooperation with machinery and chemical producers that will perform in an acceptable performance without the use of melamine. This study will introduce the project in more detail.

KEYWORDS: bituminous membrane carrier, nonwovens, construction.

1. Use of Nonwovens in Construction Industry

Not all nonwovens end in disposable applications. A large part of production is for durable end-uses, like in interlinings, roofing, geotextile, automotive or floor covering applications etc. Nonwovens used in construction market are made of mainly polypropylene, polyester and glass fiber nonwovens. Nonwovens are used for thermal and acoustic insulation as well as for weather protection. Nonwovens are increasingly being employed to save energy in building and construction.

While glass mat and spunbond polyester substrate for roofing are probably the largest and most recognized markets for nonwovens in the construction market, nonwovens are actually found all over buildings, particularly in new construction, where they are replacing other substrates such as paper and felt. According to industry estimates, the use of nonwovens in construction applications is growing in the mid-single digit range. This growth can largely be attributed to innovation at the roll goods level as producers are finding new ways to apply their products in construction. In fact, many producers think of themselves as total "building envelope" providers, offering complete barrier protection for homes in the form of housewrap, roof liners and flashing products [2,4].

Polypropylene (PP) and Polyester (PES) are the dominant materials used in geotextiles and construction fabrics. Polypropylene nonwoven fabrics are also used in other construction applications such as vapor barriers in roof constructions. All applications have specific requirements as to performance and life-time expectations. Effect additives can be used to modify the properties of nonwoven and broaden their applications. In addition to PP and PET; nonwovens made of glass fibers are also widely used in the construction industry. The main advantages of nonwovens made of glass fibers are; fabrics stability under thermal conditions (mainly shrinkage behaviour), flame retardant proporties, strength and no water aborbancy. [1,3,5]

A range of binders suitable for industrial nonwoven applications such as fiberglass roofing, specialty mat and high-temperature polyester webs are also used. These binders impart the range of flexibility, dry and wet tensile strength, hydrophobicity and ease of formulation required in these applications. In addition, webs bonded with such binders have the hot tensile strength necessary to withstand a variety of manufacturing and end-use conditions and can be formulated as sole binders or as cobinders with aminoplast resins [5].

2. Use of Nonwovens in Roofing Industry for Weather-proofing

In this section, the use of nonwoven fabrics for roofing industry, mainly for weather-proofing applications, are explained. It should be noted that nonwovens used for other segments of the construction and roofing industry (i.e. thermal and acoustic insulation) and the use of nonwovens in geotextile and flooring applications as well as the applications with traditional textiles has not been included within the scope of this study.

2.1 Roofing Tile Underlayment

Roof underlayments are designed to protect the roof sheathing and structure from moisture and penetration. With all the seams and potential leak points in a roof, there has to be a layer of protection between the roofing materials and the house. That's where roofing underlayment materials are mainly used.

Roofing underlayment is mostly used under shingles, shakes, tiles, slate and metal roofs, it is important that it resists tearing away from nails-even in high winds.

Some examples of water proofing roofing underlayments are listed below:

- Aluminum foil + nonwoven laminated composites
- Vapour impermeable film + nonwoven laminated composites
- Breathable membrane + nonwoven laminated composites
- Micro-perforated films
- Self adhesive underlayments
- Asphalt-saturated building papers
- Bitumen coated plastics like reinforced polythene, polypropylene, PVC or aluminium-foil-coated polyester.

Synthetic underlayments are typically made from polypropylene, polyester, or fiberglass fabric which weighs less than felt building paper. They can be manufactured with an anti-slip surface and can withstand exposure to the weather conditions for about six months. These new membranes are lighter, stronger, and faster to install than traditional felt paper, expensive but are they worth the extra expense[6,7,8].

Figure 1 shows a photograph from the Typar brand synthetic roofing underlayment product, while Figure 2 shows a photograph from the field application of a roofing underlayment.

Figure 1: Typar brand Underlayment[6]

Figure 2: The application of Tyvek brand roofing underlayment [9]

Breathable films and composites are used more and more often on a wide basis as high-strength breathable roofing underlay material for the construction industry. Breathable membranes, made of polythene or polypropylene, are resistant to water penetration from above, but are permeable to water vapour from inside the house. Breathable membranes are designed to allow the release of water vapour, without the need for roof ventilation[10,11]. Figure 3 demonstrates the use of roofing underlay consisting of a breathable membrane.

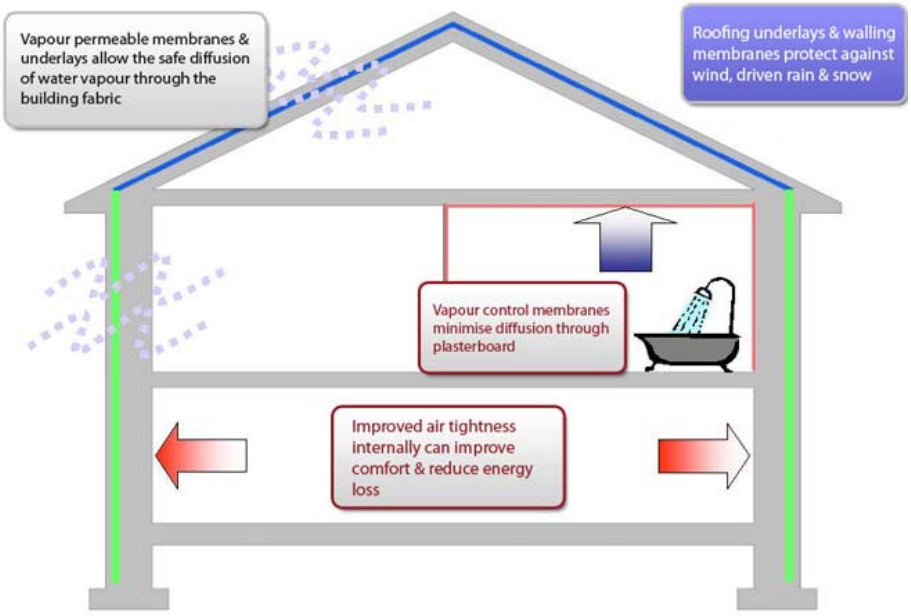

Figure 3: Demonstration of how Daltex's construction underlays and membranes work[12]

2.2 Shingle

Roof shingles are a roof covering consisting of individual overlapping elements. These elements are normally flat rectangular shapes that are laid in rows without the side edges overlapping, a single layer is used to ensure a water-resistant result. Shingles are laid from the bottom edge of the roof up, with the bottom edge of each row overlapping the previous row by about one third of its length.

Roofing shingles are ideal for use on a range of buildings such as bus shelters, stables, sports pavilions, beach huts, chalets, summer houses, etc.They can also be used for vertical cladding on houses and flats. Roofing shingles are suitable for use on any building, temporary or permanent, domestic or commercial, with a roof pitch from 20° to vertical. When applied in accordance with the fixing instructions, Roofing shingles are easily installed and will provide a long lasting, highly decorative, weatherproof roof finish in a variety of pitched roof situations[13,14]. Figure 4 and 5 shows the use of shingles in roofing industry.

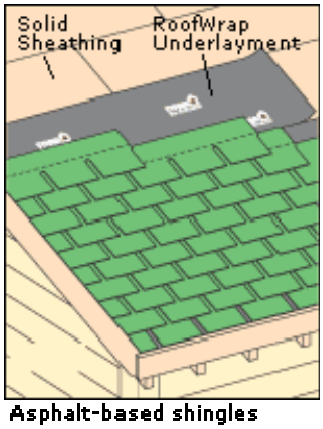

Figure 4: Demonstration of the use of underlayment and shingle

Figure 5: Application of shingle

Shingles have been made of various materials such as wood shingle, slate shingle, asbestos-cement, bitumen-soaked paper covered with aggregate (asphalt shingle) or ceramic. Due to increased fire hazard, wood shingles and paper-based asphalt shingles have become less common than fiberglass-based asphalt shingles[15]. Nonwovens made of glass fiber are the most common used material for shingles.

2.3 Bituminous Roofing Membrane

Polymer-modified bituminous membranes were developed in Europe in the mid-1960s and have been used in North America since 1975. The use of polymers as a roofing material is continuously increasing. The function of a roof is to protect the building from environmental factors such as light, wind rain, snow loads, temperature changes, hail and storms. Therefore, the material used on a roof must withstand those factors for many years.

Most types of roofing materials are bituminous and synthetic (polymeric) roofing membranes. The most commonly used roofing and waterproofing is made by combaning asphalt or coal tar pitch (bitumen) with felts or mats or fabrics.

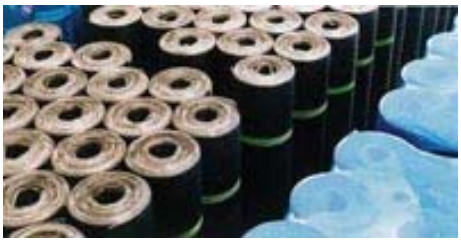

Figure 6: Bituminous membrane rolls with different minerals

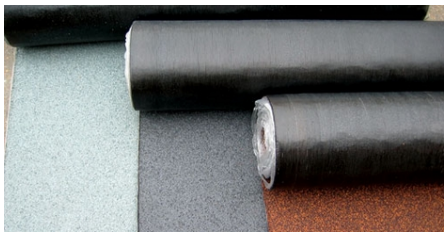

Figure 7: Bituminous membranes

It is produced in web form and supplied in rolls. Both sides are covered with mineral materials (e.g. sand) in order to help prevent the coating from running off when exposed to heat or from sticking together in the rolls and to provide protection from atmospheric conditions[16,17,18].

Bituminous membranes are made up of more than one product:

- Bitumen - Mixed with a filler (limestone or sand) component such as sand. Polymers are added to the bitumen such as APP (atactic polypropylene) a plastic additive that gives rigidity and tear resistance, or SBS (styrene butadiene styrene) a rubber additive that gives more elastic benefits.
- Base Products - Polyester, fibre glass, rag fibre (hessian), and paper. These products are bought in roll format and are pulled through the bitumen mixes on huge rollers. The base

product becomes saturated in huge tanks by the tar like bitumen substance, creating rolls of waterproof material.

- Mineral - The small granules are added to the top of the felt, decreasing the products fire vulnerability.
- Thin, transparent film - This product is added to the base of the felt during manufacturing on all torch-on products. This stops the felt from sticking to itself when rolled up during the packaging process[19].

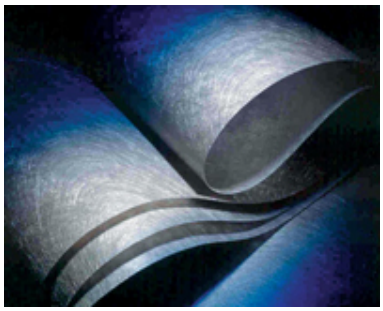

Figure 8: Polyester nonwoven carrier

Figure 9: Application of bituminous membrane on a roof

The base product is the layer used as carrier and it is the layer that is exposed to high temperature during the bitumen coating process. This layer is also giving the necessary strength to the end product and has certain performance requirements like dimensional stability, bitumen absorbancy, and thickness. The most comman nonwoven carriers are made of glass fibers and polyester nonwovens.

3.Project for development of a Bituminous Roofing Membrane Carrier

Nonwovens stabilize or reinforce commercial asphalt roofing systems and the use use of nonwovens as carriers for bituminous roofing membranes constitute a major market, especially for those materials that maintain a sufficient level of mechanical properties and dimensional stability at the bitumen impregnation temperature, roughly between 180 and 200C.

Polyester nonwovens are synthetic materials with a melting point of about 265C. Therefore this high processing temperature causes polyester to shrink. It is important to have a certain dimensional stability for a smooth process. Since the shrinkage is not homogenous, the end product's physical uniformity is deformed. Current products those are imported to Turkey for this purpose uses a combination of melamine chemicals which are considered as harmful chemicals to give the dimensional stability. Melamine is described as being harmful if swallowed, inhaled or absorbed through the skin. Chronic exposure may cause cancer or reproductive damage. It is eye, skin and respiratory irritant. During the fixing process to give dimensional stability, the operators may be exposed to melamine during chemical preparation and drying process.

The development of a carrier that does not incorporates the use of melamine chemical requires a deep study to improve the fiber bonding techniques (i.e. mechanical bonding, binder bonding) to make a dimensionally stable polyester nonwoven suitable for bitumen coating application. The future of this study will include a development of a polyester spunbond nonwoven carrier fabric in cooperation with General Tekstil San. Tic. AS. / Gaziantep to be used as carrier for bituminous insulation material with certain dimensional stability without the use of melamine. An experiment set-up would be necessary to be developed to check the dimensional stability of the carrier.

Conclusions

The use of technical textiles and nonwovens in the building and construction industry has solved a number of technical building problems and enabled new working practices to be introduced. Only a few weatherproofing end uses on roofs are briefly described in this study.

The use of nonwovens in the roofing market has grown steadily for the past three decades or so as end users crave the benefits that several types of nonwovens bring to the final product. Basically, two types of roofing mats use nonwovens technology--wetlaid glass and spunbond polyester. According to industry estimates, these two types of roofing mats comprise about two-thirds of roofing systems used in modern roofing styles[4,20].

A polyester spunbond nonwoven is used as carrier for bitumen coating process. Development of a dimensionally stable carrier that still meets the expectations of the coating companies without the use of melamine chemical as binder is a challanging project for a nonwoven producer. Trials and test are necessary to be made to develop a spunbond nonwoven carrier in cooperation with machinery and chemical producers that will perform in an acceptable performance without the use of melamine.

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UTILIZATION OF RECYCLED POST CONSUMER CARPET WASTE FIBERS AS REINFORCEMENT IN LIGHTWEIGHT CEMENTITIOUS COMPOSITES

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ABSTRACT

A large amount of post-consumer carpet waste is discarded into landfills. The need to recycle this waste is increasing due to the lack of available landfill spaces in many parts of the world, environmental concerns, and resource conservation. Fibers from carpet waste have been successfully used as reinforcement in concrete, typically at 0.1 to 1% volume fraction, for enhanced toughness. In this study, lightweight cementitious composites were fabricated that were reinforced with recycled carpet fibers at up to 25% volume fraction. The density of the lightweight composites ranges from 0.7 to 1.0 g/cm3, which was about 30 to 40% of the density of typical concrete. Besides moisture and termite resistant, the lightweight composites were very tough and could be cut and fastened with ordinary tools and nails. Both three-point bending test and drop weight impact test were performed and the test results are reported in this paper. The lightweight composites are suitable for applications such as underlayment and wall panels for buildings, as well as for outdoor structures.

Key Words: recycled fibers, construction material, fiber reinforcement, cementitious composites

1. INTRODUCTION

World fiber production has been steadily increasing in the past few decades, now exceeding 64 million tons per year. In the United States of America alone, about 11.9 million tons of textile waste was generated, accounting for 4.7 wt % of the total municipal solid waste, and 15.9% of textile waste was recovered in 2007 [1]. The outlets of the recovered textile waste include reuse, material recycling, and energy recovery. To enhance the environmental benefits of recycling, more effort is needed on research and development for better technologies that are cleaner, more energy efficient, and less expensive. Considering the diversity of fibrous waste and structures, many technologies must work in concert in an integrated industry in order to have any noticeable impact on fibrous waste recovery [2].

Most of the fibrous waste is composed of natural and synthetic polymeric materials such as cotton, wool, silk, polyester, nylon, polypropylene, etc. Frequently different types of polymers and other materials are integrated to form an article, such as blended textiles, carpet, conveyer belts, composites, to name a few. Post consumer carpet provides an example of complex materials systems that are very difficult to recycle. However, since carpet is more consistent in structure and material composition than most other single fibrous products, and because of the large volume of carpet waste, significant effort has been devoted to carpet waste collection and recycling.

The U.S. carpet industry consumes about 1.4 million tons of fibers per year, including nylon (60%), polyolefin (29%), polyester (10%), and wool (0.3%). Among the nylon face fiber, about 40% is nylon 6 and 60% is nylon 6,6. The type of carpet is classified according to the type of face fibers used. A nylon 6 carpet, for instance, contains not only nylon 6 face fibers but also backing fibers (polypropylene) and adhesive (latex and filler). About 70% of the carpet produced is for replacing old carpet, typically after 5-10 years of service. The rate of carpet disposal is about 2-3 million tons per year in the U.S. [3], and about 4-6 million tons per year worldwide. The tufted structure (Figure 1) is the most common type of carpet with a 90% market share. It typically consists of two layers of backing (mostly polypropylene fabrics), joined by $CaCO_3$ filled styrene-butadiene latex rubber (SBR), and face fibers (majority being nylon 6 and nylon 6,6 textured yarns) tufted into the primary backing. The SBR adhesive is a thermoset material, which cannot be remelted or reshaped. The compositions of typical carpet waste are shown in Figure 2.

In a fiber recycling industry capable of processing a large amount of the waste discarded, a collection network is needed to provide sufficient and consistent supply of post consumer fiber waste at reasonable cost. Some technologies such as nylon 6 depolymerization can convert waste into

desirable products, but they are only limited to certain types of waste such as nylon 6 carpet. Other technologies must coexist so that most of the waste collected can be utilized for profitable recycling, without quickly saturating any market of a product or having to discard some of the waste into landfills. As the past experience has shown, it cannot be economically competitive if only a fraction of the carpet waste collected can be recycled, while the rest has to be sent back to landfills. Many technologies are available and more are being developed to recycle fibrous waste [2,4].

Using carpet waste fibers to make cement boards has been investigated in this study. To convert carpet waste into fibers for cement boards, only simple shedding is needed, avoiding expensive component identification and separation. Even unidentified waste stream and residue from many other recycling processes can be used. The overall process is low cost and the market for the product is very large.

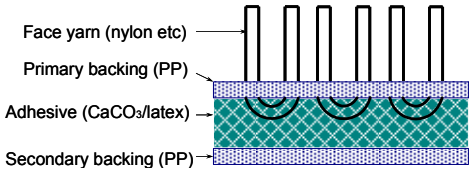

Figure 1. Tufted carpet structure

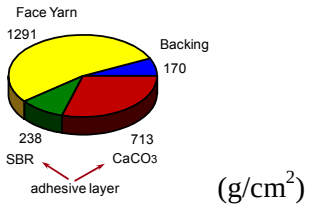

Figure 2. Typical carpet composition

2. LIGHTWEIGHT CEMENT BOARD

The lightweight cement boards developed in this study have a very high fiber content, up to 20 wt. % and are very light in weight (0.7-1.0 g/cm^3) with a porous structure. In comparison, the typical concrete has a density of 2.4 g/cm^3 and the typical lightweight concrete has a density of: 1.7 g/cm^3. The lightweight cement boards developed in this study can be easily cut with ordinary tools and they work well with nails and screws.

The lightweight cement boards are prepared using fibers from post consumer carpet containing nylon and polypropylene (PP) fibers after coarse shredding. Fiber length =50-70 mm, and Portland cement: gray and white.

Sample preparation involves the following steps:

1. Cement, fibers and water are mixed in a container
2. Placed in a mold by hand
3. Allowed to cure for 7 days
4. Cut with ordinary saw for testing

Table 1 illustrates the fiber/cement/water ratios of the samples prepared and their densities. It is noted that density decreases with increase in fiber content, and it increases with increase in cement content.

Table 1 Fiber/cement/water ratios and density

Sample	Weight ratios			Density
No.	Fiber	Water	Cement	g/cm^3
1	0.200	1.081	1 (Gray)	0.678
2	0.159	0.690	1 (Gray)	0.841
3	0.150	0.608	1 (Gray)	0.848
4	0.128	0.690	1 (Gray)	0.953
5	0.200	1.081	1 (white)	0.729
6	0.150	0.608	1 (white)	0.943
7	0.100	0.595	1 (white)	1.001

3. FLEXURAL PROPERTIES

The flexural properties of the lightweight cement boards are measured in a three-point bending on an Instron machine. The specimens are about 30 mm in height. The test configuration is shown in Figure 3. Five specimens are tested for each sample. Typical test curves are shown in Figure 4.

The flexural test specimens failed in a ductile mode. To characterize the toughness characteristics, Toughness Index (TI_5) is used, which is defined in Figure 5. For brittle material, TI_5=1, for elastic-plastic materials, TI_5=9, and for strain softening materials, TI_5 is between 1 and 9. The toughness index values for the test samples are summarized in Table 2, from which is can be observed that all the samples show similar toughness index values and their behavior is close to that of an elastic-plastic materials. Figure 6 shows that the flexural strength and modulus of the samples decrease with the fiber to cement ratio.

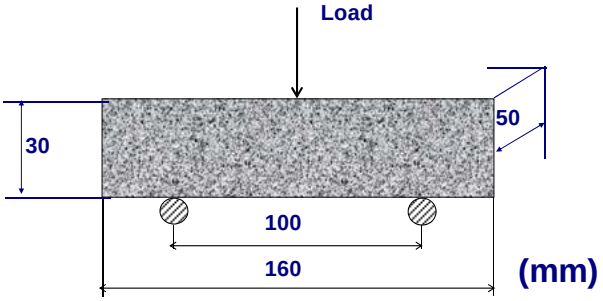

Figure 3. Three point flexural test configuration

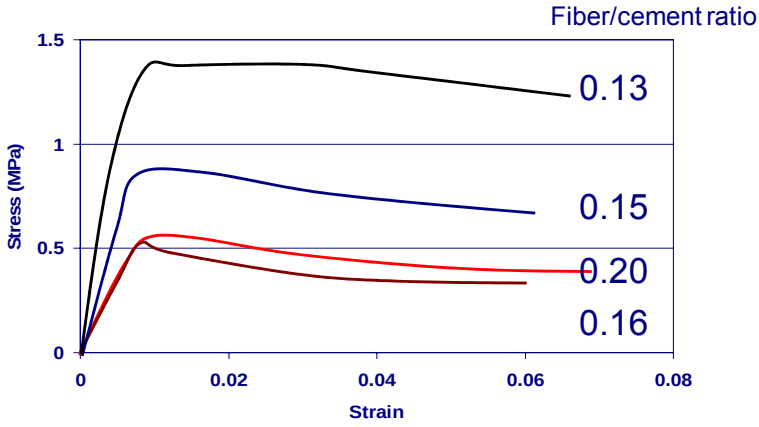

Figure 4. Typical flexural test curves (Gray cement specimens)

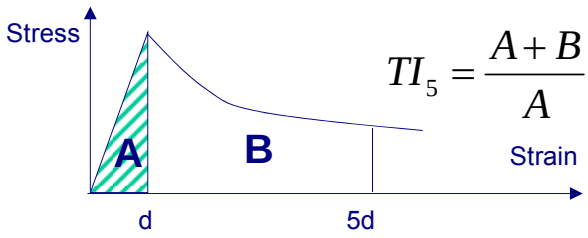

Figure 5. Definition of Toughness Index

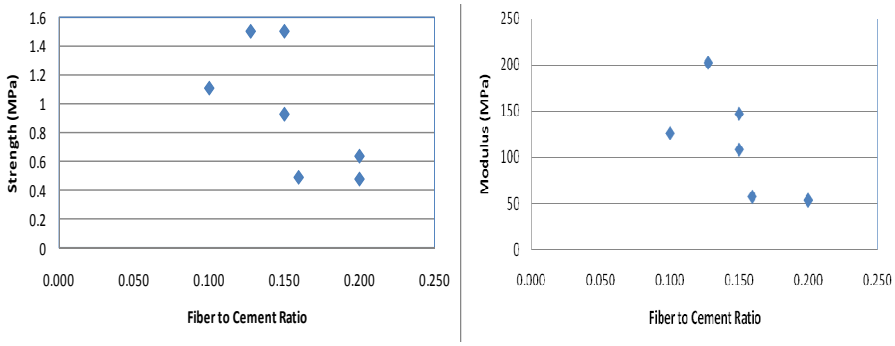

Figure 6. Flexural strength and modulus versus fiber to cement ratio

Table 2. Flexural Toughness Index

Sample	Weight ratios			TI_5
No.	Fiber	Water	Cement	
1	0.200	1.081	1 (Gray)	7.62
2	0.159	0.690	1 (Gray)	7.34
3	0.150	0.608	1 (Gray)	7.56
4	0.128	0.690	1 (Gray)	7.94
5	0.200	1.081	1 (white)	7.85
6	0.150	0.608	1 (white)	7.76
7	0.100	0.595	1 (white)	7.50

4. IMPACT PROPERTIES

The impact test is performed on an Instron Dynatub tester. The impact velocity is 2.15 m/sec. The specimen dimensions are 100 x 100 x 28.3 (thickness) mm. Energy absorption and maximum force are recorded. Figure 7 indicates that the impact energy is not sensitive to the fiber to cement ratio. This is due to the total absorption of the impact energy at the test level by the specimens, as most damages are not visible from the back side. The maximum impact force, however, decreases with the fiber to cement ratio and increases with the density of the samples.

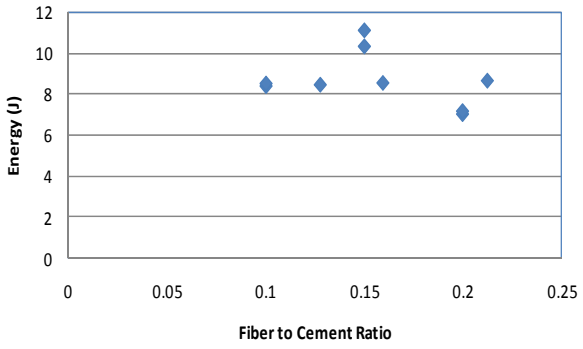

Figure 7. Impact energy vs. fiber to cement ratio

5. SUMMARY

A large amount of fibrous waste is disposed of in landfills each year. This not only poses economical and environmental concerns to the society but also represents a waste of resources. In this study, lightweight cement boards are developed. Their characteristics include: lightweight, tough, easy to handle and install, moisture, mold, and termite resistant. This method of fiber recycling may work together with other technologies to maximize the use of waste collected. This method of recycling only requires simple shedding, thus avoiding expensive component identification and separation.

Even unidentified waste stream and residue from many other recycling processes can be used. The overall process is low cost and the market for the product is very large. Potential applications include underlayment board for tiles, wall panels replacing dry wall for wet locations, and outdoor patio tiles and stones.

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WET FINISHING FOR NONWOVENS – VERSATILE PROCESS CONCEPTS FOR ADDING VALUE TO NONWOVENS

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ABSTRACT

For the use as top layers in baby diapers and incontinence products spunbond nonwovens often receive a hydrophilic finish. The low add on of suitable spin finishes by kiss roll applicator is a long established process in the nonwoven industry.
A complete process concept has been developed by Andritz Küsters and a product range tailor-made for the demands of the spunbond production at speeds of up to 1,000 m/min.
For all processes of chemical wet finishing the interaction between machine and chemistry is of vital importance. The technological concept was created in close cooperation between Andritz Küsters and leading suppliers of finishing chemicals. This resulted in a process engineering customised to the special requirements and properties of the finishing liquors used.
This complete concept includes preparation, storage, dosing and application of the added surfactants as well as the subsequent drying. Also the market demands of quality control and reproducibility have been met by a new process control & documentation system.
Outstanding features of the concept are minimum fabric impact, prevention of bacterial growth by excellent liquor handling as well as special flexibility and maximum production stability.

Keywords: wet finishing of spunbond nonwovens, diaper, top sheet, hydrophilic application

1. GENERAL

The following paper will show technical aspects of the wet finishing process of spunbond nonwovens. The main focus will be on hydrophilic treatment for the final use in absorbent hygiene products.

2. ABSORBENT HYGIENE PRODUCTS

Modern disposable baby diapers and incontinence products have a layered construction that allows the transfer and distribution of liquid (urine) to an absorbent core structure, where it is locked in.
Basic layers:

1. cloth-like back sheet: an outer shell of breathable polyethylene film or a nonwoven and film composite that prevents wetness and soil transfer
2. absorbent core: an inner layer of a mixture of cellulose pulp and superabsorbent polymers (SAP) for wetness absorption

3. ADL: acquisition and distribution layer that transfers wetness to the absorbent layer
4. top sheet: a layer nearest the skin made of nonwoven material

The construction is kept together by adhesives. Tapes are used to keep the diaper securely fastened.

Latest diaper generations are distinguished by their ultra-thin design with a fluff-pulpless core. Here the cellulose pulp of the absorbent core is substituted by more use of SAP, which leads to a 20% slimmer design with no sacrifice in performance. Additionally it was announced by diaper producers that the decrease in weight leads to reductions in key environmental indicators like global warming potential.

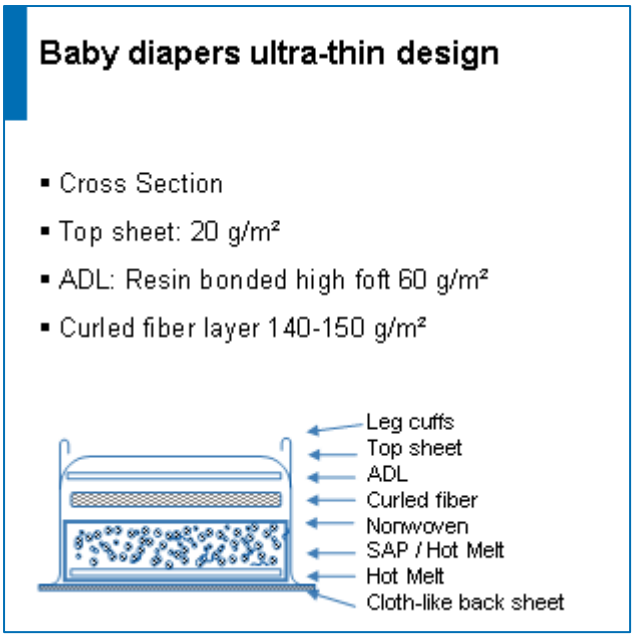

Figure 1: Baby diapers ultra-thin design, basic layers

Beside the main function of locking urine a modern diaper must fulfill user-linked attributes like body conforming, stretch ability, cloth-like aesthetics, skin care, odor prevention as well as convenience.
Worldwide a market of 415 billion converted products is estimated for 2010, thereof 29 billion adult care, 127 billion baby care and 259 billion femcare products.
With a statistic consumption of 4,380 units in the first 42 months and approx. 675,000 newborn babies in Germany in 2009 the statistic leads to a request of 2,957 billion diapers. This request is accompanied by the sales of 2,891 billion units at the same time. This corresponds to a market share of 97.8 %. Latest analyses show an even higher consumption of approx. 5,500 units in the first 42 months.
The global consumption of disposable baby diapers and training pants will grow at an average annual rate of 2.8 %. The growth in undeveloped market regions of the world continues to be the primary source of this volume growth.
The above described market size shows the importance of the end product and all linked processes within the value chain.

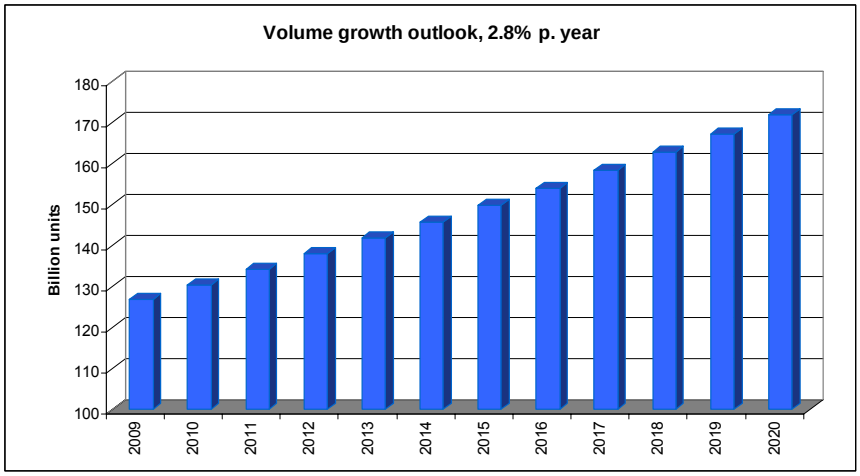

Figure 2: Baby care market, global consumption estimation

Baby Care Product Demand / Consumption

Age	Average Units/Day	Sum
0-12 Month	5,0	1825
12-24 Month	4,5	1643
24-36 Month	2,0	730
36-42 Month	1,0	182

~ 4380 units (taped/pants) / baby in 42 month

Figure 3: Baby care product demand / consumption

3. PROCESS DEMANDS

Spunbond nonwovens based on PP polymers have hydrophobic properties. When used as top sheet material, the surface that is in contact with the baby's skin has to be hydrophilic, because the liquids (urine) have to flow into the diaper core. In order to change the hydrophobic into the needed hydrophilic polymer properties a surfactant is applied by a wet finishing process during the spunbond production. The surfactants are basically an emulsion of cationic or anionic components and demineralised water. The surfactant treatment reduces the surface tension of the nonwoven, reduces the contact angle with the liquid and allows it to pass. Flow dynamics within the diaper core prevent liquids from returning to the surface.

On closer examination of the value chain of spunbond nonwovens there are several different demands from converter to producer and finally to machinery, chemicals and raw material supplier. Converters have the main focus on nonwoven properties.

In the particular case of hydrophilic finishing these properties are linked to the oil pick up (OPU). The oil pick up is the pure surfactant remaining on the nonwoven after the drying process. The OPU has a direct impact on all relevant tested properties like liquid strike-through time, multiple liquid strike-through time, coverstock wetback and run off.

On the other hand nonwoven producers have to take into consideration the profitability, reliability, reproducibility and efficiency of their processes. All the mentioned demands of converters and producers have to be considered by the interacting of chemicals and machinery suppliers in order to achieve the required quality objectives.

The following example shall give an idea of how challenging the process of hydrophilic finishing is. Depending on the surfactant, either hydrophilic or permanent hydrophilic, an oil pick up of 0.3 to 0.7% has to be applied. The chemical suppliers recommend an emulsion concentration of up to 10%. Treating a 12 gsm PP spunbond nonwoven with a wet pick up of approx. 10% the applied volume is not more than 1 µm high at an even distribution over the nonwoven width. High speeds up to 1,000 m/min and the hydrophobic properties of PP spunbond make it difficult to apply a water based emulsion. The market tendency of thinner and lighter products (<10gsm) makes it even more difficult to apply any surfactant with an even distribution.

4. HYDROPHILIC FINISHING

The single-sided low add on with the kiss roll applicator is mainly used in the hydrophilic or permanent hydrophilic finishing of nonwovens, inline at production speeds of up to 1,000 m/min. In addition, further spin finishes, such as anti-statics or care products, are well suited for this application. Today's state of the art process supplier Andritz can deliver the complete range from dosing, application to drying as well as inline process control customised to the special requirements and properties of the spin finishes used.

4.1 DOSING

The machine concept is of particular importance as the products finished on the kiss roll applicator are used in the area of hygiene and because the spin finishes used are prone to bacterial contamination due to the lack of preserving agents. This is why the liquor guiding is designed to prevent any dead zones, to allow all parts of the system to be easily cleaned and as little as possible liquor to be in the process. These process requirements were taken into account by the design of the preparation and dosing station neXdos. To prevent bacterial growth and contamination the entire system is geared to allow for continuous and slight liquor movement. All tubing has gas-welded seams to prevent liquor build-up here, too. Foam formation is prevented through level-controlled mixers and liquor feed below the liquor level.

At the same time the shear sensitivity of certain liquors is counteracted with the choice of a suitable pump technology. This sophisticated handling of the liquor and its individual properties warrants best production quality.

Figure 4: neXdos preparation and dosing station

4.2 APPLICATION

The basic principle of the kiss roll application is shown in the graphic below. An applicator roll rotates in the liquor trough and picks up an even liquor film on its surface. This is then transferred onto the web. The fabric is led by two guide rolls to touch the applicator roll only lightly – just “kissing” it – hence the name kiss roll applicator.

The crucial feature of the kiss roll process is the friction between applicator roll and web. Due to a high difference speed the desired low add on of approx. 10% wet pick-up (WPU) is achieved. In order to guarantee even and reproducible process conditions, the liquor level in the trough must remain constant. This is attained through an overflow. The surplus liquor is channelled back into the trough. Together with the liquor continuously added (according to consumption) liquor circulation is created. The liquor is constantly kept moving. This guarantees a constant liquor quality without liquor depletion and simultaneously prevents contamination and bacterial growth.

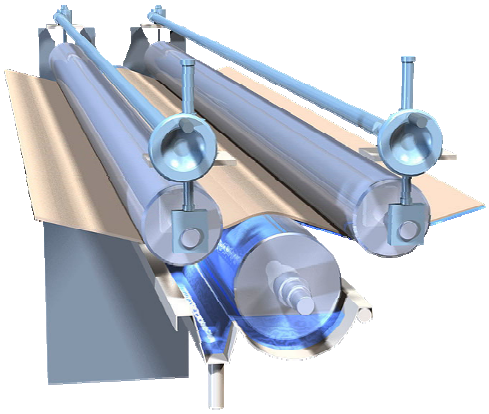

Figure 5: principle of low add on application by kissroll applicator

With the machine concept neXkiss Andritz Küsters has introduced a product range tailor-made for the demands of the spunbond production at speeds of up to 1,000 m/min.

The newly developed neXkiss plus incorporates special flexibility and maximum production versatility. Outstanding features of the machine concept are the compact design and with this the little space requirements, as well as short web guiding which warrants maximum production stability and minimum fabric impact.

The following overview shows by way of material run schemes and short descriptions the manifold production possibilities the concept offers through the combination of individual machine elements.

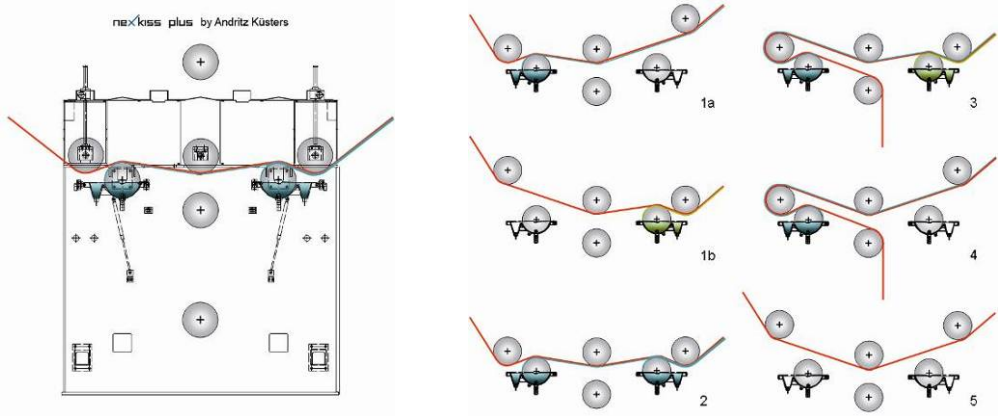

Figure 6: neXkiss plus principle, material run schemes

1a and 1b – Single-sided application and quick spin finish change

2 – Single-sided application, adding up

3 – Two-sided coating

4 – Single-sided application on the back of the fabric

5 – Machine by-pass

4.3 DRYING

Andritz Perfojet, leading supplier of spunlace technology, has almost 15 years of experience in high capacity and high efficiency drying. As a result, the PERFOdry air through dryer is designed with dual temperature zones and separate burners with independent temperature control. This unique design allows a perfect optimisation of the air speeds and temperature at the wet end and at the dry end. Low maintenance costs and downtimes are also unique features of this dryer. As an example, the bearing boxes are located outside the heated area for an extended lifetime of bearings and low maintenance costs. And the roll surface cleaning and maintenance is highly facilitated by the "roll-out" design.

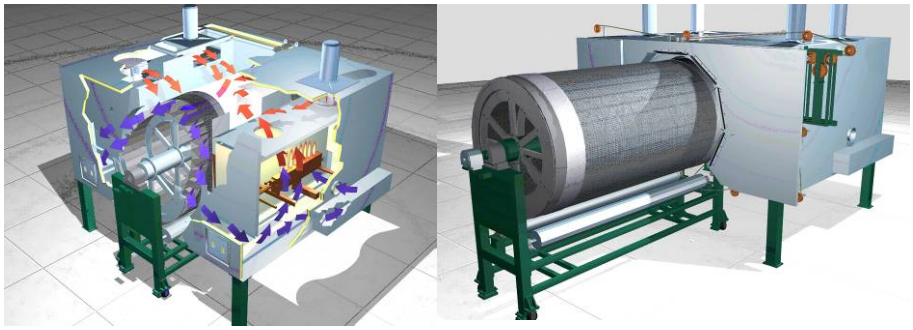

Figure 7: PERFOdry, high capacity and high efficiency dryer

4.4 PROCESS CONTROL

For the use as top layers in baby diapers and incontinence products spunbond nonwovens often receive a hydrophilic finish in the form of stripes due to special performance requirements of the diaper.
The precise setting of the stripe application is a very elaborate process which, until recently, was only possible by investing a lot of time, generating a considerable quantity of waste and under a high degree of process uncertainty.
Position and width of the stripes set at the kiss roll applicator vary during the process. This, among others, is due to material tension, temperature impact in the dryer and different shrinkage behaviours of coated and uncoated zones. In addition, the amount of spin finish applied is so low that it cannot be recognised by the naked eye after drying.
neXdetect is a measuring technology which reliably detects the position and width of the invisible chemical application in the form of stripes on the dry material during the running production process. The system compares the actual values with the target values and tolerances, the specification selected earlier from a recipe administration. The operator receives information about deviations from the specification immediately, together with recommendations on how to correct the process.

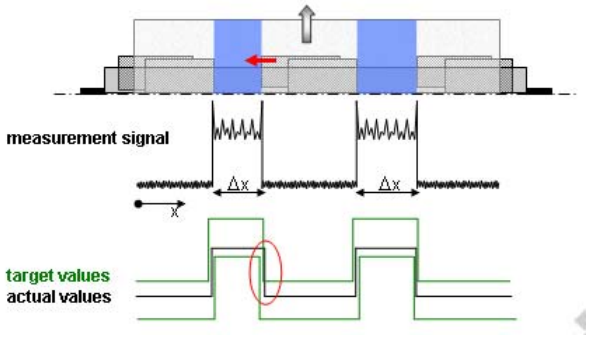

Figure 8: neXdetect principle, measuring of stripe application

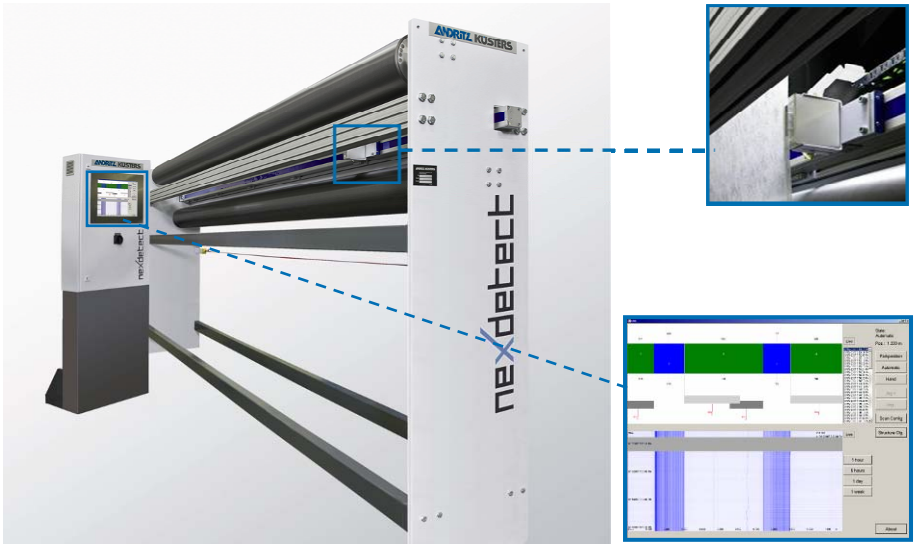

Figure 9: neXdetect measuring head and display

5. OUTLOOK

The hydrophilic properties of the nonwoven material are guaranteed by the oil pick up (OPU). The inline measurement of the OPU is not possible today. Normally a very time consuming batch inspection by samples is made during running production. By this method a consistent quality control, as required by a modern process, is impossible.

The OPU is a function of Wet Pick Up (WPU) and surfactant concentration. Thus the optimal process control is a combination of automatic dosing and controlled application. The new patented process by Andritz allows a controlled WPU.

In order to feed the needed quality and quantity of the spin finish emulsion to the applicator an automatic dosing system calculates the necessary mass flow rates of demineralised water and surfactant. The recipe considers all corresponding production parameters like material weight, width and speed. The

single controlled mass flows are pumped via a static mixer to the application trough. If needed a dwell time tank can be placed intermediary with sensitive shear force stirring. Additionally the dosing can be equipped with heat exchangers for temperature control.

Besides the speed (rpm) of the application roll the WPU is influenced by emulsion viscosity, roll surface, immersion bath depth, web tension and enlacement angle. To make sure that the needed quantity of spin finish emulsion is added completely to the nonwoven web, the speed of the application roll is controlled. The control variable is the liquor level in the trough. If the liquor level remains constant the dosed (input) and added (output) quantity of spin finish emulsion must be even. I.e. the dosed quantity (WPU) must be added completely to the nonwoven web. If the nonwoven web would not pick up all available spin finish the liquor level in the bath would swell.

Securing the right concentration and mass flow of the spin finish emulsion should guarantee the requested OPU. This patented process solution minimizes in addition toady's operating errors like wrong dosing or adjustment of the kiss roll applicator by changes in spin finish viscosity.

An additional patented improvement for a better homogeneity of the liquor film on the application roll during high speed processes underlines the continuous development process of Andritz wet finishing equipment.

The speed control of the application roll is a very sensitive adjustment. The higher the rpm of the application roll the higher is the theoretical pick up. But especially at high speeds the applied quantity and corresponding rpm is not a linear function. With the use of an enlaced doctor belt which is fixed across the application roll the function is kept linear. Thus the WPU can be controlled more sensitively. Additionally the porous belt homogenizes the liquor film on the application roll and reduces the rip off of the film (fish eyes).

Air turbulences created by the speed of the nonwoven in front of the application roll also have a negative impact on the application process. Film rip offs are the consequence. First tests have shown that by the correct positioning of the doctor belt the working surface for such disturbances can be reduced to a minimum.

With the technologies neXdos, neXkiss, PERFOdry and neXdetect Andritz Küsters and Perfojet offer a comprehensive process concept for low add on in the nonwovens industry which has been tailor made for high speed application in the spunbond production.

ZETA POTENTIAL OF PP AND PET NONWOVENS FUNCTIONALIZED WITH AMMONIUM COMPOUNDS – RELATION WITH BIOLOGICAL PROPERTIES

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ABSTRACT

Surface modification of textiles is usually performed to improve various functional properties, such as wetting, adhesion, antibacterial activity, etc. Functionalization of textiles can be obtained thanks to different techniques, such as physical vapour deposition (PVD), grafting, using electroless deposition, chemical vapour deposition (CVD), using enzymes or nanoparticles, sol-gel process, layer-by-layer deposition, plasma treatments or using aqueous solutions. Thus, surface modifications can be provided either by physical interactions (which do not involve chemical reactions with fabrics) or by chemical interactions (which involve chemical reactions on the fabric surface), and functional compounds or polymers can be added to the fabric surface to provide different functions.

For instance, in order to reduce the spreading of pathogenic diseases by contamination (transfer) and colonization of bacteria on surfaces, biocidal materials are developed to prevent fabric surfaces, including nonwovens, from bacterial and fungal growth. Thus, ammonium compounds or polymers were deposited on polypropylene (PP) and polyethylene terephtalate (PET) nonwovens by a traditional textile finishing way, using a normal dipping–pad–dry method.

Biological tests, such as viability and vitality tests were used to determine both the cytotoxicity of active chemicals and functional nonwovens, according to the European Standards ISO10993-5.

Both the inhibition zone test and zeta potential measurements revealed the good fixation and the presence of active substances on the surface, which persist even after washing.

Key words: Nonwovens, ammoniums compounds, functional polymers, padding, zeta potential.

1. INTRODUCTION

Among the various ways available to modify the surface of textiles, we can quote ammonium compounds, which can be use either as cationic softeners or antibacterial agents.

Various approaches to surface modification can then be used:

• changes of the physico-chemical properties of surface such as the wettability (hydrophilic / hydrophobic), the surface charge (electrostatic forces involved) or the roughness (topography),

• chemical grafting of molecules on the surface or the deposition of molecules [1]. This technique will be developed in this study.

In the production of textile fibers (both processing and finishing), electrokinetic measurements seem to be a interesting and suitable tool in characterizing the surface properties of fibers such as the adhesivity of various chemicals, mechanism of washing, modification of surfaces by adsorption of ionic surfactants, etc. At each stage of pretreatment or treatment, the zeta potential, as a function of pH or of the concentration of a surface active agent, could indicate surface modification.

Zeta potential [2] is the electrical potential at the shear plan between a charged surface and a liquid when moving with respect to each other, according to the electrical double layer or Stern layer model (Figure 1). It originated from the dissociation of acidic or basic functional groups on the polymer surface and the preferential adsorption of cations or anions in competition with the adsorption of water molecules. Thus, the measurement of streaming potential is used to determine the electric charge of a surface.

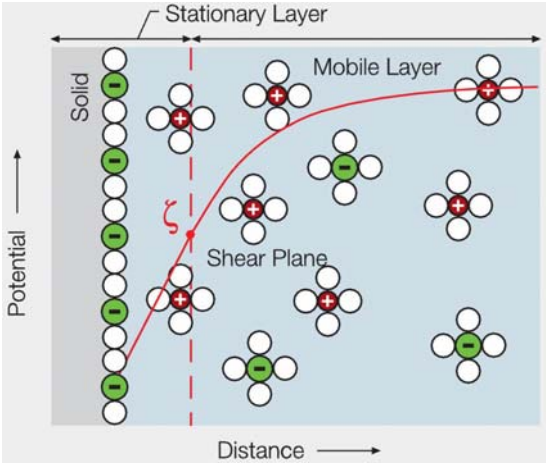

Figure 1. Stern model [3]

The electrokinetic potential at the textile fibers/solution interface is commonly measured by the streaming potential technique. A plug of fibers is usually formed and the hydrodynamic pressure difference is applied across the plug. The laminar flow of electrolyte through the plug induces the electrokinetic effect, i.e., potential difference at both ends of the plug sensored by a pair of reversible electrodes, such as Ag/AgCl reference electrodes. The extended Helmholtz-Smoluchowski equation can be used to calculate the zeta potential, defined by the following relationship:

$$\xi = \frac{E}{P}\frac{\eta}{\varepsilon\varepsilon_0}\lambda \quad \text{avec} \quad \frac{\eta}{\varepsilon\varepsilon_0} = 16.32 - 0.35197T + 0.00351T^2$$

where ξ is the zeta potential (mV), E the streaming potential (mV), P the applied pressure (mbar), , η the dynamic viscosity of the measuring fluid and λ its conductivity (mS/cm), $\varepsilon\varepsilon_0$ the permittivity of the electrolyte and T the temperature (°C).

An increase in negative zeta potential with increasing values of pH is due to an increase in the dissociation of superficial acid groups. In the case of basic groups on the surface, the positive electric charge increases with the reduction in pH. The formation of the double electric layer thus is mainly caused by the dissociation of acid functional groups. A low value of the isoelectric point indicates an acid character of surface. [5]

2. MATERIALS AND METHODS

2.1. Materials

Two textile structures, of different chemical nature and manufacturing, were studied:

• a PET (polyethylene terephthalate) nonwoven of 200 g/m², manufactured by the Nonwoven Platform of IFTH (France) according to a dry way, and consolidated by hydroentranglement (thickness: 0.78 mm),

• a PP (polypropylene) nonwoven of 30 g/m², obtained by a melting way (meltblown technology of extrusion-blowing) (thickness: 0.25 mm).

2.2. Surface modification

Three antibacterial agents were used to functionalize the surfaces of nonwovens:

• an antibacterial molecule QA of quaternary ammonium type (soluble in water) is used in association with a binder (2%), on PP nonwovens,

• two functional polymers, P1 (quaternary ammonium) and Px (triamine), both soluble in ethanol (Catalyse Ltd), on PET nonwovens (Figure 2a and b).

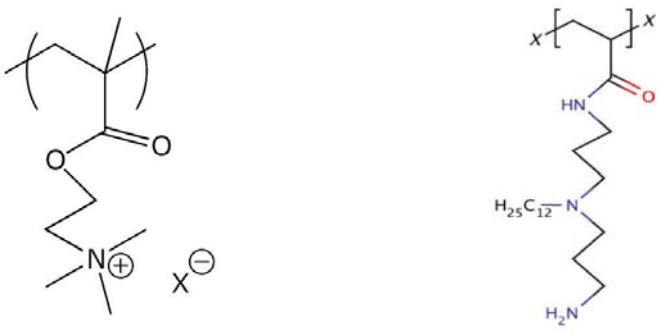

Figure 2. a) Molecule of P1; b) Molecule of Px

The application of these active principles on nonwovens is made by impregnation in the formulation bath and squeezing between two rollers under pressure (4 bars; 2 m/min; 3 passages). The nonwovens are then dryied (110 °C for 2 min), followed by a curing step (150 °C for 1 min 30 s for formulations with binder) in an oven.

Finally, the functionalized materials undergo 3 cycles of washing with distilled water (at 37 °C with a bath ratio of 1/100), to eliminate the unfixed chemicals. The bath of washing is renewed at each cycle. Stored washing water is then analyzed for each cycle of washing (dosage of AB by Gas Phase Chromatography; of P1 by potentiometry; and of Px by pH measurements).

2.3 Surface characterizations

2.3.1. Inhibition zone test (GRB, ISO 20743:2007)

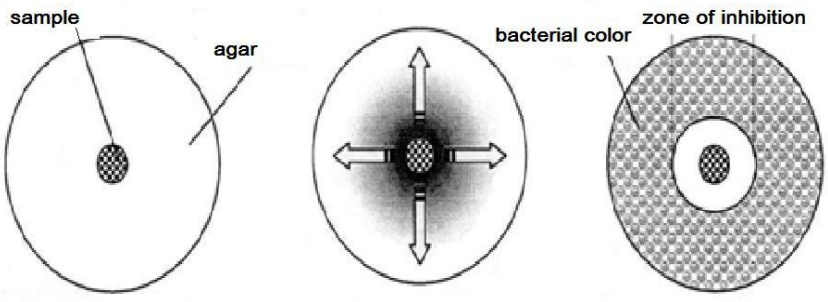

Figure 3. Schematic principle of the agar diffusion method (11 mm diameter disks)

The agar diffusion method (with agar uniformly inoculated with a suspension of the bacteria to be studied) or method of discs, made in a petri dish disk (Figure 3) was used to confirm the fixation of ammonium compounds or polymers on the nonwoven surface. Briefly, the bacterial suspension (*S.aureus* CIP224) was spread on the surface of an agar plate, where functionalized nonwovens were then placed. After a 24h incubation at 37 °C, inhibition of the proliferation of the bacteria were measured with a ruler and recorded in mm.

2.3.2. Biological tests (GBR, ISO 10993-5)

For biological tests, according to the International and European Standards (ISO 10993-5/EN 30993-5), 11 mm-diameter disk samples were used for each group. All in vitro cell incubations were performed at 37 °C in a 5% CO_2 atmosphere and 100% relative humidity in an incubator.

2.3.2.1. Viability test

The viability tests evaluated the 50% lethal concentration LC50 by using the colony-forming method with the L132 epithelial cells. Cells were exposed to increasing concentrations of each antibacterial agent (0 to 50 µg ml^{-1}), without renewal of the growth medium during the experiments. After 9 days, the medium was removed and the colonies were coloured with crystal violet (0.2 wt.%). The clones were then counted using a binocular microscope. At least five repeated experiments were performed in triplicates for each concentration. Results are expressed as the mean percentage ± SD with respect to the control (100%), and are compared with nickel as positive control. [7]

2.3.2.2. Cell vitality test

After gamma sterilization, sample disks from functionalized nonwovens maintained by rings were placed in the bottom of 24-well plates. L132 epithelial cells were then gently seeded in each well, and the wells with no sample disk but only cell suspension served as controls. After respectively 3 and 6 days of incubation, without renewal of the medium, the culture medium was removed from each well and 500 µl of a diluted solution of Alamar Blue (10%), a non-toxic and fluorescent dye, was deposited in each well. After 3h of incubation, 200 µl of each well solutions were transferred into 96-well plates and the absorbance was measured by fluorescence (Twinkle LB970TM Berthold) at 560 nm. The cell vitality rate was calculated as the absorbance of living respiratory cells (indicative of the metabolic activity) on functionalized nonwoven samples divided by that of control cells. Three samples were used in each group for the test. A minimum of five separate experiments for each group were conducted and final results were expressed as the mean percentage ± SD with respect to the control culture (100%). [7]

2.3.3. Streaming potential measurements

Experimentally, the measurements of the zeta potentials of nonwoven fabrics were performed with a ZETACAD (CAD Instruments, France) zeta meter using a cylindrical glass cell for fibrous or granular samples (Figure 4). This apparatus measures the electrical potential difference generated by the imposed movement of an electrolyte solution through a fiber plug. The liquid is forced throught the fiber plug using nitrogen gas and its pressure is controlled by a pressure sensor. The cell is mounted between a pair of Ag/AgCl wire electrodes to measure the electrical potential difference between the plug ends.

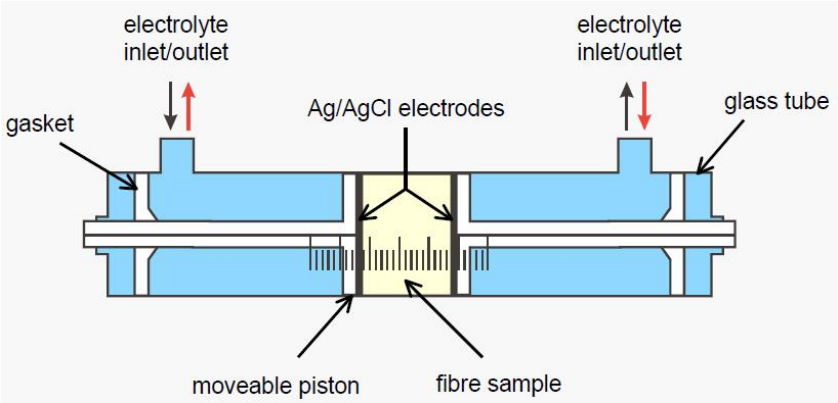

Figure 4. Drawing of a cylindrical cell used in zeta potential measurements [4]

Sample preparation

The samples to be studied by streaming potential measurements have to be mechanically and chemically stable in the aqueous solutions used for the experiment. First, the geometry of the plug must be consolidated in the measuring cell. This can be checked by rinsing with the equilibrium liquid through repeatedly applying ΔP in both directions until finding a constant signal, and by eliminating air

bubbles in the capillary system. Another issue to consider is the necessity that the solid has reached chemical equilibrium with the permeating liquid (during 24h before measurements).

The streaming potential was measured in a 10^{-3} M KCl solution at different pH (by adding either HCl or KOH at 10^{-1} M), by measuring ΔE as a function of ΔP.

3. RESULTS

3.1. Viability test

The first biological test was carried out to determine the cytotoxicity of the three ammonium compounds and functional polymers. Polymers P1 and Px both induced mortality rates in L132 epithelial cells for 25 mg l^{-1} (ppm) and QA molecules for 3 mg l^{-1} (ppm). Thus, these chemicals are more cytotoxic than the positive control (nickel, at 35 mg l^{-1}).

3.2. Inhibition zone test

The observation of this test showed that there was no diffusion zone for all P1 or Px-functionalized PET nonwovens, which meant that there was a good fixation for these functional polymers to the PET nonwovens after washing, which also implied the optimal cycles of washing process.

However, the QA-functionalized PP nonwoven showed a slight diffusion zone (around 1.5 cm), which meant that even after three washing cycles, a tiny amount of QA molecules still remain unfixed to the PP nonwovens.

3.3. Vitality test / Cytotoxicity

A high vitality was observed for L132 cells in direct contact with untreated PP or PET nonwovens (Figure 5). After respectively 3 and 6 days, a vitality of 6-3% with P1 and 9-5% with Px was found on PET nonwovens that showed a strong and significantly decrease of cellular activity.

With QA molecules, cell vitality on PP nonwovens also decreased significantly, but to a much lesser extent than with P1 or Px functional polymers.

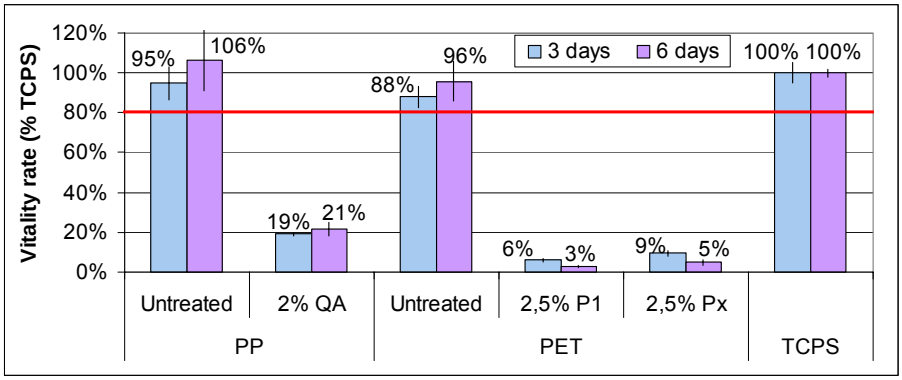

Figure 5. Cell vitality test on epithelial cells of functionalized PP and PET nonwovens after 3 and 6 days of incubation

Thus, whatever the concentration and the nature of the antibacterial agent, the functionalized and washed nonwovens show a toxicity towards the epithelial cells (no biocompatibility). This means that it remains many active chemicals on the surface of the functionalized materials, even after washing (otherwise, there will be no toxicity).

An optimization of the formulation may be interesting to minimize the toxic effects of these treatments of functionalization.

3.4. Zeta potential measurements

3.4.1. Functionalized nonwovens with P1

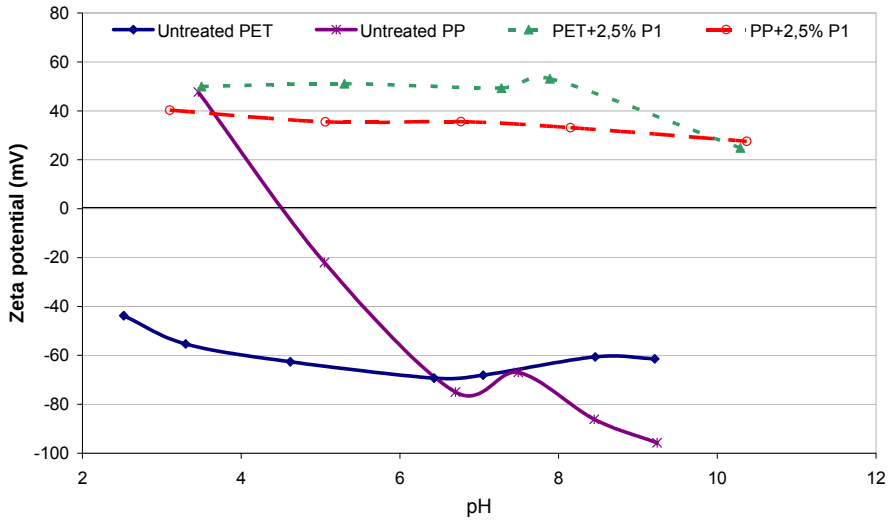

Figure 6. Evolution of the zeta potential of PP and PET nonwovens functionalized with 2.5% of P1

The zeta potential vs. pH curves (Figure 6) show the expected behavior for unmodified PP nonwovens: although the unmodified polypropylene has no dissociable groups, its isoelectric point (IEP) is in the acidic range around pH 4.5. This can be explained by a preferential adsorption of anions from solution, i.e. OH^- from the always present autodissociation of water, which creates a negative surface charge. [6]

Concerning untreated PET nonwovens, zeta potential is negative, meaning that the PET nonwovens are negatively charged at their surface. At basic pH, these negative charges resulted from carboxylic group dissociation of PET.

At the opposite, for both PP and PET nonwovens functionalized with the cationic polymer P1, the zeta potential is positive whatever the pH value. That means that there are positive charges on the surface of nonwovens induced by the quaternary ammonium of the polymer P1. These charges are the same whatever the pH. We can conclude that the cationic polymer P1 remains at the surface of both PP and PET nonwovens after washing.

3.4.2. Functionalized nonwovens with Px

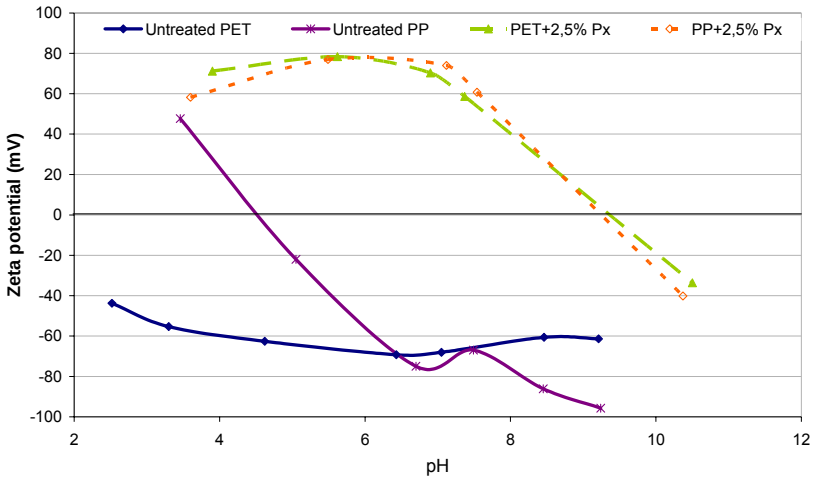

Figure 7. Evolution of the zeta potential of PP and PET nonwovens functionalized with 2.5% of Px

For both PP and PET nonwovens functionnalized with the polymer Px, Figure 7 shows a positive zeta potential until a pH = 9.5. Over this value of pH, also called IEP, the negative zeta potential is still going on decreasing with the increasing alkaline pH. Amine groups of polymer Px are protonated at acidic pH thus leading to positive zeta potential. After pH = 9.5, since polymer Px is not charged, it can be explained by a preferential adsorption of anions (OH^-) on the surface of nonwovens.

3.4.3. Functionalized nonwovens with AB

For both PP and PET nonwovens functionnalized with the QA molecules, the zeta potential remains positive until a pH = 8.5 (Figure 8). Thus, for these QA-functionalized nonwovens, zeta potential varies with the pH, and becames negative in alkaline area. However, quaternary ammonium should have stable positive zeta potential (as described with polymer P1). The decrease of the zeta potential after pH 7 lets us presume that the surface of these nonwovens is only partially covered.

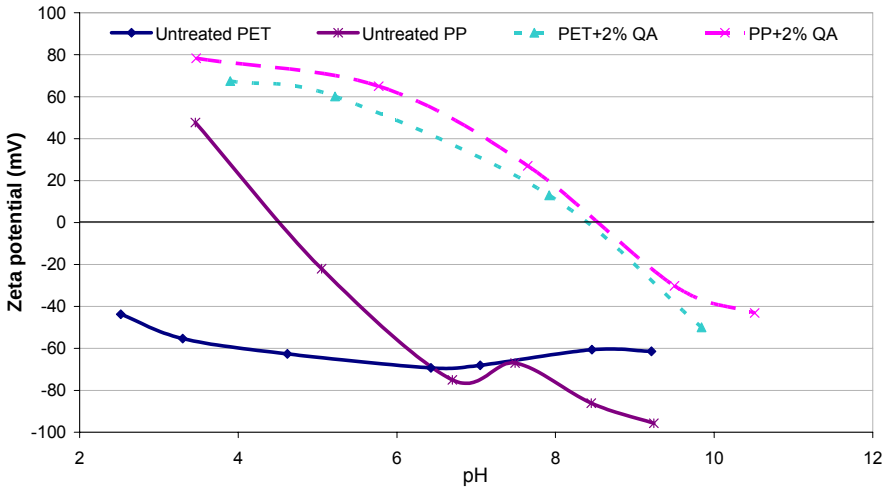

Figure 8. Evolution of the zeta potential of PP and PET nonwovens functionalized with 2% of QA

4. DISCUSSIONS AND CONCLUSIONS

After determining (by the cell viability test) the rather important toxicity toward L132 epithelial cells of the ammonium compounds and functional polymers used in this study and their rather good fixation on the PP and PET nonwovens (by diffusion test), it was shown by cell vitality test that the functionalized nonwovens, even after three washing cycles, present a high and significant toxicity with biological medium. Cytotoxicity (cell vitality test) is not directly dependant on toxicity of chemicals (cell viability tests) but is also related to the organization of these on the surface of nonwovens.

Zeta potential as a function of pH is a very sensitive method for characterizing electrokinetic properties of nonwovens which are mainly determined by the chemical composition of the surface, and the presence or absence of surface functional groups. Both original PP and PET nonwovens show a rather hydrophobic surface where the adsorption of electrolyte ions causes the surface charge and the negative zeta potential.

The positive zeta potential at acidic pH confirms the surface modification of the nonwovens with:

• total embedding of PET fibers by functional polymers (P1 or Px)

• partial embedding of PP fibers by antibacterial molecules of QA.

The three different functionalizations (with chemicals susceptible to be used as antibacterial agents) have a significantly different effect on the zeta potential curves. P1 looks like a permanent quaternary ammonium since it doesn't depend on the pH (always positive zeta potential), but is influence by either the structure or the nature of the substrate. At the opposite, Px and QA present respectively similar zeta potential curves for both PP and PET nonwovens. The curves of functionalized nonwovens are shifted to more basic conditions (IEP around pH 8-9 for Px and QA).

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3D MODELING FOR CLOTHING PRODUCTS BASED ON SURFACE MESHING

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ABSTRACT

The paper presents 3D modeling, synthesis aspects of modeling and numerical simulation of clothing in the virtual environment, highlighting the benefits realization and verification of prototypes in virtual environment.The starting point is represent by fabric simulation in the virtual environment. The clothing 3D modeling requires informations about fabric structure properties, nature and the geometry specifications of the shapes.

The fabric behavior is influenceted by its raw materials structure, his composition and the finishing technology. The textile surface properties are affect by more aspects, such constituent yarns properties, yarn geometry structures, interactions between threads and fabric model. The overall properties are complex, there are observing the non-linearity, anisotropy and hysteresis.

Clothing products virtual modeling arises from the need to simplify the process of design and manufacturing. Simulation is necessary to visualize the shape and garment appearance, and its behavior and response to various requirements.

Concerns in this area have resulted in the techniques establishment of discrete or continuous, static or dynamic modeling for simulation the textile surfaces used in the clothing or decorative product. Also, has tried to simulate dynamic behavior of the clothing on virtual models, using the finite element method.

Unfortunately, like many real phenomena, it is impossible to accurately model clothes, or to simulate them motion. This would require modeling the quantum level. Even if they understand fully the implications of physics, the problem would be in terms of computational intractable.

Keywords : surface meshing, textile surface, 3d simulation, finite element

1. INTRODUCTION

The 3D simulation is using the finite element method (FEM). The textile material is divide in triangular surface meshes and after they are determining the loading conditions (figure 1).

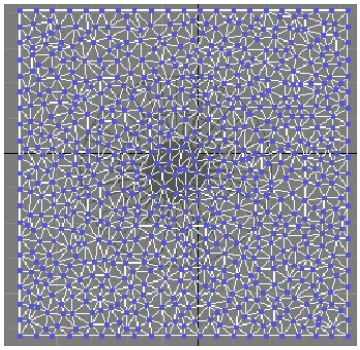

Figure 1: Simulation of the textile surface using FEM

Textile surface can be described by its geometry and physical properties and can be perceived as a two-dimensional surface is moving in a three-dimensional space. For virtual modeling it must be known

parameters like length, width, thickness and density of the textile surface. Simulation in virtual environment involves the knowledge of internal and external forces that act on the textile material and analyze the tensions and strains that may occur in collision with a rigid body.

In the last twenty years, have implemented a variety of techniques to address a virtual simulation of textile surface. Community engineers solved this problem using finite element methods. A detailed study of the early concerns in this area can be found in Ng and Grimsdale[1]. A year later, Gibson and Mirtich[2] presented a study less customized, but generally in computer graphics techniques for deformable model.

Simulation of dynamic behavior requires the knowledge of textile surface forces acting on the textile surface and internal knowledge of the collisions nature.

Particle-system based modeling technique is based on the theory of elastic springs. Particle-system based model has the potential to be defined by several parameters, such as the amount of particles, constant elastic traction (horizontal and vertical direction), bending (in vertical or horizontal), shear, damping constants , friction and stiffness.

3D modeling of textile surface was proposed 3 techniques:

- continuous modeling ➔ material is modeled as an elastic surface and is done by finite element simulation [1].

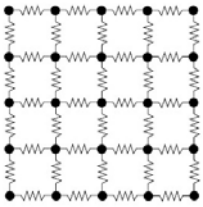

Figure 2 : Discrete modeling

- discrete modeling ➔ material is considered as a mechanism of thread(figure 2).
- dynamic modeling ➔ material is modeled as a moving body, on which internal and external forces act.

Generally, surface textiles - fabric, is made up of structures of warp and weft threads, woven together to form different structures. Overall surface properties of textiles are affected by many factors, such as constituent yarn properties, model weaving, yarn geometry structures and the interactions between threads. As a result, the overall properties of the fabrics are extremely complex, observing the non-linearity, anisotropy. In decoration product, textile material suffer some deformation due to multiple requests (bending, stretchung, friction) in multiple directions.

To capture the complex behavior that occurs in the textile material, modeling shall be made at a scale of resolution in the visible interactions between threads [6].

Internal forces like bend, stretch, and shear allow the fabric to deform in a realistic manner. External forces such as gravity, wind, and collisions make the textile surface to interact with its environment. In the absence of these forces, a piece of fabric will remain a flat plane[7].

A simulation of textile surface should be effective and reflect the true reality. Systems capable of real-time animation can produce great results, but uninteresting for textile, because results are not reliable and can be used to predict how you will look and behave in the real world textile surface. Simulation of high fidelity the textile surface require hours to produce a few seconds of animation. Simulation of 3D textile surface material is an important step in the design of products for items for interior decoration. Virtual simulation helps to the analyze prototypes that will be made from textile material and quickly find the best prototypes. The advantage of simulation in virtual environment is offering new alternatives in product design.

2. MODELING METHOD USED FOR DIFFERENT ASPECTS OF THE TEXTILE SURFACE

Simulation is the process of replicating the movement and deformation of a piece of fabric to mimic how the textile surface would react in the real world.

The cloth is flexible and determine by a complex drape configuration. Generally, surface textiles - fabric, is made up of structures of warp and weft threads, woven together to form different structures. Overall surface properties of textiles are affected by many factors, such as constituent yarn properties, model weaving, yarn geometry structures and the interactions between threads intersite. As a result, the overall properties of the fabrics are extremely complex, observing the non-linearity, anisotropy and hysteresis.

Discrete modeling technique is based on the theory of elastic springs. Discrete model (model based on particles) has the potential to be defined by several parameters, such as the amount of particles, constant elastic traction (horizontal and vertical direction), bending (in vertical or horizontal), shear, damping constants , friction and stiffness.

Textile surface can be modeled as a set of particles joined together by elastic springs (lengths of wires). Rigidity yarns and weaving points defining the surface properties of textile virtual model.

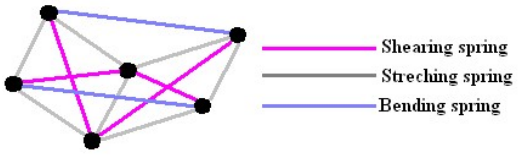

Figure 3 : Particle – based model

For virtual textile surface modeling when stretching, bending or shear, they are using 3 types of springs (figure 3) :

- for stretching springs are used to define a mesh of the polygonal surface, whereby the textile surface is represented;
- for bending (waving) springs used bows made by the union of 2 nodes which have arcs (links) common;
- for shear springs use bows made by interconnecting nodes belonging to a polygonal mesh in the surface but are not adjacent.

3. RESULTS : DYNAMIC SIMULATION OF TEXTILE SURFACE

Using different parameter settings, it is possible to simulate different types of textile surfaces. A known problem of the discrete models is the superelastic effect [5], small elastic constant produces unreal behavior of textile surface (due to excessive extension)(figure 4). To simulate as closely as textile surface starts to define the area of textiles as a polygonal surface mesh composed of several (small sized rectangular areas), obtained through the mesh surface.

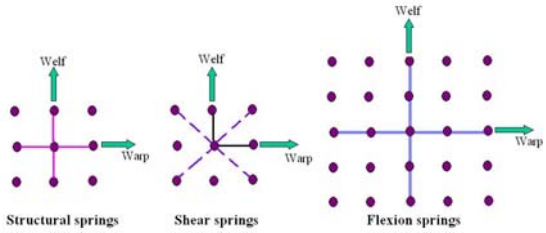

Figure 4 : Mass – spring model by Provot[4]

The simulation and visualization of the fabric behavior in virtual environment, comes with the following necessary requirements:

- Geometric definition of product parts and objects (figure 6) that will interact with the textile surface (figure 5);

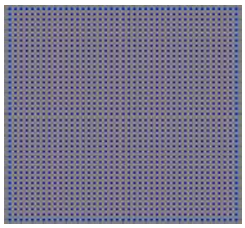

Figure 5: Textile surface- virtual modeling

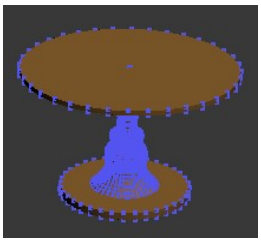

Figure 6: Collision object such as a table

- Optical laws simulation (rendering);
- Laws of dynamic simulation (forces, acceleration, speed, energy);

- Interaction with ambient environment (collision detection and response). Simulation is mainly concentrated textile surface interactions between different parts of the textile surface and other objects.
- Definition of constraint points (pins).

If the first 2 problems are classical problems 3D, the last 2 require solving problems[6]:

- Textile material behavior in simulation ➔ simulation of textile material relates to the mechanical model adopted to approximate the behavior of surface parts textile. May be a parametric model to facilitate simulation of different materials (cotton, wool, silk, ...).
- Handling constraints ➔ constraints concern the limits of movement of the product, such as those caused by the seams of the parties or by placing a fabric drapes on rings
- Collision detection: to detect collisions between the product and other bodies (human or objects around) but also between different parts of the product (auto collision).
- Physical answer : any collision require a response to be interpreted to be simulated the effects of friction and resistance.
- Cloth density mesh.

The cloth mesh density is show how dense the mesh has to be to achieve the waiting results. Making the mesh too dense will slow down the system, while having your mesh at too low resolution might not give you the folds or detail you want to see (figure 8).

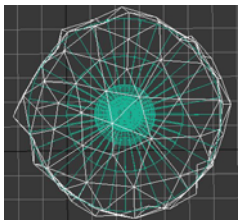

Figure 8 : Mesh density = 0.06

Using the 3dmax software, we can simulate te collision between the textile surface and the table [7].

The Garment maker turns a shape into a garment panel, that can be use in cloth simulation. First it must define the textile surface like a cloth (figure 9) and the table like a rigid body. The cloth modifier using is set to have a 0.4 density.

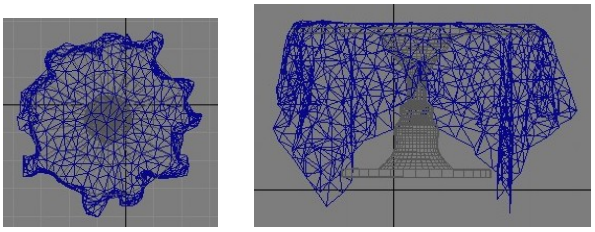

Figure 9: Textile surface meshing (mesh density = 0.4)

A simulation of textile surface should be realistic and must reflect the natural behavior of the fabric. The textile surface simulation of high fidelity require hours to produce a few seconds of animation. Fabric simulation is an approximation of how real fabric would react under certain circumstances.

4. CONCLUSION

The benefits of modeling and virtual simulation of textile surface are:

➔ checking the correspondence between product characteristics and destination of its use;

➔ time economy;

➔ achieving optimal physical prototype;

➔ economy of materials;

➔ high productivity of personnel responsible for physical realization of prototypes;

➔ quick response to market requirements.

Design of products for interior decoration and clothing products involves the modeling and simulation of 3D textile surface material and it is required the hardware and software from last generation.

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A CASE STUDY ABOUT STICKING OF POLYMERIC PACKAGE TO AUTOMOBILE SEAT UPHOLSTERY SURFACE

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ABSTRACT

Automobile industry is preferred to use polymeric materials like polyethylene which can be recycled, as a package material. Widely used PE packaging materials are generally low density polyethylene (LDPE) or linear low density polyethylene (LLDPE) types. Due to the behaviour difference of the both PE types to heat, the effectiveness from sun lights has changed. Automobile seat package material choosing is important especially in summer depending on weather conditions, production and waiting time; due to the thermal behaviour difference of the PE types.

Keywords: polyethylene, automobile seat upholstery, heat, black

1. INTRODUCTION

The usage of polymeric materials has increased day by day in daily life within the last 50 years. As well as most of fibres which are used for production of the conventional textile materials are polymers, the technical textiles products as fire retardant and high performance fabric are also made from polymeric materials. Also floor coverings, door-window systems, wall coverings, beach and sea materials are produced from polymeric materials too [1]. By the development of the technology, developments of the existing polymers are taking place according to the generated demand, like polyethylene (PE). The various types of polyethylene and different characteristics of every type enable PE usage in a wide range. Different usage areas need different characteristics [2].

After packaging of seat assembles of new produced cars with PE film, these new cars are parked in a open park. During the period of leaving cars in the park and transfer of them, all cars stay in the park and time by time these cars location may be changed by an authorized person. Especially in summer session the sun light directly go into cars through windshield on to the seat assembles specially on front seats.

Although all types of PE composed of CH_2-CH_2 molecular structure; macromolecular structure, macromolecular chain length and molecular orientation generate different types of PE. The types of commercial PE are low density (LDPE) which density is between 0,910-0,925 g/cm^3, linear low density (LLDPE) which density is between 0,910-0,925 g/cm^3, high density (HDPE) which density is between 0,941-0,965 g/cm^3 and ultra high molecular weight (UHMWPE) which density is between 0,93-0,94g/cm^3. Contrary to HDPE, which is rigid due to linear macro molecular chain, LDPE is flexible because its macromolecular chain has branch. UHMWPE composed of extremely long macromolecular chain and the polymer chains can attain a parallel orientation greater than 95% and a level of crystallinity of up to 85% [2, 4].

The type of PE can be identified from the difference of macromolecular structure, orientation and chain length by using analytical test devices. In addition these tests, fiber tensile strength should be used for differentiate of high performance and conventional fiber types [1].

2. MATERIAL AND METHOD

This study focus on the solving of a problem related to sticking package materials on to seat upholstery fabrics of new produced cars during staying in open park areas in summer seasons. Having getting on to the car which was under sunlight and sitting on the car seat in daytime and transfer the cars from one location to an other, the sticking problem (figure 1) was seen after getting

out the driver from the car. Although some of packaging films caused this type of problem, the others did not cause it in same conditions with respect to season, park conditions and upholstery fabric properties (physical and color aspects).

The upholstery fabric is a laminated fabric composed of woven fabric as a upper surface, foam as a filling and knitted fabric as a lining. Lining material color is white, the woven fabric color is heavily black and the foam is ecru.

Figure 1: An ımage of the sticking problem between the upholstery fabric and the package film

Two different examinations were used in this study. One of them is analyzing the problem by analytical devices with using DSC and FT-IR, the other is examination of the problem by microscope. Analytical examination applied both to the stuck part of the packaging film, not-stuck part of the packaging film, not used packaging film which is same lot and not used packaging film which is not same lot with the film that caused sticking problem.

3. RESULT AND DISCUSSION

According to microscopic analyses results the package film was not melted and only stuck onto black part of the upper surface fabric and did not stick onto the red and blue yarns (Figure 2). The sticking character of the packaging film somewhat like loading something to press a softened (heated about t_g point) packaging film onto upholstery fabric, and exactly not like result from melting of the packaging film. Although all yarns which are contact with package film are polyethylene-teraphtalate, the differences between red, blue and black yarns are the color and yarn motion in the weaving structure.

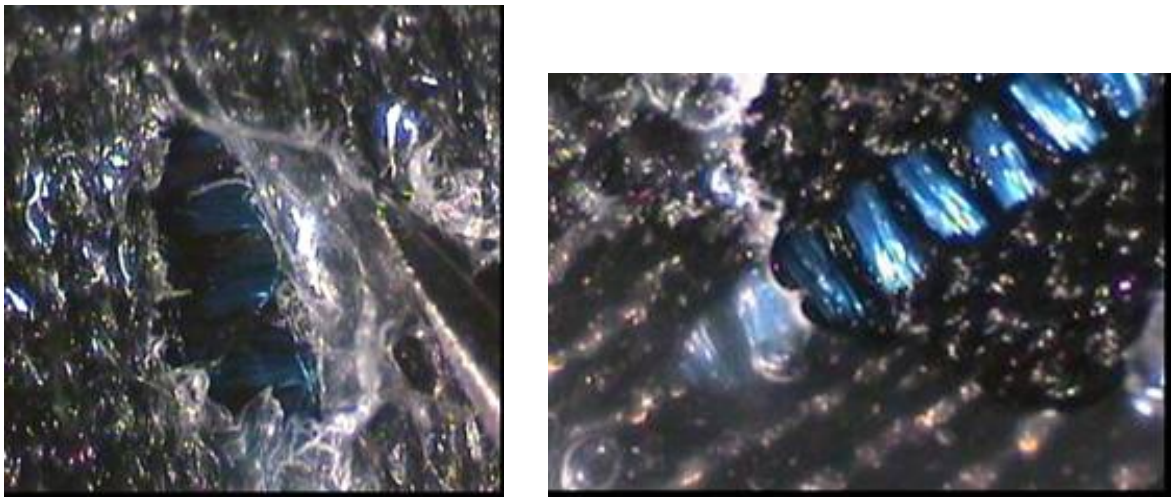

Figure 2: A view of microscobic analyses

According to FT-IR and DSC analysis results, the packaging film which caused the sticking problem was LDPE, the troubleless packaging film was LLDPE (Table 1, Figure 3 and 4. From the FT-IR spectra of the stuck part and not stuck part of the packaging film, there was a pick at the point of 909 cm^{-1} which belongs to vinyl group. From the FT-IR spectrum of the not used but the same lot packaging film, there was not any pick at the point of 909 cm^{-1} (Figure 4). DSC thermogram also proved the formation of this type of group due to the decomposition of molecule, because the thermogram of the stuck and not stuck part of the packaging film involves many t_g points. Normally, as seen from not used but same lot packaging film's thermogram LDPE give one t_g point (Figure 3). It is known that LLDPE involve vinyl group but LDPE does not involve this group [1, 3]. In our opinion, this group was formed results from decomposition of the branch on PE macromolecule. The decomposition was propagated by the sunlight and the color of the yarn.

It was observed from DSC thermogram that although the melting point of the LDPE is higher than LLDPE's melting point, t_g point of the LDPE is lower than the LLDPE's t_g point (Figure 3).

It is known that black materials absorb all light beam that come on to the surface and transfer this light energy to the heat energy. It is known that the temperature of inside of the car raise high levels.

Table 1: The properties of not used and same lot packaging film, not used but not same lot packaging film, stuck part of the packaging film and not stuck part of the packaging film

Parameters	Sample Identification			
	stuck part of the packaging film	not stuck part of the packaging film	not used and same lot packaging film	not used but not same lot packaging film
Crystallinity Ratio (DSC)	%21	%24	%28	%30
Melting point	107,2	105,2	108,9	105,7
Onset point	98,0	99,8	102,4	99,5
t_g	1. 43,6 2. 65,4	1. 66,3 2. 79,3	49,6	53,8
Material type (FT-IR and DSC)	Polyethylene (PE)	Polyethylene (PE)	Polyethylene (PE)	Polyethylene (PE)

Obtained data which are that t_g point of the LDPE lower than the LLDPE's, the surface color of the upholstery fabric was black, fiber composition of the upholstery fabric was synthetic, the problem was occurred in the summer seasons, the problem was only seen in some cars which has black upholstery fabrics with the package of LDPE, the problem was not seen when the cars upholstery color different from black with the package of LDPE and the problem was not seen with the package of LLDPE if upholstery fabric color is black or not indicate that the reason of the problem was that the black upper surface fabric absorbed all sun light beam which go through windshield into car and go through film package onto fabric surface, and then transfer this light energy to the heat energy, after a long time, the surface temperature of the upholstery fabric raised over the temperature of the LDPE's tg point. Because of that the package material was softened and at that time getting on the driver into car, and sitting down on the seat, the softened packaging material was forced to stick on to the surface of the fabric and get cold at this position.

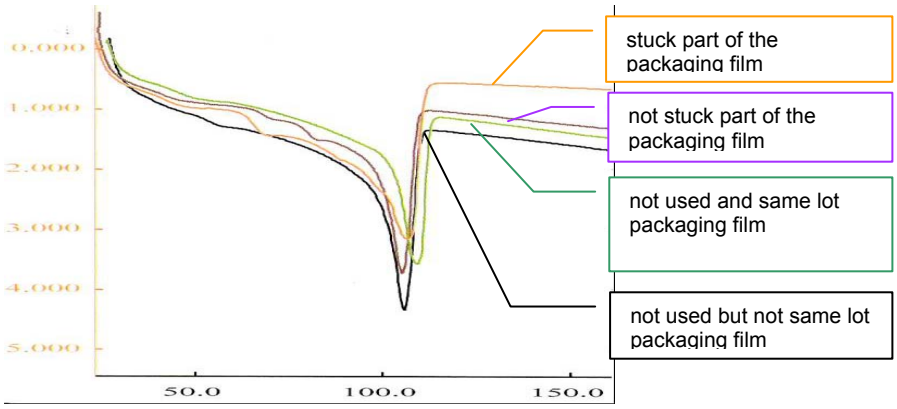

Figure 3: DSC thermograms for not used and same lot packaging film, not used but not same lot packaging film, stuck part of the packaging film and not stuck part of the packaging film

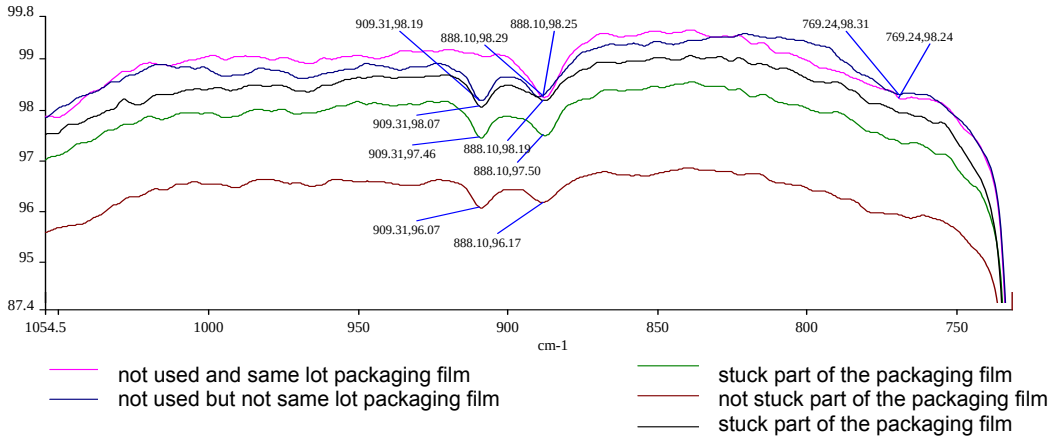

Figure 4: FT-IR spectra for not used and same lot packaging film, not used but not same lot packaging film, stuck part of the packaging film and not stuck part of the packaging film

4. CONCLUSIONS

The choice of the PE packaging film materials are very important especially in summer seasons when used upholstery fabrics with black color. Unlike LDPE packaging film, LLDPE packaging film does not cause this type of sticking problem. Because of that using LLDPE films are better than the using of LDPE films. The characterization of the PE with respect to its types can be carried out in TÜBİTAK-BUTAL according to BUTAL MH 007 standard inspection method.

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A NEW ERA IN ARCHITECTURE: TECHNICAL TEXTILES

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Technical textiles in the 1980s, the appearance and aesthetic characteristics of the term, technical features and performance for every day the increasing diversity of developed products and manufacturing techniques described is a term that has to be exposed. Because of the richness of this rapidly growing field, complex relevance to express "industrial textiles" term has remained insufficient. Another definition, specially designed or processes within any product, feature alone to fulfill a specific purpose are used in technical textile materials. Technical textiles, high technical and quality requirements (mechanical, thermal resistance, electrical resistance, such as ...) that meet the technical functions of this offer and have the ability serve as materials.

Variety of uses for technical textiles are at the present time. Some of these are, agricultural textiles (Agrotech), Construction textiles (buildtech), Technical clothing (clothtech), clothes and shoes and similar slip of the technical components, Geological textiles (Geotech), home textiles (HomeTech), industrial textiles (indutech), medical textiles (medtech), motor vehicles for the textiles (mobiltech) Automotive, ships, trains and air transport for the textiles, Ecological textiles (oekotech), packaging textiles (packtech), protective textiles (Protech), Sports textiles (sportech) like.
In Turkey and popularity never endlessly serving sectors not falling "construction industry" roll. Changing zoning status, new manufacturing techniques, functional obsolescence, disaster, investment needs, such as construction of new buildings because of the sense of the services sector to continue to provide non-stop. Requires both the construction of architecture faculty, on the other hand, in the sector service providers to implement new materials have been following and have been trying. As a result of the need for developing new materials have created excitement in architectural designs.
Construction Textiles (Buildtech) used as materials for many different reasons and may be preferable to have positive features. Also, technical textiles for use in buildings, low weight, as well as provides mechanical advantage. The rapidly growing population needs and meet the urgent requirement in these areas by geological and climatic conditions created by the struggle of the obligation because of the world textile production structures, composite materials against earthquakes in the measures taken to increase use, as exciting new techniques to reveal possible.
Coarse structure in the construction industry have both fine structure, finish and complete job, also has many products that can be used for decoration materials. Because they are high-tech, high strength, special interests ahead with elastic Emirates or coatings. Acoustic insulation materials, sewer and irrigation systems, artificial grass, Awning fabrics (home and garden materials for the textiles), coating, laminating or bonding the ground for material, combustible materials, flame-resistant carpets, power will ignite decoration materials and curtain fabrics, electrical insulation can be given as examples of suchproducts.

In this study, together with what happens in technical textiles technical textiles in the construction sector of the space, the situation in Turkey, will focus on current practices and preferences. An exciting product range and in every sector with the use of the material in both Engineering and architectural structures in our face with the output of the sector in recent years, winning one of the most successful material for the technical textiles to be in the memory is targeted.

Key words: Materials - Technical Textiles - Construction Textiles - Design - Construction Sector

A STUDY ON THE VISUAL EFFECTS OF STAINLESS STEEL YARNS IN WOVEN FABRICS

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Abstract

Today, different visual effects on woven fabrics in fashion and design context are served to individual`s tastes and they are one of the factors which guide the textile design and the technological developments.

The innovations in fiber science have been initially developed for the military and medical purposes, but later for daily-use. Fashion and design had an impact on the outgrowth of the fiber innovations.

Fashion and textile designers use new materials to show different visual effects of their designs considering the functionality of the product. One of these new materials is stainless steel. Stainless steel is produced in continuous filament forms combining flexibility of conventional yarns with high temperature resistance, thermal and electrical conductivity of steel. They are used in work clothing and carpets to discharge the statically electricity in safe. These yarns have become one of the interests of the designers.

This paper presents a study on the different visual effects of stainless steel yarn in the combination of single and double weaves structures. 6 samples of fabric are produced in single, double or multiple weave structures and evaluated in view of the use of stainless steel yarns in combination with different materials, structures, constructions and weft-warp density.

Keywords: Stainless steel yarn, single and double weave structures, visual effects

Introduction

Nowadays, designers have been pushing the limits of design and innovation by combining new materials with traditional techniques. They have incorporated unusual materials produced for different purposes and textiles for everyday wear in fashion concept. Stainless steel is one of these materials. For instance, Paco Rabanne used metal plates linked by stainless steel rings to form a dress in 1965.

The use of stainless steel as a textile fiber was an outgrowth of research for fibers to meet aerospace requirements. Stainless steel fibers were developed in 1960.

Superfine stainless-steel filaments (3-15)micrometers) are a bundle of wine wires (0,002 inch) pickled in nitric acid and drawn to their final diameter.

Stainless steel fibers are produced as both filament and staple. They can be used in complex yarns and cab be either woven or knitted. Only 1 to 3 percent of the staple fiber is needed to blend with other fibers to reduce static permanently (Rodolph, Langford, 129).

Superfine filaments of stainless steel and aluminium are made and added to fabrics in various ways. Stainless steel is employed as core yarn and wrapped around core yarns or used alone. Stainless steel is used in carpet backings to reduce static electricity. As the heat of a fire increases, the metallic fibers conduct some of the heat away from the fire, thereby decreasing the heat of the flame (Collier, Tortora, 2001, 229).

The Stainless steel yarns are continuous, flexible, durable and electrically conductive. The stainless steel multiflament is used in a wide range of applications related to anti-static, intelligent textiles, signal transfer, power transfer, heat resistant sewing yarn, termal conductivity. The yarn can be woven,knitted,sewn,quilting and embroidery techniques (Bekeart,Bekinox ® VN,March,2007).

Stainless steel is not only used for its functional properties, but also for its visual and tactile characteristics. *Jakop Schlaepfer Co. AG of St Gallen, who won the Swiss Textile Design Competition in 1995, have developed a collection of fabrics including combination of textile and metal. Reiko Sudo of Nuno Corporation uses a technique whereby stainless steel is applied to a fabric to create fluid and shiny surface. Irene Van Vliet, a dutch designer, uses copper and steel in combinations with synthetic and natural yarns and fascinated with the possibilities for woven metals with textiles (BRADDOCK, Sarah E., O'Mahanay, Marie,* 2005, 20)

In this study, the visual effects of stainless steel yarns in woven fabrics will be examined. In view of the designs yarn count, wefts per cm, weave and fabric structure will be taken into account with the features of different material and yarn qualities. The effects will be evaluated in two strands 1) assessment and classification of visual effects , 2) yarn count, wefts per cm, weave, and the contribution of the other material and yarn qualities. Whether the functionality and the visual effects of stainless steel can be evaluated altogether will be discussed.

Material

In the sample woven fabrics 20/2 Ne Cotton was used as warp yarn and, Bekinox VN*12/1x275/100Z/316L (9,1 Nm), VN 12/2x275/175S/316L (2 Nm) , VN 14/1x90/200Z/316L(9,1 Nm) stainless steel, 20/1 Ne cotton and polyester fancy yarn were used as weft yarn. Table 1 lists the properties of the yarns in sample fabrics.

The sample woven fabrics had plain and weft rib and single, double and overshot weave structures (Table 2) and they were produced on automatic Sulzer Ruti shuttle loom in 100 cm width.

Table 1. Material Properties of Warp and Weft Yarns in Sample Fabrics

Fabric sample No	Weft yarn type		Warp yarn type
	Upper Face	Back face	
1	14/1(9,1Nm) ,12/2(2 Nm) stainless steel yarn	20/ 1 Ne cotton	20/ 2 Ne cotton
2	14/1(9,1 Nm) stainless steel yarn	polyester fancy yarn	20/ 2 Ne cotton
3	12/1 (4 Nm) stainless steel yarn	20/1 Ne cotton	20/ 2 Ne cotton
4	12/1 (4 Nm) stainless steel yarn	12/1 (4 nm) stainless steel yarn	20/ 2 Ne cotton
5	12/1 (4 Nm) stainless steel yarn	polyester fancy yarn	20/ 2 Ne cotton
6	12/1(4 Nm) stainless steel yarn	polyester fancy yarn	20/ 2 Ne cotton

Method

The starting point of this study is that stainless steel may create puffy, voluminous, crinkle and shiny effects on fabric surface. A preliminary fabric was initially designed to examine the possibilities. The preliminary fabric, which was produced on an automatic shuttle loom, had plain weave, and

single and double layer structures made using 20/2 Ne cotton warp and 14/1 (4 Nm) and 12/2 Nm stainless steel weft. It had a dimension of 110x 15 cm (figure 1, ÖNLÜ, 2009). The preliminary fabric had voluminous, puffy, nearly crinkle and relief texture as expected.

5 fabrics were designed following the preliminary fabric to create the effects in combination with stainless steel, different materials, structure and construction. In the first stage of designing, the type, density and number of warp and weft yarns, structures, and constructions were described.

To reveal puffy, relief and shimmering visual effects of the designed fabrics, 3 steps were followed in the design process.

1- Choices of different material

2- Choices of structures

3- Choices of constructions.

Cotton and fancy yarns together with stainless steel yarn were chosen for weft in

order to make surfaces puffy, relief and shimmering. Single layer and multiple weave structures were employed for fabric structures.

In the third stage of designing, constructions, plain and weft rib, were preferred in a way that the visual effects could be combined with the chosen material. Table 2 lists the structures and constructions of the sample fabrics.

Table 2. Material properties of warp and weft yarn in sample fabrics

Fabric sample No	**structure**	**construction**
1	Double layer, single layer	plain
2	Single layer, extra weft	Weft rips, plain
3	Double layer, single layer	Weft rips, plain
4	Double layer, single layer	Weft rips, plain
5	Double layer, single layer	Weft rips, plain
6	Double layer, single layer	Panama, plain

Those materials excluding stainless steel, structures and constructions in sample fabrics were chosen in conjunction with the designs and, they are used in raw and white colors to emphasize the color effect of stainless steel.

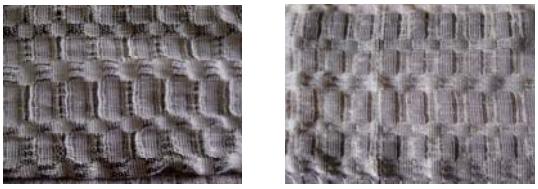
Production data of the sample fabrics are listed in table 3.

Table 3. Production datas of sample fabrics

Fabric sample No	Warp density, ends/ cm	Weft density picks/ cm	Reed number	Fabric dimension Width x length (c m)
1	10	10	100	100x 13
2	20	19	100/2	100x13
3	20	17	100/2	100x7
4	20	17	100/2	100 x 5
5	20	19	100/2	100 x 7
6	20	19	100/2	100 x 5

EVALUATION OF THE EXPERIMENTAL WOVEN SAMPLES

14/1 (9,1 Nm) and 12/2 (2 Nm) Stainless steel yarns have created a shimmering, puffy and relief effect on sample fabric 1`s surface in depending on the single and double layer fabric structures. The use of 20/1 Ne cotton yarn as weft on the back of the fabric has resulted with a different visual effect than the upper face. This fabric has a more softer touch than other sample fabrics due to the low warp-weft density (figure 1, Önlü,2009).



Upper Face Back Face

Figure 1: Weaving Fabric (warp:20/2 Ne Cotton, weft: 9,1Nm, 2 Nm stainless steel yarn, 20/1 Ne Cotton) Nesrin Önlü,2009

Polyester fancy yarn and stainless steel yarn have been used as weft yarn in sample fabric 2. This fabric has a solid touch due to the stainless steel and the weft-warp density. The stainless steel has fashioned a puffy effect along with shimmering effect on the striped areas. The puffy effect has been increased with the use of polyester fancy yarns as extra wefts on the back of the striped areas in the fabric (figure 2, Halaçeli,2010).

Upper Face Back Face

Figure 2: Weaving Fabric (warp:20/2 Ne Cotton, weft: 9,1Nm, polyester fancy yarn) Havva Halaçeli,2010

The use of 20/1 Ne cotton in combination with stainless steel as weft and the decrease of weft density has made the sample fabric 3 softer than sample fabric 2. The fabric has a shiny appearance. The combination of fabric structures, construction and materials, stainless steel and cotton, have created puffy and relief effects (figure 3, Önlü,2010).

Upper Face Back Face

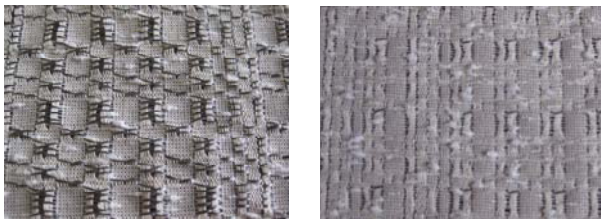
Figure 3: Weaving Fabric (warp:20/2 Ne Cotton, weft: 4 Nm stainless steel yarn, 20/1 Ne Cotton)

Nesrin Önlü,2010

In sample fabric 4, stainless steel was employed as weft. The double layer structures woven with panama weaves has formed a loose structure and increased the shimmering degree of stainless steel (figure 4,Halaçeli, 2010).

Figure 4: Weaving Fabric (warp:20/2 Ne Cotton, weft: 9,1Nm, polyester fancy yarn) Havva Halaçeli,2010

Sample fabric 5 has a puffy, voluminous and relief effect. The polyester fancy yarn increased the overall texture of the fabric. The a smaller amount of stainless steel in the fabric and the weft density of 19 picks per cm decreased the shimmering effect (figure 5, Önlü,2010).



Upper Face Back Face

Figure 5: Weaving Fabric (warp:20/2 Ne Cotton, weft: 4 Nm stainless steel yarn, polyester fancy yarn)

Nesrin Önlü,2010

In sample fabric 6, stainless steel has been used along with polyester fancy yarn. The large amount of the double layer structure in fabric provided the revealing of stainless steel strongly and increased the shimmering effect on surface. Relating to the designs of the fabric, the combination of plain weave in single layer and weft rib in double layer have formed a relief effect. The plain weave part on the surface created collapsed places on the fabric surface while the double layer structure created voluminous areas (figure 6,Önlü,2010).

Upper Face

Back Face

Figure 6: Weaving Fabric (warp:20/2 Ne Cotton, weft: 4 Nm stainless steel yarn, polyester fancy yarn)

Nesrin Önlü,2010

Table 4. Different visual effects of stainless steel yarn in woven fabrics

Fabric Sample no	Visual effects
1	Relief, shimmering
2	puffy, voluminous, shimmering
3	Puffy, tissue effect, relief, shimmering
4	puffy, voluminous, shimmering
5	Puffy, tissue effect, relief, shimmering
6	Puffy and shimmering

4. Conclusion

As it is understood from the evaluations of the fabrics stated in table 4 and the data of given fabrics, the sample woven fabrics have a voluminous, puffy, relief and shimmering effects due to the use of stainless steel. The use of single and double layer structures in the same fabric, plain weave in single layer, and weft rib in double layer and, stainless steel in one layer, a different type of yarn in the second layer have created different appearances on upper and back faces of the fabric.

The choice of different material, count, structure and type of yarns, construction, weft densities and weave structures which are related to the designs have resulted in differents in visual effects which are intended to obtain with stainless steel yarn. The voluminous, relief, puffy and shimmering effects of the stainless steel yarn are more prominent on the upper face of the sample fabrics 1, 2,3,5,6 due to the use of stainless steel in combination with the chosen weave, density and weave structures in the upper layer of the double layer structures. In the sample fabric 4, stainless steel 12/1 has been used in both layer, upper and back, resulted in same appearances of both faces of the fabric, upper and back.

It is assessed that all of the 6 sample woven fabrics containing stainless steel have elongated when exposed to a heat source and, the voluminous effect was increased. The fabrics have taken their original form when the heat source is removed. Same effects have been obtained when they are exposed to sunlight. This feature due to the heat sensitive and conductive characteristics of the stainless steel suggests that fabrics woven with stainless steel, especially when used as a curtain, get a more marvelous look with voluminous and puffy effects and change in shape with the heat change aside from being a heat source in winter times.

With their antistatic characteristics, stainless steel yarns can be used as clothing also. They create a protective shield reducing static shock in computer-use areas for people who are sensitive to little electrical releases.

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*VN ---/--x ----/----/-----

a b c d e f

a) Diemetr of flaments b) Number of plies c)Number of flaments

d) Torsions per meter e) Twist direction f)Standard

AN INVESTIGATION ON IMPROVING THE WRINKLE RECOVERY OF WARP KNITTED AUTOMOBILE UPHOLSTERY FABRIC

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ABSTRACT

Nowadays, the importance of automotive textile is developing incrementally. Owing to the fact that, inside in a vehicle there is considerably great using area of textile fabrics, the studies on developing these textile products, especially automobile upholstery fabrics carry on. By thinking all methods to produce upholstery fabric, the importance of warp knitting method is great. The reason for this can be traced that production of it is highly efficient and it realizes low cost with high fabric performance at relatively low fabric weights.

In this study the wrinkle recovery behavior of warp knitted automobile upholstery fabric is examined and investigated to improve. Therefore, five 100 % polyester fabrics are knitted with three-bar tricot machine under same conditions in a conventional mill and all fabrics are laminated with pur polyurethane and another warp knitted fabric produced by two-bar tricot machine as lining. The fabrics are differentiated each other by changing their production properties. And the wrinkle recovery of all ten fabrics measured at regular intervals. At the end of this study, it is examined that while using softening agent during dyeing is inefficient to wrinkle recovery, while it makes wrinkle best when it is added at fulard. First fixation is useful for covering surface from wrinkling. Finally, using more elastic yarn deteriorates the wrinkling behaviours of fabrics.

Key Words: automotive upholstery fabrics, warp knitting, wrinkle recovery, polyester, lamination.

1. INTRODUCTION

Mobility is a fundamental requirement of all human activity whether it falls into either of the two categories of work or play. Cars embody personal freedom and for some an expression of individuality. People are spending more time in their cars, commuting longer distances to work on a daily or weekly basis. Therefore users have some demands from car seat cover fabric as are high abrasion resistance and resistance to UV degradation. The fabric must last the life of the car, well over ten years but most car buyers are not mechanically minded and if the car seats look worn, they will assume that the engine and the rest of the car is also worn.Car seat covers must include high tear strength, resistance to mildew, low water absorbency, excellent resilience and of course wrinkle resistance [1]. Wrinkle resistance of fabrics is one of the most important factors, which affects the aesthetic and easy care properties of clothing [2].Wrinkle resistance in a fabric is a result of either a better recovery from a wrinkling deformation, or a higher resistance to wrinkle formation [3]. The importance of wrinkle recovery to garment appearance is a major concern of consumers in determining clothing serviceability and longevity [4]. Factors that affect wrinkle development include fiber type, bending performance of fiber, fiber diameter, yarn twist, weft-warp density, fabric construction and fabric thickness [5].

There are many studies about wrinkle resistance; some of them are examined in this paper. Jian et al studied on analyzing the wrinkle properties of fabrics by using wavelet transform method. They found an objective evaluation to analyse wrinkle behavior of fabrics [6]. Kuzuhara and Hori investigate the effect of 2-Iminothiorone Hydrochloride on wrinkle recovery property of wool. They proved that increasing the number of SS-groups in wool fabrics improves the wrinkle recovery [7]. Yang and Huang evaluated the wrinkle degree of fabrics with a photometric stereo method for fabric 3 D surface constructions. Their results showed that there was a good linear relationship between the index value and the wrinkle degree of the pattern [8]. Can et al studied on the effect of crease resistant finish on wrinkle recovery and they observed that crease resistant finish increases the wrinkle recovery angle of 100 % cotton plain fabrics significantly [5].

The use of fabric softeners is a well-known technology for reducing the formation of wrinkles or for imparting a degree of wrinkle resistance in fabrics. However, the use of certain softeners can lead to significantly lower fabric stiffness than in the reference fabric, this results in more wrinkling deformations more than reference fabric [3]. So, in this study softeners are added to fabric in two different processes to analyze which one is more suitable way on improving wrinkle resistance. And also to see the effects of fixation and the amount of elasticity on used yarn, different fabrics are manufactured.

In this search, it is studied to answer the car users' requirements by ensuring the wrinkle free car seats, therefore by using different processes four fabrics except from the reference one are produced. By the end of this study it is aimed to find most convenient process to produce car seat fabric.

2. MATERIAL AND METHOD

2.1. The Fabrics Properties Used in This Study

In this study there are two groups of fabrics; the fabrics which are first group are without lamination and the fabrics which are in the other group are with lamination. Specimens are knitted for world markets, warp knitting method to produce car seat cover takes the largest share of all trim material. The reason for this can be traced the highly efficient production methods which realize low cost with high fabric performance [1].

Five different fabrics (one of them is the reference fabric) are produced in a commercial warp knitting mill for developing the wrinkle behavior of upholstery fabrics. Because of the fact that, fabrics are used with lamination for being car seat produced five samples are laminated. Automotive fabrics are laminated for a number of reasons, the two most important being to improve abrasion resitance and secondly to ensure some flame retardancy properties. Early heavy knitted automotive fabrics were coated to control fabric stretch [1].

The fabrics are coded as A, B, C, D, and E. The descriptions are summarized in Table I.

Table I. Fabrics descriptions.

Codes of Fabrics	Description

A	Reference Fabric
B	Softening agent addition during dyeing
C	Different yarn using during knitting
D	Elimination the first fixation
E	Softening agent addition at foulard

The fabric A is the reference fabric. It is knitted from 100 % polyester (110 denier with 36 filaments) by means of three-bar tricot warp knitting machine. The process order for this fabric is like: knitting, then first fixation at 190 ºC, dyeing and then last fixation.

The fabric B is again knitted from 100 % polyester (110 denier with 36 filaments) by means of three-bar tricot warp knitting machine. The process order for this fabric is like: knitting, then first fixation at 190 ºC, dyeing and then last fixation but in this type, 2 % water based polyethylene silicon softening agent is added to fabric during dyeing.

The fabric C is again knitted from 100 % by means of three-bar tricot warp knitting machine, but in this type of fabric used yarn is more elastic than the reference fabric's yarn as 20%. The process order for this fabric is like: knitting, then first fixation at 190 ºC, dyeing and then last fixation.

The fabric D is again knitted from 100 % polyester (110 denier with 36 filaments) by means of three-bar tricot warp knitting machine. However, in this type of fabric process order is changed like: knitting, dyeing and fixation.

The fabric E is again knitted from 100 % polyester (110 denier with 36 filaments) by means of three-bar tricot warp knitting machine. The process order for this fabric is like: knitting, then first fixation at 190 ºC, dyeing and then last fixation but in this type, 2 g/l water based polyethylene silicon softening agent is added to fabric after dyeing during the fabric passes over ram by foulard.

2.2. The Lamination Used in This Study

For the first part of study the fabrics are used lonely but for second part the fabrics are laminated. After lamination the fabric becomes three layered fabric as shown in figure 1. The up layer is essential fabric which is knitted from 100 % polyester by three bared tricot type warp knitting machine. The middle layer is foam layer and it is produced from Polyurethane with 2 mm thickness and 28 kg/m^3 density. The down layer is used as lining fabric. It is knitted from 100 % polyester by two bared tricot type warp knitting machine.

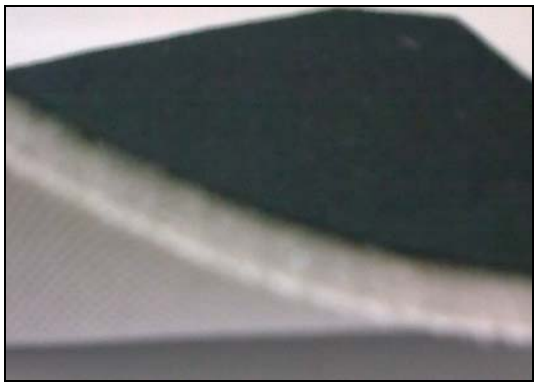

Figure 1. Three layered laminated fabric.

Lamination is the joining together of two materials and is one of the fundamental processes in the production car interior trim. Usually a third material is used as the adhesive, but sometimes one of the materials being joined can itself act as the adhesive as in flame lamination [1].

Lamination method used in this study is flame lamination method as shown in figure 2. The gas flame burner 1 melts the surface of the foam, which then acts as the adhesive for the scrim fabric. On the other side, burner 2 melts the other surface of the foam, which then acts as the adhesive for the face fabric. Thus three separate materials are fed in and a single triple laminate emerges [9].

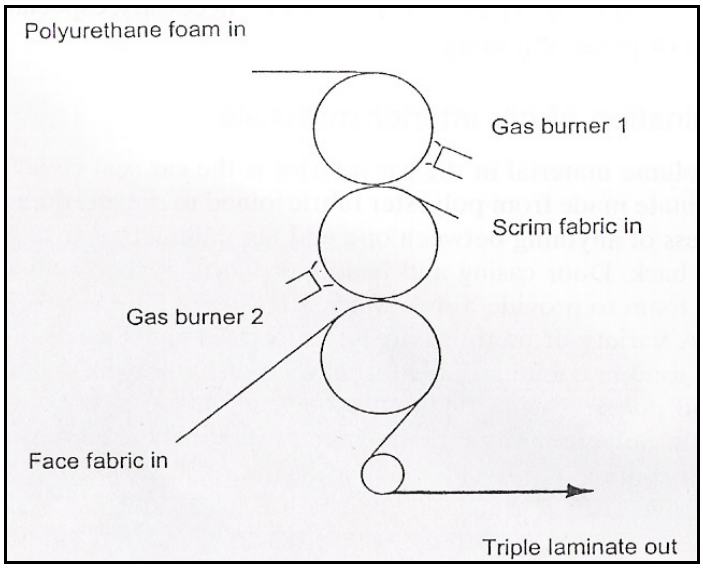

Figure 2. Flame lamination of the fabrics [9]

The fabrics are used as automotive upholstery as laminated but in this research the wrinkle recovery attitudes of both fabrics without lamination and fabrics with lamination are tested to see the effect of lamination to mentioned developments.

2.3. Wrinkle Recovery Test Used in This Study

Wrinkle recovery tests are done according to AATCC Test Method 128-1999, “Wrinkle Recovery of Fabrics-Appearance method” by AATCC machine; and the results are evaluated by AATCC “Wrinkle

recovery replicas" [10]. By using AATCC machine the mechanism of creating wrinkled fabrics starts. In this operation, the fabric forms as a tube shell and two edge warp round the two flanges. Then a 3, 5 kg weight sets above the upper flange which is movable. Therefore, the upper flange by using a pilot bar rotates 180 degrees and rolls downward. This operation causes the fabric wrinkles and because of fabric properties, the fabric after the deformation returns to the primary state and also according to the atmospheric standard conditions in accordance with wrinkle recovery replicas illustrate five grades of wrinkling as shown in table 2 [11].

Table 2. AATCC wrinkle recovery replicas

Grade number	Appearance definition
1	Deeply crumpled appearance
2	Crumpled appearance
3	Moderate crumpled appearance
4	Slightly crumpled appearance
5	Completely smooth surface

3. RESULTS

These evaluations are conducted at standards conditions (21±1°C, 65±2% RH) without concerning the effect of temperature or moisture on the fabrics. According to AATCC Test Method 128-1999 the evaluations are done after the fabrics are waited in this condition 24 hour but in this study after test 3 evaluations were done as evaluating instantly after wrinkling, after 30 minutes of air condition and after 24 hour of air condition because by evaluating the wrinkling degree after 24 hour the difference between developments can not be seen clearly. And also it is thought that 24 hour may be very long time when it simulates real car seat, because usually a car is used again before than several hours after leaving the car.

3.1 Wrinkle recovery results of fabric without lamination

Figure 3 represents that the wrinkle recovery behavior of fabrics without lamination after wrinkling instantly, 30 minutes later and 24h later. In accordance with the figure the reference fabric A, crumpled moderately after instantly evaluation but its crumpling attitude got well as one grade after 30 minutes then it did not change by the time 24 hour. The wrinkling behavior of fabric B was similar to fabric A. Fabric C initially crumpled moderately like fabric A and B but after 30 minutes its surface smoothness did not change like them. However after 24 h its surface got well as one grade. The fabric D crumpled worse than all other four fabrics but by the 30 minutes its smooth got well as two grade different from all other fabrics and its wrinkling degree did not change by 24 h. The last one, fabric E showed linear change in crumpling attitude by the time; grade 3,4 and 5 respectively.

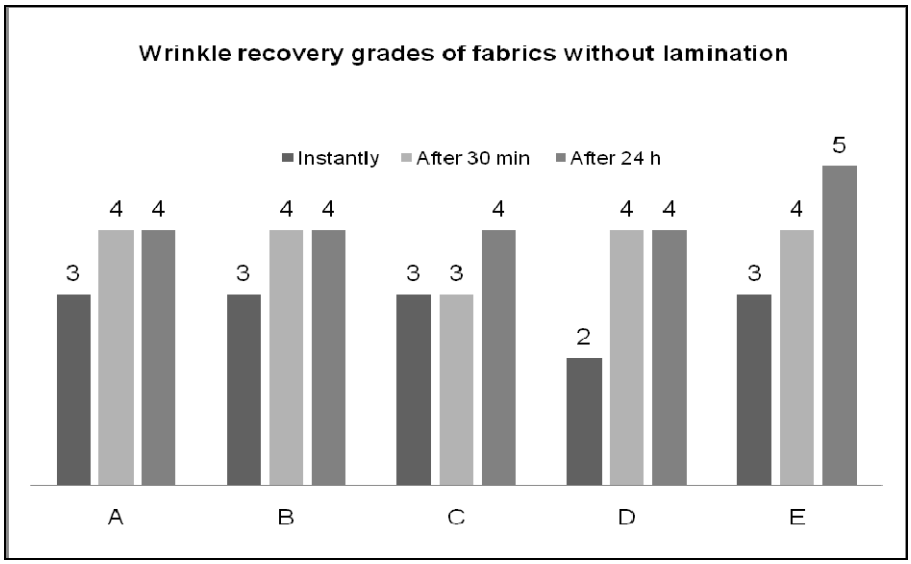

Figure 3. Wrinkle recovery of fabrics without lamination

3.2 Wrinkle recovery results of fabric with lamination

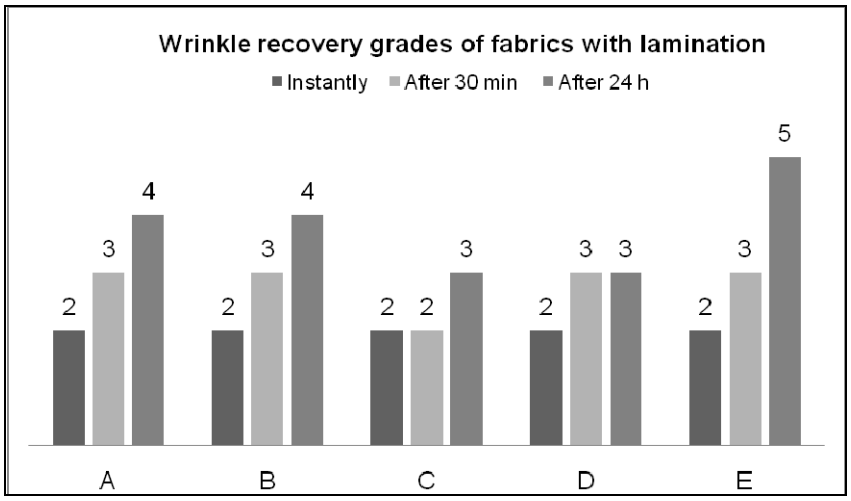

Figure 4. Wrinkle recovery of fabrics with lamination

According to figure 4 the wrinkle recovery behaviors of fabrics with lamination after wrinkling instantly, after 30 minutes and after 24h are examined. Figure shows that the reference fabric A, crumpled as grade 2 like other four fabrics and after 30 min its wrinkling was moderately crumpling and it changed to slightly crumpling by the time 24 hour. The wrinkling behavior of fabric B was similar to fabric A. Fabric C initially crumpled moderately like fabric A and B but after 30 minutes its surface smoothness did not change like them. However after 24 h its surface got well as one grade. The fabric D crumpled like all other four fabrics and by the 30 minutes its smooth got well as one grade and its wrinkling degree did not change by 24 h. The last one, fabric E showed best behavior after 24 h.

4. CONCLUSIONS

In this study wrinkling behaviors of automotive upholstery fabrics knitted produced by warp knitting in a commercial mill are examined and four different development methods for getting well the wrinkling attitude are investigated.

- The fabric A is the reference fabric of the mill. It is seen that lamination deteriorates the wrinkle recovery but after 24 hours both of them crumples slightly.
- Apparently, it can be said that using softening agent during dyeing inefficient to wrinkling because wrinkling behaviors of fabric A and fabric B are similar to each other.
- It is evident that, using more elastic yarn deteriorates the wrinkling of fabrics, because fabric wrinkling of fabric C is worse than the reference fabric.
- Clearly it is decided that, the first fixation is useful for covering the surface from wrinkling because of the fact that crumpling of all other four fabrics are better than the fabric D.
- It is observed that by using softening agent at foulard, the fabric without lamination and the fabric with lamination present completely smooth surface after 24 hours.

Therefore it is thought that softening agent may be useful to develop wrinkling behavior of fabrics used in automobile upholstery.

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ANTISTATIC AND ANTIBACTERIAL TEXTILES FROM METAL COATED FIBERS

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Textile fibers with novel functions have recently been of increasing interest to both academic and industrial community. Today, a wide range of nanoparticles with various structures can be immobilized on the fibers, bringing new properties to the final textile product. Different methods have been used to functionalize textile materials. For instance, magnetron sputter coating can be applied, which is one of the most commonly used vacuum techniques. Since the antistatic and antibacterial activities of various metals are well known, in this study, we performed magnetron sputtering technique to coat fibers with thin metal films. The polypropylene synthetic fibers (10-100 um in diameter) coated in high vacuum with electrical conductors such as Ag and Ti metals. Because our magnetron sputtering chamber has only planar target, the fibers were deposited in two runs. The electrical conductivities of deposited fibers were measured as a function of deposition thickness. It is possible to discharge the static charge by a very thin conductor, 20 nm or less, on the surface. It is found that as small as 10 nm deposition increases the conductivity five orders of magnitude with surface resistance of 2.1 x 10^7 ohm/sqr. Therefore, the fibers were coated with thick enough Ag and Ti to provide antistatic properties. These fibers were weaved into fabrics, and antistatic and antibacterial properties of these fabrics were also investigated. Furthermore, the mechanical properties and durability were obtained. The homogeneity of deposited layer on the conductivity of fibers will be discussed in addition to design of new vacuum deposition chamber.

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APPLICATION OF TECHNICAL TEXTILE IN THE MEDICAL FIELD AND A STATISTICAL STUDY

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ABSTRACT

Among technical textiles, medical textile is manufactured using highest technology, which also provides highest added value.
Within last several years, technical textiles started to gain increasing importance in the textile and ready-to-wear clothing industry. Also, it is estimated that smart textile will comprise substantial part of textile and ready-to-wear clothing sectors in terms of value.
Smart textile has a wide range of use including Hygiene and Medical Technical Textile (Medtech), transportation technical textile, Industrial Textile (Indutech), Protective Wear (Protech), Building and Construction Textile (Builtech), Agricultural Technical Textile (Agrotech), Active Sport and Spare Time Textile (Sporttech), Home Technical Textile (Hometech), Package Technical Textile (Packtech), Cloth Technical Textile (Clothtec), Ecological and Environmental Technical Textile (Oekotech) and Food Technical Textile.
It is possible to divide medical textiles, subject of our study, into three main topics:
Surgical textile, textile used in extra-corporeal devices and care and hygiene textile.
Following are included in surgical textile; sutures, vascular tissues, heart valves and fabrics used for treatment thereof, artificial joints, fabrics used for treatment of hernia, artificial bone, bandages, gauze and medical tapes. Each of artificial kidney, artificial liver and artificial lung is also textile used in extracorporeal devices. Bedding, protective wear, surgical wear, drapery, cleaning cloths are referred as care and hygiene products.
Medical textiles have some special features such as biocompatibility, protection against micro-organisms, antibacterial activity, biodegradability and protection against fire, which are all related with human health.
Care and hygiene products can be manufactured using woven, braided and non-woven surface techniques.
Based on the definition, non-woven textile comprises a group included within scope of many fields, but considered as a separate group due to the function performed and the structural conformation.
Technical textile and industrial non-woven market in the world had grown by 3,5 percent until 2010 and it is estimated that volume of this industry reached 23,8 million tons corresponding to 126 billion U.S. dollars in value. In this end, it is inevitable that non-woven products will be increasingly used in medical textile.
In our study, in order to reveal field of use, extensity and benefits of medical textile products, a survey study was performed in private and public hospitals operating in Istanbul.

Key words: Medical Textile, Technical Textile, Non-woven, Private and Public Hospitals in Istanbul

INTRODUCTION

Technical textile is the most rapidly developing field of the textile sector, which is also most open to the technological advances and innovations. It is necessary to closely follow up medical and hygienic technical textile, as this field, among technical textiles, is the one with fast development and it is comprised of a large product spectrum, but more important than all, it is closely related with human health. Parallel to the increasingly aging population of the world and raise of life expectations, demand to the hygiene and medical textile will continuously increase. It is obvious that advances in this field

will offer new market opportunities and infinite alternatives to our textile manufacturers. Moreover, developments and advances in the field of medical textile will make important contributions to resolution of increasingly chronic healthcare problems in our country. Within this context, R&D studies should be conducted in order to reach rapidly progressing technological studies performed in this field all around the world and investments should be lead to this field.

In the section comprising statistical part of our study, we made our efforts in order to reveal out which of medical textile materials are often used in a part of hospitals located in Istanbul and which of them were more frequently required.

1. WHAT ARE TECHNICAL TEXTILES?

Due to divergence in intended use and specifications of products used in technical textiles field, there is no complete consensus on general and comprehensive definition of “technical textiles”.

Definitions of technical textile commonly used and definitions made by different sources are included below:

“Technical textiles include textile materials and products comprising fabric and fiber components selected primarily considering performance and specifications rather than aesthetic and decorative characteristics for use in the fields other than wearing, home furniture and floor coating." (1)

“Technical textiles are textile materials and products generally manufactured for intended end-use except wearing without a specific protection purpose, home textile, furniture and floor coating.” (2)

“Technical textiles are materials with technical functions and meeting high technique and quality requirements (mechanical, heat, electrical, resistance etc). (3)

However, a more general and comprehensive definition of technical textile can be made as follows; “All textile other than for conventional wearing and home textile are technical textiles”. (4)

Technical Textiles were first compiled under 12 classes depending on application site by Messe Frankfurt organizing International Technical Textiles Fair, namely Techtextil Frankfurt. However, in this classification, several products are included in more than one fields based on intended use and thus, decisive borders could not be delineated. In general, short descriptions of those classifications can be made as below:

A) Agrotech: Agriculture, horticulture and foresting;

B) Buildtech: Building and construction;

Clothtech: Technical components of footwear and wearing;

D) Geotech: Geotextiles and construction engineering;

E) Hometech: Furniture, upholstery and floor coating components;

F) Indutech: Filtration, cleaning and other industrial fields of use;

G) Medtech: Hygiene and medical fields of use;

H) Mobiltech: Automobiles, vessels, railways and rockets;

I) Oekotech: Environmental protection practices;

J) Packtech: Packaging;

K) Protech: Individual protection and property protection;

L) Sporttech: Sports and leisure time practices. (5)

1.1. HISTORY OF TECHNICAL TEXTILE

Roots of technical textiles lie back as much as conventional textiles. There are evidences that woven fabric and mesh were used for road construction and stabilization of marshy ground during and before Roman Age. These are first samples of materials referred today as geotextile and geogrid.

Beginning for manufacturing of technical textiles is regarded as production of sail cloth for vessels. (5)

Use of technical textiles are encountered in manufacturing or air balloons at the end of 18th Century, of roof of first vehicles in the 19th century and wings of air crafts at the beginning of 20th Century. Due to light weight and high resistance, wings of first aircrafts were manufactured from fabric. (6)

Largest advance in the field of technical textile is the invention of synthetic fibers at the 20th century. The first synthetic fiber, namely polyamide, was invented in 1939. High performance fibers started to be manufactured in '50s and '60s both partially replaced natural fibers and they created new fields of use. Synthetic fibers are considered acceptable in many fields due to their high endurance, high elasticity and flexibility and high resistance against chemicals, flame and corrosions.

1. 2. HISTORY OF MEDICAL TEXTILES IN THE WORLD

The history of medical textile in the written history is very old and it is known that surgical sutures, the known implantable textile materials, had been used around B.C. 2000. However, substantial advances were experienced after synthetic fibers were invented in ‘50s. The advance rate accelerated when nonwoven surfaces were invented in 1960 and when it was scientifically evidenced in 1985 that use of single-use products in operation rooms reduced risk of post-operative infection by 56 percent.

Medical-surgical single-use products form the second largest market for non-woven fabrics. It is required to construct high-efficient facilities in order to manufacture nonwoven textiles used in the medicine and hygiene industry in a cost-effective and environmental-friendly manner.

1.3. WORLDWIDE UTILIZATION RATE OF TECHNICAL TEXTILES

It is estimated that technical textile products reached 19,68 millions of metric tone by a 3,3 % percent increase between 2000 and 2005 based on quantity.

According to David Rigby Associates, an international investigation company with a particular study on medical textile, it is expected that the world’s technical textile market will grow by 3,8 % per year based on quantity before 2010. Thus, it is also estimated that in the 2010, worldwide consumption of technical textile will reach 23,8 millions of metric tone in terms of quantity and the market value will be 126 billion United States Dollars. Again, according to same investigation company, technical textile manufacturing based on regions will be as defined in the Table 1.

Table 1. Worldwide technical textile consumption estimates by regions

Worldwide Technical Textile Consumption Estimates by Regions Unit: 1000 Metric tons			
	2005(*)	**2010(*)**	**Change, %**
North America	4.774	5.591	17
South America	1.004	1.230	23
West Europe	4.107	4.760	16
East Europe	666	817	23
Asia (excl. China)	5.220	6.348	22
China	2.871	3.808	33
Other Regions	1.041	1.219	17
Total	19.683	23.773	21
(*) estimation			

(Source: David Rigby Associates)

Based on utilization fields, estimations on consumption of technical textiles are included in Table 2.

Table 2. Worldwide Technical Textile Consumption Estimates by Utilization Fields

Worldwide Technical Textile Consumption Estimates by Utilization Fields Unit: 1000 Metric tons			
	2005(*)	**2010(*)**	**Change, %**
Agrotech	1.615	1.958	21
Builtech	2.033	2.591	27
Clothtech	1.413	1.656	17
Geotech	319	413	29
Hometech	2.499	2.853	14
Indutech	2.624	3.257	24
Medtech	1.928	2.380	23
Mobiltech	2.828	3.338	18
Pachtech	2.990	3.606	21
Protech	281	359	28
Sportech	1.153	1.362	18
Total	19.683	23.773	21
(*) estimation			

(Source: David Rigby Associates)

2. TECHNICAL TEXTILE MAIN PRODUCT GROUPS

Technical textile market can be examined under four main product groups. These are as follows:

- ***Yarns and fibers;***
- ***Fabrics;***
- ***Nonwoven products,***
- ***Composite materials,***
- ***Others: This involves products such as rope, cord and filling materials, which are not suitable for other four groups. (7)***

3. DEFINITION OF NONWOVEN SURFACES

Rapid growth in the textile industry is today clearly evident in a large application range besides meeting covering and other daily needs of people. Processing only natural fibers in the previous periods, textile technology invented synthetic fibers in the length of time due to inadequacy of natural sources and classical definition of textile was shifted in '60s and '70s to involve non-woven textile surface manufacturing techniques, parallel to the worldwide technological advances. Other than those weaving or knitting methods, surfaces created by combining fibers via particular techniques is referred as non-woven surfaces. In other words, name of the product with specific tissue or surface created by attaching fibers, not processed into yarn, with each other using various methods is regarded as Non-Woven Surface. (8)

3.1. MANUFACTURING METHODS OF NON-WOVEN SURFACES

The most significant factor influencing manufacturing of non-woven products is brought forward as raw material and production technology. Raw materials can be considered as fiber and chemical materials. Taking costs into account besides many physical properties, type of fiber can be selected as staple fiber or continuous fiber based on application site.
As it is known, staple fiber is characterized with the fiber cut in various lengths and it is used in divergent processes such as carding, air process, wet process, punching and weaving with water jet.

3.2. SPECIFICATIONS OF NON-WOVEN SURFACES

Recent highly advanced material technology enables production of very fine infinite fiber rather than production of thick fiber. Studies on non-woven surfaces accelerated following '50s and significant advances were made particularly in manufacturing of non-woven surfaces. On the contrary to woven surfaces which are formed by vertically intersecting fibers, non-woven fibers are characterized with multi-directional and complex structure of fibers. This complex structure in non-woven surfaces provides character of isotropic material (ability to have same level of resistance under external forces influencing almost all directions).
Previously, the only known non-woven surface was felt. Today, non-woven surfaces can be obtained via several methods other than felting besides woven or knitted textile surfaces. Non-woven fabrics are manufactured by gathering fibers into a layer or cheesecloth followed by reinforcement of those layers by a method ensuring permanent attachment of them. Specifications of non-woven fabrics depend on preparation means of fiber cheesecloth, type and diameter of the fiber used, thickness of cheesecloth and methods used for reinforcing the structure.
First examples of non-woven fabrics were not attractive in terms of appearance, feel and drape properties. Characteristics of those fabrics were developed, but they are still lacking feel and

drape ***properties in comparison with woven and knitted fabrics. Adhesives attaching fibers in the non-woven fabric prevents bending and slipping movements enabling double folding of the fiber when it is desired to lay the fabric to cover something. (9)***

In addition to mentioned features, following properties can also be expected with regards the final utilization field:

- ***Good ability to shape***
- ***Adequate resistance to cleaning solutions in the dry and wet form***
- ***High absorbability***
- ***Free of toxic and allergic material***
- ***Non-pilling surface***
- ***Corrosion resistance***
- ***Dimensional stability***
- ***Ability to keep the shape***
- ***Ability to remove wrinkles at particular extent***

3.3. ANTIMICROBIAL PROCESSES APPLIED ON NON-WOVEN SURFACES

A particular feature desired in medical textile products is the antimicrobial feature of the products. Non-woven textile materials with such feature should not only kill microorganisms, but they should also be safe in terms of human and environmental health and they should not negatively influence other features of the product.

Antimicrobial material can be defined as a natural, synthetic or semi-synthetic material which kills microorganism including bacteria, fungi and molds and prevents growth or reproduction of them. The world naturally contains thousands of chemical materials killing microorganisms. Many of them are natural materials such as plant or animal extracts and arsenic, lead, tin, mercury and silver. However, many of them may be toxic for human and environment during application. Therefore, textile product is added antimicrobial materials during antimicrobial finish processes and thus, activities of microorganisms are ended. As a result of those processes, unpleasant odor, infection and re-infection and damage of fiber material is avoided. Those procedures should not lead to allergic influences, materials used for this purpose should be compatible and they should not cause bodily injuries and their light, sweat and washing purities should be in good condition. Water-solubility of the antimicrobial material for better application on textile material reduces washing resistance of this process. Various chemicals are used in the antimicrobial finish procedures. Here, the important point is the washing resistance of those chemicals. Most of studies are conducted for increasing resistance of those procedures against washing. (10)

4. WHAT ARE MEDICAL TEXTILE PRODUCTS?

Surgical Textiles

Operation sutures
Prosthesis implants
Soft tissue implants
Orthopedic implants
Textile products used in cardiac operations

In vitro devices

Artificial kidney
Artificial spleen
Artificial liver
Artificial heart
None

Care and hygiene products

Lint
Pads
Gowns
Gauze
Plasters
Wound protective covers
Masks
Gloves
Surgical tools
Surgical gloves
Overshoes
Bed lining
Towels
Bandages
Cleaning cloths
Operation gowns

4.1. FIBERS USED IN MEDICAL TEXTILE

As a consequence of developing present fibers depending on the polymer technology, producing new fibers and increasing sorts of textile structures, those products suitable for use in many fields of medicine and surgery are known as medical textiles and they are used for medical care and hygiene of human and animals. Besides combination of the incorporated endurance and flexibility, ability to offer wide range of products, multi-functional character, and biological compatibility with environment and tissue and ability combine with various materials are among features of medical textiles. (11)

The non-bonded surfaces most commonly used in current medical wearing are non-woven surfaces. Mainly, three types of fibers are used in the manufacturing of the non-woven surface used in the fields of medicine/surgery, healthcare/personal care and cosmetics.

-Cotton

-Rayon

-Wood pulp, cotton linter

Synthetic fibers such as PES, PA, PTFE, PP, carbon and glass fibers are commonly used in medicine and surgery. (12) The significance of wood pulp in those fields is obvious. It not only provides desired properties to the products, but it is also associated with many advantages over synthetic fibers, as it is suitable for applying a capillary system.

Products used in the field of medicine-surgery, which is a significant market for non-woven surfaces, are more commonly comprised of single-use products. In this sector where hygiene is particularly of importance, care should be taken to avoid environmental hazard and to ensure cost effectiveness during manufacturing process.

Recently, names of non-woven fabrics most commonly used in medical textiles are Spunlace, SMS (spunbond –meltblown-spunbond) and Spunbond. Wood pulp and polyester fiber blend (55 % cellulose – 45 % polyester) is used for producing sunplace surfaces and the product is subjected to high pressure water for obtaining mechanic bonding. SMS surfaces are comprised of 3 independent layers bonded by thermal means or adhesives. Superior and inferior layers are made from spunbond and mid-layer is made from meltblown material. Spunbond materials are obtained from continuous fibers made by melting polyester later and shaping it via spinning method. Table 3. (13)

Table 3. Fibers used in the field of biomedical

Medical Use	Fiber Material	Features for Medical Use

Fiber materials for hospital	Cellulosic, nylon, polyester	Sterilizable, ease of use, no dust formation
Operation suture	Catgut, silk, cotton, nylon, polyglycolic acid, polylactic acid, polypropylene, polyethylene-terephthalate, polybutylene-terephthalate	Sterile, knot resistance, biocompatibility, ease of processing, soft
Surgical bandages Tissue adhesives	Collagen, oxycellulose, fibrin, polyurethane	Ease of preparation, biocompatibility, resorbable, sterility
Artificial vessels	Dacron, Teflon, collagen, polyurethane, polyglycolic acid, polyether-urethane	Blood compatible, porous structure, resorbable, ease for tissue growth
Artificial skin (skin, dermis)	Silicone/nylon, polypeptides, silicone/collagen	Prevention of infection and fluid loss, resorbable, pain reduction, adhesion to tissue surface
Soft tissue implant	Silicone, polylactic acid, collagen	Pain reduction, adhesion, resorbable
Artificial joint	Polymethylmetacrylate, high molecular polyethylene, silicone	Mechanic endurance, abrasion resistance, non-loosening
Artificial bone	Polyethylene/apatite, carbon fiber polyethylene terephthalate, glass ceramic	Appropriate mechanic force, bone adherence (compatibility), resorbable
Artificial kidney	Cellulose, polymethyl acrylate, co-polyethylene, vinyl alcohol, polyacrylonitrile, polycarbonate, chitin, chitosan	Suitable mechanic endurance, permeability, blood compatibility
Artificial lung	Silicone, polypropylene, polysulphone, polyethylene, Teflon	Gas exchange effect, blood compatibility, prevention of blood plasma leak
Artificial liver	Carbon fiber, cellulose, polyether-urethane	Blood compatibility, absorbing activity

(Source: Hongu T., Phillips G.O,"New Fibers", Ellis Horwood Limited,1990, p.160)

Table 4. Non-implantable Materials used for Wound Care

Product Type	Fiber Type	Textile Structure	Functions
Wound bandage Wound contact layer Absorbent pad Main material	Silk, PA, viscose, PE, Cotton-viscose, Viscose -polyester	Woven, knitted, nonwoven Nonwoven Nonwoven, knitted	Applying a particular drug on wound or skin, preventing the wound against infection, absorbing blood and secretions, facilitating healing
Bandage	Cotton, viscose, PA, elastomer fiber	Woven, knitted, nonwoven	Fixing the bandage on the wound
Light-weight support materials	Cotton,viscose, elastomer fiber	Woven, knitted, nonwoven	Fixing the bandage on the wound
Orthopedic materials	Cotton, viscose, PES, PP fibers and polyurethane foam	Knitted, nonwoven	
Plaster	Viscose, cotton, PP, plastic film, PES glass fiber	Woven, knitted, nonwoven	Applying drug to the skin, preventing movement, attaching wound limbs, pain killing
Gauze	Cotton, viscose	Woven, knitted, nonwoven	Absorbing fluids and secretions
Tampon	Viscose, cotton linters, wood pulp	Nonwoven	Absorbing fluids by inserting into any body spaces

(Source: Rigby A.J.,Anand S.C.,Miraftad M.,"Medical Textiles"TextileHorizions, December 1993, p.42-45 Böttcher P.,"Medical textiles": Current Status and Trends,ITB Nonwovens,4-5,1995)

4.2. PRODUCTS INCORPORATING MEDICAL NON-WOVEN SURFACES

Plasters

According to Turkish standards plasters are medical materials, which are used for fixing wound care materials made of flat-knitted cloth made of cotton, viscose or combination of both or containing rubber- or acrylate-based sensitive adhesive homogenously applied on internal layer of plastic film and for closing wounds and keeping small areas immovable. (14)

Wound plasters with adhesive should be characterized with soft, bending and highly absorbable material. Non-woven should have a special structure that the plaster does not firmly attach to the wound and it can be clearly removed.

Wound bandages

Wound bandages are generally made from cotton net, but, they are largely replaced with non-woven surfaces. Because, the net may cause drawbacks such as adhesion to the wound and pilling. Materials used as principal material of wound bandages are largely same materials used for wound plasters. However, based on specifications and high corrosion resistance, spunbond non-woven materials are also commonly used in this field. Spunbond non-woven materials are characterized with stretching feature which ensures comfort of the body. Non-woven materials produced using spunlace method can be used in this field. Most significant advantages of them include softness and high stretching under minimum load.

Non-woven Compresses

In aluminum coated compresses, non-woven materials are used where cotton or viscose fiber layers covered by cellulose non-woven materials coated by aluminum, which allows permeation inflow of the secretion. Similar products are suitable for products with 200-400 g/m2 absorbent layer and for products with both layers made of non-adhesive synthetic fiber.

Folded Compresses

Folded compresses are made by overlapping net and non-woven fabrics. Samples of this group include viscose/cellulose (or viscose/cellulose/polyester) based spunlace products, cleaning cloths and compresses.

Orthopedic Tampon Bandages

Orthopedic bandages used particularly beneath the plaster are made from synthetic fibers which are cleaner than non-bleached cotton which contains natural impurities and as a consequence, causes unpleasant odor under humid atmosphere. Non-woven orthopedic bandages should be soft. Moreover, they should be easily removed and they should adhere each other. Surface of the material should be suitable for handling the fabric with wet hands.

Operation room materials

Gowns: As degradable non-woven fabrics are easily sterilized, they are commonly used at operating theatres. Various designs for different types of non-woven fabrics are suitable for protective hats used by male and female staff. Materials used in this field are non-woven fabrics made from cellulosic fibers that are fixed parallel to each other.

Bonnets, gloves: Operation masks, bonnets and gloves should be easily worn, soft, flexible, air-permeable, absorbent, sterilizable, breathing and impermeable to fluids and bacteria and be resistant against tearing.

In order to ensure sterile environment during operation, sterile gloves with various sizes should be used at hospitals. Expectations including impermeability to water and bacterial, absorbing the secretion, permeability to air and water vapor mechanical stability features are different than that of operation gowns. In general, non-woven fabrics with single or both layers coated with film are used for

covering small areas. For example, while front side is made of non-woven and polyethylene film composite, back side can be only made of non-woven fabric. Operation bonnets and caps used by doctors at hospitals and operating theatres are generally produced by paralleling cellulosic non-woven using spunlaid or combing machine. Besides, water jet and fixing methods are increasingly gaining importance.

Degradable Plasters

Non-woven fabrics achieved a huge success in the field of degradable adhesive plasters. Those plasters are competing with films made of viscose filament yarns and plastics. Their advantages include softness and ease of removal from the skin. Thanks to the roughness of acrylic adhesive layer, air-permeability desired by the consumer can be ensured. Porosity is of importance for air-permeability. Porosity of the material is the most significant factor which determines growth of human tissue of encapsulation rate of the implant. Due to porosity, growth of human tissue and fusion of attachment is ensured. (16)

Non-woven surfaces contain binder over 60 percent. Cellulosic fibers are generally used for providing ease of tearing. All non-woven fabrics aerodynamically obtained, fixed by water jet and immobilized crosswise are used depending on the application. Single-layer non-woven materials and their stamp-like construction are more suitable as they are more resistant against internal tearing. Adhesive plasters may coat a large part of the wound. They do not contact each other within wound cover as a paper layer is inserted between non-woven layers.

Cover Material for Absorbent Compresses

Non-woven fabrics filled with cotton or cellulose and used for cover absorbent compresses are similar to napkin. They should allow release of secretion without adhering to the wound and they should enable sterilization with all conventional methods and have softness of textiles. Some non-woven fabrics are appropriate for manufacturing from polyester fiber immobilized with fibers lacking good adherence property. Traditional cellulose net compresses can be developed by coating it with parallel fixed non-woven fabrics.

Pads

Pads retaining fluids such as urine, blood and purulent matter is a composite material comprised of a protective inner later, an absorbent mid-layer and another external layer. Interior layer is generally made from polyester padding and polypropylene non-woven material, mid-layer is made from super-absorbents (viscose) and exterior layer is coated with PE film.

Operation sutures

Sutures are surgical materials in natural or synthetic structure which are used for approaching tissue and binding blood vessels until wound healing is ensured due to the resistance adequate to endure

tension without a mechanical support. Some fibers used as suture include flax, nylon, mopilen and resorben.

5. FUTURE OF MEDICAL TEXTILES IN OUR COUNTRY

A difficulty is experienced to access production capacities and product spectrum of companies as technical textile investments in our country is very recent, productions are kept confidential and no information inventory is created in this field.

Classical textile manufacturers in our country regards this market life buoy due to narrowing in the Textile and Ready-Wear Market, increasing successes of "Technical Textile" in the European and American markets and pressures of the China on the market. However, this market requires know-how. And, this also leads to the necessity of qualified work force, new technology and ability to see product range with high added value. (17)

Economic balances changed in January of 2005 when quotas limits were removed and a new age was started in the Turkish textile and ready-wear sector. Change was inevitable throughout this period. In order to take a large share from rapidly growing technical textile sector, it is required to add new "know-how" on principal textile knowledge.

Fourteen companies manufacturing technical textile in Turkey were ranked in first 500 large companies in the research conducted on 2006 by İstanbul Chamber of Industry. The fourteen companies manufacture industrial yarns, cord fabric for vehicle wheels, big-bag, synthetic yarn and woven fabrics, glass fiber and protective military wears and equipments.

Whole medicine and healthcare sector is an important consumer of technical textiles. We may mention anti-microbial and anti-static fabrics made from natural fibers coated with 99.9 % pure silver as an example for new products developed in this field in our country.

Surgical gowns and sterile fabrics protective against small volumes of bodily fluids, which may possible be contaminated with AIDS or hepatitis virus, are increasingly demanded. Dysfunctional arteries and veins are undergone bypass surgery using tube-shaped finely woven materials, while damaged ligaments in the heart and knee can be replaced with strong textile supports. Fine fibers used for suturing the wound following the operation and classically made from silk are rapidly replaced with biologically compatible polymers. (18)

Different types of fabric structures used at hospitals can be produced as a consequence of intensive researches and inter-sectoral cooperation. Due to utilization of results obtained from studies conducted by both medicine and textile sectors in this field, it will be possible to gain "high quality, intended, therapy supporting and economic" products. An interesting example for this condition is woven fabric which is incorporated drug micro-capsules and is realized by collaboration of "weaving and herbal medicine disciplines". The drug within structure of this fabric required for treatment of long-term diseases such as eczema, arthritis and even depression contacts with skin throughout the day and the drug is slowly released. This method is highly effective as the drug is released directly to blood circulation due to skin contact. Drug will prevent the stability for months and the fabric can be

manually washed without losing effect of the drug. Diani Irani, the designer of this drug referred as “Treating fabric”, stated that they may design wearing specially formulated for individual requirements". (19)

Spatial separation of the patient and the doctor had opened doors of a field referred as “telemedicine”. Telemedicine refers to use of electronic information and communication technologies for offering healthcare services when patient and doctors are spatially separated. Reduction in prices due to decreased costs in informatics and communication technologies and facilitations experienced in use of those technologies and accessibility by a large part of the population enabled improvement of telemedicine applications. (20)

Importance of medical textiles in the field of telemedicine is based on the ability to monitor medical parameters of the patient via sensors and communication systems integrated into the wearing and to communicate them to the physician, hospital or emergency department. However, drugs can be administered to the patient using integrated electronic system and drug-administering special textiles according to medical instructions. Those technologies enable continuous medical monitoring and optimal medical care especially for elder and chronic patients without delay and costs arising from hospital or doctor’s office visits. In addition, ability to monitor body functions of the patient even at his/her home shall offer huge gains for safety and life quality of patients. Telemedicine may play a key role in reducing the heavy load on public healthcare services without conceding the quality of the treatment. (21)

Due to increase in elder population in developed countries and in figures of employed women as well as raised wealth level of societies, demand for hygiene and care products has recently experienced a strong increase. A large part of those products are consumed in developed countries. However, it is expected that a strong demand will occur to hygiene and care products in the developed countries in the close future.

Parallel to the increasingly aging population of the world and raise of life expectations, demand to the hygiene and medical textile will continuously increase. As it can be observed in above mentioned examples, technical developments in textile industry and benefits resulting from those advances seem not to end. It is obvious that developments in this field will offer infinite opportunities to textile manufacturers. Moreover, developments and advances in the field of medical textile will make important contributions to resolution of increasingly chronic healthcare problems in our country. Within this context, R&D studies should be performed for manufacturing products fulfilling above mentioned demand and investments should be accordingly lead.

6. LITERATURE SEARCH

Studies conducted on medical textiles are as follows:

In the study titled “Technical Textiles and Field of Use” conducted in 2007 by M.Diren, S.Ilgaz, D.Duran, G.Başal, T.Gülümser and I.Tarakçıoğlu, information is given on technical textiles, their fields of use and development status in the world and in Turkey.

In the study conducted on the subject of "Antimicrobial Fibers" in 2006 by G.Süpüren, A.Çay, E.Kanat, I. Tarakçıoğlu, production techniques of antibacterial fibers and importance of them for human and environmental health are addressed.

In the post-graduation thesis of A.Emek titled "World Market of Technical Textiles, Production and Export Opportunities in Turkey" on 2004, information on definition of technical textiles, the product classes, market, export and import status of technical textiles was provided.

In the study titled "Non-woven / Technical Textiles" conducted by K.Duran, G.Sayıt, İ.Bahtiyari in 2004 and also published in TAD Journal, increased importance of disposable non-woven fabrics in the field of medicine due to risk of infection caused by classical textiles was addressed.

In the study titled "R&D Studies in Textile and Technical Textile Applications" conducted by Y.Ulcay in 2007, development graph of technical textiles was stated in the form of proportional data. Importance of R&D on technical textiles was emphasized.

In the study titled "Technical Textile Sector Research" conducted by A.Özdizdar in 24, definition and utilization fields of technical textiles were addressed in details and data and graphs were presented on which product is preferred in which sector, utilization volumes and export and import status.**

In the report titled "General and Recent Information on Technical Textile" presented on June 2008 by R&D and Legislation Office of ITKIB General Secretariat, general information on technical textiles, Position of technical textiles in markets of Third World, status of technical textiles in Turkey and import and export figures were included.

In the study titled "Advances in Medical Textiles and Fields of Use" conducted by E.Çetin, T.Kazaz., S.Racapov, B.Demir in 2007, fields of use of medical textile products and the raw materials of those products were addressed. Importance of non-woven fabrics in the manufacturing of medical textiles was emphasized.

In the study titled "Technical Textiles without Protective Texture" conducted by K.Duran, İ.Bahtiyari, R.Atay in 2007, protective features of technical textiles were studies in details.

In the study of O.Pamuk, Z.Öndoğan titled "A Research on Determination of Views about Surgical Gowns of Surgery Staff" conducted in 2008, necessary features of surgical gowns and particularly textile materials used in the field of medicine were included.

7. INVESTIGATION

In the investigation section of the study, state hospitals and private hospitals located in Istanbul are selected as main mass and employees 190 hospitals selected among all hospitals using randomized sampling methods were reached. One hundred sixty eight surveys were included in the analysis, as they were completely filled. At the assessment and analysis stage of surveys, SPSS 16.00 software was used.

First 7 questions of the questionnaire form consisted of 15 questions were included to determine demographics of responders. Other questions were intended to measure awareness level of medical

textiles and various dimensions for awareness of medical textiles among state hospital employees and private hospital employees and diversity of views were addressed.

7.1. RESULTS

When demographics of survey participants were examined, it was found that 75 % was female (126 individuals) and 25 % was male (42 individuals). Numbers and percentages of study participants distributed to age groups are given in Table 5. Of all participants, 35 % was in the age group of 20-30 years, 44,6 % was in the 31-40 years group, 17,9 % was in the 41-50 years group and 2,4 % was in the 51 or older group. When education status was considered, 22 % had high school degree, 67,9 % had university degree, 8,9 % had post-graduate or higher degree (Table 6).

Table 5. Age distribution

Age Range	Frequency	Percent
20-30	59	35,1
31-40	75	44,6
41-50	30	17,9
51 years and older	4	2,4
Total	168	100,0

Table 6. Education Status

	Frequency	Percent
Primary school	2	1,2
High School	37	22,0
University	114	67,9
Postgraduate and Higher	15	8,9
Total	168	100,0

Of the hospitals where the study was conducted, 61,9 % was state hospital, 20,2 % was private hospital and 17,3 % was university hospitals. Duration of employment is given in the Table 8. Of all participants, 35,1 % had occupation duration of 1-5 years and 30,4 % had 15 years or longer occupation periods. It is observed that employees with occupation period of 1-5 years, 6-15 years and over 15 years had almost identical distribution.

Table 7. Type of Hospital

	Frequency	Percent
State Hospital	104	61,9
Private Hospital	34	20,2
University Hospital	30	17,9
Total	168	100

Table 8: Occupation Period

Occupation Period	Frequency	Percent
1-5	59	35,1
6-10	27	16,1
11-15	31	18,5
> 15 Years	51	30,4
Total	168	100,0

When work distributions of the participants were examined, it was found that 68,5 % was nurse, 11,3 % was doctor, 11,3 % was administrative staff and Director and 8,9 % was technical staff (Table 9).

Table 9: Profession

	Frequency	Percent
Doctor	19	11,3
Nurse	115	68,5
Technical Staff	15	8,9
Administrative Staff and Director	19	11,3
Total	168	100,0

Responses given to the “Which one of following medical textile products you are aware?” asked for the extent of awareness of particular medical textile products by healthcare employees are given in the Table 10.

Table 10: Awareness Percent of Medical Textile Products

MEDICAL TEXTILE PRODUCTS	NUMBER OF INDIVIDUALS STATING AWARENESS FREQUENCY	PERCENT (%)
Operation sutures	140	83,3
Prosthesis implants	61	36,3
Soft tissue implant	46	27,4
Orthopedic implants	49	29,2
Textile products used in cardiac operations	21	12,5
Artificial kidney	19	11,3
Artificial spleen	7	4,2
Artificial liver	7	4,2
Artificial heart	22	13,1
Wound Bandages	153	91,1
Gowns	164	97,6
Gauze	162	96,4
Medical Tapes	150	89,3
Wound protective covers	92	54,8
Masks	158	94
Gloves	155	92,3
Surgical tools	112	66,7
Surgical socks	94	56
Overshoes	142	84,5
Bed lining	144	85,7
Towels	118	70,2
Bandages	130	77,4
Cleaning cloths	129	76,8
Operation gowns	132	78,6

Within scope of the study, medical textile products were collected under three main topics including surgical textiles, in vitro devices and care and hygiene products and efforts were made to determine awareness level. As it can be seen in Table 10, most commonly recognized surgical textile product is operation sutures with 83,3 percent. Second rank is occupied by prosthesis implants with 36,3 percent and orthopedic implants are in the third rank with 29,2 percent. The least recognized product group is textile used in cardiac procedures and the group is only known by 12,5 % of healthcare staff participated in the study. Awareness rate of medical textile products referred as in vitro devices is extremely low. Most commonly known member is artificial heart with 13,1 percent, while least known members of this group included artificial spleen and artificial liver. Care and hygiene products are found to have high awareness level and among this group, products with high awareness levels are gowns (97,6 %), gauze (96,4 %), masks (94 %) and gloves (92,3 %). Of this group, products with least awareness level are surgical socks with 56 % and surgical tools with 66,7 percent.

Another question asked in the questionnaire form is **"Which of followings can be Raw Materials used in the Production of Medical Textile Products"** which aimed to measure awareness of raw materials, used in the manufacturing process of medical textiles, by healthcare staff. Responses of those questions are given in Table 11.

Table 11: Raw Materials used in Production of Medical Textile

	Frequency	Percent (%)
Cotton	147	87,5
Wool	37	22
Viscose	31	18,5
Silk	102	60,7
Flax	48	28,6
Polyester	77	45,8
Polyamide	30	17,9
Nylon	49	29,2
Orlon	14	8,3

When awareness rates of raw materials used in the manufacturing process of medical textile products are compared, it is observed that products with highest awareness rates are natural fibers (wool, silk, flax) and additionally that healthcare staff also know regenerated and synthetic fibers (viscose, PA, PES) increasingly used in the current medical textile products.

Rates of responses given to the question "Which of below Medical Textile Products are used at your hospital?" is given in Table 12 based on hospitals.

Table 12: Utility Rates of Medical Textile Products at Hospitals

MEDICAL TEXTILE PRODUCTS	STATE HOSPITALS (%)	PRIVATE HOSPITALS (%)	UNIVERSITY HOSPITALS (%)
Surgical Textiles			
• **Operation sutures**	**85,7**	61,8	79,3
• **Prosthesis implants**	17,1	50	**58,6**
• **Soft tissue implant**	18,1	32,4	**48,3**
• **Orthopedic implants**	15,2	**41,2**	37,9
• **Textile products used in cardiac operations**	1,9	14,7	**24,1**
In vitro devices			
• **Artificial kidney**	0	2,9	**6,9**
• **Artificial spleen**	1	0	**3,4**
• **Artificial liver**	0	2,9	**3,4**
• **Artificial heart**	0	**8,8**	6,9
Care and hygiene products			
• **Wound Bandages**	**88,6**	73,5	79,3
• **Gowns**	**89,5**	76,5	82,8
• **Gauze**	**89,5**	73,5	82,8
• **Medical Tapes**	**85,7**	61,8	82,8
• **Wound protective covers**	34,3	41,2	**65,5**
• **Masks**	**88,6**	70,6	86,2
• **Gloves**	**89,5**	73,5	86,2
• **Surgical tools**	60	64,7	**69**
• **Surgical socks**	36,2	44,1	**65,5**
• **Overshoes**	72,4	64,7	**79,3**
• **Bed lining**	73,3	58,8	**79,3**
• **Towels**	59	55,9	**79,3**
• **Bandages**	65,7	52,9	**79,3**
• **Cleaning cloths**	**81,9**	61,8	79,3
• **Operation gowns**	72,4	64,7	**82,8**

When utility rates of medical textile products by hospitals were examined, it was observed that products other than operation sutures in the surgical textile group are more commonly used at private hospitals and university hospitals. It may be speculated that overall awareness level is low for in vitro devices, but the awareness level is relatively high at university hospitals in comparison with others. Considering care and hygiene products, state hospitals and university hospitals more commonly use medical textile products.

Frequencies and percents of the response obtained for the question “In your opinion, what are benefits due to use of medical textile products?” asked for obtaining views of healthcare personnel on use of medical textile products are given in Table 13.

Table 13: Benefits Due to Use of Medical Textile Products

	FREQUENCY	PERCENT (%)
Convenience for cleaning	115	68,5
Single-use	136	**81**
Anti-bacterial	134	**79,8**
Protection against infections	143	**85,1**
Protection for Staff and Equipment	119	70,8
Compatibility with the Body	107	63,7
Improvement of Healing	91	54,2
Ease of Use	129	76,8
Light Weight	86	51,2
Lack of Chemical Material	69	41,1
Non-adherence to the wound	76	45,2
Light-weight and Comfort when used as wearing	81	48,2
Ease of Sterilization	107	63,7

When Table 13 is examined, protection against infections is deemed of first priority by healthcare staff among benefits due to use of medical textile products, while single use is given second rank and ease of use is regarded in the third rank. Awareness level on benefits of medical textile products including lack of chemical material and non-adherence to wound is low.

Of the participants, 73,2 % answered to the question “When medical textile products are compared with previously used products, which would you prefer?” that they would prefer medical textile products and 23,8 % left the question blank and 3 % marked answer of Others.

7.2. RELATION ANALYSIS

In this section of the study, presence of a relation between medical textile products and demographics of healthcare staff is examined.

Considering awareness of medical textile products, difference between female healthcare staff and male healthcare staff is tested using independent samples t test (22) and it was found that there was no statistical difference at significance level of 0,05 (t= - 1,367, sig. : 0,173).

Difference among age groups for awareness level of medical textile products was examined using anova test (23) and no difference was found (F= 1,548 sig. :0,204)

Difference among education status groups for awareness level of medical textile products was examined using anova test and a difference was found at significance level of 0,05, and it was determined that staff with postgraduate and master degree had more information on medical textile products (F=3,383 Sig.:0,020).

Considering awareness level of medical textile products, difference between types of hospitals was examined using anova test and no difference could be found (F=1,481 Sig.:0,230).

Considering awareness level of medical textile products, difference between doctors, nurses and administrative staff was examined using anova test and no difference was found (F=0,581 Sig.:0,560). However, when ranking was considered, awareness level of medical textile products was in the decreasing order from doctors, nurses to administrative staff.

With regards the awareness level of medical textile products, difference in terms of occupation period was examined using anova test and no difference was found (F=1,693 Sig.:0,171).

8. CONCLUSION AND RECOMMENDATIONS

Increased wealth of the society, rapid advances in the technology and increased expectations for life quality caused an increase in demand for hygiene and care products. It is inevitable that the demand will continue to increase throughout following years. Therefore, companies operating in the textile sector, one of pioneering sector in our country, are required to monitor technological advances in the field of medical textile, to support R&D studies and to ensure labor opportunities.

When conclusion of the study is examined, it is observed that healthcare staff prefer to medical textile products providing protection against infections and single use products which offers practicability. In overall terms, it was found that those products are commonly used when state, private and university hospitals were examined.

Awareness of medical textile products was examined according to gender, age groups, education status, hospital type, profession and occupation period and a difference was found only for education status. It was found that individuals with postgraduate and master degree had more information on medical textiles.

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BIOMIMETICS AND BIO-INSPIRED TECHNICAL TEXTILES

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ABSTRACT

Biomimetics, stated in other words as biomimicry, is a novel term that simply relates how principles and processes in nature can be mimicked using present science and technology. Mankind has been inspired from the nature throughout centuries either knowing or senseless and that contributed to the advancement of human civilization. Textiles are one of the most important components in human life and their function is not only for covering body, but also they can be given additional values for functionality with respect to needs/applications. That's why biomimetics is a very good supportive factor to achieve this aim and it has an adequate basis to engineer products such as bio-inspired technical textiles. There are many success stories regarding bio-inspired textiles such as Kevlar which was designed after a deep biomimetic investigation on spider silk for ballistic protection, lotus effect inspired from lotus flower for self-cleaning and super-hydrophobicity and Stomatex mimicking a leaf stomata for a smart breathing mechanism and so on. On the other hand, it has still not been achieved that insulation quality of a goose feather or it still couldn't be mimicked that the structure of a tree that can live up to thousands of years for designing better performance composites. Aim of this study is to inform about biomimetics and about bio-inspired technical textiles that designed with a biomimetic approach. The study is comprised of two parts; first two parts informs about present biomimetic applications in technical textiles and the principles they are based on and the third part informs about future expectations.

Keywords: Biomimetics, Biomimetic Fiber Engineering, Technical Textiles, Biologically Inspired Textiles, Impact Energy Absorption.

1. INTRODUCTION

Biomimetics is the investigation of nature based systems and biological methods in order to design of new engineering systems and modern technology.

It is a very important question that should be asked here is as the world continues to evolve about 3.85 billion years, how life has survived with a number of nearly 3 million species. Actually, the species mentioned above had very little brains and they had no machines, no tools in order to survive. However, the mankind has relatively an enormous brain and has lots of machines and sophisticated tools to ease its life. But unfortunately, despite all advantages to the primitive species, mankind has been destructed nature more, instead of inspiring from it [1].

Fiber engineering is a multidisciplinary engineering branch and came out with a collaborative effort of a various disciplines such as material science, polymer science and textile technology. The aim of biomimetic fiber engineering is to corroborate the working principles of these disciplines with biological inspirations and to develop more resistant, multi-functional new generation products particularly in the technical textiles field [2].

The success stories which have already been carried out regarding excellent designs and engineered products will be discussed along with this part. The further part of this study will give a brief description about a biomimetic approach developed by Çağlar Sivri within Biomimetic Fiber Engineering program started in Swedish Center for Biomimetic Fiber Engineering in Stockholm, Sweden.

1.1. Kevlar

Kevlar, as a high performance fiber developed by mimicking the structure of the spider silk, represents a very important sample to the biomimetic fiber engineering.

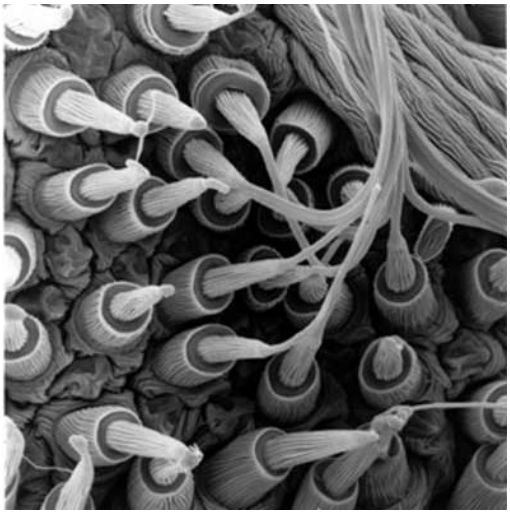

Figure 1: The fiber forming unit of a Spider [2]

Very unique structure of the fiber forming unit enables spider to produce ultra-thin fibers with high toughness (Fig.1).

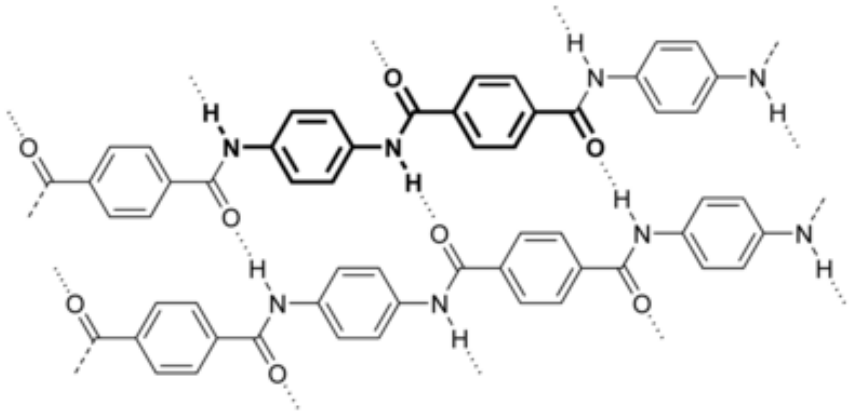

Figure 2: Chemical structure of a Kevlar fiber [2]

Figure 2 illustrates the chemical organization of the Kevlar fiber developed with an inspiration from spider silk. The ultra-crystalline structure supported with benzene rings along with the hydrogen bonds provides Kevlar an extremely strong profile. That's why one can easily find its applications as body armor, cut-proof material and as a reinforcing material in composites.

1.2. Self-Cleaning Fabrics

Self-cleaning fabrics that was developed via an inspiration from lotus plant is another important success story in the development of biologically inspired textiles.

a) Lotus leaf **b)** Superhydrophobicity-Lotus c) Nano-level bumps effect

Figure 3. Lotus plant and its unique surface properties [3]

In lotus flower, with every raindrop, the contact angle with water and dirt is minimized thus enabling the surface self-cleaned due to the biphasic micro/nano organization at the surface (Fig. 3). When this principle was applied onto the textile fabrics through lotus inspired chemicals, it increases surface roughness of the fabric and makes it a self-cleaning fabric [4]. GreenShield trademark is one of these multi-functional textile finishes [5].

1.3. The Leaf Stomata: A Novel Inspiration Source for Breathable Mechanisms

The other important finding that has been applied to the technical textiles using biomimetic principles is the development of novel breathable fabrics via mimicking the breathing mechanism of the stomatal pores in the leaves.

One group of researchers working in the British Defense and Clothing Agency has applied the breathing activity of pores in the leaves to the fabrics in order to provide higher performance to the soldiers who works under extreme conditions [6].

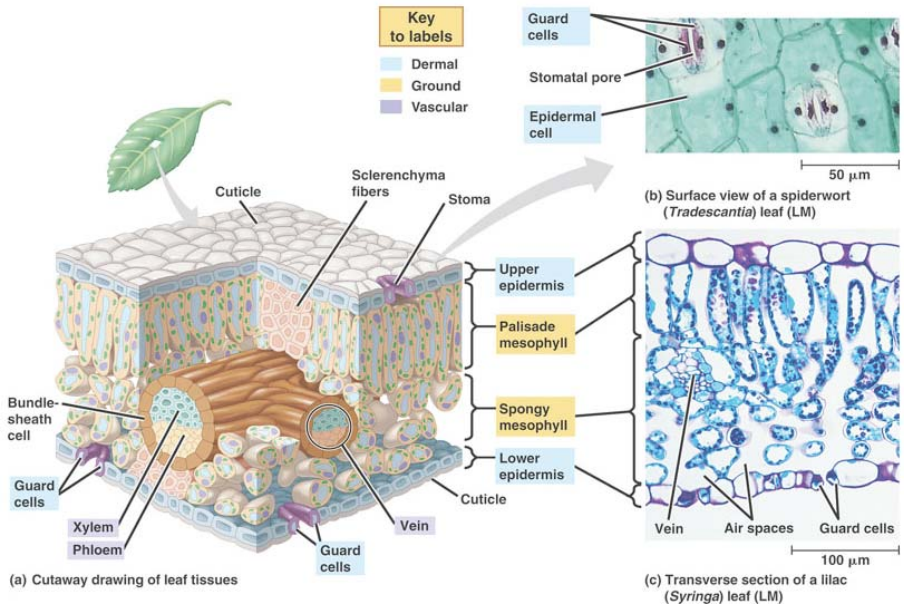

Figure 4. The organization of a stomatal pore along with the leaf tissues [7]

Physiologically, a leaf opens its stomatal pores (Fig. 4) when the heat increased in its micro-climate and closes if it needs to avoid heat loss.

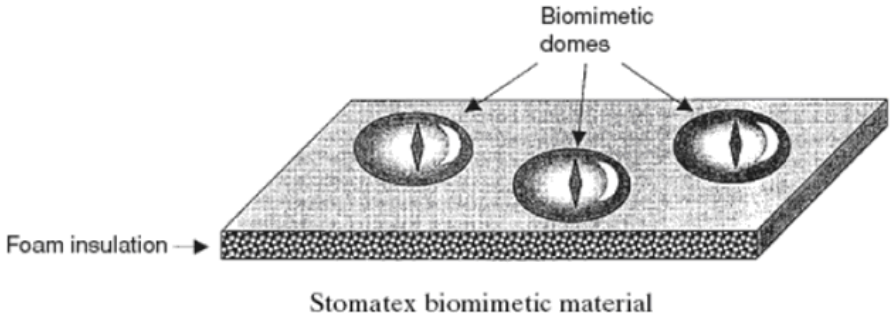

Figure 5. Stomatex biomimetic insulation foam material

The Akzo Nobel Company has patented this phenomenon by developing a neoprene based Stomatex biomimetic insulation foam material incorporating convex domes for breathable clothing (Fig. 5). These biomimetic domes mimick the leaf breathing mechanism by making a controlled vapor release [6].

2. WOOD AS A BIOMIMETIC INSPIRATION MODEL ORGANISM

Wood is the one of the most abundant material present in the nature. Even though it seems very simple, when its inner structure investigated in detail, there are very interesting constituents and there is a complex but hierarchical organization between these constituents resulting in a post-modern system. Cellulose, hemi-cellulose and lignin are main components make up the structure of wood and make it an excellent composite. It is such an interesting material that this structure causes some of trees to live up to thousands of years. That's why when this complex structure entirely understood then extremely strong, long life and nature friendly nano/bio composites could be designed. In addition, as a material incorporating confrontational features such as toughness and lightness, wood has always been an inspiration source for research.

2.1. Cellulose

Wood has many components in different amounts but the biggest content is supported by cellulose. The chemical structure of the cellulose $(C_6H_{10}O_5)$ is based on polysaccharides that are forming long chains. Cellulose is the most abundant natural polymer in the world and represents a building block for many materials in the nature. It is a renewable and an organic compound and it can be used itself as well as can be used with other materials in the form of a complex. Finally it is found in fiber wall of many different plants. It has many functional features but the impact absorption is the forefront.

2.2. Impact Absorption Function of Wood for Biomimetic Designs

It is a little known but very important fact that most bullet-proof vests have been designed by mimicking the structure of wood. The structure of wood is formed from tubular fibers providing wood a high toughness. When a wood cell was broken inward, then it absorbs impact energy and separates

itself from other cells surrounding it. Even the broken areas create a crack along the fibers, general wood structure remains without damaging and even the wood is broken, it has strength to bear a certain extent of force [8].

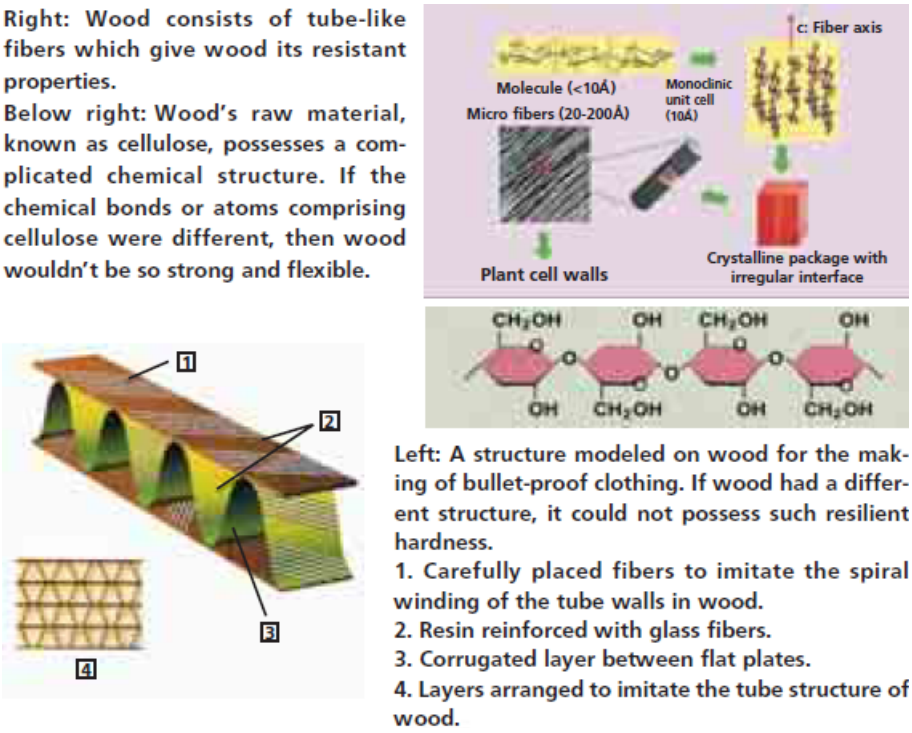

Figure 6. The biomimetic model inspired from wood for bullet-proof vest design [8]

A material produced by mimicking the design of the wood (Fig. 6) has shown 50 times higher toughness to the present synthetic materials.

3. A NOVEL BIOMIMETIC APPROACH TO IMPROVE IMPACT ABSORBTION IN BULLET-PROOF VESTS

Even though the highly sophisticated design offered by nature, bullet-proof vests has some weakness point and they may give rise to some damages on the body such as fractures. The vest can bear greater amount of impact energy but the control of this energy is not easy in some cases.

The solution for this problem may lay behind an investigation on cell wall formation of the wood and particularly on micro-tubules. Micro-tubules play an important role in fiber wall biosynthesis of the wood and they are directly associated with the proteins within the cell wall. They also bridge over cellulose, hemi-cellulose and lignin. That's why when the micro-tubules (Fig. 7) were damaged then the cell wall biosynthesis ends.

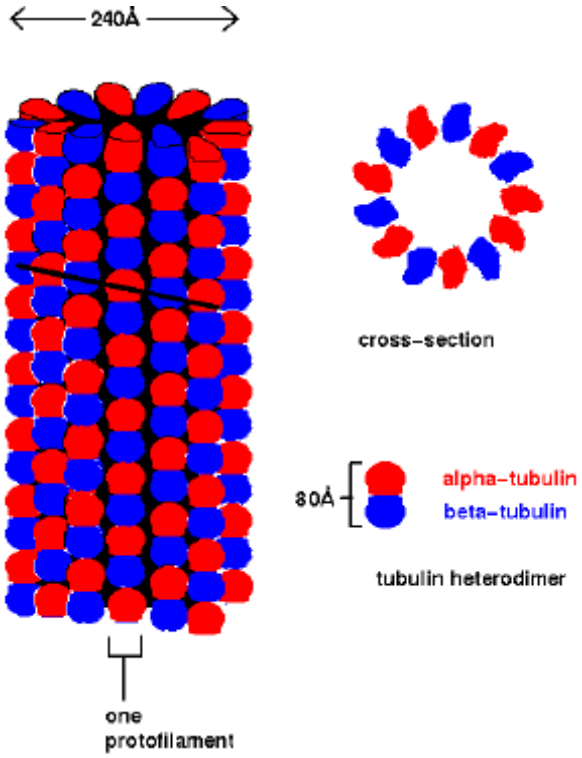

Figure 7. The structure of a micro-tubule [2]

The micro-tubules are aligned together with the cellulose in the cell wall (Fig.8).

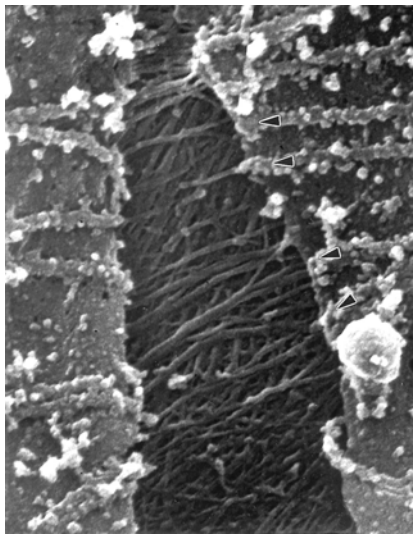

Figure 8. The Micro-tubule and cellulose alignment in the cell wall

The hierarchical structure of the cell gives an idea about relationship between inner-cell constituents such as cellulose, hemi-cellulose, lignin, micro-tubules and plasma membrane.

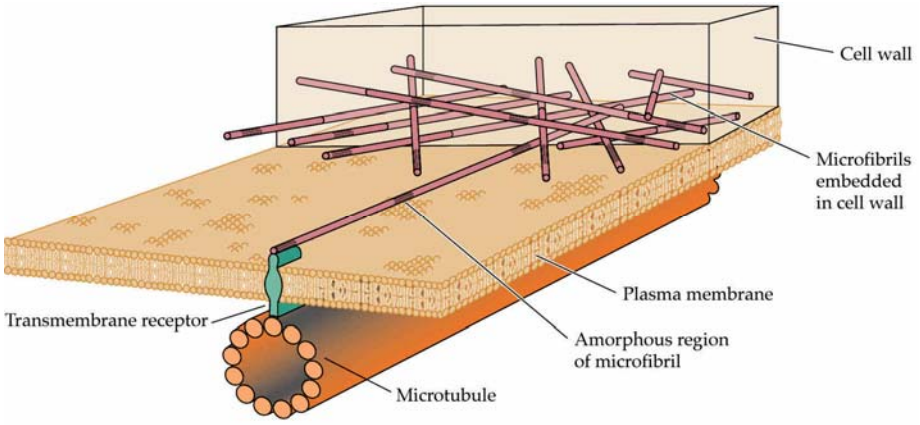

Figure 9. The relationship between micro-tubule and cell wall [2]

When a cell's structure discussed in detail, it can be seen that the cell wall is settled over plasma membrane. This plasma membrane is settled right over the micro-tubule. Because of that reason, micro-tubule is the carrier of the plasma membrane and consequently it is the carrier of the cell wall (Fig. 9).

The micro-fibrils embedded in the cell wall communicate with micro-tubules via a trans-membrane receptor.

According to the approach developed by Çağlar Sivri based on information given above and some other observations, improvement of mechanical properties of micro-tubules may cause to a more robust cell wall and then it can bear higher forces and might have a better impact energy absorption. Achieving this type of structure is only possible with a biomimetic modification.

Biomimetic modifications enable proteins to accept different type of substrates by changing their active sides. Right at this point, with the aim of reinforcement, it may be possible to eliminate the breaking problem of micro-tubules by changing the active side of proteins that associated with micro-tubules and associating proteins with a material or preparing a complex incorporating micro-tubules and another material that will enable micro-tubules to be supported. When an appropriate material found for association or complex process and applied to the micro-tubules then the problem should have been solved.

Finally, after the successful transfer of this biomimetic modification to the bullet-proof vest production process, it will improve the impact absorption and will eliminate problems caused by weak structure.

4. CONCLUSIONS

Lots of the problems has been solved by using biomimetics in our day and it was expected the same for the future. The developments such as self cleaning fabrics eliminating detergent use for cleaning of textiles, high resistance and tough materials such as Kevlar and breathable fabrics mimicking the leaf breathing mechanism have shown that how biomimetics helped innovations.

In addition to the innovations mentioned above, the ongoing study mentioned here offers an approach to the analysis of cellulose, wood and its constituents at nano scale in order to eliminate problems in body due to the weak impact energy absorption with the use of ballistic vests.

However, it was still kept the survival secret by the trees living for thousands of years in fact it shows that there is much more distance to be covered. And also the worry has just focused on performance in our day, but in future it will be focused on development of the nature friendly materials that will perform as much as synthetic materials presently used.

ACKNOWLEDGEMENTS

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CHARACTERIZATION OF CONDUCTIVE POLY(N-METHYL PYRROLE)-POLY(ACRYLONITRILE-*CO*-VINYL ACETATE) COMPOSITE FILMS

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ABSTRACT

In this study, Poly(N-Methyl Pyrrole) (PNMPy)- Poly(Acrylonitrile-*co*-Vinyl Acetate) (P(AN-*co*-VAc)) composite films were fabricated by chemical oxidative polymerization of N-Methyl Pyrrole(NMPy) on P(AN-*co*-VAc) matrix. Different amounts of n-methyl pyrrole were added into the P(AN-*co*-VAc)-DMF solutions to achieve the polymerization of NMPy. The composite films were investigated by using spectroscopic and electrical characterization methods.

Key Words: conductive textiles, NMPy, composite film

1. INTRODUCTION

Electrically conductive polymers have attracted much attention due to their electrical, electrochemical and optical properties. Polypyrrole (PPy) is one of the significant conducting polymers due to its relatively easy processability, high electrical conductivity, good stability, relative ease of synthesis and good redox reversibility. However, PPy is limited in practical use due to fragile structure and insolubility, and lack of stability. Polyacrylonitrile (PAN) and its copolymers are generally used in textile applications due to its good mechanical-thermal properties and low costs. Development of textiles with new properties (i.e., electrical conductivity) has received great attention in recent years with wide applications in the fields of electromagnetic interference (EMI) shielding, electrostatic dissipating, antistatic and energy storage [1-5]. Recently, some efforts have been focused on the preparation of metal nanoparticle/conductive polymer composites or using an insulator polymer matrix to make semi conductive structures [6-9].

In this study, solution casting method was applied to obtain PNMPy- P(AN-*co*-VAc) composite thin films. Effect of the amount of NMPy on the resulting spectroscopic properties of composites was investigated.

2. EXPERIMENTAL

2.1. Materials

PAN copolymer containing 10% mass ratio vinyl acetate (synthesized in the laboratory), dimethylformamide (Merck), N-methyl pyrrole (Aldrich) and ammonium cerium (IV) nitrate (CAN) (Merck) were used as received.

2.2 Preparation of PNMPy-P(AN-co-VAc) Composite Thin Films

P(AN-co-VAc) was dissolved in DMF and NMPy (i.e., 50 and 150 µl) was added to the solution. This solution was mixed for 1 h. After 1 h, the initiator cerium (IV) (30% amount of NMPy) was added to the solution to polymerize NMPy. Temperature was increased up to 80˚C to obtain a viscous solution. This viscous solution was casted as a film on a glass substrate. The casted solutions were dried in vacuum stove (600mmHg) for 24 hours at 60˚C.

2.3. Characterization

The infrared spectrum of thin films was obtained by "FTIR reflectance spectrometer" (Perkin Elmer, Spectrum One, with a Universal ATR attachment with a diamond and ZnSe crystal). AC electrical conductivity measurements were performed by Novocontrol Broadband Dielectric Spectrometer (Alpha-A High Performance Frequency Analyzer, frequency domain 0.001Hz to 3GHz).

3. RESULTS AND DISCUSSION

3.1. FTIR-ATR Spectrophotometric Analysis

The effect of PNMPy content on composite films was investigated by FTIR-ATR spectrophotometer.

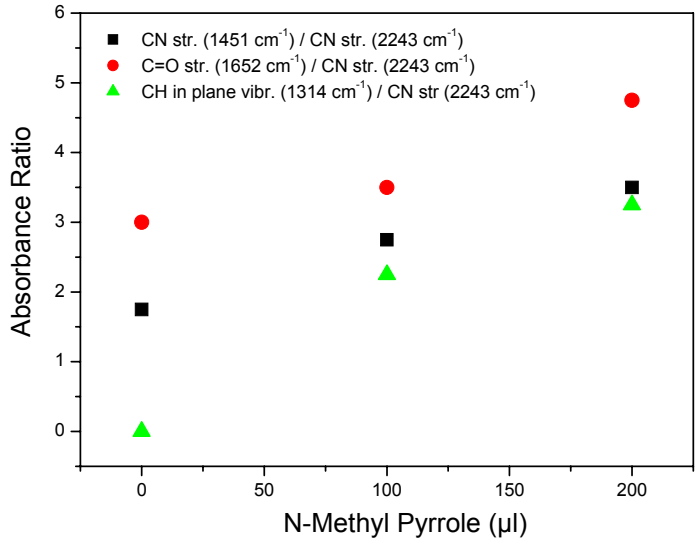

Figure 1. Change of absorbance ratios (FTIR-ATR) as a function of initially added N-methyl pyrrole concentrations in the PNMPy/P(AN-co-VAc) composite films

The absorption band appearing at 1666 cm-$^{-1}$ corresponds to C=O stretching of DMF was shifted to 1652 cm^{-1} in the presence of PNMPy. It might be due to interaction between the C=O group of DMF and N-R group of PNMPy in composite films. In the presence of PNMPy, a new absorption band appeared at 1314 cm^{-1} corresponds to CH in plane vibration peak and its intensity increased by the addition of pyrrole. The band observed at 1454 cm^{-1} corresponds to CN stretching for PNMPy (Fig. 1). Its intensity is increased by the increase in N-methyl pyrrole content. These results indicate that PNMPy formation can be followed by FTIR measurements in composites [9].

3.2 AC Electrical Conductivity

AC Electrical conductivity measurements were carried out at room temperature (25 ˚C). The frequency dependent electrical conductivities of composite films have been presented in Fig. 3.

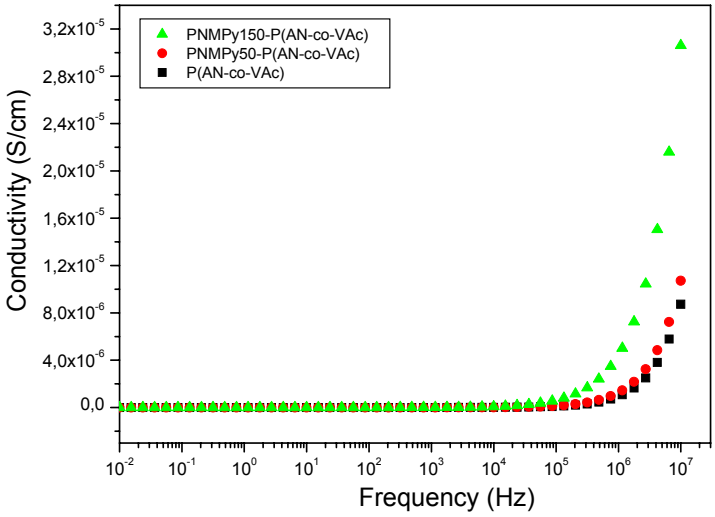

Figure 3. AC Conductivity of PNMPy-P(AN-co-VAc) composite films

A plateau is observed for composite films at lower frequency range up to 10^5 Hz resulting in the AC electrical conductivity is independent of frequency. At higher frequencies (10^5–10^7 Hz), there is an obvious increase in the composite film conductivity with increasing frequency. The increase of AC conductivity at higher frequencies originates from the charge motion in the amorphous region [9, 10].

4. CONCLUSIONS

In composite films, the intensity of the CN stretching vibration peak (1454 cm^{-1}) was increased by the increase in NMPy content. This indicates that the incorporation of PNMPy into the composite structure. A linear relationship was determined between the absorbance ratios of functional groups corresponding the conjugated polymeric units and initial NMPy concentrations. An obvious increase was observed in the conductivity with increasing frequency at higher frequencies (10^5–10^7 Hz)

ACKNOWLEDGMENTS

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COMPARATIVE STUDY ON THERMAL COMFORT PROPERTIES OF KNITTED FABRICS PRODUCED BY NATURALLY COLORED COTTON AND WHITE COTTON

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ABSTRACT

As a natural fiber, cotton is still the most widely used fiber type in all over the world today. But dyeing process of cotton is an important pollution source as well as being an important cost for this fiber. Furthermore, in recent years, textile consumers are becoming more sensitive about textile products with respect to human health. So, naturally colored cotton (NCC) fiber which has been known for a long time received more attention and commercial products of NCC fiber are preferred by consumers in the textile market. The aim of this study is to compare the thermal comfort performance of knitted fabrics produced by NCC and white cotton. NCC, (brown color) and white cotton used in this study were cultivated under the same climatic conditions by Nazilli Cotton Research Institute. These two fiber types were then processed in a ring spinning mill as Ne 30/1 carded knitting yarns with twist factor (α_e) of 3,7. The produced NCC and white cotton yarn types were knitted by a 20 inch diameter and 60 feeders single jersey knitting machine. A part of produced white cotton fabric was dyed to the color of brown NCC fabric to prepare the samples. Consequently, air permeability, water absorption, water vapor permeability, thermal conductivity and thermal resistance properties were tested to compare comfort properties of the samples. Results show that NCC fabrics have similar thermal comfort behaviors to white and dyed cotton fabrics, so using NCC fabric instead of dyed one is advantageous because of eliminating dyeing process.

Key Words: naturally colored cotton, self colored cotton, brown cotton, thermal comfort

1. INTRODUCTION

Clothing is needed to protect body against hostile climatic conditions and to assist in the thermo regularity responses of the body. Thermal insulation properties play a crucial role for a human's heat maintenance. Comfort is one of the most important attributes of textiles used in clothing. Clothing comfort is influenced by fabric factors, fiber conductivity, fabric parameters, air conditioned within the fabric, environment factors like temperature and humidity and at last human factors like color and fashion [1-2-3]. The literature generally classifies clothing comfort as; thermal comfort, tactile comfort and aesthetic or physiological comfort. Thermal comfort is related to clothing comfort because the main function of the garments is to constitute a regulation system for keeping body temperature at the mean value even if outer atmospheric conditions and physical activities change [4-5].

There are many researches about thermal comfort properties of knitted fabrics. Özdil et al investigated the thermal properties of rib fabrics produced by different yarns. They found that while yarn twist and count increase, thermal resistance decrease and water vapor permeability values increase [5]. Frydrych et al studies on thermal properties of fabrics produced by Tencel and cotton. They proved that Tencel fabrics have lower thermal conductivity and thermal absorption values than cotton fabrics [6]. Marmaralı et al studied on hermal comfort properties of knitted fabrics containing elastic yarns. It is concluded that by using more elastic yarn resulted in more thermal resistance and less thermal conductivity and relative water-vapor absorption [7]. Yi et al studied with natural dyed fabrics to investigate comfort behaviors of them. It is reported that after dying water-vapor permeability, air permeability, and moisture regain values increase however, wickability and dynamic water absorption decrease because of widening of spaces in the fabrics.

Increasing public interest and awareness on the environmental issue have let the textile manufacturers to use less hazardous materials to minimize the effects of disposals on the environment. Naturally colored cotton fibers are considered potential eco-friendly materials and they avoid the use of synthetic pigments which in general contains toxic materials such as heavy metals [8].

Although there are some researches about the physical properties of fabrics produced by naturally colored cotton but the thermal comfort properties of those fabrics are not well explored, therefore they need to be studied. This study aims to investigate the thermal comfort properties of naturally colored cotton fabrics.

2. MATERIALS AND METHODS

The NCC which is light brown in color and the white cotton (Şahin-2000) fibers used in this study were cultivated under the same climatic conditions by Nazilli Cotton Research Institute. The NCC and the white cotton fibers were spun into yarns in an industrial carded ring spinning mill. Fabrics were produced by a commercial, 20 inch diameter and 60 feeders circular knitting machine as single jersey. Then white cotton fabrics were dyed with a similar color to NCC cotton fabric. The fiber properties of cottons used in the study is given in Table 1.

Table 1. Fiber properties of cottons

	Şahin 2000	**NCC**
Fineness(Mic.)	3.94	3.83
Length(UHML)	29.0	27.53
SCI	143	101
Maturity Index	0.86	0.84
Uniformity Index	83.1	82.1
SFI	8.30	11.16
Strength (g/tex)	30.50	25.20
Elongation (%)	5.7	6.3
Rd	80.3	43.6
+b	10.3	20.9

The NCC and the white cotton fibers were spun into yarns in an industrial carded ring spinning mill as Ne 30/1 knitting yarns. All the production parameters of both types of cottons were remained constant as shown in Table 2. The yarn parameters of the sample cotton are given in Table 3.

Table 2. Production parameters of yarns

Number of card sliver, Ne	0.120
Number of draw frame sliver, Ne	0.120
Number of roving, Ne	1.10
Spindle revolution, r.p.m.	12500

Table 3. Properties of yarn samples

	NCC	**Şahin 2000**
Yarn number (Ne)	30	30
Twist factor (α_e)	3.7	3.7
Breaking Strength (gf)	257,4	295,6
Breaking Elongation (%)	4.8	4.6
Um	13.31	14.67
CVm	16.9	18.70
Thick place (+50%/km)	294	463
Thin place (-50%/km)	49	110
Neps (+50%/km)	524	600
Hairiness	7.15	7.11

All yarn and fabric samples were conditioned according to ISO 139 before tests. Thickness of the knitted fabric samples were measured by Paramount thickness tester according to ISO 5084. Fabric weight values were measured according to TS EN 12127. Number of courses and number of wales were determined by a magnifying glass at 5 randomly selected regions of the sample fabrics. Fabric properties of samples are given in Table 4.

Table 4. Fabric properties of samples

Samples	**Properties**			
	Fabric Thickness (mm)	**Fabric Weight (g/m²)**	**Number of wales per cm**	**Number of courses per cm**
NCC	0,47	154	16	20
Dyed	0,45	153	16	20
White	0,46	154	16	21

Air permeability properties of fabrics were tested by SDL Atlas Digital air permeability tester according to ISO 9237. 20 cm² test area was used and 100 Pa air pressure was applied during the test. Twenty measurements were done for each sample fabric and an average of twenty measurements was taken for each sample.

Water absorption properties of fabric samples were determined considering AATCC 79-2007 after dry relaxation and after three successive washings. Washing treatments were done according to AATCC 179-1996.

Thermal absorptivity and thermal resistance were measured by means of Alambeta instrument and water vapor permeability was measured by means of Permetest instrument under standard atmospheric conditions.

To evaluate the results statistically, SPSS 11.0 was used and one-way ANOVA was applied to analyze the importance of variation.

3. RESULTS

As a result of this experimental study, air permeability, water absorption, water vapor permeability, thermal resistance and thermal conductivity test results of sample fabrics are given.

3.1. Air Permeability

Air permeability is defined as the resistance to flow of air from a specific surface area. Air permeability is affected from the type of fiber, fiber fineness, the type of yarn, count of yarn, production method and construction and applied treatments. Air permeability is related to comfort property of fabrics consequently; air permeability is related with fabric breathability [9]. In this study, air permeability of knitted fabrics is examined to observe the effect of fiber production method and dyeing. Figure 1 presents that air permeability of dyed fabrics is more than the white fabric; additionally air permeability of white fabrics is more than the NCC fabric.

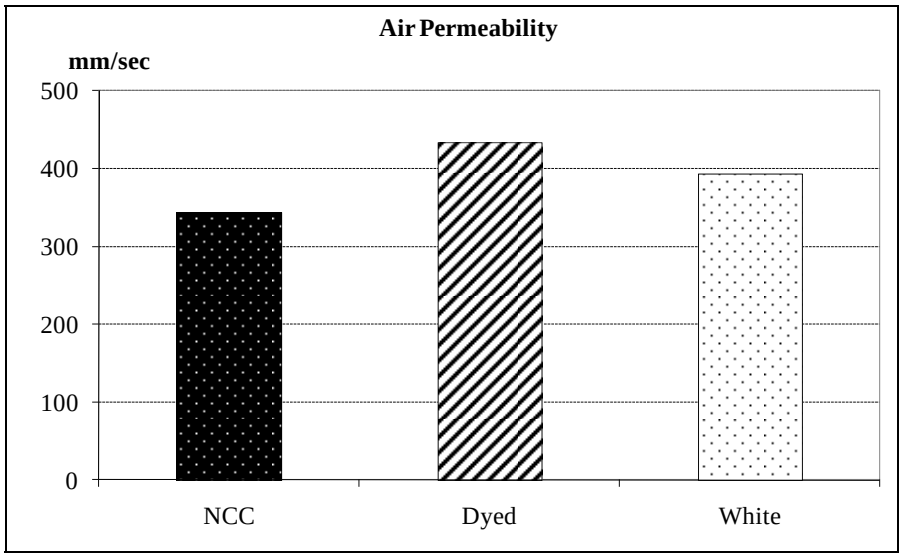

Figure1 Air permeability values of knitted samples

3.2. Water Absorption

Water absorption means transferring time of water drip from surface to back side of the specimen. Factors such as fiber size and shape, yarn structure, fabric construction parameters, desizing, scouring, dyeing and laundering of cotton are all found to have an influence on the wetting behavior of fabrics [10]. The fabrics used in this study are observed after dry relaxation and laundering for the water absorption property analyze. Table 5 shows that after dry relaxation none fabrics are transferred water drip to back side before 60 seconds; and also this situation continues for white and NCC fabrics after laundering, whereas dyed fabric water absorption is realized after 6,2 seconds.

Table 5 Results of water absorbency for knitted fabrics

Sample	Water absorbency (seconds)	
	After dry relaxation	After five washing
NCC	60+	60+
Dyed	60+	6,2
White	60+	60+

3.3. Water Vapor Permeability

With the increasing of porosity, the water vapor permeability also increases [5]. In this study the fabrics are knitted by the same count of yarn in the same knitting machine with same parameters. Additionally, the thickness, weight and the number of wales in 1 cm and the number of courses in 1

cm are virtually same each other as shown in Table 1. Therefore the type of fiber used in fabrics (not raw material) and the dyeing effects on water vapor permeability are examined. Figure 2 represents that water vapor permeability of dyed fabrics is less than the NCC fabric; additionally water vapor permeability of NCC fabrics is less than the white fabric. Moreover, the test results were assessed at significance levels $p \leq 0,05$ and $p \leq 0,01$. The one way ANOVA test exhibited that the water permeability of fabrics was not different each other, or the difference is insignificant according to ($p \leq 0.01$) at 1% significance level.

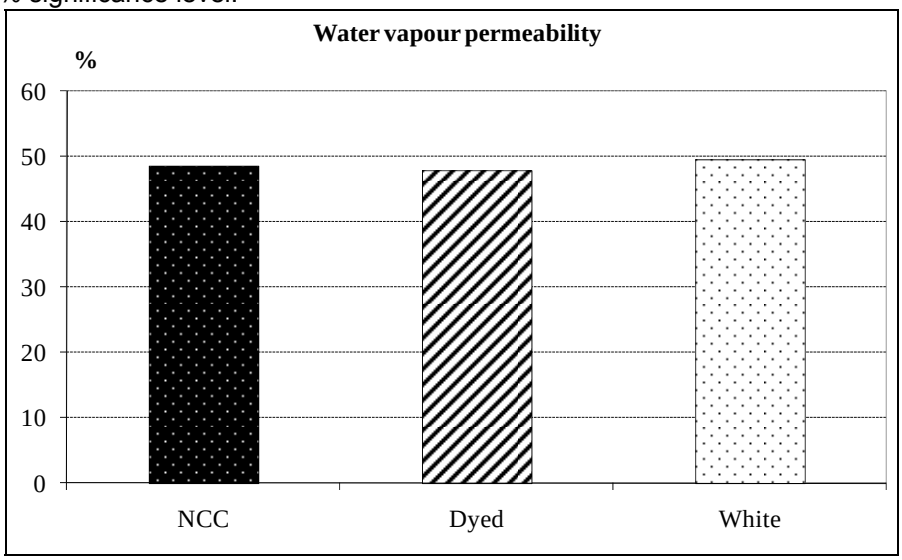

Figure 2 Water permeability values of knitted samples

3.4. Thermal Resistance and Thermal Absorptiveness

3.4.1. Thermal resistance

Thermal resistance is an indication of how well a material insulates [11]. Figure 3 presents the thermal resistances of knitted samples. In accordance with the graphic, it is concluded that the results are closed each other therefore, the test results were assessed at significance levels $p \leq 0,05$ and $p \leq 0,01$. The one way ANOVA test exhibited that the fabrics are in the same group, or the thermal resistance of differences of fabrics is insignificant according to ($p \leq 0.01$) at 1% significance level.

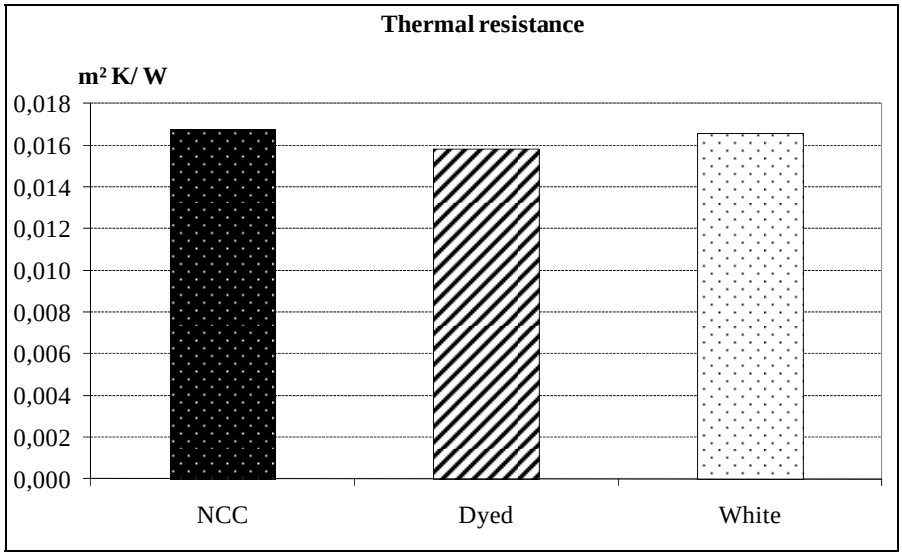

Figure 3 Thermal resistances of knitted samples

3.4.1. Thermal absorptiveness

Thermal absorptiveness is the heat flow which passes between the human skin and the contacting material [12]. Figure 4 shows the thermal absorptiveness of three knitted samples. According to the figure the absorptiveness of all samples are similar to each other so to analyze the results objectively, the test results were assessed at significance levels $p \leq 0,05$ and $p \leq 0,01$. The one way ANOVA test exhibited that the fabrics have same conducting property, or the difference of fabrics' thermal absorptivity is insignificant according to ($p \leq 0.01$) at 1% significance level.

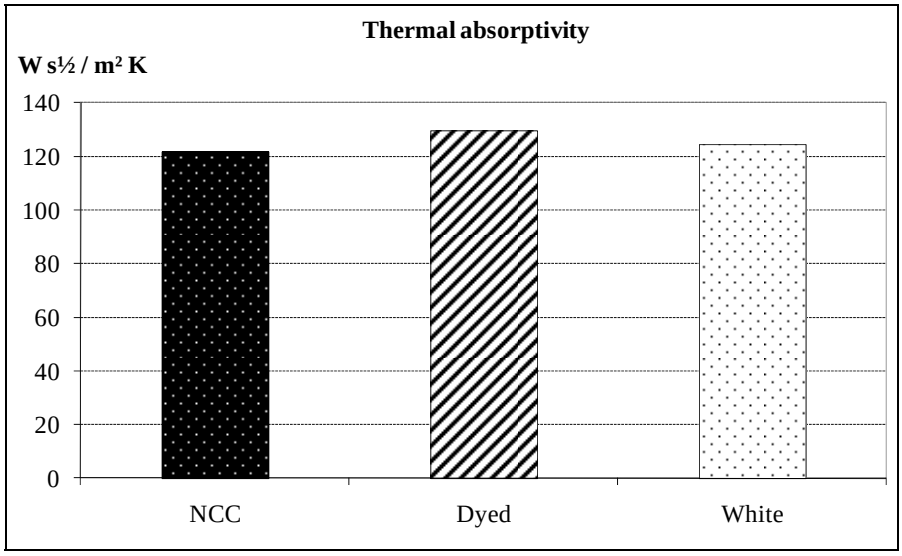

Figure 4 Thermal absorptiveness values of knitted samples

4. CONCLUSIONS

Experimental studies show that the water vapor permeability, thermal resistance and thermal absorptivity results for naturally colored cotton are quite similar to the values obtained for conventional white cotton (dyed and white). However, air permeability of white cotton fabric is slightly higher than naturally colored cotton fabric and also observed that dyeing improves the air permeability of fabrics because of widening of the porous of the fabrics.

The study show that, in general, the thermal comfort values naturally colored cotton is somewhat lower than the conventional white cotton but may fit to human body requirements.

ACKNOWLEDGEMENT

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COMPARISON OF FLAME RETARDANT EFFECT OF ZINC BORATE AND PHOSPHOR BASED ADDITIVES IN POLY(BUTYLENE TEREPHTHALATE)

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ABSTRACT

Neat Poly(butylene terephtalat) (PBT) is highly combustible. Therefore it should be rendered flame retardant for a lot of applications. The most common flame retardants for PBT are based on halogenated or phosphorus compounds. The demand of new innovative flame retardants for textile industry is increasing.

The main aim of this study is to investigate the flame retardant performance of zinc borate and to compare phosphor based additives in PBT polymer. For this aim PBT granules obtained from KORTEKS/Bursa Phosphor based flame retardant powder was supplied by BUSAN/Bursa. Zinc borate powders bought from Grate Lake Chemicals Company/USA.

Firstly size reduction process was applied for reducing the particle size of the zinc borate to the nanometer scale to obtain higher surface area. Then PBT granules were mixed by the variable amounts of nano sized zinc borate and phosphor based powders (10, 20, 30 wt.%) for twenty minutes with mechanical stirring. Polymer additive blends were processed in a twin screw Micro Compunder (DSM Xplore) at 250 ^{o}C. Bar-shaped specimens (100x10x4 mm) for the LOI (Limit Oxygen Index) tests were prepared by pressing at the microinjection device (DSM Xplore). The neat PBT used as a standard was treated in the same way. The combustion performance of the formulations was studied by the LOI test following the ASTM D 2863 standard. Properties of flame retardants were characterized by X-Ray diffraction (XRD), Scanning Electron Microscopy (SEM) and thermal gravimetric analysis (TGA). Thermal analysis was carried out using a Netzsch/STA 409 PG. Standard measurements were performed at a heating rate of 10 ºC/min in an argon air flow from 20 to 800 ºC. The transformation energetics and the mass change of all the samples were measured and compared.

ECOLOGICAL COMPOSITE NONWOVENS FOR TECHNICAL END-USES

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ABSTRACT

The paper is presenting researches on structures of needlepunched nonwovens, made of environmentally friendly natural raw materials, used for technical applications. The needlepunched nonwoven technology can be considered, with some edges, as an ecological technology because it is not using any type of chemical as adhesive to bond the fibrous web. Two raw fiber materials for two different end-uses have been processed. The cotton fibers treated by alkaline boiling and bleaching process as well the indigene wool fibers and hairs have been processed to obtain the ecological needlepunched nonwoven products used for medical absorptive product as well in furniture industry. The nonwoven products made from wool fibers are representing the way to use some indigene raw material resources. The nonwovens have been evaluated by the functional characteristics as the absorption capacity as well the average surface weight, tensile and elongation characteristics.

Key words: natural fibers, cotton, wool, composite, nonwovens

1. PROBLEM STATEMENTS

Ecology (from Greek: οἶκος, oikos, "house, household, housekeeping, or living relations" ; -λογία, -logia, "study of") is the interdisciplinary scientific study of the distribution and abundance of organisms and their interactions with their environment [1, 2]. In other words, ecology is the branch of biology that studies relationships between living organisms and the non-living components of the environment in which they live [1, 2].

This paper is presenting the ecological fibers and nonwoven end-uses by some point of view, as well the way to obtain wool and cotton based nonwovens.

Types of ecological fibers are as follows [3, 4, 5]:

- organic ecologic cotton with genetic modifications has the some physical-mechanical properties but with the advantages for being without pesticides;
- bast fibers of flax and hemp, jute, ramie, or other cellulose fibers such as coconut, pine-apples, abaca;
- protein fibers from vegetables, example being the soy fiber (as a "vegetal cashmere" of luxury and eco-friendly with a aesthetic property as "the second skin" and being a natural amino-acid has many relief properties on skin);
- natural protein fibers, such the wool fibers that sometimes are not pretty pleasant for some persons having sensitive skin;
- natural silk fibers from worms of silk, threads from artificial spider of special characteristics;
- other ecological fibers such as chitosan, bamboo, corn vegetables.

On the other hand, it shall mention that not all fibers which are believed to be green and eco-friendly are so, and that is because of too many treatments or processes for harvesting or for processing into final application, even the bamboo textiles are not so green which is as a tree.

By a general point of view, the main applications of the nonwovens for ecological purposes are including for [4, 5, 6, 7]:

- filters made from cotton, wool, polyacrilic, ceramic, etc.;
- agrotextiles of special properties contributing to the ecological crops;
- geotextiles for environmental protection, landscaping, etc.;
- cleaning, absorbent or protective materials against the polutions;

- furniture made from wool and horse haires.

The needlepunched nonwoven technology should be considered, with some edges, as an ecological technology because it is not using any type of chemical as adhesive to bond the fibrous web.
Normally, all ecological natural fibers even if they have a lise surface, but only that have a enough length to loop, can be used to obtain needlepunched nonwovens, as examples of fibers being the following [4, 5]:

- cotton of 1.2...2.6 dtex finnesses and 10...60 mm length, with low percentage of impurties, for hygiene, medical, bandages products;
- bast such as hemp and flax for composite structures of reciclability and bio-degradability properties;
- wool for technical applications;
- rayon of 3.8...7.1 dtex or 13.1...16.5 dtex finnesses, and 60...100 mm length, for hygiene and sanitary structure products, absorbent structures for environmental issues;
- recycled for new raw material source, for thermal os sound insulation;
- animal haires of horses, pigs, cows, goats, which are processed in mixture with other types of fiber, for technical applications such as carpets, thermally insulations, special apparel, special felts etc.;
- natural silk in mixture with polypropylene for decorative wall coverings;
- jute in mixture with polypropylene, for agrotextiles to protect soils until development of crops;
- manila for special paper;
- palm tree treated in special alkaline conditions can be replacing the manila, coconut tree, sisal or jute for hydro-insulation applications;
- kenaf for interior cars' s insulation components of low surface weight;
- coconut tree for filling materials of the fishing and sailing products;

The reasons for using wool fibers in nonwoven products are because of fiber absorbency, resistance to flame, fire resistant, and resistance to compression properties.
The wool fiber is a hygroscopic fiber; it takes up moisture in vapor form. Tiny pores in structure make the fiber semi-permeable, allowing vapor to pass through to the heart of the fiber, can easily absorb up to 30% of its weight in moisture without feeling damp or clammy. The capacity to absorb makes wool fiber a "temperature regulator" because it can protect the body in both cold and warm conditions.
Because wool contains moisture in each fiber, it resists flame without chemical treatment. Instead of burning freely when touched by flame, wool chars and stops burning when it is removed from the source of fire. Wool is self-extinguishing. It will not support combustion; this is why wool blankets are recommended for use in extinguishing small fires.
Resistance-to-compression values are useful in assessing the suitability of wool for specific end-uses.
Wool is naturally safe. It does not have to be specially treated to become non-flammable. While it can catch alight, it will not flare up nor support a flame. Instead of burning freely, once the flame is removed a cold ash is left which can be brushed away immediately. Wool does not melt when burned, and so cannot stick to the skin and cause serious burns. Because of its fire-resistant qualities, wool blankets, furnishings and carpets in your home are necessary insurance, and wool for clothing (particularly children) will protect from accidents associated with fire. Firemen wear wool uniforms, and fire-fighters in rural areas should always ensure they dress themselves in wool before rushing to fight a fire.

The paper also is presenting researches on medical products made by nonwovens technologies with a high absorption capacity for emergency cases on battlefield or other types of disasters.
The nonwoven technology has the fastest growing of more 10% yearly within the textile industry [4, 7, 8].
The nonwoven products are realized from cotton fibres treated by alkaline boiling and bleaching processes to improve the characteristic performance of products. Products of 200 g/m^2 to 300 g/m^2 average basic weight, with high liquid absorption capacity can replace the woven gauze medical products have been obtained by needlepunching process.
The end-uses of products are for absorbent pads, bandages, bed linen, blankets for hospitals, burn dressings, cast liners, swabs, puffs, absorbent puffs, component of face masks, finger bandages, heat packs, incubator mattress, medical filters, procedure packs, medical equipment, wound dressings, etc.
The pulp fibres have been also used to diversify the nonwoven products for very special medical end-uses with a very high liquid absorption capacity [5, 6, 7, 8].

As an innovative technology to obtain environmentally products, the cellulose fibres nonwoven technology is more widely used to obtain environmentally friendly products [9, 10, 11].
From the cellulose fibres category, the fibres of cotton are the most customary fibres for nonwoven products for a very large area of end-uses including the medical products.
The criteria that have determined to obtain the nonwoven based medical products mainly have been the following: no indigene nonwovens for medical applications; the lower cost to obtain the medical nonwovens by less process steps (by number and by length) compared to the classical woven gauze process steps, as well the less raw materials, energy and labour; the highest absorption capacity compared to the classical products;
The most consumers perceive that the cotton is a superior fibre.
The general cotton fiber characteristics [3] that could determine the end-uses of nonwovens and cotton processing are shown in Table 1.

Table 1: The cotton fibre characteristics

Property	Value
Fineness, μm	12 - 20
Length, mm	12.7 - 30.5
Moisture regain at 65% r.h., 20°C, %	7 - 8
Dry tenacity, cN/denier	3.00 - 5.00 cotton is 20% stronger when wet
Wet tenacity, cN/den	3.50 - 6.00
Breaking extension, %	6.8
Absorbency, %	8 - 11 at standard conditions
Coefficient of friction	0.25 for raw dry cotton, strongly changes for treated and/or wet fibre

The main general characteristics which can influence the applications of the cotton fibres for technical nonwovens are the soft hand, the good absorbency, the good strength and abrasion resistance.
The main chemical properties that could determine the end-use of cotton nonwovens are: cotton swells in a high humidity environment, in water, in concentrated solutions of certain acids, salts and bases; cotton is attacked by hot dilute or cold concentrated acid solutions; cold weak acids do not affect cotton; cotton degradation is usually attributed to oxidation, hydrolysis or both; cotton is extremely susceptible to the biological degradation (micro organisms, fungi, etc) [3, 10, 11].
The trash content is highly correlated to leaf grade of the sample. High trash content is not desirable for medical nonwovens. The neps sometime detract from visual appearance. For some end-uses of cotton nonwovens, such as very high absorbent products, the neps seems not to be very negativist characteristics. The scouring is accomplished by saturating the cotton fibre with a caustic soda (sodium hydroxide) solution. In nonwovens, the cotton fibres are generally used in their bleached form.
The cotton fibres are used in the manufacture of nonwovens either alone or in a blend. The various processes for nonwoven production are carding, carding-lapping for fibrous web forming and then hydroentangling, needlepunching or thermally processes to bond the fibrous webs.
The needlepunched cotton nonwovens provide highly efficient filter media based on the irregular fibre shape and absorption properties. The increasing of the tenacity in the wet condition can be an important advantage for cotton filters. The regular length staple cotton should be considered for needlepunching since longer lengths perform better. Even though cotton staple has random length distribution, an enough long fibre must be in a regular staple to form strong fabrics. The fibre finishing operation is critically in during the needlepunching process. A good lubrication is needed to prevent bleached cotton fibre damage and needle breakage. The special needles are recommended.
The cotton characteristics need in nonwoven products to be considered are excellent absorbency and feels comfortable against the skin, good strength both wet and dry, and moderate dimensional stability and elastic recovery.
The cotton nonwoven advantages are: cotton nonwovens can be recycled, re-used or disposed off by natural degradation conditions; cotton is a readily renewable resource with long-term supply assurance; the purity and absorbency of bleached cotton are utilized in growing medical and healthcare applications produced especially by the Spunlacing process.

The cotton nonwoven disadvantages are: bleached cotton fibre for nonwoven application is a relatively new fibre. It is a comparatively expensive fibre; cotton use is still restricted to specialized applications. This situation is likely to change in the future as the price is further reduced and availability increased.

2. RESEARCH COURSE. METHOD USED. RESULTS

2.1. Reasearches on nonwovens made from wool fibers

The indigene wool fibers were used to obtain nonwovens by the following process steps:

- Wool fibres → Washing – Fats removing – Removing the vegetable impurties → Fibre batt forming & Powerding → Preliminary carding → Fibrous web forming by carding-lapping → Needlepunching → Item 1 of low average surface weight.
- Item 1 → Doubling → Needlepunching → Item 2 of high average surface weight.

Some process parameters are as folows: 12 m/min fleece feeding spees, 1.88 m fleece width, 1.95 m fibrous web width, 22.6 g/m^2 fleece average surface weight, and conventional needles.
In Table 1 are presenting the wool fiber characteristics from raw fiber to fibers from the nonwoven product.

Table 1: Wool fibres's characteristics

Characteritic	Values of fibers' characteristics from		
	Raw fiber	Carded fiber	Carded-lapped-needlepunched fibrous fiber
Fiber's finnesse, dtex	32.5	30.61	40.25
Fiber's length lf , mm	167.55	241.75	227.3
Tensile resistance, cN/fibră	71.4	72.2	79.6
Breaking elongation, %	18.76	19.2	18.92

There not significant variation of the breaking force and breaking elongation, from the raw fibers to the fibres evaluated from nonwovens obtained by carding-lapping-needlepunching process. It must be emphasized that the nonwoven being not deeply needlepunched it was possible to take off fibres for trials.
The main physical characteristics of the products are given in Table 2.

Table 2: The main physical characteristics of products

Item	Average surface weight (g/m^2)	Thickness (mm)	Apparent density (kg/m^3)
Item 1	179.76	3.61	49.79
Item 2	345.67	6.91	50.02

The results are showing the following aspects:

- Two products were obtained by less process steps and average surface weight surface, Item 1 of 180 g/m^2 and Item 2 of 350 g/m^2;
- Both products have 50 kg/m^3 density; the density is influenced by needlepunching process but also by fiber's specific density.

The H5K-T SDL Atlas electronic dynamometer type has been used for tensile and elongation characteristic testing in the following conditions: movement clamp speed 0,001-1000 mm/min, 2000 mm distance between clamps and specialized software for 300 international standards [12].
The trials have been accomplished by respecting the EN ISO 9073-3/1997 Nonwovens-Tensile and Elongation norms in the following working conditions: 50 N load range, 250 mm extension range, test speed 100 mm/min, 200 mm gauge length, and 250 mm x 50 mm specimen's dimensions.
Individual data for tensile force and elongation, the mean values, standard deviation and coefficient of variation have been registered as well the designing the strength-elongation diagrams for the direction 0º-180º (MD- machine direction), 45º-225º, 90º-270º (CD-cross direction), and 135º-315º directions. Table 3 is giving the mean values resistance characteristic data of the nonwovens obtained.

Table 3 Tensional proprieties of the nonwovens obtained

Trial direction	Item 1		Item 2	
	P [N]	ε [%]	P [N]	ε [%]
0º - 180º (MD)	4.667	101.08	52.29	120.67
45º - 225º (Oblically)	8.633	107.23	97.78	90.92
90º - 270º (CD)	19.158	62.27	138.47	71.83
135º - 315º (Oblically)	14.450	77.98	69.88	93.75

The end-uses of the wool nonwovens are the following [4, 5, 13]:

- Absorbents to clean the petroleum lose by unexpected accidents to reduce the ecological disasters on seas, fluvial, oceans, etc.
- Wool absorbents can be recycled and can be the alternatives to the synthetic materials fabricated for the same reason.
- The wool nonwovens from indigene fibers with a higher roughness, such as the Item 1 and Item 2, could have an influence on the absorption capacity.
- Components for furniture as mattresses, or diverse protective materials.

2.2. Cellulose nonwovens obtained by needlepunching process

The raw materials for experiment have been the following:

- Cotton fibres of 23.8 mm the medium length, treated by alkaline boiling process and blenching alkaline boiling process.
- Pulp fibres to diversify and to obtain composite structures with high absorption capacity, low cost and bulky size.
- Woven gauze made from cotton to encapsulate the absorbent cotton nonwovens to increase the consumer's "confidence".

The medical nonwoven products have been obtained as simple and as composite nonwoven structures.

To increase the absorption capacity, the degree of white, and the purity, the cotton fibres must be cleaned-up by alkaline boiling including bleaching by a continuously process or in autoclave. By alkaline boiling process and simultaneously bleaching process, the cotton fibres result in 100% purely cellulose state. The process of alkaline boiling including the bleaching was done by including in recipe the hydroxide of sodium NaOH, peroxide (H_2O_2), stabilizer for peroxide, as well a warmly and cold washing.

The process to obtain the nonwovens was of carding-lapping and needlepunching, as well process for including the pulp fibres. For needlepunching process, the 15 x 16 x 36 x 3 ½ R221 G 82012 Groz-Beckert needle types have been chosen [4].

The characteristic considered to be evaluated is the liquids absorption capacity. By start, it must to mention that the classical woven gauze as an absorbent manufactured has the absorption capacity around of 800%.

The absorbent product characteristics are presented in Table 4.

Variants of absorbent sponges, without or with including the pulp fibres and then encapsulating into woven gauzes, are presented in Table 5.

Table 4: The characteristics of the needlepunched absorbent products

Characteristic	Product / Value		
	II-C *	II-D **	II-E ***
Average surface weight, g/m^2	200 - 300	200 - 300	200 - 300
Thickness, mm	4 - 6	2 - 4	2 - 4
Apparently density, kg/m^3	50 - 80	50 - 100	50 - 80
Absorption capacity of liquid - water, %	160	1665	2672
Strength & compactness in wet state	Low	Very high	Very high
* - raw cotton; ** - alkaline boiled cotton; *** - bleached alkaline boiled cotton			

Table 5: The characteristics of the absorbent product variants

Characteristic	Product & Value			
	II-D1	II-D-p	II-E1	II-E-p
Average surface weight, g/m^2	200 - 300	300 - 700	200 - 300	300 - 700
Thickness, mm	3 - 6	7 - 10	3 - 6	7 - 10
Absorption capacity (water), %	1624	3000 - 3400	1800	3000 - 3400
Strength & compactness in wet state	Very high	Very high	Very high	Very high
II-D1 - alkaline boiled cotton product & encapsulated into woven gauze; II-D-p - alkaline boiled cotton product including pulp fibres by a simple stratification, and encapsulated into woven gauze; II-E1- bleached alkaline boiled cotton product and encapsulated into woven gauze; II-E-p - bleached alkaline boiled cotton product including pulp fibres and encapsulated into woven gauze				

It may be noticed that the average surface weight of products is adaptable by the beneficiary requirements. The obtained nonwoven products prove an instantaneously sinking capacity into liquid, prove a sufficiently softness and enough pleased touch to be used as absorbent products into contact with body skin or even a wound.

3. CONCLUSIONS

The results on wool nonwovens are concluding to the following aspects.
By carding-lapping fibrous web process and needlepunching can be obtained nonwovens of very low average apparently density made from wool fibers. For some types of wool nonwoven end-uses the tensile resistance is a requirement, and for others the very low apparently density is a requirement. The tensile and elongation trials, done on specimens taken by directions, as examples being 0º-180º (MD), 45º-225º, 90º- 270º (CD), and 135º-315º, are shown relevant differences between both items obtained by needlepunching. The nonwoven products made from wool fibers are representing the way to use some indigene raw materials resource.
The useful of indigene natural raw material resource could be representing the real opportunities for sheep farmers, nonwoven producers, and furniture producers, consumers of products, on industrial or small industry. Unfortunately, the ecological nonwoven products are few representing on the nonwoven production industry, but are starting to increase. The researches will be accomplished by adding the hors hair to made wool-hors hair nonwovens composites for technical applications.
The changing of the cotton fibre characteristics must be accomplished by ecological treatments of alkaline boiling / bleaching alkaline boiling.
For cotton medical nonwovens, the treatments definitely are contributing to the increasing of absorption capacity performances. All treatments and processes must be set-up without minimum damages on cotton fibres in terms of surfaced changes and not to be decreased its processability. By adding the pulp fibres into nonwoven structures for medical product end-uses is increasing the absorbency characteristic performances. The treated cotton nonwovens encapsulated into the woven gauze are increasing besides the medical product performances also the “confidence” of the medical staff and/or of the patients to be usefully for medical sector.
The products obtained in this research can be also considered environmentally safe because of high biodegradability. In emergency cases or any disaster the high absorbent nonwoven medical products is a way to be helpfully.

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EFFECT OF SLIDING SPEED ON THE FRICTIONAL PROPERTIES OF NONWOVEN FABRICS PRODUCED FOR MEDICAL PURPOSES

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ABSTRACT

Technical textiles are one of the faster growing sectors of the global textile industry. Nonwovens are commonly used in the medical and applied healthcare and hygiene sectors. Mechanical contacts can be especially problematic for medical area in connection with skin diseases, wound healing and prevention of decubitus. Therefore, it is necessary to study the frictional characteristics of the medical textiles. A patented laboratory instrument was designed at the Çukurova University based on horizontal working principle of accessing friction coefficient of fibrous textile surfaces. The tested materials were nonwoven fabrics produced by spunlace methods (air laid and water jet entanglement). It has been tried to investigate friction properties of polyester (PES) nonwoven fabrics which are produced with different weights. The experimental results are statistically analyzed using Design Expert 6.06. to determine the significance of the effects of friction coefficient. Although there is a decrease in time contact between two surfaces, fabric roughness can be detected boardy at high sliding speeds.

Key Words: nonwoven, coefficient of friction, medical textiles, spunlace

1. INTRODUCTION

Technical textiles are one of the faster growing sectors of the global textile industry. The world textile industry is moving rapidly toward the manufacture of high-added value textile structures and products such as medical textiles, protective textiles and smart textiles. Textile materials used in the medical and applied healthcare and hygiene sectors are an important and growing part of the textile industry [1].

Medical textiles include a vast range of applications; beddings, blankets, sheets, pillowcases, diapers, protective clothing's, surgical clothing's, surgical covers, operating gowns. They can be single use or reused and they are in constant contact with the human skin during usage. Interaction with the human senses is therefore an important performance property. When touched by the human hand, friction is one of the first feelings and therefore friction coefficient is an important parameter.

Ramkumar et al have been studied frictional characteristics of nonwoven fabrics. Results indicate that as the speed of testing increased, frictional resistance increased [2]. Gerhardt et al investigated skin-textile contact and friction interactions using a purpose-built friction device in combination with a validated skin model. Textile Friction Analyser (TFA) measurements allow the objective and reliable study of the tribology of the skin-textile interaction. It is indicated that skin-fabric friction is very complex interplay between textile construction parameters (e.g. yarn design/morphology, surface structure of fabric type, finishing), rubbing duration and physical sliding conditions on skin-simulating materials and human skin [3]. Derler et al carried out tribological experiments of textile against human skin (finger). As a results, a realistics skin model in combination with an objective friction test method would be very useful for the textile industry and allow the efficient development of new textiles with improved and skin adaptive surface and frictional properties for sport and medical applications [4]. Lima et al tested non active medical spunlace and spunbond nonwovens frictional properties. FrictorQ measurements could be used for obtaining of comfort parameter [5].

In this study, friction tests have been applied on nonwoven fabric specimens produced with different weighted polyester based spunlace technique with testing device that work on horizontal platform. The aim of this study is to investigate the influence of the speed of testing on friction against nonwoven fabrics. As a result of this study, it has been observed that fabric density, applied force, sliding velocity and fabric direction are effective parameters on fabric-fabric friction coefficient of the nonwoven fabrics.

2. MATERIAL AND METHODS

2.1 Materials

In this study, 100% polyester nonwoven fabric specimens produced with spunlace technique have been used as testing material. Specimens have been tested according to Textiles-Test Methods for Nonwovens-Part 3: Determination of Tensile Strength and Elongation; ISO 9073-3;1989 [6] and Textiles-Test Methods for Nonwovens-Part 4: Determination of Thickness; ISO 9073-2;1995 [7] standard under convenient conditions and values given in Table 1 have been obtained. These tests have been applied so as to determine some of the physical characteristics of nonwoven fabrics that are used for sampling purposes.

These fabrics have been used as a disposable diaper, protective clothing's, surgical clothing's, surgical covers, operating gowns. Therefore, friction coefficient of nonwoven fabrics appears as an important factor in most of these usage areas.

Table 1. Physical properties of nonwoven fabric samples

Fabric Weight (g/m^2)	Thickness (mm)	Density (g/m^3)	Tensile Strength (N/5 cm)		Elongation (%)	
			MD	CD	MD	CD
100	0.75	1.333	312.2	355.1	49.7	49.6
120	0.82	1.463	123.5	123.7	65.0	45.1
150	0.75	2.000	188.9	303.8	59.5	52.1
200	0.96	2.083	357.4	754.6	78.1	59.9
250	0.94	2.660	385.1	756.1	60.8	61.9

2.2 Methods

For the purpose of this study, frictional properties of nonwoven fabrics have been tested on horizontal platform experiment device.

It is developed mechanism which is shown in Figure 1 by designing and extra changes upon conventional universal tensile tester in order to perform friction experiments. The designed and manufactured device consists of anti-friction rollers (3,4), non-stretch yarn (5), a sled (6) and a sled bed (7). A Non-stretch yarn (5) is passed through rollers (3,4) to upper carrier claw (1) of tensile tester. Fastening the sample to the circular sled (6) made of circular 50 mm in diameter delrin material is ensured by using a clip in proper dimensions. Nonwoven fabric (10) sample which is covered on sled (6) is lay out in the same direction with horizontal platform.

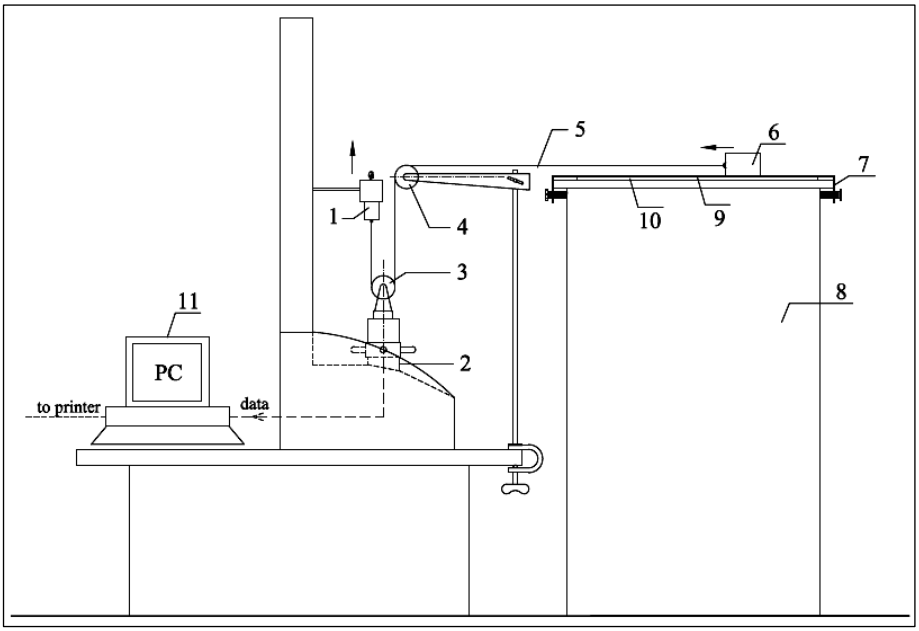

Figure 1. Horizontal Platform Experiment Device [8,9,10]

(1. Upper Carrier Claw, 2. Load Cell, 3,4. Anti-Friction Roller, 5. Non-strectch Yarn, 6. Sled, 7. Sled Bed, 8. Experiment Table, 9. Sponge, 10. Fabric, 11. Computer)

Sled bed (7) is designed with the aim

of stretching the fabric (10) on experiment table (8) so as to hold it stable and to prevent slipping, curling, twisting or folding during the experiment. While the upper carrier claw (1) of developed device is moving at a specific speed, it also pulls delrin sled (6) and as a result a friction occurs between two surfaces. At the same time, the load changes stemming from fabric surface structure created during the movement are perceived by load cell (2) and created in graphical and numerical values by the computer (11).

3. RESULTS AND DISCUSSION

Frictional behavior tests have been performed with 3 different load (7.4, 13.1 and 20.2N), two fabric direction Machine Direction (MD), Cross Direction (CD) and 3 different point of samples. As a result of friction tests, the highest value at the beginning of movement has been accepted as static friction resistance; the mean of values read afterwards has been accepted as kinetic friction resistance. Attention was paid to make sure that the specimen placed on horizontal platform and the specimen attached to delrin part are slightly strained and fabric rubbed to different parts of the fabric. Figures 2 and 3 have been obtained using the friction coefficients obtained from the tests.

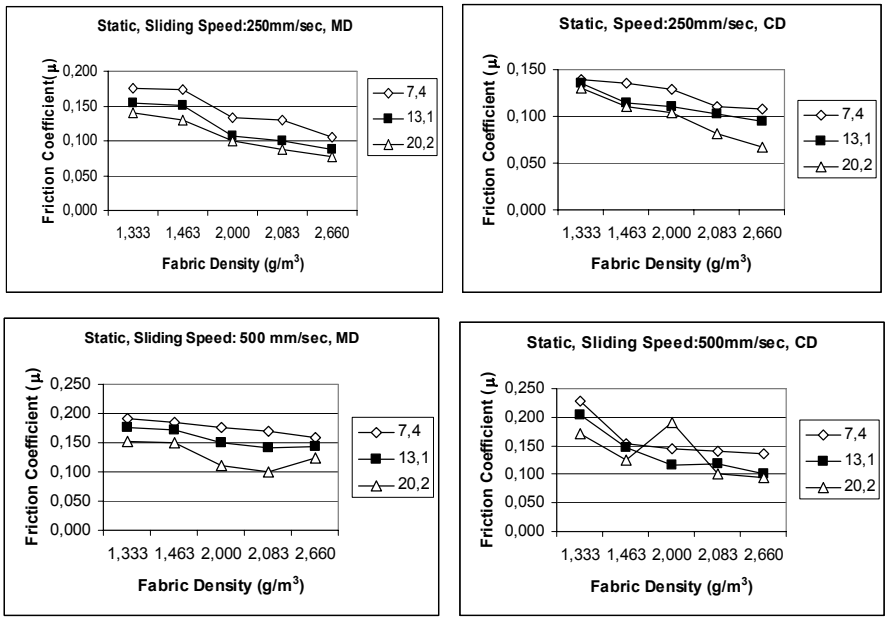

Figure 2. Static coefficient of friction

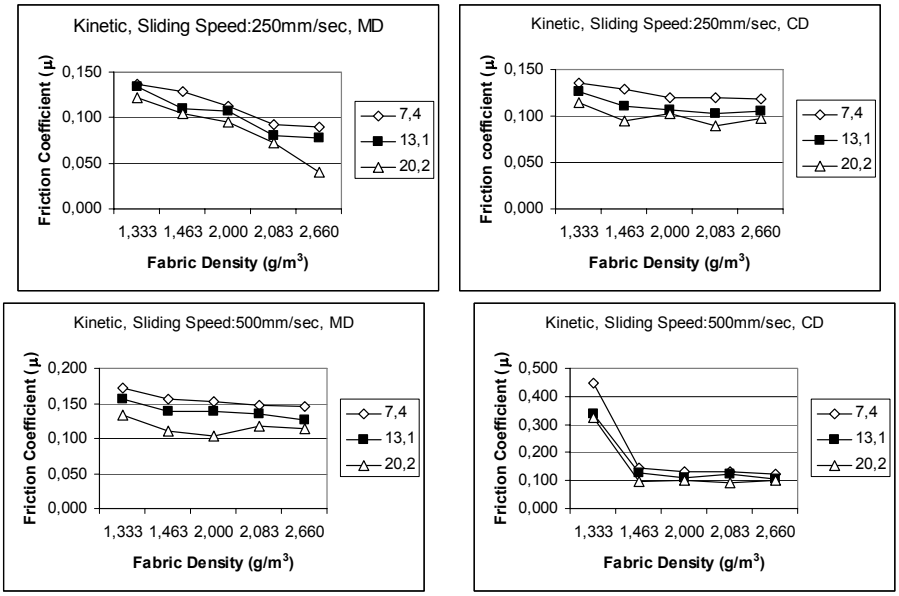

Figure 3. Kinetic coefficient of friction

It has been observed that nonwoven fabrics with higher fabric density have lower friction coefficient compared to fabrics with lower fabric density. Nonwoven fabric specimens used in the study was created by carding method and fixed with water jet. Hydroentanglement nonwoven fabrics are formed by the interlocking of fibers resulting in loops. Spunlace surface specimens produced with this production method have a softer and more textured structure. Surface features and the loop of the fibers in hydroentanglement offer more resistance while delrin sled is moving on fabric surface. Heavier fabrics have higher fiber density than the lighter fabrics. When the fiber density is increasing, there is a greater tendency for the fibers to have intense looping.

Another observation is that, as the sliding speed increases, there is a rapid surface interaction between the delrin sled and nonwoven fabrics. When delrin sled is forced to move/slide on fabric surface, it is met with more resistance because of surface rougness.

It has been observed that static friction coefficients are usually higher than kinetic friction coefficients. It has been found out that, as the applied force increases, friction coefficient decreases. The reason of which is attributed to the fact that, as the force applied on fabric specimen increases, compression, flatting and therefore relative smoothening of fabric surface is observed.

Statistical analysis of the obtained results:

Variance analysis at α = 0.05 significance level has been conducted on the data obtained from experimental studies using Design Expert 6.06 statistical package program. Obtained ANOVA tables are summarized below, where a (f) value under 0.05 means that evaluated factor has a significant impact.

During statistical analysis, fabric direction, which affects physical and mechanical features was taken as categorical (by name), and fabric density, applied force and sliding speed were taken as numerical (digital) factors.

When the ANOVA table (Table 2) is examined, it can be seen that fabric density, applied force, sliding speed and fabric direction of nonwoven fabrics have significant impact on the static friction coefficient values. In addition, when the interaction between and within factors are examined, it can be said that fabric density x sliding speed has significant impacts.

Explanatory percentage of the model which confirms data, R^2, has to be calculated. According to Table 2, R^2 value of the model turned out to be 0.85, in which case the terms in the model can be

explained almost 85%. This case shows that the model established for static friction coefficient describes the relation between dependent variables and independent variables with a considerably high accuracy and that experimental study is accepted as accurate.

Table 2. Anova table (Static Coefficient of Friction)

Factor	**F value**	**Prob>F**	
Model	0.035	< 0.0001	Significant
Fabric Density	0.010	< 0.0001	Significant
Applied Force	0.012	< 0.0001	Significant
Sliding Speed	3.554E-003	< 0.0001	Significant
Fabric Direction	3.938E-003	< 0.0001	Significant
Fabric DensityxSliding Speed	8.449E-004	0.0114	Significant
Total	0.041	49	
R^2	0.8688		
R^2_{adj}	0.8539		
R^2_{pred}	0.8329		

(A:Fabric Density, B: Applied Force, C: Sliding Speed, D: Fabric Direction)

When the ANOVA table (Table 3) is examined, it can be seen that fabric density, applied force, sliding speed and fabric direction of nonwoven fabrics have significant impact on the kinetic friction coefficient values. And also according to Table 3, R^2 value of the model turned out to be some 0.84, in which case the terms in the model can be explained almost 84%.

Table 3. Anova table (Kinetic Coefficient of Friction)

Factor	**F value**	**Prob>F**	
Model	0.021	< 0.0001	Significant
Fabric Density	3.016E-003	< 0.0001	Significant
Applied Force	7.875E-003	< 0.0001	Significant
Sliding Speed	2.467E-003	< 0.0001	Significant
Fabric Direction	5.178E-004	0.0138	Significant
Fabric DensityxSliding Speed	1.015E-003	0.0008	Significant
Fabric DensityxFabric Direction	9.956E-004	0.0009	Significant
Sliding SpeedxFabric Direction	2.672E-003	< 0.0001	Significant
Total	0.025	49	
R^2	0.8667		
R^2_{adj}	0.8445		
R^2_{pred}	0.8003		

(A:Fabric Density, B: Applied Force, C: Sliding Speed, D: Fabric Direction)

4. CONCLUSIONS

Based on the obtained results and the statistical analysis it is possible to draw the following conclusions:

- Horizontal platform friction test device measurements suggest that its results could be used as a comfort parameters of fabrics.
- Fabric density, applied force, sliding speed, fabric direction and production method are parameters that affect friction behaviors. Determination of friction characteristics of textile surfaces (woven, knitted and nonwoven) can be evaluated as an important criterion for ensuring surface aesthetic and comfort.
- As the sliding speed increases, friction force will increase and large force is needed to overcome static and kinetic friction force.

- It has been concluded from examined fabrics that as applied normal load increases, friction coefficient tends to decline in both systems. As the pressure on fabric specimen increases, it leads to compression, flattening and relative smoothening of fabric surface, which decreases friction coefficient.
- Test results show that as fabric density increases, nonwoven fabrics with more stable structure have lower friction coefficient.
- Friction coefficients have been found as lower in CD direction of the fabric than in the MD direction, which is attributable to the fiber/filament settlement at the fabric formation stage.

ACKNOWLEDGMENTS

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EFFECTS OF PYRROLE DERIVATIVES ON POLYURETHANE POLYPYRROLE COMPOSITES

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ABSTRACT

The oxidative matrix polymerization of pyrrole derivatives in the presence of polyurethane has been studied. The influence of the pyrrole derivative type and content on the electrical properties of the composite films was analyzed. Also FTIR–ATR analysis of composite films was carried out by FTIR-ATR reflectance spectrophotometer.

Key words : polyurethane, pyrrole , oxidative polymerization, FTIR-ATR spectrophotometer, conductivity

INTRODUCTION

In general, polymers are good insulators. The combinationof conventional polymers with conductive polymers or filler allows to create polymeric materials with good electrical properties. Conductive polypyrrole (PPy) has received much attention, because it can be prepared easily by chemical oxidation and it has relatively good stability in the conducting oxidized form. However, the disadvantages of PPy are their hard, brittle, and nonprocessable character[1]. One of the methods for improving the mechanical properties of PPy is the preparation of composites from a conducting polymer and an insulating polymer. This method improves the mechanical properties of PPy[2]. Polyurethane is a material that offers the elasticity with the toughness and durability. Polyurethane (PU) is composed of polyether or polyester soft segments and a diisocyanate-based hard segments. Conductive polymers have been the focus of considerable research over the past several decades

with applications in products such as rechargeable batteries, bio- and chemical-sensors, transducers, antistatic coatings, and EMI shielding[3].

In this study, PU/PPy composites were prepared by chemical polymerization of pyrrole in polyurethane matrix with a strong oxidizing agent ceric ammonium nitrate (CAN). The advantage of this method is technical simplicity,short polymerization time and high homogenity.

2. Experimental

2.1. Materials and chemicals

Thermoplastic polyurethane was taken from Flokser Co.(Istanbul,Turkey)(molecular weight 75 000, GPC result). The solid content of PU was 35 wt. % in dimethyl formamide (DMF). Pyrrole (C_4H_5N, Aldrich Co. Ltd., analytical), Dimethylformamide (DMF,$(CH_3)_2NC(O)H$, Riedel-de Haen, analytical), ceric ammonium nitrate $(NH_4)_2[Ce(NO_3)_6]$, CAN, BDH analytical), methanol and ethanol (technical) were used for washing.

2.2. Apparatus

The characteristic functional groups of the samples were analyzed by using a Fourier Transform Infrared Spectroscopy in the Attenuated Total Reflection Mode (Perkin Elmer FTIR-ATR Spectrum One with a universal ATR attachment with a diamond and ZnSe crystal). The AC measurements were performed using Novocontrol Broadband Dielectric Spectrometer (Alpha-A High Performance Frequency Analyzer, frequency domain 0.001Hz to 3GHz).

2.3. Preparation of PU/PPy Composites

Polyurethane/polypyrrole composites were prepared using chemical oxidative polymerization of pyrrole in polyurethane matrix with three components. Homogeneous composite films were obtained by solution casting method. Firstly polyurethane was dissolved in DMF. A calculated amount of pyrrole monomers was added to the definitive volume of polymer solution and stirred until homogeneous solution was obtained. Ceric ammonium nitrate (CAN), used as an oxidizing agent, was added into the solution including PU and pyrrole monomers. Polymerization of pyrrole immediately occurred. The polymerization process was carried out at room temperature. Excess solvent evaporated by applying heat to obtain homogenous and viscous solution, the solution was poured onto a glass plate and allowed to dry in a vacuum oven for 1 day at 80ºC. The black PU/PPy composite films were removed from glass plate, washed with ethanol. Composite films were prepared by using a three-component system so weight of pyrrole amount was calculated and reported according to pyrrole percentage of the three components.

3. Results and discussion

FTIR-ATR spectroscopy is an effective method of investigating the interaction between polyurethane, polypyrrole andCe(III) [Ce(III): $Ce(NH_4)^+_2(NO_3)^-_6$]. Effect of pyrrole content and type on composites was investigated. In Figure 1 and 2, the spectrum of PU, PU/ PPy and PU/PNMPy are shown. The spectrums for PU, PU/ PPy and PU/PNMPy composite films contain the characteristic peaks for oxidized polypyrrole. The vibrations at 1455 cm^{-1} (pyrrole ring), 1309 cm^{-1} (in plane=C-H) mark the presence of oxidized polypyrrole [4]. The two vibrations in pyrrole ring [5] are visible at 1463 and 1529 cm^{-1}. 1529, 1463 cm^{-1} C=C, C-N stretching vibrations [6,7,8,9]. The C- H in-plane vibrations at 1309 cm^{-1} was observed in the composite films [10]. The intensity of the band, which is at 1309cm^{-1}, was increased by the addition of n- methyl pyrrole and pyrrole(Fig.1 and 2).

The PU/PPy showed the peaks ~1640 cm^{-1} (the peak for C=O groups). The presence of the carboxylic groups on the polyurethane is likely to give the interaction between the polymer and PPy. It is due to the hydrogen bonds which were formed between –COOH groups of polyurethane and NH groups of the PPy [11,12]. The peaks at 1383 and 1433 cm^{-1} are characteristic of the in-plane vibration of pyrrole ring, [13]. The bands at 1437 cm^{-1} and 1383 cm^{-1} are assigned to CH_2 scissoring and CH_3 symmetric bending modes.

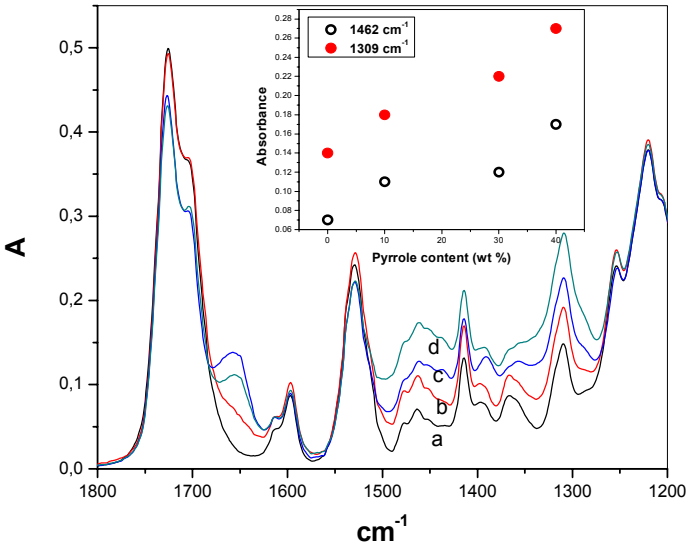

Fig. 1. FTIR-ATR spectrum of PU and PU/PPy composites (a. PU, b. PU-10 %Pyrrole, c. PU-30%, d. PU-40 %Pyrrole)

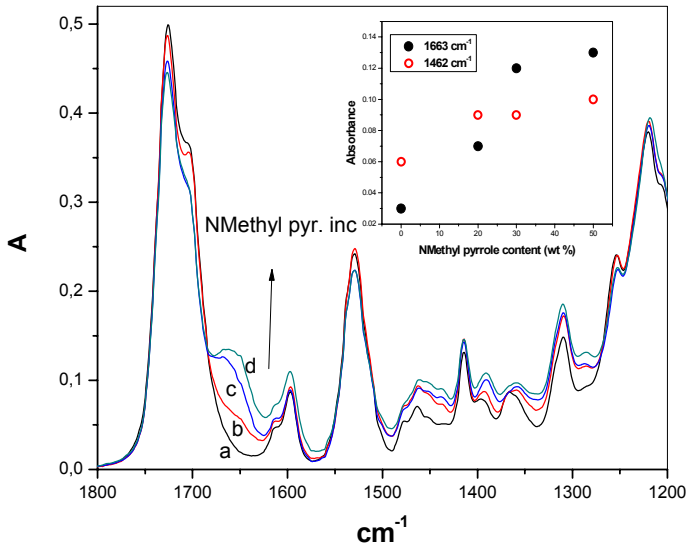

Fig. 2. FTIR-ATR spectrum of PU and PU/PNMPy composites (a. PU, b. PU-20% NM Py, c. PU-30% NM Py, d. PU-50% NM Py)

The electrical conductivity of the composites depends on the extent of dispersion, geometry and interactions of the components[11]. The influence of the amount of Py and NMPy in PU/PPy and PU/PNMPy composites on their electrical conductivity were investigated. The room temperature conductivity of PU/PPy and PU/PNMPy composites are shown in Fig. 3 and 4. The conductivity of the composites increased with increase in pyrrole content. Also, in Figure 3 and 4, we see that the conductivity of composites increases with increasing PPy peaks in FTIR-ATR spectra. This is a proof of the increase of conductive component in the

structure. Also, in Fig. 5, we see the conductivities of the composites which have different pyrrole derivatives in it.

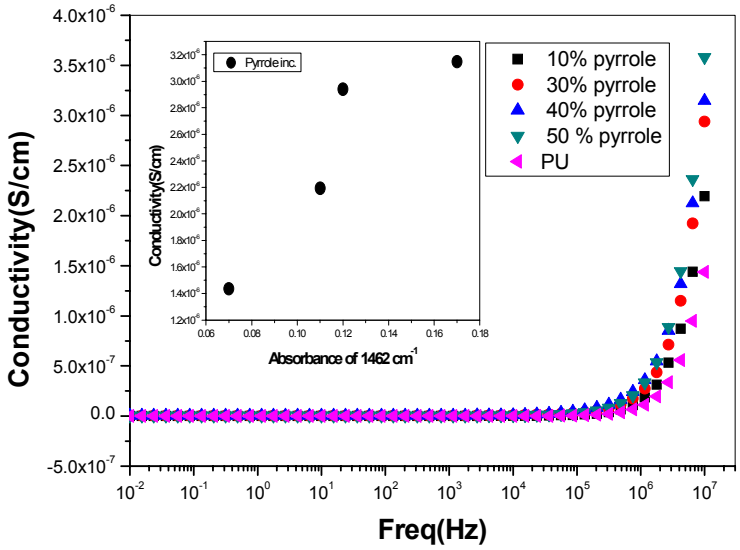

Fig. 3. Conductivity of PU/PPy composites at different pyrrole concentration and the relationship of conductivity and absorbance changes of 1482 cm^{-1}

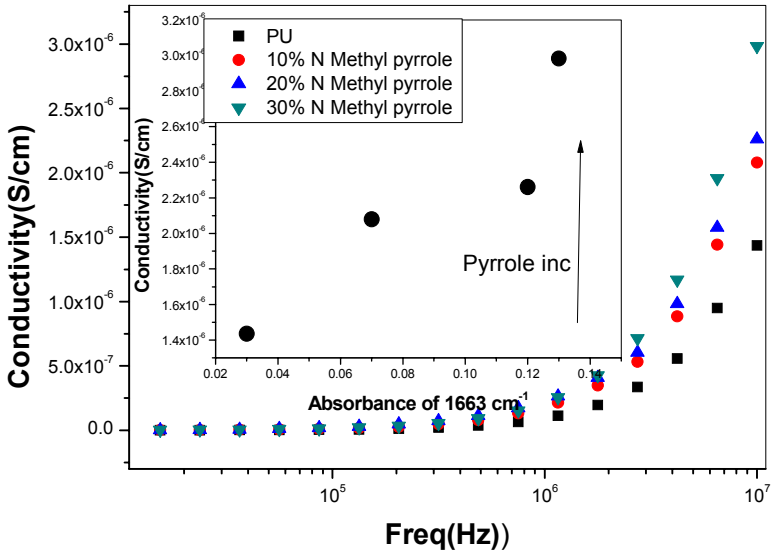

Fig. 4. Conductivity of PU/PNMPy composites at different pyrrole concentration and the relationship of conductivity and absorbance changes of 1663 cm^{-1}

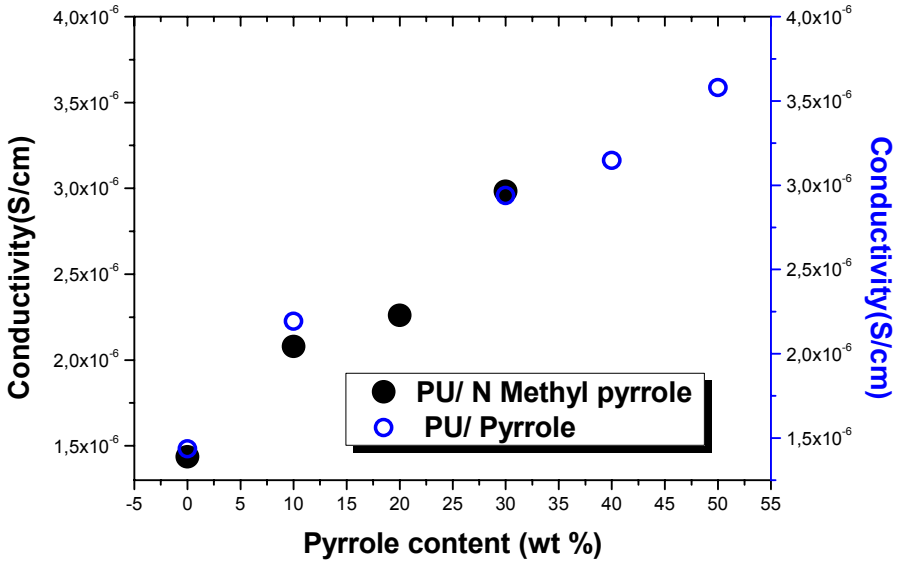

Fig. 5. Conductivity of PU/PPy and PU/PNMPy composites (at 10^7 Hertz) versus pyrrole content in the composites

4. Conclusions

In this system, the monomer pyrrole molecules were able to mix with the PU matrix and the oxidative polymerization process resulted in PU/PPy and PU/PNMPy composites. We showed the relationship between conductivity and FTIR- ATR results and effects of pyrole derivative on conductivity and FTIR-ATR. We see the conductivity of composites increases with increasing PPy picks in FTIR-ATR spectra. It is a proofness of the increase of conductive component in the structure.

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ELECTROSPINNING OF POLYESTER AND NYLON 66 NANOFIBROUS MEMBRANES FOR FILTRATION

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ABSTRACT

Nanofibers/nanowebs of Nylon 66 and poly(ethylene terephthalate) (PET) have been obtained by electrospinning. Different fiber morphologies were obtained for Nylon 66 and PET electrospun nanofibrous membranes when different polymer concentrations were used. These electrospun nanofibrous Nylon 66 and PET membranes are good candidates for filtration due to their specific properties such as very small pore size, large porosity, and high specific surface area.

Key Words: electrospinning, polyester, nylon 66, nanofibrous membrane, filtration

1. INTRODUCTION

Electrospinning is the most versatile method for fabrication of nanofibers due to its simplicity and cost effectiveness. The nanofibers can be electrospun from a wide range of polymers that are soluble in various solvent systems. Electrospun nanofibers/nanowebs are very good candidates as a membrane with high adsorption capacity for effective filtration purposes due to their unique properties like small pore size, large surface area to volume ratio and high porosity [1-6].

Electrospinning is a simple process in which a polymer solution or melt is subjected to high voltage and the fibers which have diameter in the range of few microns to few hundred nanometers are produced in the form of nonwoven [4-8]. Thus, electrospun nanofibrous membranes have a much higher capacity to collect the fine particles due to their large surface area to volume ratio and nanoporous structure.

Nylon 66 is an important semi-crystalline thermoplastic polymer with dimensional stability, toughness, attractive mechanical strength, and chemical resistance. Therefore, Nylon 66 is commonly used for filtration, textiles and engineering field [7,8].

Poly(ethylene terephthalate) (PET), is a widely used polymer having good thermal and mechanical characteristics and show chemical resistance to most of the solvents. It is mainly used in textiles, food packaging, engineering plastics, electronics, tissue engineering and filtration as well. [9,10].

In this study, Nylon 66 and PET nanofibers/nanowebs were obtained by electrospinning. Formic acid/chloroform (75/25) and trifluoroacetic acid/dichloromethane (50/50) were used as solvent for Nylon 66 and PET, respectively. Polymer concentration, tip-to-collector distance and applied voltage were optimized in order to obtain bead-free uniform nanofibers. The morphology of the resulting electrospun nanofibers/nanowebs was examined by scanning electron microscope (SEM).

2. EXPERIMENTAL

2.1. Materials

PET pellets were kindly supplied by Korteks (Bursa, Turkey). Nylon 66 (relative viscosity 230.000 - 280000) pellets were purchased from Sigma-Aldrich. Solvents; formic acid, chloroform, trifluoroacetic acid and dichloromethane were also purchased from Sigma-Aldrich and were used without further purification. Solutions of PET at different concentrations (15% and 20% w/v) were prepared in 50/50 v/v mixture of trifluoroacetic acid and dichloromethane. Formic acid/chloroform (75/25) (v/v) was used as solvent system for Nylon 66 with different concentrations (5% and 10% w/v).

2.2 Electrospinning Process

The homogeneous solution of Nylon 66 and PET solutions were placed into a 5 ml plastic syringe with a metallic needle. The syringe was fixed horizontally on the syringe pump and the high voltage power

supply was used. The feed rate of the solution was set as 1mL/h by a syringe pump. The other electrospinning parameters were as follows; applied voltage=10-15 kV, and tip-to-collector distance=10-15 cm. Fibers were deposited as a nonwoven fibrous mat on cylindrical metal collector plate covered by a piece of aluminum foil.

3. RESULTS AND DISCUSSION

Different fiber morphologies were obtained for Nylon 66 and PET electrospun nanofibrous membranes when different polymer concentrations were used (figure 1 and figure 2). The average fiber diameters were calculated from the SEM images. The morphological characteristics of the resulting nanofibers were given in table 1. Beads were formed when the polymer concentration was low for both of polymers. When the polymer concentration was increased, typical circular fibers were obtained for PET; however, ribbon-like fibers were obtained for Nylon 66 which possible due to the rapid evaporation of the solvent. It was also observed that the diameter of the fibers were increased as the polymer concentration increased or tip-to-collector distance and applied voltage decreased.

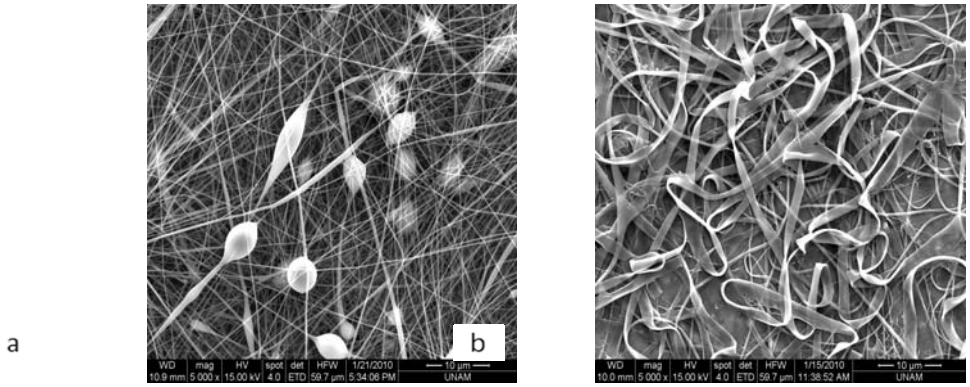

Figure 1. SEM images of electrospun Nylon 66 nanofibers obtained from formic acid /chloroform (75/25) solutions (a) 5% Nylon 66, (b) 10% Nylon 66 (w/v)

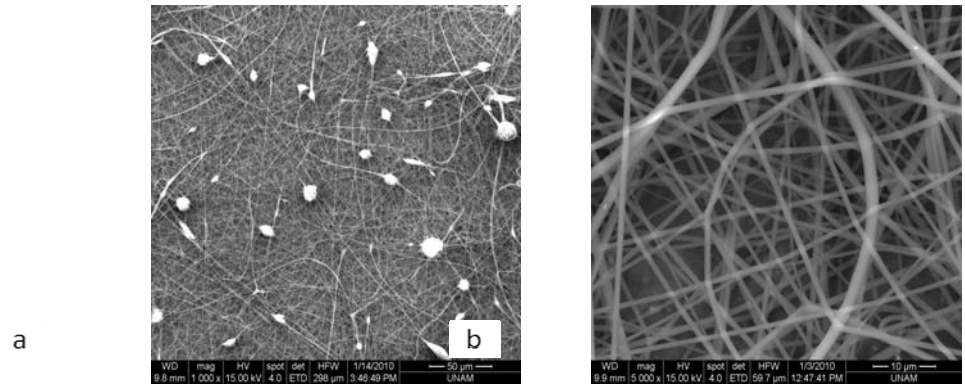

Figure 2. SEM images of electrospun PET nanofibers obtained from trifluoroacetic acid/dichloromethane (50/50) (v/v) solutions (a) 15% PET, (b) 20% PET (w/v)

Table 1. The morphological characteristics of the resulting nanofibers (Electrospinning parameters: applied voltage=15 kV, tip-to-collector distance = 10 cm, feed rate = 1mL/h.)

Solutions	% polymer[a] (w/v)	fiber diameter (nm)	Fiber morphology
Nylon 66	5	149±63	Nano-fibers with beads
Nylon 66	10	865±811	Bead-free ribbon-like fibers
Polyester	15	337±60	Nano-fibers with beads
Polyester	20	854±221	Bead-free circular nanofibers

[a] With respect to solvents

4. CONCLUSIONS

Nylon 66 and polyester (PET) nanofibers/nanowebs were produced by using electrospinning technique. Formic acid/chloroform (75/25) and trifluoroacetic acid/dichloromethane (50/50) were used as solvent for Nylon 66 and PET, respectively. The influence of polymer concentrations, tip to collecor distance and the applied voltage on the morphology, uniformity and dimensions of the electrospun nylon 66 and PET nanofibers/nanowebs were investigated by SEM. Bead-free uniform nanofibers of PET with circular shape and nylon 66 nanofibers having ribbon shape were obtained as a nonwoven. These nanofibrous structures are appropriate as a membrane for filtration due to their very small pore size, large porosity, and high specific surface area. As the future work, our goal is to develop functional nanofibrous membranes for filtration application by adding functional additives into the nylon 66 and polyester nanofibers/nanowebs.

ACKNOWLEDGMENTS

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EVALUATION OF GEOTEXTILE DRAIN FILTER PERFORMANCE BASED ON AVAILABLE DESIGN STANDARDS

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One of the major problems to use subsurface drain is pipe clogging and envelopes by mineral materials. Such as process is the result of disturbances of soil structure during drain installation. Drain filter selection follows definite rules and neglecting them can result in project failure. Current study is based on performance evaluation of three kinds of Geotextile filters in comparison with mineral filters. Two soil samples of northern Khorram Shahr (1.65m deep) were obtained for the study. Physical and chemical analysis on samples showed the soils do not have major differences in texture and particle size distribution (PSD). Original recommendations based on previous studies on synthetic filters in terms of PSD curve and soil texture was PP700 type. Two other types were also chosen as the upper and lower boundaries of the main choice. The performance of three types of Geotextile filters (PP450, PP700 and PP900) was assessed in terms of clogging potential using ASTM-5101standard test. Also, mineral blanket was designed according to the USBR criteria. Experiment was conducted in three treatments and completely on random. The test was conducted in laboratory, using physical model for infiltration (according to the ASTM D-5101 standard) and by creating 4 different hydraulic pressure head (25, 50, 75 and 100cm). In the study, changes in outflow from soil-geotextile system, hydraulic conductivity, gradient ratio and hydraulic conductivity ratio were analyzed in 4 filters. The results showed: (1) in terms of gradient ratio, none of the filters were found sensitive to clogging; (2) outflow from mineral filter was 2 to 3 times greater than for geotextile; (3) hydraulic conductivity ratio of mineral filter for PP450, PP700 and PP900 geotextile filters were 3.47, 4.17 and 5.57 respectively; and (4) comparing outflow and hydraulic conductivity variations, geotextile filter of PP450 type performance was found the best.

Key words: Drainage, Filters, Geotextile, optimization, Gradient Ratio and Khorram Shahr.

FABRIC DRAPE EXAMINATION USING RING-CONTROLLED EQUIPMENT

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ABSTRACT

Drape testing has been one of the main methods to determine 3D textile properties as the obtained test results can be used in textile draping simulations. In drape tests, the effects of material, structure and finishing of textiles as well as the mechanical properties of fabrics have been studied extensively, although the deviation of the measured parameters and the reasons behind such deviations have always caused problems. Researchers also studied drapability under dynamic effects and measured dynamic drape by rotating textile samples. It was found that drapability can change significantly due to the dynamic effects and the change in strain can have different impacts on different textile materials. On the other hand, tests cannot always reveal reproducible results since the dynamic effect is not always uniform.

In this study an apparatus was mounted on the Sylvie 3D Drape Tester, which uses a 3 dimensional scanning technology and records surface data of draped textiles to obtain a well defined dynamic effect on textiles during draping. Using this ring-controlled instrument, the reproducibility of test results and possibilities of dynamically influenced measurements were investigated. The tests were carried out on 100% cotton plain woven fabrics with different parameters.

Key Words: Fabric drape, drape testing, dynamic drape

1. INTRODUCTION

Drape measuring systems are popular to determine 3D properties of textiles as the measured results can be used for the simulation of the drapability of textiles. However, there is a problem with high deviation in measured parameters as the reason behind it is not known well. As many earlier study indicated, the material, structure and finishing method of the fabric, as well as mechanical effect of the examination are all influencing factors for drapability test results [1]. Researchers also studied drapability under dynamic effects and measured dynamic drape while the textile samples were rotated. It was found that drapability can change significantly due to dynamic effects and the change in strain can have different impacts on different textile materials. On the other hand, tests cannot always reveal reproducible results since the dynamic effect is not always uniform.

Apart from static drape, the measurement of drape in dynamic state has gaining importance in terms of real-wear simulations. One of the first studies on dynamic drape has been carried out by Stylos and Zhu [2] as they developed a system called M3 which can deal both static and dynamic measurement. The dynamic measurement was realized by rotating the sample supporting disc. Later Yang and Matsudaira [3] introduced a new parameter named as revolutionary drape, D_r, where a fabric sample is turned around at a speed of 200 rev/min. Same researchers introduced another parameter for dynamic state, D_d, which indicates drape of fabric in a pendulum type of movement and such a drape was reported as a better simulation of human body in movement [4]. Similarly, Shry et al. [5] also indicated that static drape is not enough to forecast dynamic movements and measured dynamic drape of fabrics at a speed of 100rev/min and 125 rev/min.

The Sylvie 3D Drape Tester developed at BME [6], different from the popular Cusick Drape Meter, records all surface data of draped textiles with a 3 dimensional scanning technology, and the evaluating computer system defines the usual drapability data, i.e. node number and drape coefficient.

According to the literature we suppose that the drapability of textiles will differ at different levels of stress. The Sylvie 3D Drape Tester was supplemented with a tool with the help of which drapability could be determined after different but exactly defined dynamic effects [7]. This apparatus is a ring shaped plate which can have different diameters. Using this ring-controlled instrument the reproducibility of test results and possibilities of dynamic measurements were investigated. The tests were carried out on 100% cotton plain woven fabrics with different parameters.

2. MEASURING SYSTEM

The table of the Sylvie 3D Drape Tester (Figure 1) at the initial state is in the same level with the base plate. The table has a diameter of 180 mm. The diameter of the fabric sample is 300 mm. During the tests, the centre of the sample has to be set exactly on the centre of the table, and warp and weft directions have to be parallel with the specified directions. A computer controlled motor lifts the table, assuring that drapability is always studied at the same speed and under the same dynamic effects. During the measurements, four laser emitters project laser lines on the fabric sample in order to determine the cross-section and four cameras record the lines over the laser emitters. The cameras and the laser emitters are mounted on a measuring frame. The frame moves with a determined step distance during scanning the surface of the fabric sample. The computer controlled instrument is constructed in a black box in order to provide darkness during the measurement. After all photographs are taken, the computer downloads the pictures [6].

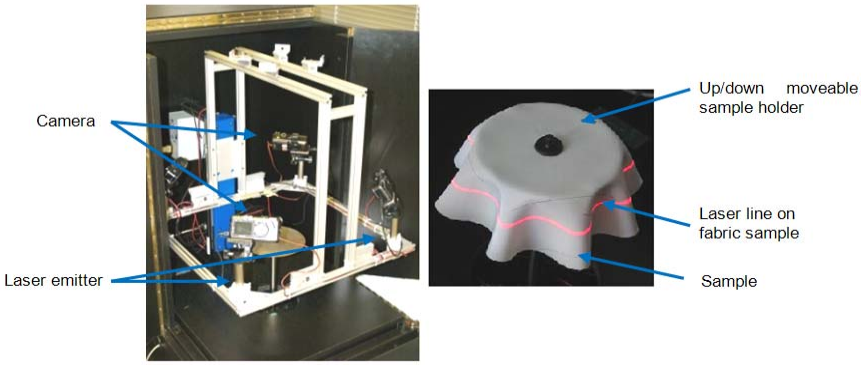


Figure 1 Sylvie 3D Drape Tester

To examine the dynamic effect on the fabric sample, the instrument was completed with a special tool having different dimensions. The tool is a ring with different internal diameters. The external diameter of both rings is 350 mm, and the internal diameter of the first one is 240 mm, while that of the other one is 210 mm (Figure 2).

For the sake of simplicity, the ring that has 240 mm inner diameter will be referred to as the 240 mm ring hereinafter, whiles the ring that has 210 mm inner diameter as the 210 mm diameter ring.

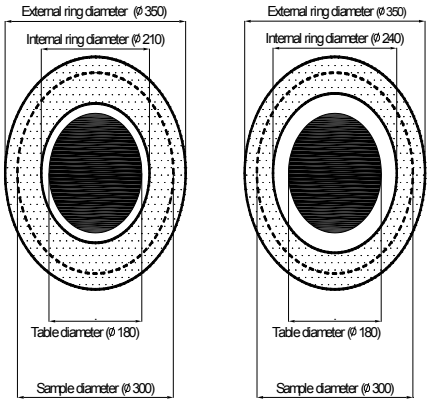


Figure 2 Dimensions of rings

When the table moves up, the fabric sample is drawn through the inner hole of rings (Figure 3). During this process, the fabric is subjected to a dynamic effect. We suppose that the ring with smaller internal diameter has larger dynamic effect on the drapability of the fabric [7].

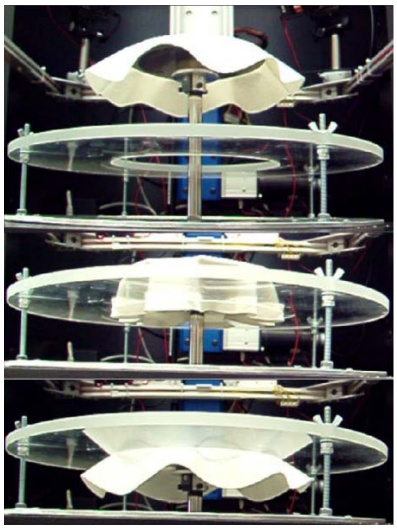


Figure 3 Drape tester completed with rings

3. MEASURING RING CONTROLLED DRAPABILITY OF TEXTILES

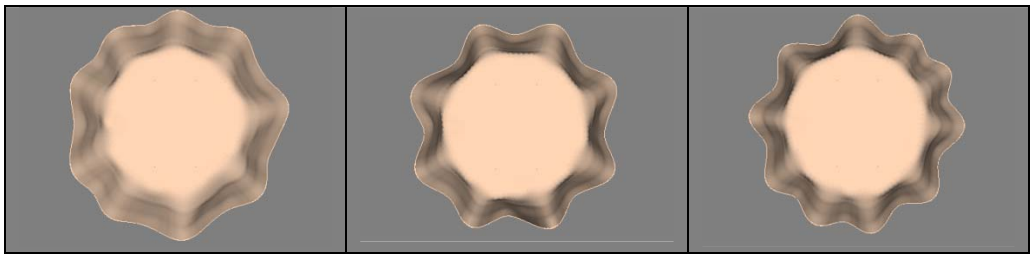
Three cotton samples were examined with the Sylvie 3D Drape Tester completed with rings. The fabric samples differ in the twist direction of the yarns they are composed of. Detailed properties can be found in Table 1 below.

Table 1 Main properties of the examined textile samples

No.	Material	Type		Density [g/m^2]	Type of weave	Yarn count		Yarn density [1/10mm]		Twist direction	
		warp	weft			warp	weft	warp	weft	warp	weft
P1	cotton	OE-rotor	OE-rotor	158.6	plain	Nm 34	Nm 34	26	22	Z	Z
K2	cotton	OE-rotor	OE-rotor	148.6	plain	Nm 34	Nm 34	26	22	Z	S
F3	cotton	OE-rotor	OE-rotor	156.2	plain	Nm 34	Nm 34	27	22	Z	Z+S

Three samples of all the three fabrics were measured (alternately with their top and reverse side) 10 times without the ring, and 10 times with the two rings. In both cases, the same relaxation intervals were kept between the measurements.

Different dynamic stress situations are modeled with rings with different inner diameters. When the table moves up, the test materials are drawn through the inner hole of the rings. If the measurement is carried out without any ring, the draping process can be considered as quasi static. Measuring with different rings simulates the process of throwing the material on a table at different speeds and that is closer to a real wearing situation.



a) b) c)

Figure 4 Measuring with different rings
a) No ring, b) Ring D240, c) Ring D210

When rings are used, draping ratio and wavelength of the edge curve of the material decreases, the number of waves increases and draping geometry shape is more moderate. The smaller the inner radius is, the more influence it has. Figure 4 shows the different resulting simulations.

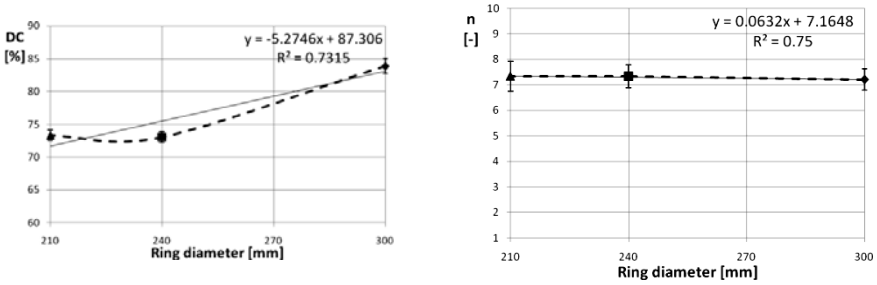
4. TEST RESULTS AND DISCUSSIONS

Altogether 30 measurement results were obtained during the measurements for all the examined fabric samples in both static and dynamic mode and the test results are summarized in Table 2. In order to be able to handle all results in a uniform way, the measurement carried out without a ring was considered to be a test with a ring that has an inner diameter of 300 mm, which is exactly the diameter of the fabric sample. In this case, obviously the ring could not have affected the measurement, since it could not even touch the sample. However, this way all the results can be graphed and evaluated in common diagrams as a function the ring diameter. Figure 5 illustrates the average values and the deviations of the drape coefficients and node numbers as a function of the ring diameter.

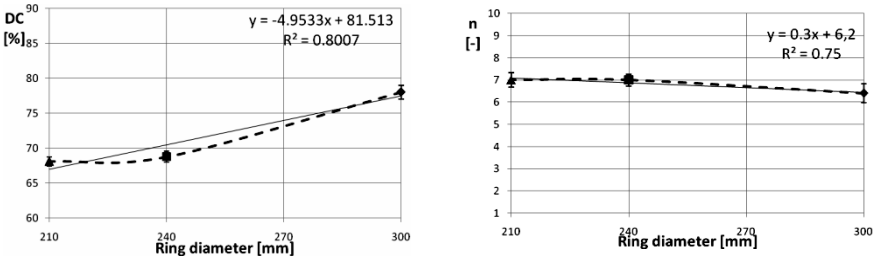
Table 2 Test Results showing mean drape coefficient values and deviations

Ring diameter	300 mm		240 mm		210 mm	
P1						
	DC	**n**	**DC**	**n**	**DC**	**n**
	[%]	**[-]**	**[%]**	**[-]**	**[%]**	**[-]**
Mean	83.88	7.21	73.07	7.33	73.33	7.33
Deviation	2.29	0.82	1.63	0.90	1.63	1.18
K2						
	DC	**n**	**DC**	**n**	**DC**	**n**
	[%]	**[-]**	**[%]**	**[-]**	**[%]**	**[-]**
Mean	77.99	6.40	68.75	7.00	68.08	7.00
Deviation	1.99	0.86	1.55	0.53	1.30	0.65
F3						
	DC	**n**	**DC**	**n**	**DC**	**n**
	[%]	**[-]**	**[%]**	**[-]**	**[%]**	**[-]**
Mean	81.36	7.00	71.69	6.60	71.99	7.00
Deviation	3.73	0.87	1.80	0.74	1.06	0.53

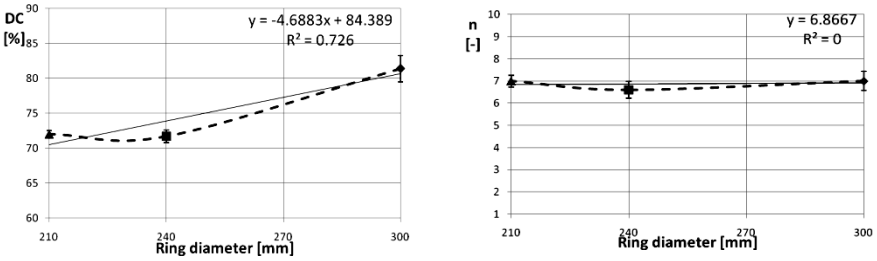
The test results show that drape coefficient changes similarly in case of all three materials as a function of the ring diameter. It can be observed that the drape coefficients measured with a 240 mm ring decreased by more than 10% compared to the measurements carried out without a ring (300 mm diameter ring) in case of all the three materials, and simultaneously the deviation of the drape coefficient also decreased significantly.



a) Drape coefficient and node number of material P1



b) Drape coefficient and node number of material K2



c) Drape coefficient and node number of material F3

Figure 5 Drape coefficients (DC) and node numbers (n) of three different materials (P1, K2, F3) with no ring (300 mm ring diameter) and with two different rings (240 and 210 mm diameter)

It can also be observed that in case of measurements carried out with a 210 mm ring, the mean drape coefficient does not differ significantly compare to 240 mm ring, however deviation decreased undoubtedly. The much lower deviation of the values measured with rings proves our assumption that the reproducibility of measurements improve as the ring diameter decreases. On the other hand, these results reveal that the node numbers do not change unambiguously, hence surprisingly node number does not seem to be applicable for the exact description of textile drape behavior.

5. CONCLUSION

Drapability is most often characterized with the drape coefficient and node number. Based on the measurements of the examined cotton fabrics with and without rings, it can be stated that the drape coefficient is much more capable of highlighting the difference in draping between different measurement methods and material types compare to the node number.

The test results also revealed well that rings have a significant impact on the draping. The results also show that both the drape coefficient and its deviation decreased significantly as the ring diameter became smaller.

In addition to the rings used in this work, we are planning to carry out measurements with a 270 mm diameter ring that is missing from the series, so that the dependence of the measured properties on the ring diameter can be evaluated at evenly distributed values within the possible range (i.e.180 – 300 mm).

According to our opinion, if draping behavior characterization of textiles is the aim, measurements with rings can give more reproducible results and might be considered as a more suitable approach for the conditions of real garment wearing compare to the measurements without rings.

6. ACKNOWLEDGEMENT

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FABRICS USED FOR PRODUCTION OF PATIENT BEDS

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ABSTRACT

Sleep is one of the most important necessities for people. During sleep, the body starts the process of an active replacement. A good bed supports the body.

Beds are formed of layers like foam, spring etc. Mattress tickings, i.e. fabrics used for production of bed, have important functions like protecting the layers of bed and increasing the sleep performance.

For healthy people, beds should support the body, prevent the pressure spots, reduce sweating. The design of medical bed must take into account of the disease of the patient. For example, beds which will be used for the patients who have the problems of heart disease, traumatology, psychology, orthopedy, mentally, physically, bed ridden, burn injuries should have different properties from each other. A patient's bed should help him to recover, provide ease for the nursing staff and prevent the patient's fall.

Mattress ticking and the parts of bed that touch the body should be determined according to medical needs. Mattress tickings of the patients who have the problems of over-sweating, fungus and allergy, should prevent the bacteria, mite and fungus by spreading the moisture quickly. For enuresis patients they should arrange the spread of moisture on the bed surface, provide quick dry of bed and prevent dirt.

Despite the great importance in terms of society health, in our country the production of patient beds has not been in the wanted level yet. The presentation will outline the procedure for producing fabrics used for patient beds.

Keywords: Mattress ticking, patient bed, medical bed, knitted fabrics

1-INTRODUCTION

Our brains are very active during sleep. Moreover, sleep affects our daily functioning and our physical and mental health in many ways that we are just beginning to understand. Although scientists are still trying to learn exactly why people need sleep, animal studies show that sleep is necessary for survival[1].

The amount of sleep each person needs depends on many factors, including age. For infants about 16 hours a day, for teenagers about 9 hours, for most adults, 7 to 8 hours a night appears to be the best amount of sleep[1].

We spend one third of our life in bed. Beds were invented in the Neolithic period and the first mattress probably consists of a pile of leaves, grass, or possibly straw, with animal skins over it. During the Renaissance, cane box was shaped or bordered, and fillings including natural fibers such as coconut fibre, cotton, wool, and horsehair. The mattress was tufted or buttoned to attach the stuffing to the cover and the edges were stitched. The box-spring which makes mattresses less lumpy, was invented in late 19th century. Innerspring mattresses and upholstered foundations became widely used, and artificial fillers became common in 1930's. Foam rubber mattresses and pillows were available for purchase in 1950[2].

(a) (b) (c)

Figure1. (a)Spring (b) Barrel spring core (c)foam mattresses[3].

The modern waterbed was introduced and gained its first widespread use in 1960's. NASA invented material that later became known as memory foam in 1970's and Tempur-Pedic introduced a mattress made from memory foam in 1992. In 1980's, air mattresses constructed of vulcanized rubber or vinyl were introduced[2].

Nowadays, the most popular cushioning materials for the bed are sprung mattresses, followed by foam, latex and visco memory foam. Sophisticated constructions, such as pocketed mattresses and imaginative relief surfaces worked onto structured foam mats which have varying degrees of porosity, all provide the comfort needed for restful sleep[4].

Many parameters determine mattress quality. Laboratory test methods have been established for some of these parameters, such as pressure distribution, skin microclimate, hygiene, edge support, and long-term stability. Other parameters, such as firmness, are more specific to the sleeper. During a night's sleep, most people use more than one position. There are 3 main sleep positions: Back, stomach and side. The sleeping position determines which part of the body will interface with the mattress, which in turn determines the amount of stress to the body. In general, firm mattresses are recommended for stomach and some back sleepers. Air, water or foam mattresses are not generally recommended for stomach and back sleepers because they do not provide this level of support. Side sleepers usually face the greatest amount of weight on the smallest areas of the body thereby creating pressure points, which reduce circulation and can be a cause of the tossing and turning during sleep. A side sleeper will probably want a softer mattress, to minimize pressure points, especially if they have a very curved or rounded figure. The medium mattresses are recommended for the majority of back sleepers. Because back sleepers need a mattress that offers enough support to fill in the gaps in the contour of the back, while at the same time providing enough comfort, according to the user's preference. Some brands offer mattresses with one softer side and one firmer side, or with adjustable firmness levels, to accommodate sleepers who share a bed[2].

For healthy people, beds should support the body, prevent the pressure spots, reduce sweating. You can find the right mattress for any preference: Whether you like to be cool or snuggly in bed; whether you are a lightweight or somewhat heavier, or prefer to sleep on your side or front.

2. MANUFACTURING OF MATTRESS TICKING FABRICS

A mattress is a piece of bedding typically consisting of multiple layers of foams and fibers, along with an innerspring unit used to provide support to one's back during sleep. Increasingly, mattresses made with various foam materials such as latex foam, visco-elastic foam and other polyurethane type foam but without metal spring units are becoming common and accepted.

The mattress core is covered by several soft materials, which provide cushioning and comfort. Some manufacturers call the mattress core by the name "Support layer" and the cushioning materials by the name: "Comfort layer". The "Comfort layer"can be divided into three sub-layers: Insulator, Middle upholstery and Quilt. Aside from the number and gauge of the coils, the upholstery layers are used to differentiate the different "qualities" of mattresses that manufacturers produce[2].

-Insulator: Separates the mattress core from the upholstery, and it is usually made of fiber or mesh.

-Middle upholstery: Comprises all types of materials on top of the insulator and beneath the quilt. It is usually made from materials that give maximum comfort: Regular foam, visco-elastic foam, felt, polyester fibers, cotton fibers, egg-crate foam, non-woven fiber pads, etc.

-Quilt: The quilt is a top layer of the mattress made of light foam or fibers stitched to the underside of the ticking, and provides the immediate soft texture that the user feels when lying on a mattress. The quilt can be firm or soft and plush.

-The protective fabric cover which encases the support and comfort layers of the mattress is called mattress ticking.

Softness, comfort and washability of mattress tickings are very important requirements from the market trends. The ticking produces the look and feel of the mattress, so it is usually soft to the touch and attractive to the buyer.

2.1. Material and Yarn Construction

During the Renaissance, mattresses were covered with velvets, brocades, or silks. In mid 18th century, mattress covers began to be made of quality linen or cotton[2]. Nowadays, most mattress tickings are made of fibers like polyester, polyamide, viscose, polypropylene, cotton, organic coton, bamboo, modal, trevira, lyocell, chitosan, coolmax etc[5].

All the studies and tests have shown that the fibers used in bed items and their blending ratios are particularly important for a relaxing sleep. The higher the moisture absorption, the drier the sleeping area and this helps to guarantee a healthy sleep. Due to its high moisture absorption Tencel is particularly well suited for use in mattress tickings. Tencel reduces the growth of these micro-organisms both automatically and absolutely natural way. As a result of the high moisture absorption, the growth of bacteria with Tencel is two thousand times lower than compared to synthetics[6].

The fiber can be used in every aspect of sleeping – beginning with mattresses and mattress pads to bed covers and linens, all the way to sleep wear. A special type of TENCEL® exists for every element of the bed; TENCEL®-powder in the mattress core, filling fibers for mattress toppers as well as bed covers and MicroTENCEL® for very fine bed linen[7].

The Lenzing Modal fiber is characterized by particularly soft and pleasant hand. It is likewise used in tickings for comforters in blends with cotton and synthetic fibers[6].

CoolMax®, made by Invista, is a tetra-channel polyester, which pulls, or "wicks", moisture away from your skin to the outer layer of the fabric. The mattresses features a removable Coolmax cover, which absorbs moisture produced by the body during sleep, resulting in a cool and relaxed sleeping environment[6].

Comforel® is the registered trademark for the INVISTA brand of bedding products. It offers down-like luxury in bedding products such as pillows, comforters and mattress pads[8].

The choice of bedding textiles depends not only on microclimatic factors such as temperature and humidity properties, but also on subjective factors like smell and feel. Bamboo has permanent and natural antibacterial properties (no chemicals needed). Bamboo has a soft hand, a cool touch and a natural, silky luster and offers higher moisture absorption than cotton[5].

PrimaLoft® is the synthetic insulation of choice for the world's leading home furnishings manufacturers. Due to its amazing softness, ease of care, anti-microbial and hypoallergenic properties, PrimaLoft has become the luxury insulation of choice for comforters, pillows and mattress pads from the world's best brands. PrimaLoft is the only hypo-allergenic bedding fill that truly mimics all the luxuries of expensive down. Made from ultra-fine microscopic fibers, PrimaLoft clusters form tiny air pockets to trap air, so you stay warm in the winter and comfortably cool in the summer[8].

Thanks to Nanotex(Nanotechnology to transform the molecular structures of fibres to create fabrics) mattress ticking, body sweat will be absorbed by the frequently washed bed linen, not by the mattress. Urine or blood spills will not be absorbed by the fibers of the ticking and can be cleaned easily without leaving a stain[5].

2.2. Fabric Construction

Most mattress tickings are made of jacquard woven fabric, jacquard lay-in knitted fabric, knitted spacer fabric, terry or velour. As an example, air mattresses are made of heavy vinyl, often with a soft suede polyester top and bottom layer. They may be inflated with an electric pump; some are attachable to an automatic power source. Mattress components consist of a variety of textiles. Generally all fabric types are quilted (figure 2).

(a) (b) (c)

Figure 2 (a) Quilted mattress ticking[9]. (b) Mattress spacer fabric[10] (b) Air mattress[11].

Fabric is the most expensive element of mattress construction. Top and sides of mattress should be soft and stretchable, allergen and dust-mite resistant, luxurious look and feel. On top/bottom/sides velour, terry cloth; and on the sides breathable microsuede or spacer fabrics can be used. You must use a good quality washable mattress pad to keep the mattress free from stains.

Consequently, firm mattresses are no longer to be recommended for people with back problems. This places new demands on the materials used: Cold foam, hydrofoam made of high-grade foam qualities, latex, and as the ultimate option point stability, Talalay latex. Mattresses adjust to the pressure of the body, and yield or provide support to ensure the optimum posture. This adaptability calls for covers which are just as flexible as the mattresses themselves. Using woven fabric, this degree of flexibility can only be created by processing special fibres. Simpler and far more cost effective, however, is the use of knitted fabric, with its natural two-way elasticity and extremely good elastic recovery.

Knitted mattress cover fabrics are gaining in popularity all the time. Knitted fabric has good point elasticity, is pleasantly soft, voluminous, permeable to air, washable and capable of production in wide-ranging different weights. It eliminates the need to use cost-intensive special yarns to achieve sufficient elasticity. Circular knit goods are less susceptible to warping and bulging, permit better further processing due to their volume, can be produced in tubular form and eliminate the need for quilting as an additional work step. Modern mattress covers are predominantly removable and washable. The use of knitted fabric allows the cover to be easily removed and replaced[12-13].

The knitting construction makes the fabric flexible and ensures comfort. Further, the fine structure (28 gauge) is soft and inelastic, which makes it ideal for matching the cover to the shape of the mattress and also eliminates creasing the company states.

When making up the mattress covers, the complete width of the fabric web is stretched over the length of the mattress. In contrast to woven covers, this method helps avoid the formation of centre creases, in particular when the mattress slats are set at different angular positions[12-13].

Mattress covers are knitted primarily using electronic circular knitting machines. The reasons for this are the patterning reliability and the high speed of pattern changeover, which turns costly hours spent resetting into economically productive time[13]. Circular knitted mattress cover fabrics are produced with weft (lay-in) patterning, spacer and plush techniques. To produce weft patterning, a weft thread (lay-in yarn) is laid in between the stitches on the fabric face and the plain stitches on the reverse side.(Figure 3) This is done by adjusting another weft yarn feeder in addition to the actual yarn feeder which lays in the weft thread in front of the actual knitting point[12].

Responding to customer's quest for the next fabric, Monarch have introduced more colors into weft knitted mattress ticking providing a completely new product. As 'Long Float' jacquards become more popular, the technicalities of knitting such a fabric creates its own problems, however, by using the intersia jacquard facility within the Monarch Design system the designer has complete control of each floating yarn. In keeping with the trends, flowers have a relief, almost plastic roundness about them creating a 3D 'artificial garden'[14].

On the ITMA 2003, the first 32 gauge electronically controlled jacquard circular knitting machine for the production of spacer fabrics with wide wind-up frame was presented by Terrot to the trade public. Spacer structures are knitted fabric constructions comprising two separate fabric webs which are joined together by spacer threads of varying rigidity. The spacer threads are generally made of PES or PA monofilament yarns. The threads of the dial and cylinder stitches are made of textured PE filament yarns, depending on their intended field of application. The degree of space or height between the two fabric faces is determined in the circular knitting machine by the setting of the dial height relative to the machine cylinder. Spacer fabric heights preset in this way can vary between 1.5 and 5.5 mm. Spacer fabrics can be subdivided into jacquard patterned and plain knitted 8-lock structures. Electronic individual needle selection in the cylinder cam of the circular knitting machine permits almost unlimited pattern repeats coupled with maximum patterning variety. The thickness and cross-section of the monofilament yarns, together with the knitted construction selected, determine the force with which the two fabric webs are kept apart. Spacer structures offer more extensive conditions for varied application, as their stable 3D structure encompasses scope for distinctive design and possesses special physical attributes. Spacer fabrics are lightweight, soft, pleasant on the skin. They offer active breathing properties, transport and absorb moisture Spacer fabrics are pressure-elastic, wash-resistant and ageing resistant and capable of sterilization. They have definable elasticity properties and thermo regulating properties[12]..

(a) (b) (c)

Figure 3. (a) Knitting structure (b) Cross section (c) photograph of weft patterning (Laid-in) knitted fabric [12].

On circular knitting machines, spacer fabrics can be economically produced even in small batch sizes. The resetting times are correspondingly reduced on circular knitting machines compared to collective needle motion knitting machines, while circular knitting machines also take up only a fraction of the space. This allows rapid responses to fast-changing markets and fashion trends[12].

Knitted spacer fabrics can be weft or warp knitted. Warp knitted spacer fabrics are the most popular choice and are produced on double needle bar rachel knitting machines at thicknesses of 1.5-10 mm although up to 60 mm is possible for certain special applications[15].

Great flexibility is associated with warp-knitted spacer fabrics because different materials may theoretically be used in guide bars. Raschel spacer structure has more advantages as it can be produced with dimensional stability and/or stretch. Also the air and water permeability of the structure can be controlled. In this method, different width of spacer fabrics can be produced without ripping or raveling structure. The force required to pres the two surfaces together (pressure resistance) is dependent on the mass of monofilaments in the structure, which means yarn count, stitch density, and machine gauge in relation to the spacer fabric[17].

(a) (b) (c) (d)

Figure 4. (a) Knitting structure of weft knitted spacer fabric (b) photograph of weft knitted spacer fabric[12]. (c)Warp knitted spacer fabric used in bed mattress [16]. (d) Mattress ticking with spacer fabric on edges [3].

At the 2006 Cologne Furniture Fair, many mattress manufacturers exhibited the latest development in warp knitted spacer textile for mattresses. These textiles provide features like optimum support for the body, specific areas which bend flexibly, and moisture wicking and temperature-control[18].

2.3. Dyeing-Printing-Finishing Techniques

The standart finishing process for woven mattress ticking fabrics: Dying, coating, finishing and quality control. On the other hand the standart process for knitted mattress ticking fabrics: Dying, finishing and quality control[19]. Generally, antibacterial, flame retardant, antistatic finishing are most preferred.

Different finishing processes can be applied to produce intelligent, functional mattress ticking fabrics with added value for the consumer. As an example, mattress ticking fabric which finishes with Aloe vera with a wide range of healing effects has some advantages: Protects, soothes and cares for the skin, improves the blood circulation, has a regenerative, anti-inflammatory and healing effect and promotes suppleness[5].

Eucalyss is a mattress ticking treatment that not only keeps mosquitoes away from the mattress, but also from the mattress environment. Eucalyss creates a natural cocoon, a true no fly zone. Millions of microcapsules are attached to the textile fibres and they are only broken when the mattress is used[5].

Antiallergenic mattress, quilt and pillow covers made by Allersearch consist of a cotton blend fabric laminated with DuPont™ Active Layer breathable, waterproof film. The covers help provide an effective barrier to dust mites and allergens while keeping the sleeper comfortably dry. Blocks dust mites and their allergens[20].

3. MANUFACTURING OF MATTRESS TICKINGS FOR THE PATIENT BEDS

The patients bed is a peace of equipment which should help him to recover as quickly as possible, and because of this medical beds must satisfy a number of special requirements[21]. A patient's bed provide ease for the nursing staff and prevent the patient's fall. The design of medical bed must first take into account of the disease of the patient. For example, beds which will be used for the patients who have the problems of heart disease, traumatology, psychology, orthopedy, mentally, physically, bedridden, burn injuries should have different properties from each other[21].

In design of medical beds mattress ticking and the parts of bed that touch the body should be determined according to medical needs. For example, mattress tickings of the patients who have the problems of over-sweating, fungus and allergy, should prevent the bacteria, mite and fungus by spreading the moisture quickly. For enuresis patients they should arrange the spread of moisture on the bed surface, provide quick dry of bed and prevent dirt.

3.1. Sleeping Problems

Sleep and sleep-related problems play a role in a large number of human disorders and affect almost every field of medicine. Sleeping problems occur in almost all people with mental disorders, including those with depression and schizophrenia. Sleeping problems are common in many other disorders as well, including Alzheimer's disease, stroke, cancer, and head injury[1].

Insomnia: can result from stress, jet lag, diet, or many other factors. Insomnia affects job performance and well-being the next day. It is often the major disabling symptom of an underlying medical disorder[1].

Restless leg syndrome (RLS): a familiar disorder causing unpleasant crawling, prickling, or tingling sensations in the legs and feet and an urge to move them for relief, is emerging as one of the most common sleep disorders, especially among older people[1].

Sleep apnea: is a disorder of interrupted breathing during sleep, sometimes hundreds of times during the night and often for a minute or longer[1,8]. Untreated, sleep apnea can cause high blood pressure and other cardiovascular disease, memory problems, weight gain, impotency, and headaches. Moreover, untreated sleep apnea may be responsible for job impairment and motor vehicle crashes[22].

Mild sleep apnea frequently can be overcome through weight loss or by preventing the person from sleeping on his or her back[1].Apnea was significantly reduced while the infants were on the oscillating water beds[23]. While on the water bed, the infants had significantly more quiet and active sleep, shorter sleep latencies, fewer state changes, less restlessness during sleep, less waking activity, and fewer jittery and unsmooth movements[24].

Merino wool bedding textiles are vable to buffer temparature extremes and changes in humidity. These bedding textiles also transport more sweat away from skin as compared to synthetic fabrics and thereby aid quality sleep. Phase change material textiles are able to dynamically stabilize temparature changes and improve sleep via encapsulated waxes[25].

3.2. Bed Sores

Bed sores can occur when a person is bedridden, unconscious, unable to sense pain, or immobile. Bed sores are ulcers that occur on areas of the skin that are under pressure from lying in bed, sitting in a wheelchair, and/or wearing a cast for a prolonged period of time. If the patient is lying flat on a bed for long period, pressure exerted by the body on to the mattress creates pressure points which can cause discomfort. When lying flat on a standard hospital mattress in the supine position, most pressure is exerted at the sacrum with %23 of the body's weight being distributed at this point which would be in contact with an incontinence product(figure 5). Once a bed sore develops, it is often very slow to heal[15,26-27].

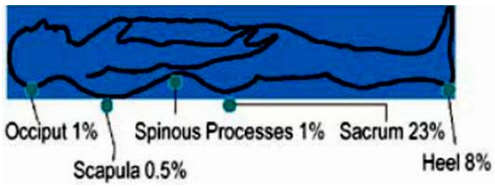

Figure 5. The main areas of pressure when the body lies flat on a bed[28].

In order to avoid bed sores in such circumstances, it is necessary to manually move the patient frequently to allow access of air to various parts of the patient's skin and to relieve continued pressure against those skin parts. Bed sores can be prevented by keeping skin clean and dry, using pillows and beds that reduce pressure. Pressure sores are normally prevented or treated separately to incontinence with use of specialist mattresses although medical sheepskin products can be used for both, offering a very dense pile for compression resistance and moisture absorption[28-29].

Figure 6. Australian HiTemp UR Medical Sheepskin[29].

By allowing sensitive body areas to be supported without pressure, spacer fabrics can prevent bed sores. These advantages have made knitted mattress covers an invaluable asset in nursing applications, for example in hospital beds[12].

The bed sore problem has been addressed recently by a number of inventions which involve the use of fluid filled mattresses which can be periodically inflated and deflated to intermittently support the patient at different points of the body, thus allowing periodic reduction of skin pressure and access to air.

3.3. Back Pains

Back-and neck pain are two of the most common and potentially most expensive complaints which patients bring to their family doctors. Twenty-four to 48 hours of bed rest lessens the pressure on the spine and on the intervertebral discs. At night or during rest, patients should lie on one side, with a pillow between the knees. Patients should sleep on a firm surface. A waterbed and air bed acts as a naturally orthopedic bed for chronic back pain sufferers[30].

3.4. Asthma and Allergy

A common disease that causes airways to tighten, asthma can be found in all ages and is easily aggravated by household conditions. Millions of people still share a bed with dust mites and they may even be making them sick.Dust mite allergens are major trigger factors for asthma, hay fever and other allergic problems. Antiallergenic mattress, keeps you dry, allows evaporation and evacuation of sweat moisture faster than the skin exudes it. The fabric/film laminate maintains its properties after repeated washings, according to Allersearch[20,31].

4. CONCLUSIONS

Sleep affects our daily functioning and our physical and mental health in many ways. For healthy people, beds should support the body, prevent the pressure spots, reduce sweating. Attractive look, softness, comfort and washability of mattress tickings are very important requirements from the market trends.

The patients bed is a peace of equipment which should help him to recover as quickly as possible. The design of medical bed must first take into account of the disease of the patient. Population aging has many important socio-economic and health consequences, including the increase in demands for patient beds.

Despite the great importance in terms of society health, in our country the production of patient beds has not been in the wanted level yet. Ticking fabric is the most expensive element of mattress construction.

All the studies and tests have shown that the fibers used in bed items and their blending ratios are particularly important for a relaxing sleep. The higher the moisture absorption, the drier the sleeping area and this helps to guarantee a healthy sleep. The choice of bedding textiles depends not only on microclimatic factors such as temperature and humidity properties, but also on subjective factors like smell and feel. The mattress tickings fabrics which produced with the aim of meeting certain requirements, make beds ideal for use treatment.

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FILTRATION APLICATIONS OF ELECTROSPUN PVA NANO FIBERS

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ABSTRACT

PVA (poly vinyl alcohol) nano fibers were produced by using electrospinning method. SEM images were taken to specify average fiber diameter. Nano fibers were spun between two PP meltblown layers to be protected from external effects and by this way nano fiber filter material was created. A new test method designed for efficiency measurements and nano fiber filter material, HEPA filter material and ULPA filter material efficiencies were tested by this test method. Results were compared with each other.

Keywords: *PVA, electrospinning, nano fiber, filters*

INTRODUCTION

Optimum air quality is needed for human living places. It is made by filters to decontaminate air and take the air quality to the level that is desired. Filters are designed to let the fresh air in and keep the impurities out.

In recent years, studies of Davies (1973), Brown (1998) and Hinds (1999) helped us to reach to the point that we are being now

Filters catch impurities by different effects and single fiber efficiency is based on the sum of three main effects . These effects are;

-Inertia effect: Air dragging particle can not pass around the fiber and sticks on fiber surface due to its inertia.

-Interception effect: If the particle diameter is very small, it is caught by fibers with the influence of electrostatic forces.

-Diffusion effect: Impurities move in zigzag ways in the air when particle diameter is below 1 µm (Brownian action). Due to this movement particles stick on fiber surface.

$$\eta = \eta_R + \eta_D + \eta_I$$

MATERIAL AND METHOD

Electrospun of PVA Nano Fibers

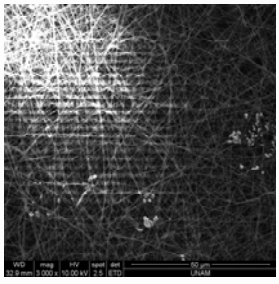
PVA is a preferred polymer for water resolution, high chemical resistance, superior physical features and bio-recyclability.

In our study, PVA with 72000 polymerization degree is provided by Merck. %12 of weight PVA solved in distillated water for the nano fiber spinning at 80-100 C by using magnetic mixer. Solutions viscosities were measured by Vibro Viskometer SV-10 and

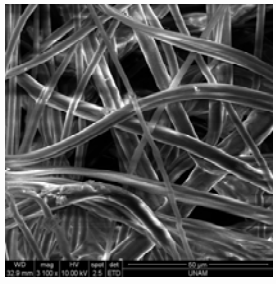
Matsusada AU-40-075 model high voltage resource (40 kV and 0,75 A max) was used for electrical charge. Polymer solutions were put into pipettes which have 50mm and 75mm inner diameters and copper wires used for electric charge. Electrical field was created by a copper plate below. Pipettes were fed by gravity at vertical position. Multiple pipette system was designed to provide homogeneity.

Several studies were done to find out the best conditions for our system and 10cm pipette-collector distance, %12 PVA concentration and 30 kV potential difference were assumed suitable. 247 nm average fiber diameter was determined on SEM measurements.

Nano fibers are weak in terms of strength and abrasion resistance. In order to eliminate this weakness and save the nano fibers from external factors, nano fibers were spun between PP meltblown surfaces which have 20 g/m^2 weight and 2-6 micron thickness as seen on SEM images. It is defined as MNM when nano fiber spun single layer between PP surfaces (M: Meltblown, N: Nano fiber) and defined MNNM when nano fibers spun two layers.



A-SEM Image Of PVA Nano Fibers



B-SEM ımage Of PP Meltblown Surface

Filtration Measurements

Particle quantity in the airflow is counted before and after air pass through filter, herefrom efficiency is calculated and filters are classified according to these values, in standard test methods.A new, half size of A4 paper closed environment designed to not damage filter material.HEPA (high efficiency particulate filter) and ULPA (ultra low penetration air) filters had been found to compare sample efficiencies .

Test Method for A4 Size Filter Material

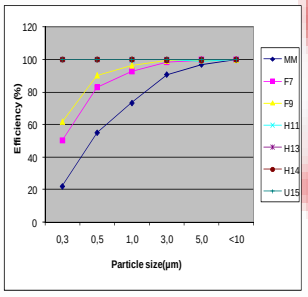
RESULTS AND CONCLUSION

Particle size (µm)	MM	F7	F9	H11	H13	H14	U15
0,3	22,08507	50,22643	61,66027	99,97094	99,98523	99,98432	99,99146
0,5	55,10827	82,97677	90,3821	99,97175	99,99255	99,97808	99,99648
1,0	73,38966	92,96301	96,53029	99,95393	99,98317	99,96259	99,99543
3,0	90,89945	98,66238	99,44251	99,90158	99,95807	99,95059	100
5,0	97,13439	99,73046	99,73298	99,22958	99,89328	99,92238	100
<10	100	100	100	100	100	100	100

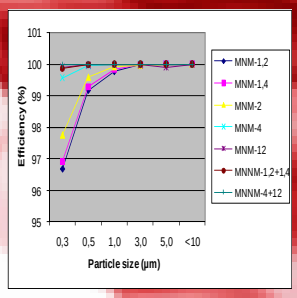
Efficiency Values of Standard Filter Materials

Particle size (µm)	MNM-1,2	MNM-1,4	MNM-2	MNM-4	MNM-12	MNNM-1,2+1,4	MNNM-4+12
0,3	96,67035	96,91301	97,7411	99,56062	99,90737	99,8619	99,9778
0,5	99,16781	99,28273	99,57327	99,94262	99,972	99,98573	99,99133
1,0	99,76358	99,84367	99,91323	99,9863	99,98013	99,9988	99,99161
3,0	99,98236	99,98413	99,96395	100	99,97613	100	99,99669
5,0	100	100	100	100	99,89418	100	100
<10	100	100	100	100	100	100	100

Efficiency Values of PVA Nano Fiber Filter Material



A-Efficiency Graphics of Standard Filter Materials



B-Efficiency Graphics of PVA Nano Fiber Filter Materials

PVA is a preferred polymer for water resolution, high chemical resistance, superior physical features and bio-recyclability.

In our study, filter material that is created by using PVA nano fibers is compared with HEPA and ULPA filters. As a result, it has been seen that MNNM-4+12 filter meterial is as effective as H-11 filter material. It is important to get these values by using electrospun PVA nano fibers as a cheaper, easy to produce, and useful material.

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FINE AND SUPER FINE KNITTED TECHNICAL FABRICS

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ABSTRACT

Goods that are produced by finer and lighter fabrics have been preferred in the last ten years because of the global warming. Finer yarn's usage in tighter woven/knitted fabrics and making the fabric finer with some finishing processes are the main ways to produce finer fabrics. The single jersey knitted structures are the most preferred knitted "thin" fabrics. The thinnest single jersey fabrics are commonly produced in E28 circular knitting machines for ages.

Since 2003, fine gauge (E32-E42) and superfine gauge (E44-E60) knitting machines were launched to meet the demands of the fashion world for fine, flowing circular knitted fabrics. These finer fabrics are more compact, smoother, uniform, lighter and more attractive than standard knitted fabrics. Fine and superfine fabrics open up new markets for the circular knitting sector.

The extraordinarily uniform and smooth superfine fabric surface differs markedly from standard knitted fabrics. The stitch wales and rows are very close. A single, dense fabric surface makes it possible to create opaque materials while still achieving very low material weights. Under optimum processing conditions, a high level of acceptable product characteristics can be achieved for ultra fine knitted fabrics. Yarn construction, yarn quality, knitting machine, knitting conditions, finishing process and finishing conditions play a particular role in superfine knitting fabric production. Dyeing and finishing techniques have to be modified when applied to such ultra fine gauge weft knitted fabrics.

By using top-grade cotton, viscose, nylon or polyester yarns (Ne 90-150), it is now possible to produce fabrics which are just as suitable for high quality underwear, transparent or printed fashion shirts, blouses and outwears as well as the medical and technical textile products.

Tightly and lightweight superfine knitted fabrics which have very small porous will be a good selection for UV protective, FR protective and clean room garments. Lightweight knitted wiping clothes have excellent cleaning performance and soft touch that won't harm delicate surfaces such as screens, eyeglasses and cameras.

This paper will give an introduction to the fine and super fine knitted fabric production and will present examples of their usage as "technical textile" products

Key Words: fine knitted, superfine knitted, lightweight, protective clothes, cleanroom clothes

1. INTRODUCTION

The concept of "Fine knitted fabric" has changed over the years. In 1974, E28-E32 gauge Terrot circular knitting machines were launched to meet demands of the fashion world for fine, flowing fabrics[1,2]. Since ITMA 2003, E40-fine gauge single jersey circular knitting machines have become a part of the textile world. Today, circular knitting machine builders produce fine and superfine circular knitting machines:

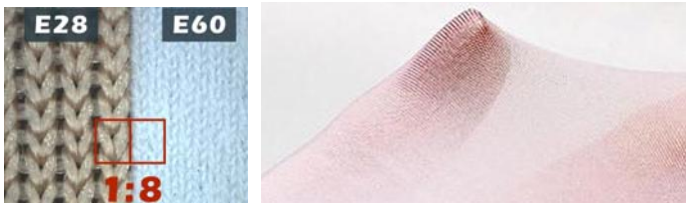
Single jersey circular knitting machines; E60 and E62,

Double jersey (Rib) circular knitting machines; E32 and E46,

Double jersey (Interlock) circular knitting machines; E42-E44-E50 [1-9].

For finer gauges, as central elements of a circular knitting machine, needle beds (cylinder and dial), sinker ring and sinkers, are important and topical trend in circular knitting machine production[10]. Engineering limitation on the knitting head has led machine builders to re-think machine geometry and in some cases has led to a complete change of knitting action. Vignoni for example, has developed an ultra fine gauge single jersey machine which does not have traditional sinker elements[9].

For T-shirt production, we commonly use fabrics which are produced by E28 gauge circular knitting machines. In producing hosiery, we use E26-E36 gauge sock knitting machines[11]. The stitches of fabric which are produced in E60 circular knitting machine, are about 8 times finer than E28 one as shown in figure 1. It is no longer possible to identify the individual stitches by naked eye. E60 fabric which has ~2,500 isolated stitches per cm² is completely dense, smooth and even[12].



(a) (b)

Figure 1. (a) E60-superfine and E28-standart fine knitted fabric photos[12] (b)DIMENSION50® -E50 gauge single jersey transparent knitted fabric[13].

Fine, smooth and elegant superfine fabrics present completely new properties such as wearing comfort and beauty for the garments. The garments are lighter, finer and much less constraining and as such offer an increased feeling of "well-being" to the wearer[12].

The superfine effect also remains unaffected after numerous washes.The tightly knitted constructions, produced on fine gauge knitting machines, provide the most durable knitted fabrics. For example, polyester microfiber knitted fabrics which are produced on E40 circular knitting machines enhance the hand of the fabric and create a smoother, pilling resistant fabric[12,14].

It is now possible to produce fabrics which are just as suitable for high quality underwears, transparent or printed fashion shirts, blouses and outwears as well as the medical and technical textile products. For example, linting resistant cleanroom clothes, gloves, masks etc., cleaning fabrics, wiping cloths for eyeglasses and cameras[1,15-16].

2. MANUFACTURING OF FINE AND SUPER FINE KNITTED FABRICS

Under optimum processing conditions, a high level of acceptable product characteristics can be achieved for ultra fine knitted fabrics. Yarn construction, yarn quality, knitting machine, knitting conditions, finishing process and finishing conditions play a particular role in superfine knitting fabric production. Processability of superfine knitted fabrics in making up is very important subject too[16].

2.1. Yarn Construction

The range of yarn count for super fine knitting machines (E44-E60) in the area of single jersey is between approx. Nm 135-Nm 250. Among the spinning processes the compact and ring systems are suitable for production of fine yarns[17]. The yarn which will be used in the production of ultra fine circular knitted fabric must meet specific requirements: Fiber fineness, friction coefficient, hairiness, fiber abrasion, crimping, yarn uniformity (particularly thin and thick places) and strength[16,17].

The right selection of fibers is decisive for spinning stability, running behaviour and for the resulting yarn quality. Fibers with suitable fiber length are decisive for an even yarn of high strength. When processing cotton, origins are required which should have a Micronaire value between approx. 1.2 dtex. As a result, there are fibers around 33 in cross-section for a yarn of Nm 250. For example Indian Suvin, Egyptian Giza 45 and Sea Island qualities are outstandingly suitable for the production of fine yarns[1,18]. Besides cotton also polyester and cellulosic fibers such as Micro-modal, Micro-Tencel or Lyocell which single fiber titer is around 1 dtex, can be used in superfine knitted fabric production[17].

2.2. Fabric Construction

Fine, lightweight circular knit goods are currently at the forefront of fashion trends[2]. Today, single jersey RL, striped single jersey, open width single jersey, jacquard single jersey, rib double jersey, interlock double jersey, jacquard double jersey and double jersey spacer knitted fabrics can be produced in modern “fine and superfine” circular knitting machines[1-9].

Ultra fine-super fine single jersey circular knitted fabrics up to a gauge of E62 are characterized by such outstanding properties as elegant drape, a supply handle and a stitch structure which is hardly visible to the naked eye[2]. Fabrics which knitted in E50 circular knitting machine are used for producing drapery & controlled stretch for gentle folds & body wrapping garments. The degree of stretch can be adjusted by changing the proportion of elastane. Increased elastomeric content, up to 40% for shape retention and performance. Fabrics are more compact for moulding and to use as print bases, having more sheen with a drape that be fits either underwear or outerwear with a sensual feel[4].

The extraordinarily uniform and smooth superfine fabric surface differs markedly from standard knitted fabrics. The stitch wales and rows are very close. A single, dense fabric surface makes it possible to create opaque materials while still achieving very low material weights. In E28 gauge circular knitting machines, light-weight knitted fabrics can be produced by selecting loose knitting adjustments and thinner yarns. However, in that case your knitted fabric will be very slack and transparent [12]. Thin, lightweight (~50g/m^2), opaque single jersey fabrics which knitted in a E60 gauge circular knitting machine, can be used for sweamwear and underwear production[19].

Super fine rib double jersey circular knitted fabrics up to a gauge of E46 and interlock double jersey circular knitted fabrics up to a gauge of E50 are used for applications in the sweamwear, underwear and outer wear sectors [2]. In fine gauge electronic double jersey circular knitting machines, with clarity of design, power stretch and with a fabric weight of less than 100 g/m² you can make a new generation of fabrics[4]. Ultra fine-super fine double jersey spacer knitted fabrics plated with elastane up to a gauge of E32 are used in the production of underwear, corsetry and the latest trend in bodies[2].

2.3. Dyeing-Printing-Finishing Techniques

Dyeing and finishing techniques have to be modified when applied to such ultra fine gauge weft knitted fabrics. The main reason is because the majority of fabrics are knitted from micro-fibre yarns of finer counts. These yarn types are much more delicate and suspectable to damage compared to yarns with traditional fibres. Fabrics made from micro-fibre yarn give magnificent draping qualities and handle etc. but can easily be damaged[9].

In order to retain the superfine fabric properties, different approaches, greater care and different methods have to be used. For example, the fabric has to be finished in tensionless state thus horizontal jet type dyeing machines are preferable. The heat setting prior to dying is also danger area; too much heat can lead to fibre damage and consequently variations in dye shades. Another factor is that the increased surface area of per unit weight of micro fibres when compared to standard decitex fibre yarns. The increased micro fibre surface area calls for dye recipe to be increased by 300% in order to achieve the same level of dye and shade depth. The color fastness factor during washing and exposure to light cam also be problematic regarding fabrics knitted using micro-fibres[9]. There are different developments in dyeing and finishing machinery to process light to medium weight woven and knitted fabric[20-24].

2.4. Make-Up Techniques

The demand for fine and very fine fabrics with delicate stitching is steadily increasing. For this reason, the standards for seams have also increased. There is a large correlation between needle-penetration forces and loop damage. The main influencing factors, which are closely related to loop damage, are sewing machine type and speed, needle thickness and shape of needle tip, as well as sewing yarn, seam direction, number of lays, product humidity and finishing. Optimized softening using the appropriate products and recipes adapted to suit the knitted structure can achieve a good level of sewability in superfine knits[25].
A new trend in innovative garment industry is the use of ultrasonic ‘sewing' machines which make it possible to stitch a garment together without a trace of needles or thread. High frequency sound waves are used in this process, to melt and bond edges of a fabric together. Ultrasonic welding is a modern, innovative and economic alternative and complementary to conventional sewing technology for superfine knitted fabrics[26].

3. FINE AND SUPER FINE KNITTED FABRICS USED IN TECHNICAL TEXTILE PRODUCTS

Technical textiles are textile materials manufactured mainly for their technical performance and functional properties rather than their aesthetic or decorative characteristics[27].The world textile industry is moving rapidly toward the manufacture of high-added value textile structures and products such as medical textiles, protective textiles and smart textiles[28].

There are a lot of invention relates to super fine knitted technical textile products such as artificial skin, protective clothes, cleanroom products, wiping cloths etc.

Skin, the human body's largest organ, protects the body from disease and physical damage, and helps to regulate body temperature. When the skin has been seriously damaged through disease or burns, the body cannot act fast enough to manufacture the necessary replacement cells[29]. Artificial skin

substitutes, used for wound and burn dressings, and other purposes are made stretchable and tear resistant by using a fine knit nylon fabric[30].

3.1. Protective Cloths

Safety and protective textiles refer to garments and other fabric related items designed to protect the wearer from harsh environmental effects that may result in injury or death. Durable protective clothing is usually made of woven of knit fabrics and is coated[31].

-UV Protective Cloths: The UPF is a term describing the sun protection provided by fabrics, and it indicates the level that a fabric can block UV rays from reaching the skin. The Skin Cancer Foundation has rated the fabric in a standard cotton t-shirt as UPF7. When the t-shirt gets wet from water or sweat, the UPF level drops by about 50%. This is one reason why UV protective fabrics are generating more and more interest, coupled with the increased awareness of skin cancer risks.

The level of UV protection provided by a fabric is dependent on two factors; the type of fiber used in garment and the density of the fabric. The tighter the weave or knit, the better its ability to block UV rays. Because the fibres of tightly fabrics are closer together, less UV radiation is able to pass through to the skin. Tightly and lightweight fabrics such as linen, cotton or hemp will also help keep you cool. Repeated washing can improve the UPF of clothes, especially cotton, by shrinking gaps in the structure[14]. However, if a fabric is stretched, the holes between the yarns open up and the UV rays can get through to your skin and the fabric will probably be less protective. This is common in knitted or elasticized fabrics[32]. But, thin, lightweight superfine knitted fabrics which have very small porous will be a good selection for UV protective garment production[33].

-**Flame Resistant Protective Cloths:** Wearing flame resistant (FR) protective apparel reduces burn injury and increase the chance of surviving a flash fire. Flame resistant fabrics are designed to resist ignition and self-extinguish when ignited. In general, a properly designed flame resistant fabric should prevent the spread of flames when subjected to intensive heat or flame. It should also self extinguish immediately as soon as the ignition source is removed. Resistance to both flame and associated heat transfer through the garment is defined as thermal protection. Fabric weight is an important parameter for thermal insulation with FR cotton materials. Important parameters when selecting flame resistant protective apparel are flame resistance, ergonimically design for wearer comfort, durability, easy maintenance and aesthetics. Comfortable, lightweight superfine knitted fabrics will be a good selection for FR protective garment production[31].

Moreover, in flat knitting sector, 18G gloves offer a fit and feel equivalent to that of bare hands, giving new meaning to the term "fits like a glove." Round and seamless, snug-fitting fingertips make them perfect for applications that require high manual precision including medical, technical and assembly work. Very tight stitches between the fingers also make them suited for use as coated turn gloves[15].

3.2. Linting Resistant Cleanroom Garments

It may also be necessary to protect the environment from peoples in the case of clean rooms[31]. A cleanroom is defined in the International Organization for Standarization (ISO) standart 14644-1 as;*"Room in which the concentration of airborne particles is controlled, and used in a manner to minimize the introduction, generation and retention of particles inside the room and in which other relevant parameters, e.g. temperature, humidity and pressure are controlled as necessary…"* [34].

The dirt and bacterial –free conditions provided by cleanrooms are essential for much modern manufacturing industry. Without clean conditions, products get contaminated and either malfunction or become hazardous to people. In recent years there has been a considerable increase in the number of cleanrooms. Clean rooms are now used for the nano technology laboratories and the manufacture of items used in computers, cars, aeroplanes, spacecrafts, televisions and many other electronic and mechanical devices, as well as the manufacture of medicines, medical devices and convenience foods[34].

Large amounts of the contamination are dispersed from the people in the cleanrooms. People may disperse particles from skin, mouth, nose and cleanroom clothing and underwear. Cleanroom garment systems protect the product from the contamination generated by personnel and can, if required, also protect personnel from products. Special clothing is worn in all cleanrooms to control the contaminations within cleanrooms. The choice of clothing will depend on what is being produced in the cleanroom. A poorer standart of cleanroom may use a cap, zip-up coat (smock) and shoe covers[34].

The most effective type of cleanroom clothing is that which completely envelopes a person. The routes of dispersion of particles are though the following parts of cleanroom clothing: Fabric, poor closures at the

neck, ankles and wrists, holes and tears. Cleanroom garments are usually sewn using low-texture, continuous filament sewing threads. Some companies use ultrasonically bonded seams to eliminate the "blow through" associated with needle holes. To minimize contamination, elasticized or knitted cuff should not collect or shed particles[34].

The type of fabric is an important consideration when choosing a cleanroom garment. Cleanroom fabrics should be resistant to linting[34]. Barrier efficiency against airborne particles is a critical performance feature of cleanroom clothing[35]. A more important property is their ability to filter the contamination generated from skin and clothes worn under the cleanroom clothing[34].

(a) (b) (c) (d)

Figure 2. Cleanroom garments (a) Shoe covers (b) Face Mask and Hood (c) Cap[36]. (d) 18G ultrafine gauge glove[15].

The clothing and its materials are subjected to a range of checks to ensure their suitability for use in a cleanroom[37]. The fabrics effectiveness can be assessed by measurement of the air permeability, particle retention and pore size[34]. Fabric weight, thickness, tensile strength, moisture vapor transmission rating and bacterial filtration efficiency etc. are measured too[37,38].

There are several standardized tests to provide comparative data on the barrier properties and particle emission of the fabric and the clothing. So far, however, there have been no standards or authorized recommendations as to which performance classes or categories of material and clothing should be used in which cleanroom classes[37].

Filtration performance is measured with the means of a Martindale Abrasion Tester that simulates the movement between undergarment and cleanroom garment by rubbing. If the particle migration of the fabric is very low, this fabric offering an excellent barrier from the garment inside to the outside[38].

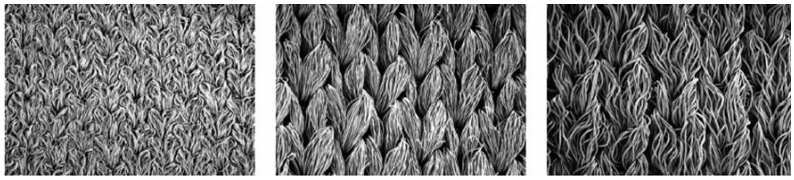
To measure the particulate matter released from the fabric of the garments Helmke Drum test method which simulates particle shedding of clothing under movement can be used. The garment under test is tumbled in a rotating drum to release particles from the surface of the cleanroom garment in a controlled manner[38]. Another test, Body Box indicates the contamination of a cleanroom by simulating the particle filtration of the clothing and the particle release of the person under real wear conditions[38].

More resistant to linting, filtration efficient cleanroom clothing can often be the least comfortable and the most expensive. Super fine fabrics which are knitted with fine yarn and tightly adjustment, will be comfortable, lightweight, smooth, and cost efficient other than woven fabrics and will be a good selection for clean room garment production[12,37].

3.3. Cleaning fabrics and wiping cloths

During the process of cleaning by wiping a transfer of mass takes place: The contamination is transferred from a surface into the wiper. At the same time, however, small amounts of the mass of the wiper are deposited onto the surface which is to be cleaned. During normal cleaning procedures, for example at home, such contaminant residue from the wiper rarely has a significant effect on the resulting surface cleanness. In highly developed industrial processes, however, such residue from previous cleaning procedures even in the µg range can have a considerable effect on the process result[39]. For this reason, cleanroom wipes used for critical applications such as optical lenses, mirrors and ultra smooth surfaces are generally high density microfilament polyester and/or nylon knits[40].

Lightweight knitted wiping clothes have excellent cleaning performance and soft touch that won't harm delicate surfaces. The cleaning efficiency of the HiTech-wipers of different manufacturers varies greatly. For The fabric shown in figure 3(a) has the best cleaning efficiency of these three wipers[39]



(a) (b) (c)

Figure 3. The surface structure of three different models of wipers[39].

The Hitecloth is a fine wiping cloth made by Xanebo. The special yarn used for this wiping cloth is 0.1 denier, an ultra-fine micro-fiber. This filament is very fine, strong, generates no particles and does not damage any surface. The wedge-shaped polyester at the cross section together with the core nylon fit the surface of any object and collects dust efficiently. After knitting with a special gauge knitting machine, Hitecloth is made to shrink with a technology that makes fabric construction highly dense, reducing the surface to 40% of its original size. The special high density treated knit fabric means extremely good absorption by the total filament surface area[41].

4. CONCLUSIONS

Since 2003, fine and superfine gauge knitting machines were launched to meet the demands of fine, lightweight circular knitted fabrics. The uniform and smooth superfine fabric surface differs markedly from standard knitted fabrics. The stitch wales and rows are very close. With this extraordinarily properties, fine and superfine fabrics will give sales opportunities in fashion. Superfine knitting machines will open up the niche markets especially in technical textile area such as wiping clothes, UV protective, FR protective and clean room garments.

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FOAM STRENGTH PROPERTIES UNDER PUNCH LOADING

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ABSTRACT

Usually soft furniture is chosen according to its upholstery material and shape. The latter depends on the foam which is a complex product. Different types of it can have significantly different properties determining three main characteristics of furniture: durability, comfort and elasticity. Foams of certain qualities are applied at specified zones of furniture which experience different types of deformations. Foam material is deformed not only in furniture manufacturing process but during its exploitation as well. The quality of foam is determined by its density, rigidity, resiliency, compression and stability properties. The aim of the research was experimental investigation and evaluation of foam systems strengths parameters under biaxial punch deformation. Typical uniaxial and biaxial tensile stress – strain curves of tested systems were compared. The research was performed with the help of punching device designed for spatial deformation of tested materials. The device was attached to the standard tensile testing machine. Radius of tested samples was R=28.35 mm. Radius of the punch was 14.35 mm. Punching speed was 100 mm/min. The objects of the investigation were polyurethane foam samples of different density and thickness.

Key words: foam, mechanical properties, biaxial deformation, punch loading

1. INTRODUCTION

Polyurethane foams (PU) are used in a variety of commercially established applications like mattresses, automotive and furniture cushions, carpet backing, packing and etc. [1] because they are easy to handle and provide excellent cushioning and physical properties. Polyurethanes can be generated from liquid components on the job site of the materials applying the techniques of pouring, frothing or spraying [2]. It must be noted that main part of polyurethane foams during their exploitation are effected by forces perpendicular to their surfaces. As a result, the shell, i.e. spatial surface, with biaxial state of deformation is formed. Up to date two biaxial deformation test methods are well known and widely used for such investigations, i.e. the membrane method (pneumo- and hydro-) and the punch method [3, 4]. These methods give good results of real loading simulation in aerostatic balloons, sails, inflatable building constructions, elements of clothing, soft packing and in other products made from thin materials. Recently their application has spread involving the testing of rubber, leather, textiles, polymer films, paper and etc. materials [5, 6].

From a technical standpoint the process of biaxial deformation is simple and samples never tear close to the clamp [6]. This allows more reliable assessment of results and a reduction in the expenses related to the number of test samples and their preparation. In spite of the wide range of experiments with various types of materials there is still significant discrepancy between theory and test results. There is only limited research work that compares the behaviour of the same material in uniaxial and biaxial deformation. Thus, the aim of this work was to investigate the behaviour of polyurethane foam in biaxial punch loading and to compare it with uniaxial tension performance. From this stand point the main task was to find dependencies between the density and thickness of polyurethane foam, and the obtained indexes of punching deformation. Also, the effect of friction between punch and tested specimen was analysed.

2. MATERIALS AND TESTING METHODS

In this research five samples: PF1, PF2, PF3, PF4 and PF5 of commercial polyurethane foams (“Vita Baltic International” company) mainly used in furniture industry were investigated. Their characteristics together with standard testing methods are presented in Table 1. The selected samples differed in density starting with 16-19 kg/m^3 and ending by 33-36 kg/m^3 but had the same limits of hardness (140-185 N) and compression stresses at 40% of deformation (3.6-4.6 kPa). Five specimens were prepared for each sample of foam density. Tensile characteristics were determined according to the standard ISO 1798:2001 *Flexible cellular polymeric materials - Determination of tensile strength and elongation at break*. Tensile speed was 500 mm/min, specimen length was 50 mm and specimen width was 13 mm. Testing was performed with “dumbbell” shaped specimens.

Table 1. Characteristics of tested polyurethane foams

Mechanical characteristics	Samples of polyurethane foams				
	PF1	PF2	PF3	PF4	PF5
Load at peak, N	15.94	15.70	15.09	16.61	17.73
Elongation at peak, mm	96.15	124.94	133.51	157.31	179.30
Strain, %	192.3	249.9	267.0	340.6	352.6
Specimen thickness, mm	12.1	10.8	10.5	10.2	11.4
Youngs modulus, N/mm^2	0.078	0.072	0.053	0.049	0.047
Density, kg/m^3	16-19	20-23	23-26	28-31	33-36
Compression stress at 40% of deformation, kPa	3.6-4.4	3.9-4.6	3.8-4.4	3.6-4.4	3.6-4.4
Hardness at 40% of deformation, N	140-185	150-190	155-185	140-185	140-185

The density of tested samples was defined according to the standard ISO 845:2000 *Cellular plastics and rubbers - Determination of apparent (bulk) density*. Compression stresses were defined according to the standard ISO 3386-1:2001 *Polymeric materials, cellular flexible - Determination of stress-strain characteristic in compression - Part 1: Low-density materials at 40% of deformation*. Hardness of samples was defined according to the standard ISO 2439:2003 *Flexible cellular polymeric materials - Determination of hardness at 40% of deformation*.

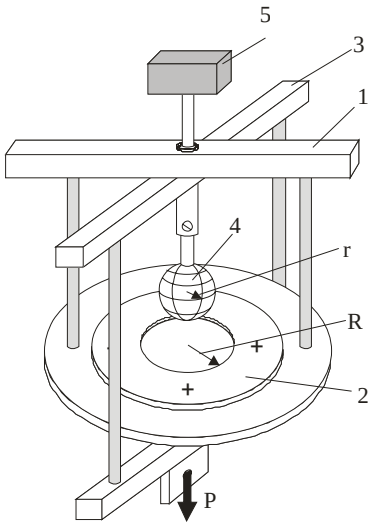


Figure 1. Biaxial punch deformation unit: 1 - sample frame; 2 - sample clamp; 3 - punch frame; 4 - punch; 5 - force gauge; *P* - loading direction

Biaxial punching deformation was carried out with samples of constant size (R = 28.35 mm) which were cut from five types of polyurethane foams different in density (Table 1) and thickness. Thus, for each density specimens of different thickness (3 mm, 5 mm, 7 mm and 10 mm) were prepared. Tests were carried out with tensile machine FP-10/1 equipped with original test unit (Fig. 1), having replaceable clamps for sample fixing and punch the size of which was r = 14.35 mm. The speed of biaxial punching was 100 mm/min. Five specimens were prepared for each sample of density and thickness. Coefficients of variation did not exceed 9 %.

3. RESULTS AND DISCUSSION

At the beginning of the research the dependencies between uniaxial deformation parameters upon polyurethane foam density were defined. As it can be seen from Figure 2 with the increase of foams density maximal stresses increase, also. This dependency can be described by exponential $y = 1.308e^{19.78x}$ (R^2 = 0.96) or by liner $y = 484.4x - 46.6$ (R^2 = 0.92) dependencies. The same tendency can be observed for the values of maximal strains: exponential $y = 8.58e^{0.003x}$ (R^2 = 0.97) or linear

$y = 0.092x - 0.709$ ($R^2 = 0.94$), respectively. Thus, with the increase of foams density almost by twice, i.e. 93 % the values of maximal stresses rises by 36 % and the values of maximal strain by 83 %.

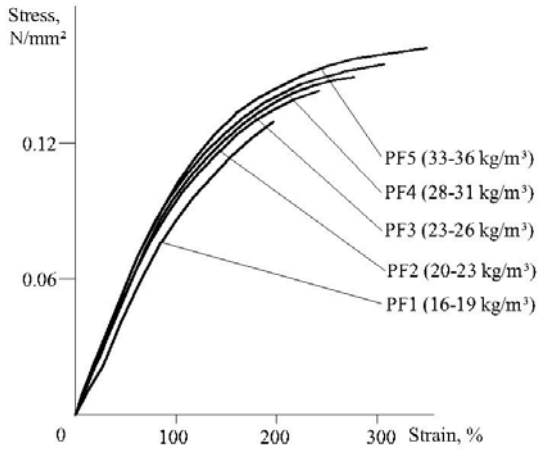


Figure 2. Dependency of polyurethane foams stress/strain relationship upon its density (specimen thickness – 10 mm)

The results of uniaxial deformation also revealed that critical tensile force strongly depends upon the thickness of foam and this relationship can be described by linear equation (R^2 = 0.988 – 0,999) for all tested samples of different density. The same can be said about the relationship between maximal strains and foams thickness (R^2 = 0.965 – 0,995). The increase of foams thickness by 70 % (from 3 mm up to 10 mm) increased critical tensile force of all five tested samples by 70 % – 77 %. Coefficient of variation did not exceed 2 % – 3 %.

During biaxial punch deformation *H* - *P* (critical punching height/critical punching force) curves were registered on the basis of which resistance parameters of tested polyurethane foams were defined (Table 2). The obtained results of punch deformation showed the same linear relationships as in the case of uniaxial tension, i.e. critical punching force *P* strongly depends upon the thickness of foam (R^2 = 0.973 – 0.997). However, no relationship was found between force *P* and the density of foam for the same thickness, as it was expected. Also, the increase of sample thickness by 30 % from 3 mm up to 10 mm increases critical punching force of all five tested samples similarly to uniaxial testing, i.e. by 65 % – 79 %. Coefficient of variation was in the limits of 0.8 % – 9.5 %. Meantime, linear dependencies of various strengths (R^2 = 0.559 – 0,968) were found between critical punching height and sample thickness for polyurethane foams of different density.

Table 2. Parameters of punching deformation of tested polyurethane foams

Parameters of punching	Thickness, mm	Samples of polyurethane foams				
		PF1	PF2	PF3	PF4	PF5
Critical punching force *P*, N	3	23.71	20.27	25.47	32.16	25.67
	5	38.07	45.80	48.20	56.00	50.00
	7	53.27	71.20	69.40	74.72	63.73
	10	71.53	94.00	91.13	92.64	87.33
Critical punching height *H*, mm	3	6.23	17.73	18.40	9.32	22.77
	5	16.33	35.70	18.85	22.30	22.70
	7	16.37	38.34	20.28	43.76	22.37
	10	16.73	38.60	21.33	46.00	46.53

Comparative analysis of uniaxial tension and biaxial punching forces (Fig. 3) revealed strong linear relationship from the standpoint of sample thickness (R^2=0.972 – 0.986). Meantime, no dependency could be set in respect to sample density variation. This can be explained by the effect of friction at the contact zone of the specimen and the punch, as well as the phenomenon of electrical charge generation during testing.

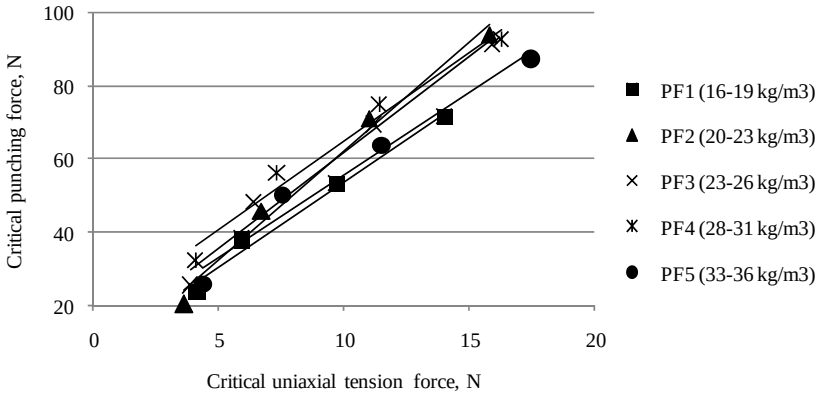


Figure 3. The relationship between uniaxial tension force and biaxial punching force

During testing it was observed that the centre of specimen tearing in biaxial deformation does not appear on the top of the punch but locates on one side of it at the place were specimen looses its touch with the punch. With the increase of punching force tearing line spreads to the sides and obtains rounded shape the radius of which is very close to the radius of the punch. It means that during deformation the zone of the specimen which is in contact with the punch due to friction forces is held almost in stabile position. Thus, maximal stresses locate at the contour line were specimen looses touch with the punch and tearing line appears there.

These results correspond to our earlier investigations related to biaxial punching deformations of textile materials and polymeric membranes. Figure 4 presents the investigations performed with woven fabric (A) and knitted material (T), as well as with PVC and PE membranes [7]. It is evident that in all these cases breaking line of the specimen was located not on the top of the punch, as it could be expected, but at the place were the specimen was loosing its contact with the punch. Thus, the effect of friction is very clear.

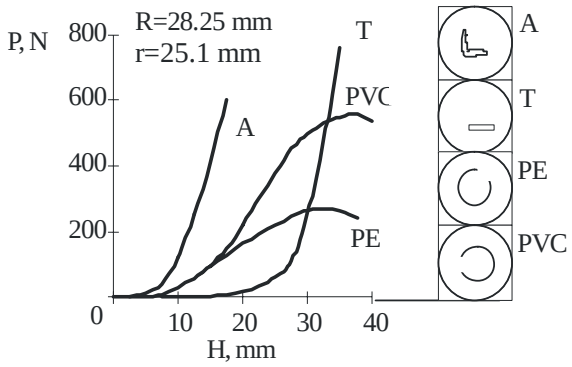
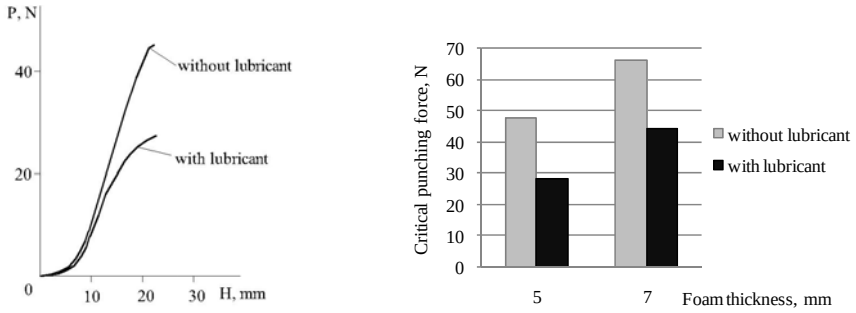


Figure 4. Typical punch forcing through curves *H-P* and sample breaking schemes for different materials

At the second stage of performed research the effect of friction upon punching resistance parameters was studied. Thin layer of commercial lubricant was spread on the surface of the punch. Typical punching curves of PF4 polyurethane foam (5 mm thickness) are presented in Figure 5a.



a) b)

Figure 5. Typical punching curves *H–P* for PF4 polyurethane foam of 5 mm thickness (a); changes of critical punching force for foams of different thickness (b)

As it can be seen, the increase of friction at the contact zone mainly influences the level of critical punching force, i.e. it increases almost by 64 %. Meantime, friction has no significant effect upon the values of maximal punching height. The latter testing was performed with two types of PF4 foams different in thickness (5 mm and 7 mm). Obtained results revealed that for thicker sample the change of critical punching force becomes less by 16 % (Fig. 5b).

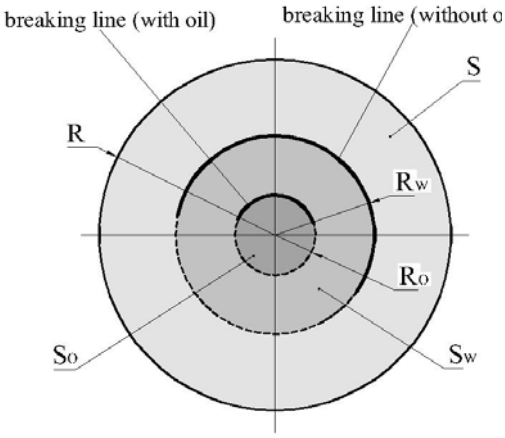


Table 3.

Area, mm2		Radius, mm	
S	2524.97	R	28.35
S_W	804.25	R_W	16.00
S_O	132.73	R_O	6.50

Figure 6. Contact zones between punch and tested specimen (*R* – specimen radius; *S* – initial specimen area)

The application of commercial lubricant on the surface of steel punch has changed not only resistance parameters of tested foam but also the shape of formed spatial shell. The projection of contact zone between the specimen and the punch reduced from S_w = 804.25 mm to S_o = 132.73 mm, as it is presented in Figure 6 and Table 3. The radius of contact zones projection after lubrication decreased from R_w = 16mm to R_o = 6,5 mm, i.e. by 59 %, as well as the area of contact zone S_w. Thus, resistance parameters and spatial shell of foam samples can be modified by friction force changes.

4. CONCLUSIONS

The results of the investigation showed that with the increase of foam density by 93 % the values of maximal stresses in uniaxial tension rises by 36 % and the values of maximal strain by 83 %. Also, it was defined that critical tensile force strongly depends upon the thickness of foam and this relationship can be described by linear equation (R^2 = 0.988 – 0,999) for samples of different density. Comparative analysis of uniaxial tension and biaxial punching forces revealed strong linear relationship from the standpoint of sample thickness (R^2=0.972 – 0.986). Meantime, no dependence could be set in respect to sample density variation. This can be explained by the effect of friction at the contact zone of the specimen and the punch. Obtained results of friction effect investigations allowed to conclude that it determined not only the level of foam samples resistance parameters, but also the shape of formed spatial shell.

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FUNCTIONAL ELECTROSPUN NANOFIBERS FOR BIOMEDICAL APPLICATIONS

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ABSTRACT

Electrospinning is the most versatile process for producing nanofibers. In this process, nanofibers/nanowebs, which have unique properties like very large surface area and nano-porous structures can be produced from many kinds of natural and synthetic polymers. Moreover, the possibility of large scale production combined with the simplicity of process make electrospinning more attractive for many applications.

Tissue engineering, drug release, wound dressing, etc. are the potential application areas for nanofibers/nanowebs in biomedical field. To obtain required functions from these structures; polymers should have properties such as; biocompatibility and/or biodegradability. From this point of view; poly(vinyl alcohol) (PVA), poly(caprolactone) (PCL), poly(ethylene oxide) (PEO), poly(ethylene oxide), cellulose acetate (CA) etc. can be considered as suitable polymers for biomedical applications due to their biofunctional properties.

In our studies; we have performed electrospinning of PEO, CA and PCL for the production of nanofibers/nanowebs. The process parameters such as applied voltage, feed rate, polymer concentration, tip to collector distance, etc. were varied in order to attain uniform and homogeneous nanofibrous structures. The production of uniform nanofibers/nanowebs of PEO, CA and PCL was achieved and these functional materials can be used in biomedical applications such as wound healing, drug delivery and as scaffolds in tissue engineering.

Key Words: electrospinning, nanofiber, nanowebs, biomedical applications, PEO, PCL, cellulose acetate

1.INTRODUCTION

Electrospinning is the most versatile method for producing ultrafine fibers which have diameter at nano size. Many different kinds of natural and synthetic polymers can be used to obtain nanofiber/nanoweb structures by using this technique. Electrospinning method bases on applying high voltage to solutions/melts of polymers. The diameter, uniformity and morphology of fibers are controlled by process parameters such as; applied voltage, feed rate, tip to collector distance and the polymer/solvent types that is used. The unique properties like large surface area to volume ratio, small pore size with high porosity and design flexibility make electrospun nanofibers more attractive for many applications such as filtration, biomedical, energy, packaging, functional textiles, etc. [1-4]

The size similarity between nano-sized materials and biological systems and the high porosity property make electrospun nanofibers/nanowebs suitable and effective especially for biomedical applications such as scaffolds for tissue engineering, drug release and wound healing applications.[5, 6]

In this study; poly(caprolactone) (PCL), poly(ethylene oxide) (PEO) and cellulose acetate (CA) polymers were used for the producing nanofibrous materials which have possibilities to be used in biomedical area such as medical textiles, scaffolds for tissue regeneration, wound dressing, drug delivery systems, etc. In order to obtain homogenous, bead-free nanofibers/nanowebs, the optimization of the electrospinning process has been achieved by varying polymer concentrations and the electrospinning process parameters like applied voltage, feed rate, tip-to-collector distance, etc. The morphology of the electrospun nanofibers was examined by using scanning electron microscope (SEM).

Cellulose acetate (CA) is a derivate of abundant and renewable cellulose. Cellulose does not melt so it must be spun from solution. On the other hand, cellulose acetate can be processed into fibers from both of melts and solutions. Mixed solvent system of acetic acid/water, chloroform/methanol, acetone/dimethyl sulfoxide can be given as examples that were used for obtaining cellulose acetate nanofibers. Nanofiber/nanowebs, which are produced from cellulose acetate by using electrospinning method, can represent semi-permeable membrane structure that make them useful for filtration, biomedical applications, etc.[7-11]

Poly(ethylene oxide) (PEO) is a water-soluble and non-degradable polymer. It is known to be a suitable model for electrospinning process because of its solubility in different solvent system beside water. Due to its biocompability and low toxicity, it is determined as a good candidate for biomedical applications. In addition, PEO is also used to assist the electrospinning of natural polymers such as chitosan, keratin, collagen, DNA, peptides and enable the electrospinnability of these materials in order to form nanofibers/nanowebs.[5, 12, 13]

Polycaprolactone (PCL) is a kind of bioresorbable polyester which has good mechanic stability, slow degradation rate and low toxicity. The scaffolds which are made of PCL nanofiber/nanowebs, can support growth, proliferation and migration of specific cells that are required for engineered tissues like muscle. Different solvent systems are available for the electrospinning of PCL such as acetone, chloroform, methanol, tetrahydrofuran ,N, N, dimethylformamide and their mixtures.[14-17]

2.EXPERIMENTAL

In this work, appropriate solvent systems were used to obtain homogenous solutions from these three polymer types; cellulose acetate (CA), poly(caprolactone) (PCL) and poly(ethylene oxide) (PEO). Dichloromethane (DMC)/methanol(4/1)(v/v), chloroform/methanol(1/1)(v/v) and water were used as solvent systems for CA (Mwt 30,000), PCL (Mwt 80,000) and PEO (Mwt 900,000), respectively. In order to get bead-free and uniform nanofibers, polymer concentrations were prepared between %7-%12 (w/v) for cellulose acetate, %10-%15 (w/v) for PCL and %3-%4 (w/v) for PEO. The electrospinning process parameters such as; applied voltage (15-20 kV), tip to collector distance (10-15 cm) and solution feed rate (0,5-1 ml/h) were varied. The morphology of the electrospun nanofibers was examined by using scanning electron microscopy (SEM).

3.RESULTS AND DISCUSSION

The optimization of electrospinning process of cellulose acetate, PCL and PEO was achieved by using different polymer concentrations and process parameters. The scanning electron microscopy (SEM) images of the electrospun nanofibers clearly show the effect of polymer concentration on the resulting fiber morphology. PEO was electrospun by using three different polymer concentration; %3, %3,5 and %4 (w/v). The bead-free uniform nanofibers were only obtained when %3,5 and %4 (w/v) PEO solutions were used (Figure 1). Cellulose acetate was electrospun by using four different polymer concentrations; %7, %8, %10 and %12 (w/v). Bead-free fiber were formed at the concentration of % 10 and %12. PCL solutions having %10 and %15 (w/v) have been electrospun and in both cases, bead-free nanofibers were obtained (Figure 3).

In figure 4, the average fiber diameter (AFD) of the PEO, PCL and CA nanofibers are shown for different polymer concentration which resulted in bead-free fibers. It was observed that thicker fiber were obtained when higher polymer concentration is used for the electrospinning. At high polymer concentration, the viscosity of polymer solution be strong enough to diminish the bending instability that means polymer jet takes less distance between tip to collector and expose less stretching that results in larger diameter.

In all cases, while beaded fibrous structures were obtained at low polymer concentrations, bead-free uniform fibers were attained at higher concentrations. Because at high polymer concentration, polymer solution viscosity reach at a definite value and supply the high chain entanglement that contributes the forming of bead-free structures.

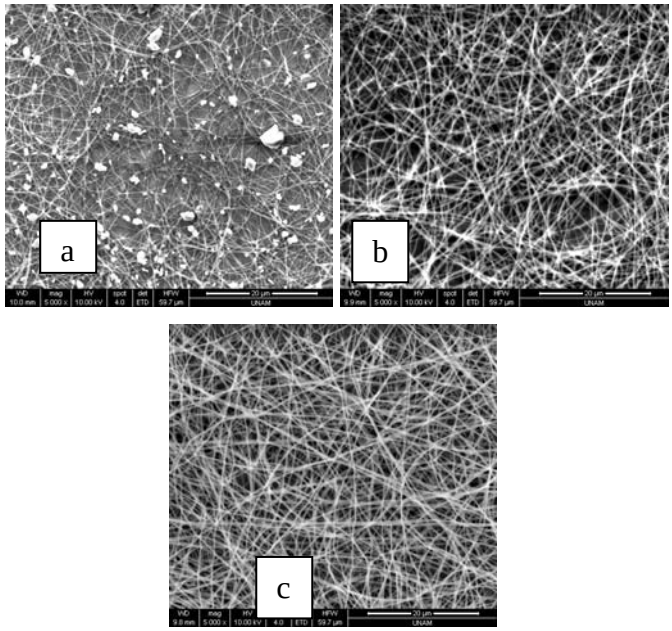

Fig. 1. SEM images of electrospun PEO nanofibers obtained from (a) %3, (b) %3,5, (c) % 4 (w/v) in water

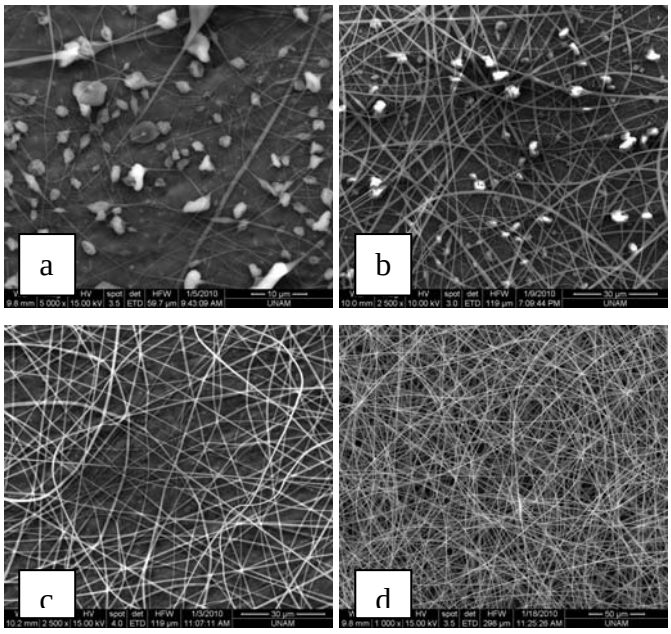

Fig. 2. SEM images of electrospun CA nanofibers obtained from (a) %7, (b) %8, (c) % 10, (d) %12 (w/v) from DCM/methanol(4/1)(v/v) solvent system.

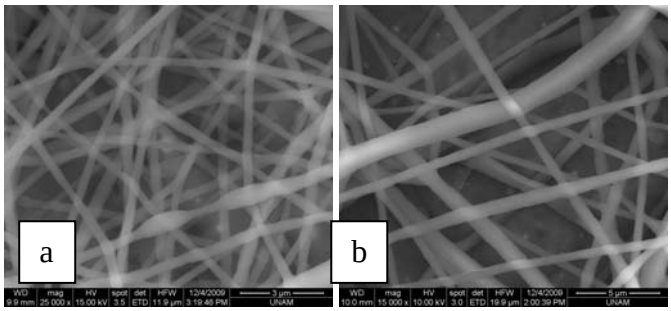

Fig. 3. SEM images of electrospun PCL nanofibers from (a) %10, (b) %15 (w/v) from chloroform/methanol(1/1) (v/v)solvent system.

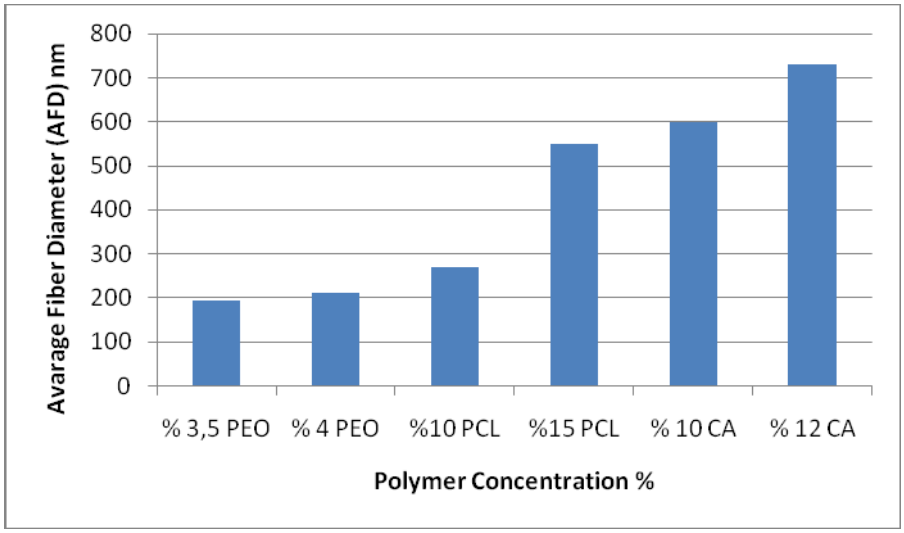

Fig. 4. AFD(nm) observed for different polymer concentrations of PEO,PCL and CA fibers.

3.CONCLUSION

We have performed electrospinning of three different type of polymers; PEO, PCL and cellulose acetate (CA) which are known for their biocompatibility and have applications in biomedical field. We have varied polymer concentration and process parameters such as applying voltage, tip-to-collector distance and solution feed rate to obtain uniform, bead-free nanofibers. We have examined resulting electrospun nanofiber morphology by scanning electron microscopy (SEM).
As a future work, functional cellulose acetate, PEO, PCL nanofibers/nanoweb will be produced by incorporating versatile additives (drugs, growth factors, antibacterials, etc) into these materials and their use in biomedical applications will be investigated.

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INFLUENCE OF CALANDERING ON PROPERTIES OF NONWOVEN NEEDLEPUNCHED GEOTEXTILES

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ABSTRACT

The application of nonwoven geotextiles in geotechnology is in a state of constant development. Their application could be a permanent or temporary structural element in the design of earthworks, the laying foundations for roads and buildings or for the reinforcement of soil.

The main functions of geotextiles are separation, drainage, reinforcement and filtration.

Geotextiles are made from natural and synthetics fibres. For temporary usage, geotextiles made from natural fibres are preferable. Synthetic fibres are mostly for long term usage, for which physical and chemical resistance and dimensional stability are required. The most common polymer used in geotextile production is polypropylene, followed by polyester and others.

The properties of geotextiles depend on the web forming, bonding and finishing processes. The tensile properties or mechanical responses include the ability of textiles to be used in a "stressed" environment. Usually, the stressed environment is known in advance and the textile is selected on the basis of the expected stresses, without it being put under more strain than the predetermined level.

The separation, filtration and drainage-in-plane functions of geotextiles are dominated by their pore space characteristics, as these determine the size of the particles and the amount of water that may be transmitted through them

Samples for this investigation are made from a blend of HTPP fibres of different lengths, in which 70% of the fibres were 90 mm long and 30% were120 mm. The fibre finesses was 6,7 dtex for both fibre lengths.

The manufacturing process for nonwoven geotextiles, as examined in this paper, is that of dry-laid web-forming by roller card. The method of web bonding for all samples was the needling process, in which samples with the same mass per unit area have been additionally calendared. The samples were manufactured in the following mass per unit areas: 200, 300 and 500 g/m^2.

For this investigation, the samples were tested for the following properties: thickness, density, tensile properties and pore size.

Key Words: geotextile, HTPP, needlepunching, calendering, thickness, tensile properties, pore size

1. INTRODUCTION

The manufacturing process for nonwoven geotextiles, as examined in this paper, is that of dry-laid web-forming by roller card. The method of web bonding for all samples was the needling process, in which samples with the same mass per unit area have been additionally calendared. The samples were manufactured in the following mass per unit areas: 200, 300 and 500 g/m^2.

For this experiment, the samples were tested for the following properties: thickness, density, tensile properties and pore size.

1.1. Manufacturing

The technology of nonwoven geotextile can be divided into four production phases: preparation of the fibres, web formation, bonding and finishing of the web [3].

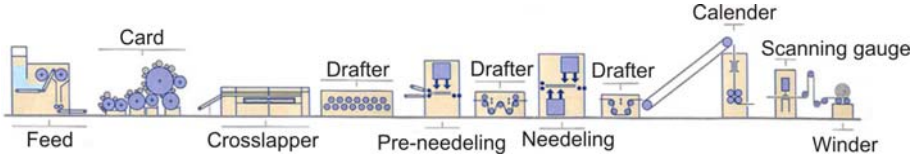

Figure 1. The technological production line for nonwoven geotextiles. NSC Nonwoven

The first phase of the preparation of fibre consists of several machines and systems, including bale openers, mixers and units for the performance of various functions.

Roller carding is the stage of web production. The main objective of carding is to separate small tufts into individual fibres, to begin the process of parallelization and to deliver the fibres in the form of a web.

Web formations can be made into the desired web structure by the layering of the webs from the card. Layering can be accomplished in several ways to achieve the desired weight and web structure.

Web bonding in this production line is carried out by needlepunching process. Needlepunched nonwovens are created by mechanically orienting and interlocking the fibres of a carded web. This mechanical interlocking is achieved with thousands of barbed felting needles repeatedly passing into and out of the web.

Further improvements to the strength and dimensional stability of geotextiles can be made with additional thermal bonding using the calendering process.

The production of nonwoven geotextiles through the above-mentioned procedure results in a product with a different surface mass – a geotextile with a higher mass per unit area of a greater strength and elongation.

1.2. Main functions and requirements

If geotextiles are used on the ground, as a foundation and material for construction, then they have more functions. Since geotextiles are in direct contact with the ground they have to meet specific requirements.

Nonwoven geotextile are commonly used for separation, filtration, drainage, protection and consolidation [2].

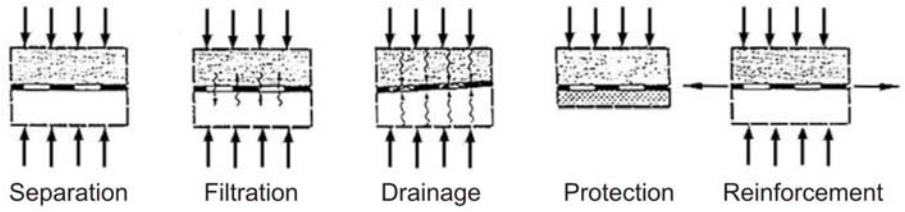

Figure 2. Diagram of a nonwoven geotextile

Tensile properties or mechanical responses include the ability of textiles to be used in a “stressed” environment and their ability to resist damage in extreme conditions. Usually, the stressed environment is known in advance and the textile is selected on the basis of the expected stresses imposed upon it, without it being put under more strain than the predetermined level [2].

Separation, filtration and drainage-in-plane functions of geotextiles are dominated by their pore space characteristics, as these determine the size of the particles and the amount of water that may be transmitted through them [4].

There are several well-known methods for determining pore size. In this paper pore size was determined according to the dry sieving method. The sieving method is used for the determination of the characteristic opening pore size, which corresponds to the specified size of the granular material passed through. Characteristic pore sizes are important for determining the filtration and clogging performance of geotextiles and thus enabling the determination of the absolute rating of filter fabrics.

1.2.1. Separation

In the application of nonwoven geotextiles for separation, a geotextile is placed between two types of soils of different sizes of granules. The task of geotextiles is to prevent the mutual penetration and mixing of layers due dynamic loads and water flow. At the same time, geotextiles need to ensure the retention of the mechanical properties of soils with coarse granules.

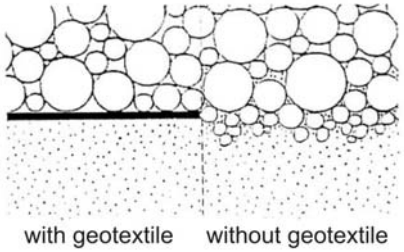

Figure 3. Geotextiles as an element in separation

1.2.2. Filtration

When used as a filter, the geotextile lies between two types of soils with different sizes of granules, or between the soil and drainage elements (eg. drainage pipes). The function of the geotextile function is the prevention of any unwanted movement of granular material as result of water flow over a long period.

1.2.3. Protection and drainage

Nonwoven geotextiles or composites for protection and drainage are placed between the soil and elements of the construction/sealing web. Geotextiles protect element for construction/web sealing from mechanical loads during construction and use as well as redirect water flows through the geotextile in-plane.

1.2.4. Reinforcement

Nonwoven geotextiles for enhancing the soil are placed between two or more types of soil, improving their ability, capacity and stability. Geotextiles absorb any generated load and transmit it to the ground with an amount of friction.

2. EXPERIMENTAL RESULTS

Thickness of samples was determined according to ISO 9863-1:2005. The samples were measured 30 seconds after applying pressures (2, 20 and 20 kPa) according to standard. The results for thickness are given in Table 1.

Density was determined according to ASTM D 1505-98, and the results are given in Table 2.

Tensile properties were determined according to ISO 10319:2008. The numerical values of the breaking force and breaking extension in both machine directions are shown in Figure 4 and 5.

The characteristic opening pore sizes were determined according to EN ISO 12956:1999. The results of the characteristic pore sizes obtained by the sieving method are given in Figure 6.

2. 1. Thickness and density

In table 1 the results are given for samples thickness.

Bonding process		**Needlepunched**			**Needlepunched and calendered**		
Mass per unit area, g/m^2		**200**	**300**	**500**	**200**	**300**	**500**
Pressure, kPa	**2**	3,19	3,82	4,42	1,15	1,59	2,31
	20	2,18	2,87	3,62	0,94	1,33	2,04
	200	1,06	1,57	2,13	0,72	1,02	1,61
Decrease of thickness between 200 kPa and 2 kPa, %		66,8	58,9	51,8	37,4	35,9	30,3

The thicknesses of nonwoven geotextiles mainly increase by increasing the mass per unit area. Calendered samples have lower thickness than samples that have not been calendered. Changes in the initial thickness under applied pressures during measurements for samples that have not been calendered were expressed in a decreasing percentage range from 66,8% to 51,8%, and for calendered samples from 37,4% to 30,3%. Significantly higher changes in thickness occur after pressures applied for samples that have not been calendered. With an additional bonding process

using calendering, the mass per unit area and applied pressures during measurement also decreases the thicknesses, and there is a clear regularity to these changes.

From the obtained results there is a noticeable need for studying characteristic pore size after the application of different levels of pressures on nonwoven geotextiles. Particularly for geotextiles, for which the changes in thickness are significant and thus the change in characteristic pore sizes is greater.

In Table 2 the results are given for the density of nonwoven geotextiles. Calendered samples have a lower density than samples that have not been calendered. There is no regularity in the changes to density of the samples.

Mass per unit area, g/m^2	Density, g/cm^3		
	200	300	500
Needlepunched	0,9823	0,9822	0,9822
Needlepunched and calendered	0,9718	0,9800	0,9767

2. 2. Breaking force and breaking extension

The value of mass per unit area related to the breaking force and breaking extension in both machine directions (MD, machine direction and CMD, cross-machine direction) are shown in Figure 4 and 5.

An increase occurs in the mass per unit area, the breaking force in the machine direction, as well as in the cross-machine direction.

The breaking force in the cross-machine direction is higher than in the machine direction.

For needlepunched samples the breaking force in cross-machine direction ranged from 15,5 kN/m to 35,3 kN/m. The breaking force for needlepunched and calendered samples in the cross-machine direction is in the range of 17,1 kN/m to 36,2 kN/m.

The breaking force in the machine direction for needlepunched samples ranged from 12,3 kN/m to 29,7 kN/m and for needlepunched and calendered samples from 13,5 kN/m to 33,5 kN/m.

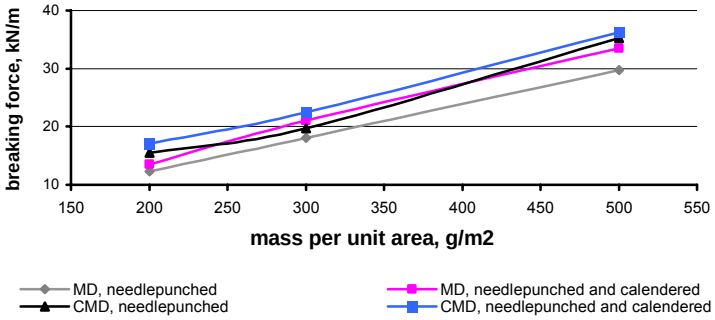

Figure 4. Mass per unit area related to the results are given of the mass per unit area related to the breaking extension of geotextiles in both machine directions.

An increase occurs in the mass per unit area, the breaking extension in the machine direction, as well as in the cross-machine direction.

The machine direction and the additional bonding process applied do not affect the breaking extension of samples. There was no regularity in the breaking extension of the samples.

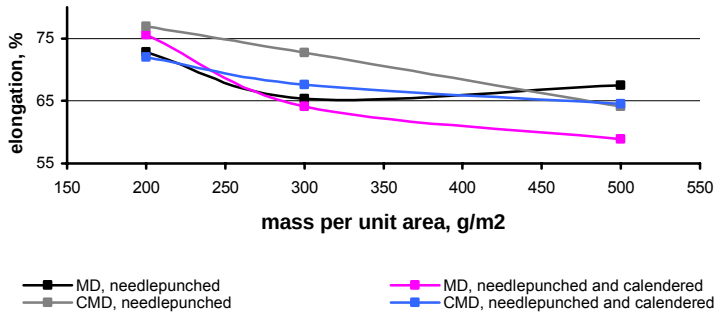

Figure 5. Mass per unit area related to the breaking extension of geotextiles in both machine directions

2. 3. Characteristic pore size

In Figure 6 the results of the characteristic pore size are given for needlepunched samples and those that are additionally calendered obtained with the dry sieving method.

With an increasing mass per unit area, characteristic pore sizes decrease. Characteristic pore sizes subjected to an additional bonding process decrease for all samples.

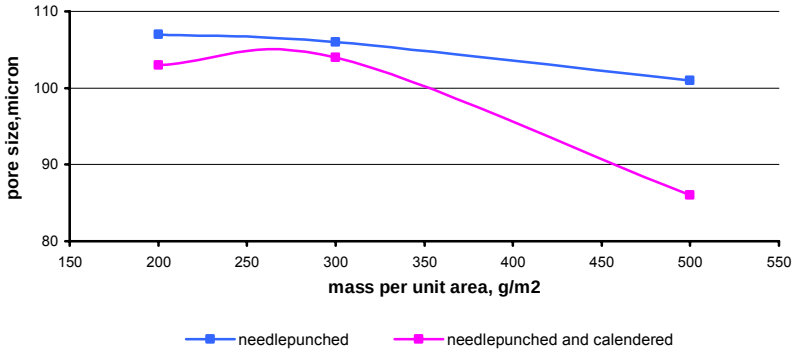

Figure 6. Mass per unit area related to the characteristic pore size of a geotextile

Figure 7 shows the thickness of samples related to characteristic pore sizes. With increasing thickness, characteristic pore sizes mainly decrease.

Needlepunched samples have larger characteristic pore sizes compared to needlepunched and calendered samples with same mass per unit area.

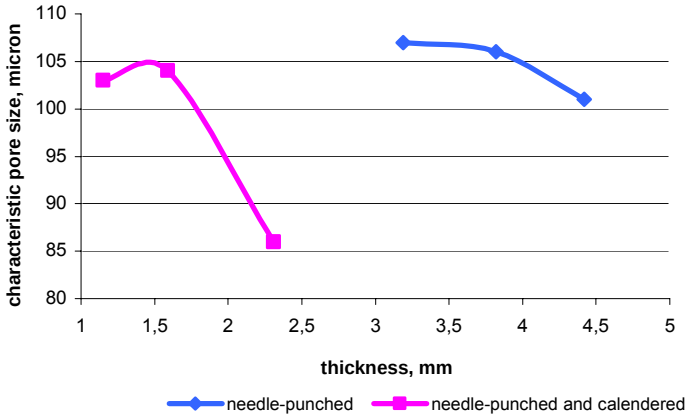

Figure 7. Thickness related to the characteristic pore size of a geotextile

3. CONCLUSIONS

Based on the experiments that were carried out it can be concluded that

- thicknesses mainly increase by increasing the mass per unit area
- calendered samples have lower thicknesses than samples that have not been calendered
- with an additional bonding process (calendering), the mass per unit area and applied pressures during the measurement has an effect on the samples' thicknesses; there is an observable regularity in the changes
- calendered samples have lower density than samples that have not been calendered; there is no regularity in the changes to the samples' densities
- the breaking force in the cross-machine direction (for needlepunched samples this ranged from 15,5 kN/m to 35,3 kN/m, and for needlepunched and calendered samples from 17,1 kN/m to 36,2 kN/m) is higher than in the machine direction (for needlepunched samples this ranged from 12,3 kN/m to 29,7 kN/m, and for needlepunched and calendered samples from 13,5 kN/m to 33,5 kN/m)
- with an increasing mass per unit area, the breaking extension in the machine direction as well as in the cross-machine direction also increases
- the machine direction and applied additional bonding process has no effect on the breaking extension; no regularity in the change in the breaking extension can be observed
- the characteristic pore size mainly decreases with an increasing mass per unit area
- with an increased thickness, the characteristic pore size mainly decreases
- calendared samples with the same mass per unit area have a smaller characteristic pore size

From the obtained results there is a noticeable need for studying characteristic pore size after the application of different levels of pressures on nonwoven geotextiles. Particularly for geotextiles, for which the changes in thickness are significant and thus the change in characteristic pore sizes is greater.

ACKNOWLEDGMENTS

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INNOVATIVE TESTING TECHNOLOGIES FOR EVALUATING THE HOMOGENITY AND THE FIBRE ORIENTATION OF NONWOVENS FOR HIGH-TECH APPLICATIONS

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ABSTRACT

Staple fibre nonwovens are used in many high-tech applications such as the automotive, aviation, filtration. The nonwovens used in these applications have a high desire on functionality and this leads to the desire to know the orientation of fibres in different nonwoven structures and also the homogenity of the structures.
Nonwovens are textile structures which are formed directly out of fibres by carding, air laid, spunlace and others. These webs are consolidated using technologies like needle punching, hydro-entanglement etc. Each of the nonwoven production technologies produces the web with fibres in different orientations and different homogenity. The fibre orientation and the homogenity define the mechanical properties and the quality of the nonwoven. Thus, these two properties have to be detected.
This work deals with technologies which have been developed at the Institut für Textiltechnik for measuring the homogenity of the nonwoven as well as for the determination of the fibre orientation of the nonwovens. In order to understand the homogenity a dielectric measuring system has been developed for determining the distribution of fibre in a multi-component nonwoven structure thus giving knowledge on the localised homogeneity of the nonwoven fabric produced. Further research has been carried out to determine the fibre orientation in a nonwoven structure. These innovative testing methods help in understanding the structure of nonwovens and help in the manufacture of knowledge-based customised nonwovens for high-tech applications.
Keywords: fibre orientation, mixing homogeneity, dielectric properties, unevenness coefficient, plate capacitor

1. Image Processing for Nonwoven Analysis

This work deals with the development of algorithms which have been used for measuring the nonwoven characteristics. Apart from other nonwoven characteristics, the distribution of fibres within the nonwoven and the distribution of fibres have been evaluated. To carry out this characterization the nonwoven is scanned and the image is used for further analysis. The region of interest which needs to be evaluated for image analysis can either be determined either manually or automatically. The analysis incorporated the following aspects:

- Percentage of thick and thin places
- Unevenness coefficient of nonwovens
- Fibre orientation in a nonwoven using the grid principle

Some of the major challenges for carrying out image analysis were the problems of image contrast equalization, filtration of the image signal and determination of objects within the image using certain edge detection and transformation algorithms. The algorithms were programmed using MATLAB, Mathworks Inc., Natick, USA.

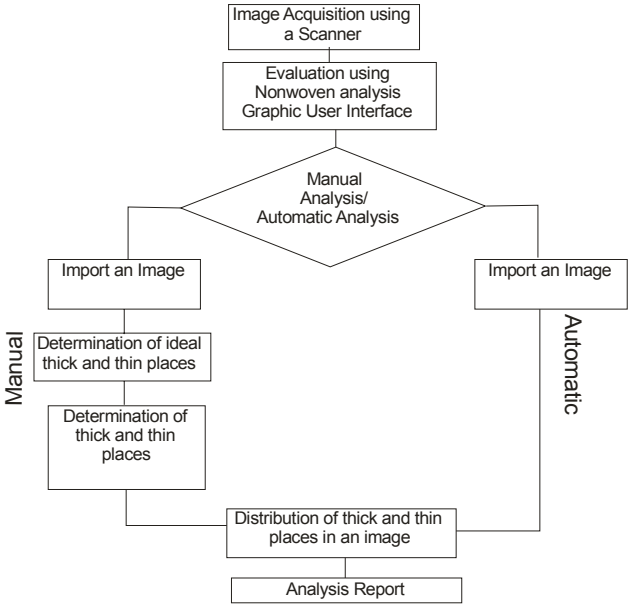

Figure 1: Flowchart for nonwoven unevenness analysis

1.1 Unevenness analysis of nonwoven

Nonwovens are produced in different basis weight. The process which has been developed can only be used for nonwovens with a lower basis weight. For the analysis a nonwoven was scanned using a conventional scanner with a very high resolution. The scanned images were then processed using a program which was formulated using MATLAB Version 7.3.0.267 (R2006b). The evaluation process can be used with the help of a graphic user interface. The flowchart of the different operations can be seen in figure 1.

Figure 2 shows the nonwoven image and also the distribution of unevenness. The original image was distributed in a grid structure and then the thick and thin places were evaluated. The individual components of the grid reveal the brightness on a scale from 0-255. The higher the pixel value the denser the sample in the grid is. Using the number of thick and thin grid elements a percentage of thick and thin places can be calculated and an unevenness coefficient can be calculated. The final analysis report presents the following parameters:

- Percentage of thin places
- Percentage of thick places
- Uneveness Coefficient

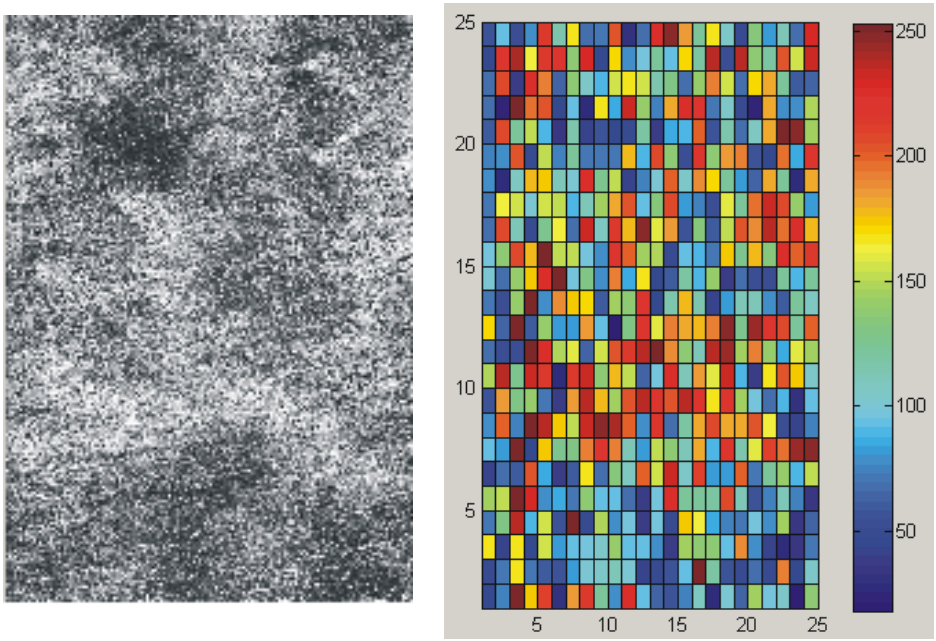

Figure 2: Unevenness of a nonwoven (a) Original Image (b) Fibre evenness distribution

1.2 Fibre Orientation in nonwovens

The analysis software MATLAB provides with a number of tools for image processing within its „Digital image processing toolbox“. To solve the problem of determination of fibre orientation, some tools from the MATLAB tool box were used. The following steps were undertaken to carry out the function of fibre orientation.

- The image was imported and was converted in a gray value image using an grey threshold filter
- Further on a threshold function is used to determine the pixels which can further be used for fibre orientation evaluations
- To carry out he further analysis a „Canny edge detection“algorithm was used to determine the fibres from the image. After the detection of fibres, the gradient of the fibres is calculated and the gradient vectors within a grid element are evaluated and are then documented.
- The next process includes the addition of the vectors and the representation of the fibre directions

This entire process does need some time. A DIN A3 size sample requires an estimated 30-40 minutes for the analysis. There is hence a great scope for the improvement of the algorithm. The results for of the fibre orientation analysis are represented in figure 3.

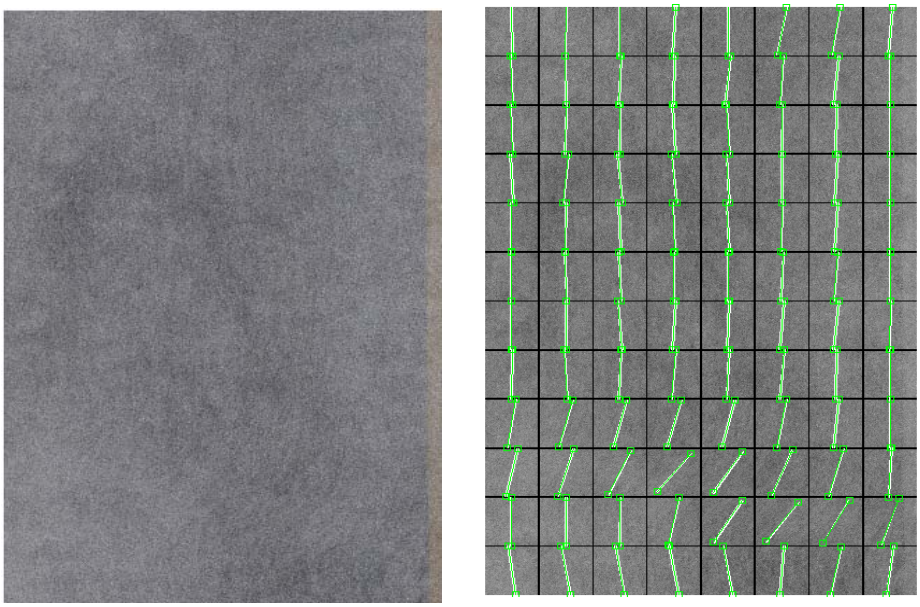

Figure 3: Fibre orientation in a nonwoven (a) Original Image (b) Fibre Orientation Vectors

1.3 Dielectric measuring method for the determination of evenness and mixing quality of blended nonwovens

Concerning the manufacturing process of nonwovens made of fibre blends, the problem often arises that an even distribution of the basis weight as well as the mixing of different fibres regarding the whole nonwoven is hard to achieve. These irregularities can be demonstrated by the application of the dielectric measuring method.

1.3.1 Physical basis

The basis of this measuring method is a plate capacitor (Figure 4).

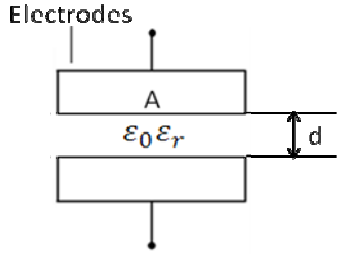

Figure 4: Plate capacitor

As soon as voltage (U) is connected to the capacitor plates, an electric field between the electrodes and a determined charge (Q) to the capacitor plates is generated, being proportional to the connected voltage. This proportionality is called capacitance (C):

$$C = \frac{Q}{U} = \varepsilon_0 \varepsilon_r \frac{A}{d}$$

The Capacitance depends on the vacuum permittivity ε_0, the distance between the capacitor plates d, the face of the capacitor plates A as well as the relative dielectric constant ε_r of the particular dielectric.

The system consists of the assembly presented in Figure 5. The upper capacitor plate consists of a measuring head and the integrated electrode. The second electrode is realized by the metal plate being embedded in the plan table. With the help of the hand wheel, the measuring head can be moved in all distances above the metal plate to the different measuring points.

1.3.2 Influencing factors

Changing environmental factors, for example air humidity and temperature, influence the measuring results (especially with natural fibres). An example for this is presented in Table 1. While no influences at all can be detected for PET nonwovens, a high relative air humidity leads to a high relative dielectric constant and thus eventually a lower capacitance. A comparison of statements concerning the basis weight under these conditions leads to varying and insignificant results.
By drying, storing (min. 48 hours) and measuring the nonwovens during consistent conditions (standard climate), the environmental effects can be systematically minimized.
Furthermore, there are system-dependent factors of influence which occur throughout the measurement process. Due to physical factors, every electrical component has a capacitive coupling with the environment. This coupling is often referred to as stray capacitive. Since it is only possible to make a significant statement about measurements via capacitive resistance of the capacitor, the additional the additional real resistances caused by cables or junctions need to be filtered.

Tab. 1: Relative dielectric constant depending on the relative air humidity at 1 MHz

Material:	εr (0% r.L.)	εr (45% r. L.)	εr (65% r. L.)
Air (0°C)	1.00059		
Water (18°C)	81.1		
Cotton (1MHz)	3.2	7.1	18
Viscose (1 MHz)	3.6	5.4	8.4
Wool (1MHz)	2.7	3.5	5.5
Polyamide (1MHz)	2.5	2.9	3.7
Polyacrylate (1MHz)	2.8	3.3	4.2
Polyester (1MHz)	2.3	2.3	2.3

These two influencing variables make a calibration of the system essential. The calibration is required to be carried out for stray capacitance as well as for the determination of real resistances. For this, the calibration tools are positioned in between the capacitor plates as the correction data is measured for every frequency. These are considered in the evaluation of the measurement results.

1.3.3 Execution of the measurements

It is a relative measurement method. A measurement is performed that compares the nonwoven consisting of blended materials with a combination of homogeneous 100 % nonwoven samples (calibration samples) of the respective blended nonwovens. The entire measurement process is performed under standard climate conditions and according to ITA-Standards. In order to eliminate environmental influences, both the blended nonwovens as well as the calibration nonwovens of both materials are firstly stored in a testing room with standard climate conditions.
For the measurement of the calibration samples, theses are consecutively positioned in between the capacitor plates as the measurement device passes through the desired amount of frequencies, measuring the capacitance of every frequency. The emerging capacitance profiles of the calibration samples form the basis weight and the mixing quality of the blended nonwoven. In order to calculate the basis weight of the blended nonwoven, the basis weight for both calibration samples has to be appointed first.
Contrary to the measurement of the calibration samples, the measurement of the calibration samples, the measurement of the blended nonwoven requires more than one measuring point to be taken into account. The blended nonwoven is positioned between the capacitor plates as the measuring head is moved along the rail towards the measuring point. A capacitance profile is evaluated for every measuring point. The basis weight as well as the mixing quality of every measuring point is determined through comparison and correlation of every individual capacitance profile with the capacitance profiles of the calibration samples. The amount of measuring points depends on the appointed measuring grid of the nonwoven to be examined. The more measuring points there are, the more accurate the results will be. Prior to commencing the measurement of the blended nonwoven, a measurement with an air filled capacitor has to be performed at every measuring point in order to filter out irregularities, unevenness and other factors if influence. Depending on the desired accuracy of the measuremet as

well as the area of the blended nonwoven, it is possible to choose between different process settings. For instance it is possible to adjust electrode spacing as well as the measuring grid according to user requirements.

1.3.4 Measurement results

The measurement results of the individual measuring points are summarized to an overall result by the evaluation software. A layout of the distribution of the basis weight as well as the mixing quality is created. According to these lay-outs, the irregularities are easily identified.
With the described method of measurement it is possible to make a significant statement about the homgenity of the basis weight as well as the homogeneity of the mixing quality of a blended nonwoven.
Subsequently to the measurement process is is possible to view all measurement results in analyses-menu as well as to compare them to other measurement results.
Furthermore, the measurement results of the individual measuring points can be appointed to their position on the blended nonwoven, allowing a thorough analysis of individual areas.
Thus, Products can be examined with regard to eveness, enabling the possibility to optimize the production process.

MECHANICAL PROPERTIES OF HYBRID STEEL FIBER REINFORCED POLYESTER COMPOSITE BEAMS AND THEIR VIBRATION BEHAVIOUR UNDER MAGNETIC FIELDS

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It is known that time varying magnetic fields induce eddy current in conductors. These eddy currents react with magnetic field and create a time varying electromechanical force. On the beams which move in an electromagnetic field, this force behaves as a contactless damper.
In this study, hybrid steel reinforced polyester composite beams are manufactured with carbon and glass fibers by hand lay method. The vibration behavior of these beams under time invariant magnetic fields is investigated experimentally. The effects of material properties and magnetic field on vibration damping is studied. Also mechanical properties of samples which are extracted from these manufactured beams are determined.

Keywords : Steel reinforced composite, damping, hybrid composite

MEDICAL TEXTILES USED IN COMPRESSION THERAPY

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Compression therapy is one of the most interesting areas about application of textiles in medical field. They are used especially for the treatment of venous and lymphatic disorders and hypertrophic scars. These textiles exerted pressure on a specific skin area to treat the illness. The pressure ranges applied to the skin area are differed according to the severe of the illness. These types of medical textiles called as “compression garments” or “pressure garments”.

In this study the types of compression garments, their usage areas and their importance are discussed and reviewed.

Keywords: Compression therapy, compression garments, venous and lymphatic disorders, hypertrophic scars.

1. Introduction

Compression therapy is applied by pressure exerted on a specific skin area. This therapy is a very effective treatment of venous and lymphatic disorders and hypertrophic scars, but the mechanism of this treatment is not fully understood [1,2]. It is applied by using compression garments, which are also called as pressure garments. They can be used as stockings, bandages or special body garments in varying degrees of compression.

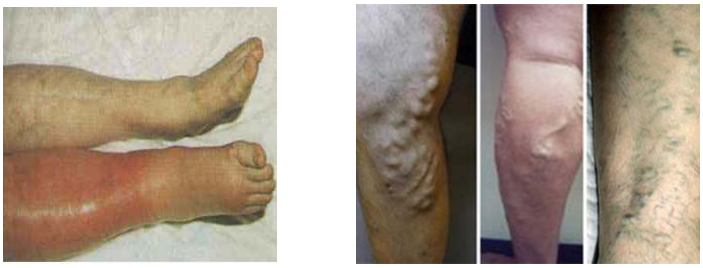
1.1 Compression Therapy For Venous and Lymphatic Disorders

The heart pumps the blood with a pressure (this pressure is 120 mmHg in normal conditions) and by the help of this pressure, the blood flows to the organs through the arteries and to the limbs without any problem. The pressure of blood returning to the heart from the body is very low due to the usage of blood in tissues especially in legs. In limbs, the valves prevent the blood flowing backwards. They are one way valves and facilitate the blood flow to the heart against the force of gravity. In a standing individual blood flows very slowly through the veins. However during walking, the blood flow is accelerated by the combined action of calf muscle pump and the foot pump [3, 4].

If the valves in veins are incompetent, the blood oscillates up and down in the segments lacking functional valves. The blood flows backward during walking and this causes the fluid loss into the tissues, then edema and venous disorders forms. Compression of veins helps the blood to flow to the heart and produces a reduction in venous reflux [4].

The venous disorders are venous hypertension, varicose veins, chronic venous insufficiency, thrombophlebitis and deep vein thrombosis (Figure 1). Varicose veins are formed with defective valves. They can be painful or totally painless. They are found on the calf, on the foot, on the thigh or on the entire leg. They are the sign of a more serious venous disease. Superficial thrombophlebitis is

a blood clot that grows lengthwise inside a varicose vein and is often associated with a vein inflammation (phlebitis). These vein sections are suddenly becomes red, warm, painful and hard. Deep vein thrombosis is the formation of blood clots in deep veins of the legs. Blood flow alteration, injuries of the vein can cause the blood clots [5].



[a] [b]

Figure 1. [a] Deep vein thrombosis of the right leg, [b] Varicose veins [6,7]

Lymphatic system consists of lymphatic vessels, tissue and organs such as bone marrow, spleen, thymus gland and lymph nodes that contain specialized cells called lymphocytes. These cells help the body to fight infection. Lymphatic vessels drain and filter fluid called "lymph" from tissue throughout the body and deliver it into the blood circulatory system via entry points into the subclavian vein. Lymphedema caused by the blockage or interruption of the lymphatic system usually involving the lymph nodes in the groin or armpit area. Cancer surgery (especially breast cancer surgery) or radiotherapy, vein stripping (a procedure to remove varicose veins), peripheral vascular surgery, burns, infection, inflammation, trauma etc can cause for the inadequate functioning of the lymphatic system [8]. In patients with venous insufficiency, lymph transport is also reduced; there occurs a collection of excess tissue proteins, edema, chronic inflammation and fibrosis [4]. Lymphedema has no cure, but using pressure garments and bandages, controlled amount of pressure on different parts of limbs may help to move the fluid and keep it from building up. Also when the lymph fluid is moved out of a swollen limb, using bandages may prevent the area from refilling with fluid; increase the ability of the lymph vessels [9].

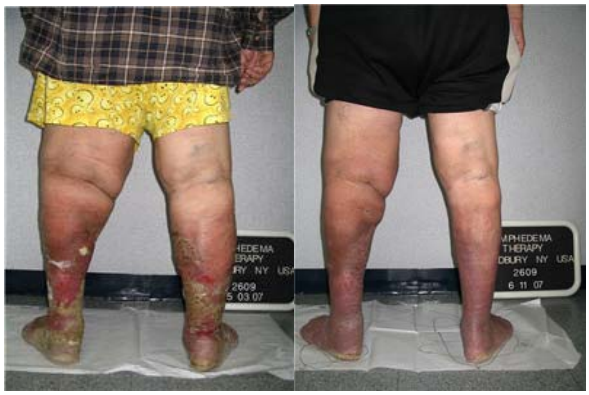


Figure 2. Lymphedema (before and after therapy) [10]

In all venous and lymphatic disorders mentioned above, compression garments are used as a therapy. Different garments are used as compression devices (Table 1).

The pressure generated by a garment is determined principally by the tension in the fabric, the number of layers applied and the degree of the curvature of the limb. This pressure is obtained from Laplace's law:

P=T/R, P=Pressure, T=Tension, R=Radius

Table 1. Major types of compression garments [11]

Stockings
Stockings classes I-IV
Tubular gradient compression
New stockings for leg ulcers
Thrombosis prophylaxis stockings
Support stockings
Bandages
Inelastic or short stretch
Long stretch elastic bandage
Other bandages
Four layer bandage

If the venous ulcers are not too large and too long-standing, then compression stockings may be used. Light compression stockings may be used for keeping the ulcer dressing in place. A second (class II) compression stocking may be used on this stocking to add its pressure, but it increases the stiffness. There are different types of stockings. For example several ulcer stockings are consists two layers. First layer (understocking) is applied over the top of any wound dressings. The second layer (stocking) is worn on the first stocking in the day time. This stocking allows the patient to clean the ulcer and change the dressing whenever necessary (Figure 3). There are also modified compression stockings with a zip fastener. Under these stockings there are liners (understockings) (Figure 3) [11, 12].

Figure 3. Compression stockings [13, 14]

Thrombosis prophylaxis stockings are used for bedridden patients who have deep vein thrombosis illness. These stockings are used only in bed rest and must not be used in standing position [11].

The compression classes of these stockings may vary from one country to another. For example a class II stocking is defined a pressure between 18-24 mmHg in UK, however 23-23 mmHg in Germany. Different test methods are also used to measure the pressure of the bandages in different countries [11, 12]. According to the European Standardization Commission, the classification of these stockings is as follows [11]:

Class I: 15-21 mmHg, minor varicose veins, functional venous insufficiency
Class II: 23-32 mmHg, slight chronic venous insufficiency or after surgery
Class III: 34-46 mmHg, smore advanced chronic venous insufficiency, leg ulcers lymphedema
Class IV: >49 mmHg, lymphedema, very severe chronic venous insufficiency

The level of compression of medical compression stockings is determined by the inlay yarn and must not change during the usage of stockings (Figure 4). The inlay yarn is responsible for comfort and movement of the wearer. In medical compression stockings 95% elastane is used and 5% rubber is used. Because elastane yarns are easily worked with, they are finer and long lasting and more resistant to oxidation damage, UV rays, ointments and body fats. They cause no allergy [15].

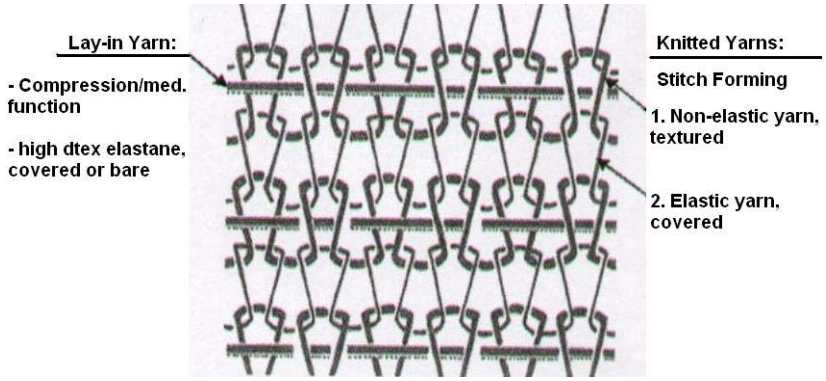


Figure 4. The structure of a compression stocking [15]

Compression bandages can be inelastic or elastic and consist of one layer or multilayer fabrics. In compression bandages the interface pressure and the stiffness are important. The interface pressure can be measured in two ways. One is measured when the patient is in resting pressure and named resting pressure and the other one is measured when the patient is moving, named working pressure [1]. The stiffness is the increase of compression due to an increase in the circumference of the leg during movement [12].

Elastic compression bandages exert pressure when it is stretched. They are easy to apply. After hours they do not loose their pressure. They are easier to use. However working pressure is less effective than short stretch bandages. They apply pressure in all the time, in resting position and also the working position. So they can cause discomfort and pain, because of this, they have to be removed during the night and worn in the morning.

Inelastic bandages or short stretch bandages exert pressure when movement causes the calf muscle to contract [1, 12]. These bandages produce much pressure when the patient is standing up or moving. They must be fitted by trained persons (bandager), because this affects the efficacy of the bandage. They remain on the leg for several days. However these bandages loose their pressure within the first hours when they worn [11, 12].

Four-layer bandages are high-compression bandages (sub-bandage pressure 35-40mmHg at the ankle) that incorporate elastic layers to achieve a sustained level of compression over time [16]. First layer consist of orthopedic wool, which provides a layer of padding to protect the areas at risk of high pressure [such as foot and ankle]. It also absorbs the exudates. Second layer is a crepe bandage and the least effective layer in the combination. It increases absorbency and smoothes the orthopedic wool layer, preserves the elastic energy of the main compression layers. Third layer consists of elastic extensible bandage, which is a highly extensible bandage that provides a sub-bandage pressure. The fourth layer is a light weight, elastic, cohesive bandage. It maintains the bandage position. This layer provides the higher level of compression [16, 17].

1.2 Compression Therapy For Hypertrophic Scars

Hypertrophic scars develop after serious burn injury or other wounds. They occur mostly in areas of thick skin and frequently develop within 8 weeks of a burn, wound closure with excess tension wound infection, hypoxia or other traumatic skin injury. These scars represent an abnormal, exaggerated healing response after skin injury. They are warm, red and/purple color, tender and may itch. They can cause pain, contractures and difficult to treat [18, 19].

Since 1970's pressure garments have been used for the treatment of these scars. The exact mechanism of how pressure influences the development or maturation of these scars is not fully understood. It is believed that these garments controls the collagen synthesis and encourages realignment of collagen bundles. They also alleviate the itchiness and pain [2].

These garments are custom made elastic fabrics and exert a pressure of approximately 25 mmHg [18, 19]. These garments are must be worn under the patients' normal clothing for approximately 1 year until the scar matures [19] and at least 23 hours a day [2]. They can be used when all burn wounds have closed sufficiently to tolerate wear [20]. The pressure of these garments decrease during usage, so these garments must changed in given periods by the therapist or manufacturers [19].

There are two main types of fabrics, used for making pressure garments for hypertrophic scars [2].

1. Ready to wear warp or weft knitted fabrics. They are available from a number of commercial companies in a variety of styles and for all the body sizes. They are cheaper than the custom made garments.

2. Custom made garments: They are usually produced by warp knitted fabrics constructed by occupational therapists or by commercial manufacturers. Weft knitted forms are also available. Fully fashion technique is used in producing weft knitted elastic fabrics by commercial manufacturers. Two or three sets of garments are supplied to the patients by the manufacturers. They are replaced every 6-12 weeks in order to maintain the required compression.

[a] [b] [c]

Figure 5 – [a] Thirty-month-old child after operative treatment for hot liquid burn in the areas of neck, breast, and shoulder. [b] Pressure garments over a silicone sheet [c] Final outcome [21]

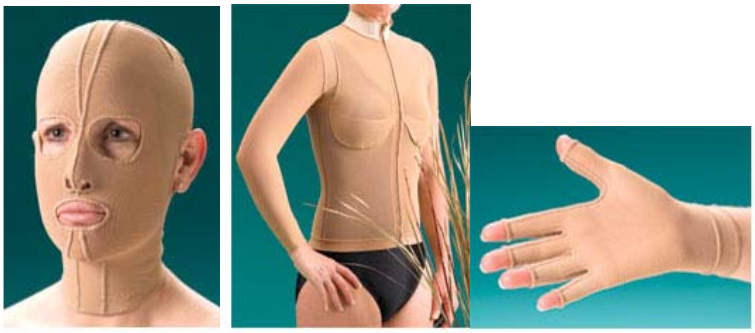


Figure 6. Some examples of the compression garments for hypertrophic scars [22].

Conclusion

Textile materials are used in many areas of medical field. The garments that apply pressure are widely used in venous and lymphatic disorders and also in hypertrophic scars to prevent and to alleviate the symptoms of the illness. Owing to this there are many studies about this subject and pressure garments will be one of the important therapies for the illness mentioned above.

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NEW METHOD FOR FUSED TEXTILE SYSTEMS RESILIENCE INVESTIGATION

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ABSTRACT

The aim of the research was to investigate the resilience properties of textile systems fused with different interlinings. Testing was performed with four samples of worsted fabrics, four different samples of adhesive interlinings and samples of their fused systems.

Special computerised pendulum impact device was applied for this purpose. During testing the pendulum was raised from the balance position and was fixed at the initial angle of 5º. When the pendulum was released the bob stroke the specimen at the lowest point of the swing. After impact the bob rebounded from the specimen and continued swinging. Pendulum rebound and impact angles were determined. Testing conditions were as follows: bob radius 30 mm, pendulum length 1.5 m. The damping swings of the pendulum were recorded for 20 s.

Rebound angles of pendulum for fused systems did not show any significant difference but for separate textile layers it was higher by ~ 16 %. At the same time the highest deformability characterised by pendulum impact angle was observed also for separate layers of textile materials. From this stand point more complex situation was observed for fused systems, because their deformability depended upon the thickness and surface density of interlinings.

The value of pendulum impact angle, i.e. deformability of fused systems, decreased with the increase of the thickness and surface density of applied interlinings. The dependency between interlining thickness and fused systems deformability can be expressed by logarithmic function (R^2 = 0.83 ÷ 0.97).

Key Words: fused system, resilience, pendulum impact device

1. INTRODUCTION

During processing, tailoring or end use textile fabrics undergo all kinds of external loads and they have to retain their shape during all period of wear [1, 2]. Stability is one of the fundamental requirements for textile fabrics that can be determined by their resilience properties. Thus, investigation of resilience properties of textile materials is of great importance [3].

Earlier investigations of textile materials pendulum impact deformation have shown that close dependency exists between their strain level and absorbed impact energy [3, 4]. Moreover linear relationship exists between fabric resilience and impact energy absorbed by pendulum [5].

Pendulum impact device provides the information about resilience properties of textile materials applying garment wear level multi-cyclic impact loads [6, 7].

Earlier investigations have also shown that resilience of textile materials can be improved by creating bilayed systems, i.e. by fusing fabrics with interlining materials orientated in proper direction [8].

Fusible interlinings are the most important components of clothes. Their properties have great influence for clothing shape, appearance, softness and durability. Interlining fabrics are used to support outer fabrics, as well as to create and maintain the required 3D shape. Careful selection of interlinings and optimal combination of them and outer fabrics is critical for garment quality [9].

The aim of this research was to investigate the resilience properties of textile systems fused with different interlinings.

2. MATERIALS AND METHODS

Bilayer textile systems composed of outer fabric and interlining were investigated. Tests were performed with four woven outer fabrics (Table 1) and four interlinings (Table 2).

Table 1. Characteristics of woven outer fabrics

Code	Weave	Area density, g/m^2	Thickness*, mm	Density, 1/cm	
				Warp	Weft
M1	Broken twill 2/2	305	1.59	10.0	9.2
M2		341	1.04	10.6	9.6
M3	Twill 2/1	330	1.63	15.0	12.0
M4	Negative broken twill	236	1.72	10.4	9.8

* thickness measured at a pressure of 49 N/m^2

Table 2. Characteristics of investigated interlinings

Code	Foundation type	Area density, g/m^2	Thickness*, mm	Adhesive, dots/cm^2
A	Nonwoven	40	0.03	118
B	Nonwoven	27	0.01	118
C	Nonwoven**	46	0.11	72
D	Woven	100	0.21	72

* thickness measured at a pressure of 49 N/m^2; ** with polyester thread in longitudinal direction

Fused textile systems were formed by MAYER pressing machine at 145°C temperature and 0.04 MPa pressure; pressing duration 15 sec.

Special computerised pendulum impact device (Figure 1) was applied for resilience properties investigation. During testing the pendulum was raised from the balance position and was fixed at the initial angle α_0 of 5º. When the pendulum was released the bob stroke the specimen at the lowest point of the swing. After impact the bob rebounded from the specimen and continued swinging.

Testing conditions were as follows: bob radius 30 mm, pendulum length 1.5 m. The size of specimen was 140 x 140 mm. Damping swings of the pendulum were recorded for 20 s.

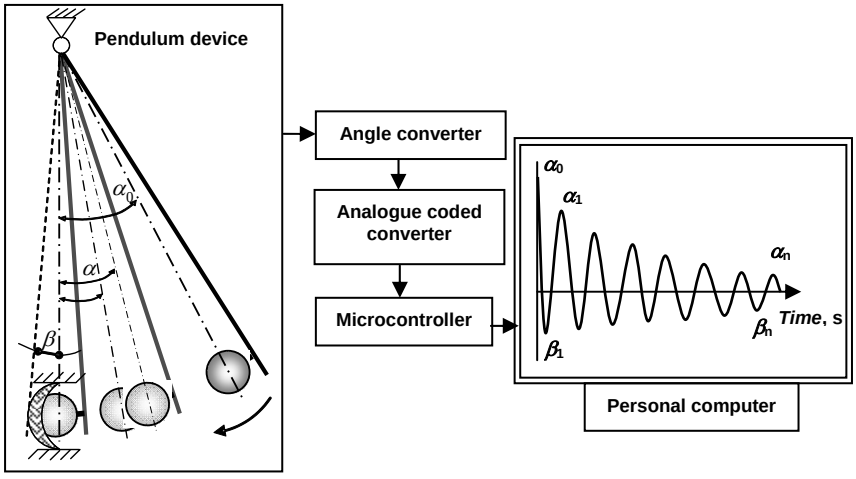


Figure 1. Pendulum impact device and registration of its vibration process

(α_0 – initial deflection angle of the pendulum, α_n – amplitudes of the rebound angles, β_n – amplitudes of impact angles)

The process of pendulum vibration was digitally registered as vibration curve. To describe materials impact behaviour the values of impact (α_{1-n}) and rebound (β_{1-n}) angles of each stroke were used.

Measured sequences of parameters α and β shows decaing pendulum swinging process which can be approximated by a certain function.

3. RESULTS AND DISCUSSION

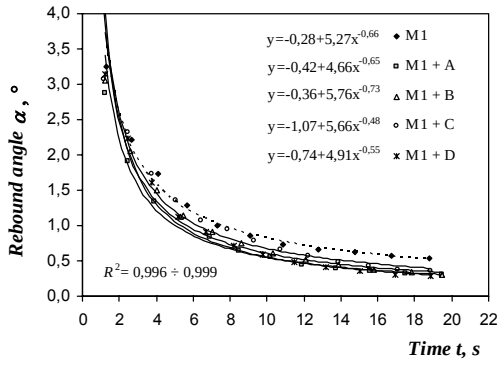
Investigations were performed with 6 specimens for each testing sample. Coefficients of variation were not higher than 6 %.

Functions describing decaing pendulum swinging process of fused textile systems with different fusible interlinings (A, B, C and D) are presented in Table 3 and Figures 2 and 3.

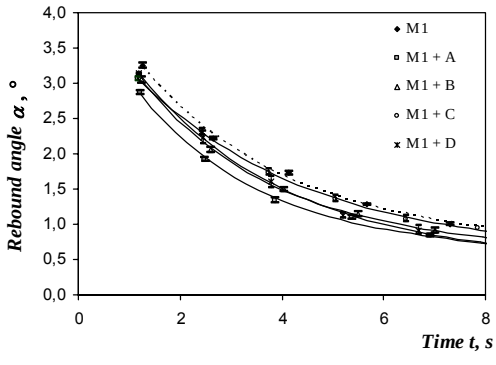
Obtained results showed that rebound angles $\alpha_{1\text{-}n}$ of fused textile systems did not show any significant difference (Figure 2) but comparative analysis of separate outer fabrics and their fused systems showed that first rebound angles α_1 (Table 3) of outer fabrics (M1, M2, M3, M4) were up to 16 % higher than those of fused systems.

Table 3. Values of first rebound angles (α_1) and impact angles (β_1) of fused textile systems

Fused system with:	M1		M2		M3		M4	
	Values, °							
	α_1	β_1	α_1	β_1	α_1	β_1	α_1	β_1
	3.25	-0.97	3.26	-0.90	3.34	-0.89	3.63	-0.81
A	2.87	-0.66	2.86	-0.68	2.92	-0.67	3.14	-0.68
B	3.05	-0.82	3.00	-0.81	3.17	-0.77	3.19	-0.73
C	3.07	-0.64	3.11	-0.64	3.15	-0.65	3.16	-0.64
D	3.14	-0.61	3.16	-0.63	3.21	-0.64	3.30	-0.63



a)



b)

Figure 2. Decaing processes of pendulum rebound angles for tested fused systems with M1 outer fabric (a); enlarged view up to 5th rebound (b)

It is evident that separate outer fabrics compared with fused systems transmit higher amount of energy for pendulum and rebound angles are higher in these cases. So, better resilience of materials can be described by higher rebound angles α_1.

At the same time the highest deformability characterised by first pendulum impact angle β_1 was observed also for separate textile materials (Table 3). From this stand point more complex situation was observed for fused systems (Figure 3 and 4), because their deformability depends on the thickness and surface density of interlinings.

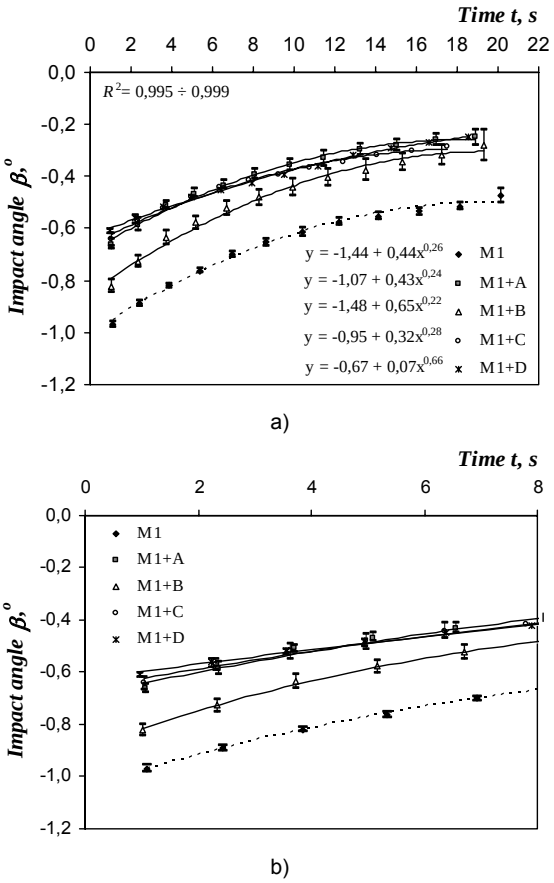


Figure 3. Decaing processes of pendulum impact angles for tested fused systems with M1 outer fabrics (a); enlarged view up to 5th impact (b)

It was observed that first impact angle β_1 of fused systems is 10 – 37 % less compared to separate outer fabrics (Table 3). Thus after fusing not only impact angle β_1 decreased but rebound angle α_1 decreased, also. It can be stated that deformability of fused systems is less than that of separate outer fabrics. Meantime the same tendency from the results of first rebound angle α_1 can not be set for the resilience properties because differencies between obtained values are insignificant (Figure 2).

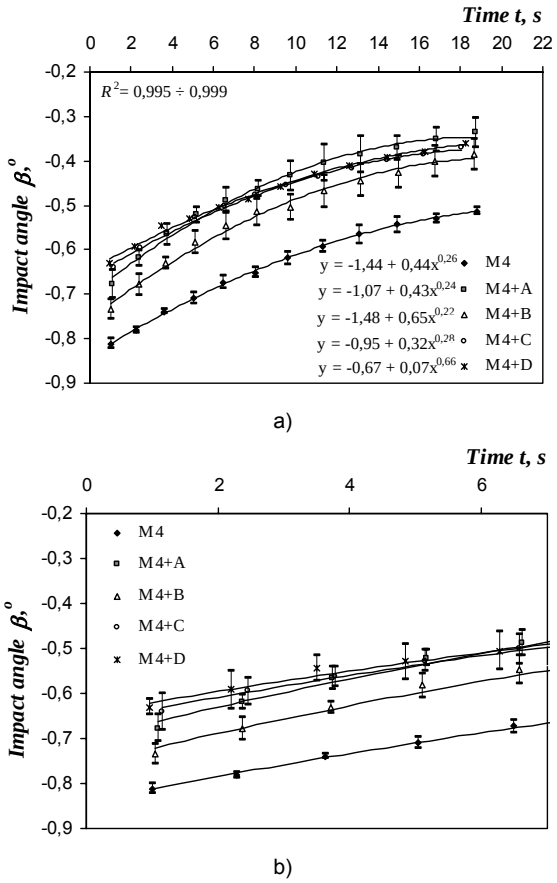


Figure 4. Decaing processes of pendulum impact angles for tested fused systems with M4 outer fabrics (a); enlarged view up to 5th impact (b)

Impact angles β_{1-n} of systems fused with interlining B is significantly higher (Figure 3 and 4) because thickness and area density of interlining B is evidently less compared to other interlinings (Table 2). Thus, the deformability of such systems is the highest. Whereas impact angles $\beta_{1\text{-}n}$ of fused systems with interlining D which is characterised by the highest thickness and area density is the least. Meantime first rebound angle α_1 is the highest (Table 3), thus the deformability of such systems is minimal while resilience is maximal. The presumption can be done that deformability and resilience properties of fused textile systems are related to thickness of interlining (Figure 5).

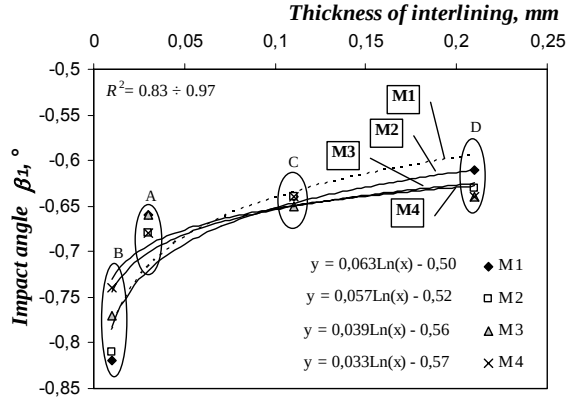


Figure 5. Relation between fused systems first impact angle β_1 and thickness of interlining

The relation between thickness of interlining and fused systems first impact angle β_1, i.e. its deformability can be expressed by logarithmic function $y = aln(x)+b$ whith coefficient of determination $R^2 = 0.83 \div 0.97$.

3. CONCLUSIONS

Investigation of fused textile systems resilience properties using pendulum impact device revealed that pendulum rebound angle did not show any significant difference using different fusible interlinings. Meantime differences between impact angles with different fusible interlinings are significant and can be used for fused systems resilience properties investigation.

Deformability of fused textile system depends upon thickness of fusible interlining: the higher thickness of interlining, the smaller impact angle β_1 of fused system is. The dependency between interlining thickness and fused systems deformability can be expressed by logarithmic function $y = aln(x)+b$ when $R^2 = 0.83 \div 0.97$.

Decaing process of pendulum impact and rebound angles for outer fabrics and fused textile systems can be describes using power function $y = a+bx^c$ with coefficient of determination $R^2 = 0.98 \div 0.99$.

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NEW TECHNOLOGIES IN THE VISION OF TEXTILE ART

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INTRODUCTION

Textiles have entered all realms of modern human beings' living through new technologies gradually prograssing from their production techniques unique to what is old to Industrial Revolution, the very turn of the associated process and through the expertises they created.

While a variety of weaving, knitting, dyeing, printing and embelishment techniques have been combined with engineering technologies, designing solutions of the above-said depend on visiual and plastic creations of surfaces and forms by textile and fashion designers.

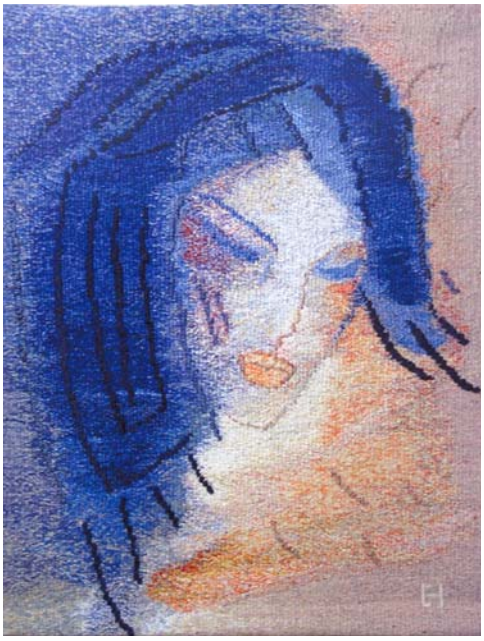

Figure 1: Ehalill Halliste, "Lady Blue"
wool; handloomed tapestry
(Drusilla Cole**, Textiles Now**, Laurence King Publishing Ltd., London, 2007, s.19)

Figure 2: Anna Maria Atturo, “Plain Weaving Yellow Warp”, 2007
nylon, cotton, hemp, wool, silver foil; hand weaving
(**Valcellina International Textile and Fiber Art Competition Award Catalogue**, Italy, 2007, s.26)

On the other hand, textile artist who utilise new technologies and material as well as traditional stufs and techniques tends to convey the language of art to the material itself, thus providing it with a very new personality distinct from that of mass production.

Figure 3: Christine White, “Cocoon”
wool; felting on Arashi Shibori
(Drusilla Cole, **Textiles Now**, Laurence King Publishing Ltd., London, 2007, s.65)

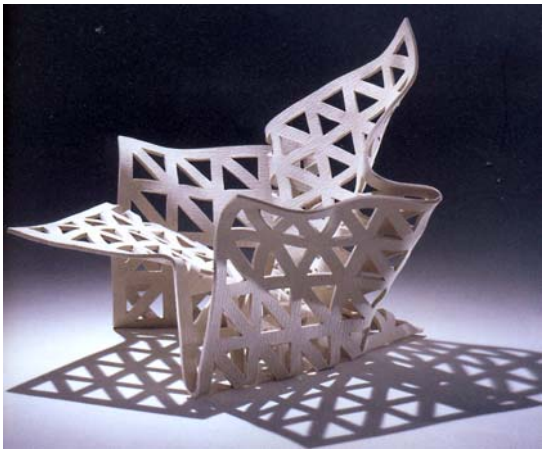

Figure 4: Louise Campbell, "Bless Your Chair", 1999
wool; felting, high-tech cutting
(**ETN Textile Forum**, 1/2010 March, Textile-Forum-Service, B.Sterk , Hannover, 2010, s.25)

The last decade we have been through has witnessed many an artist/designer who has made use of know-how and new fibers of textiles.

Textile or art of fiber appeared with art of weaving. Textile was conveyed to the platform of textile art with such significant events as International Bienalle of Lausanne held in 1960's and Exhibition of "Woven Forms" organised by American Craft Council.

Freedom of self expression of artists influenced art branches upon the World War II. Fiber artists went beyond what one is used to. First of all they went to extremes, giving up edges of cloth and then looms. They conveyed such traditional techniques as felting, knotting, knitting, sewing, dyeing and printing to the present time and used new technologies. Also they employed processes for example, techniques of transferring, photo and digital printing CAT designing, laser-aided patterning and colouring etc.

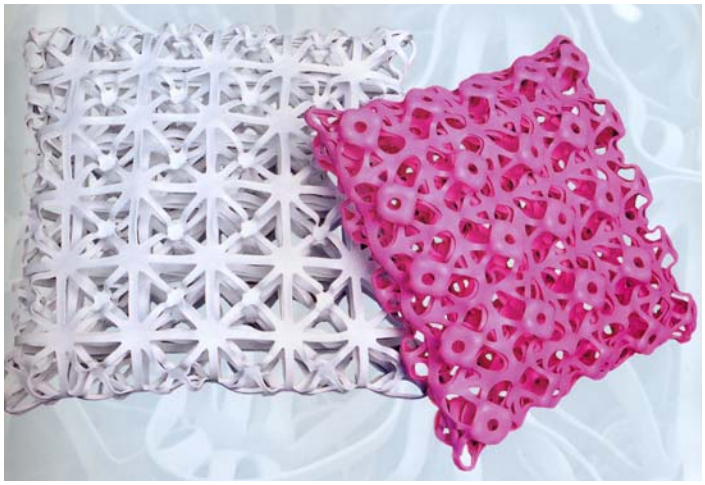

Figure 5: Lauren Moriarty, "Noodle Block Cushion", 2006
laser cut
(Chloe Colchester, **Textiles Today A Global Survey of Trends And Traditions**, Thames and Hudson Ltd., London, 2007, s.140)

An artist can benefit from both provocative and inspiring stuffs which science has provided. He/she can furnish surfaces with some features such as brightness, transparency, hardness, softness,

flaxibility, lusterlessness, weight, lightness, fluidity, ability to upright which are all properties that he/she tries to obtain using a rich spectrum of textile fibers.

Technological evolution in 21. Century presents us with endless renovations such as copper and steel wires, paper fibers, fiber glass and carbon fibers etc., as well as microfibers produced by ground, wrinkled and smashed textures using a series of finishings and new generation textiles such as nunos.

Tiny or gigantic scale examples of artistic textiles in two or three dimensions have begun to appear in art galleries, modern art museums and public premisses since 1960's.

Figure 6: Machiko Agano, "Untitled", Gallery Gallery Kyoto, 2003
Stainless steel wire, polyamide monofilament, silk thread; hand knitting
(Sarah E. Braddock Clarke, Marie O'mahony, **Techno Textiles II,** Thames and Hudson, London, 2005, s.171)

Figure 7: Aino Faven, "Mobile", Environment Piece, 1996
(**Textile Art in Finland,** Editor; Tuula Poutasuo, AKATIIMI Ltd., Hamina, 2001, s.79)

Exhibition of textile art examples is not only limited to indoor possibilities but are occasionally perceived as if they are part of the environment in which they are placed when they are expressed using universal language of the art as well.

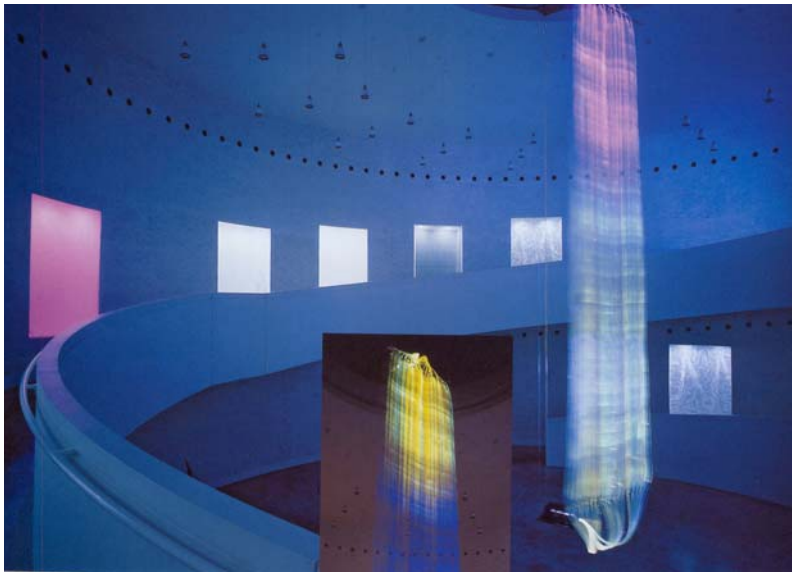

Figure 8: Astrid Krogh, "Holbein Neon Tapestry", 2002
optic fiber
(Chloe Colchester, **Textiles Today A Global Survey of Trends And Traditions**, Thames and Hudson Ltd., London, 2007, s.158)

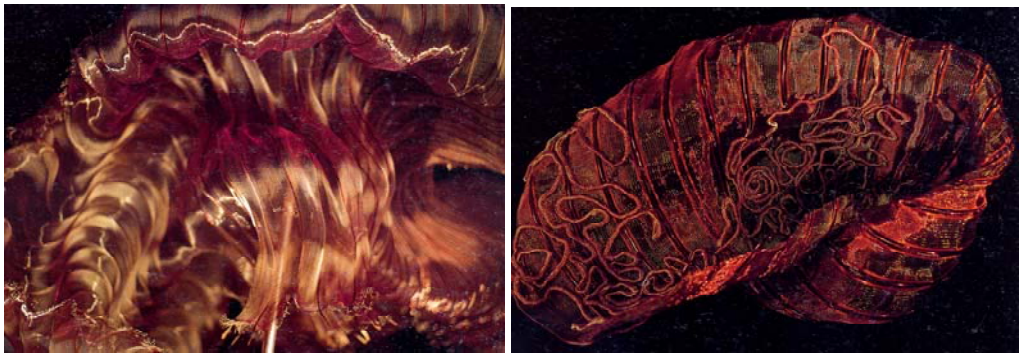

Figure 9: Alida Efstratiou, 1990
hand-woven metallic mesh
(Chloe Colchester, **Textiles Today A Global Survey of Trends And Traditions**, Thames and Hudson Ltd., London, 2007, s.158)

CONCLUSION

From traditional processes to new techniques and materials, textile artists carry collection of millennia to their very creations by studying visual and plastic properties.

Through such interactions, the art itself has close associations with techniques and materials and therefore the artist does have a word to say as well.

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ONE OF THE IMPORTANT APPLICATIONS OF TECHNICAL TEXTILES: SPORTTECH

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ABSTRACT

Due to the increase of interest in sports and outdoor activities and the influence of major sports events such as World Cup and Olympic games, this sector is expected to show a high growth rate. Today's sports and outdoor activities demand high performance equipment and apparel. The light weight and safety features of textile products have become important in their substitution for other materials. Safety, comfortable and high performance sportswears which professional athletes prefer is used by many athletes and amateurs.

Sportswears which is worn and equipments which is used by athletes in games is very important for their successes. Demand for those wears and equipments are reduced in recent years. Sports sector is open to innovations. New fibes, fabrics and coatings are being developed.

Textiles which is used sportswear consist of high performance fibre and fabric. For examples, swimmer jarsey, gymnastics wear and skiwear are made up of Spandex, Lycra and Elasthan which are very flexible and are produced poliuretan fibre (PUR). Those fibres are used combination with another natural fibres.

Although, we prefer cotton clothes daily life, in active sportswear, synthetic fibres are prefered because of not to include moisture. There are three important features in sportswear. Those are protection from wind, water and weather conditions. In addition, thermal insulation, vapour permeability and flexibility are in demand.

In this study, sporttech which is very important subject in technical textiles and sportswear are examined. Applications of sportswear are studied.

Keywords: Sporttech, Technical textile, Sportswear, Apparel

1. INTRODUCTION

Technical textiles as defined as textile materials and products manufactured primary for their technical performance and functional properties, rather than for their aesthetic and decorative it characteristics [1].

One of the important applications of technical textiles is sporttech. Textiles materials are used in all sports as sportswear, and in many games as sports equipment and sports footwear. Examples of sportswear are: aerobic clothing, athletic clothing, football clothing, cricket clothing, games shorts, gloves, jackets, pants, shirts, socks, sweatshirts, swimwear, and tenis clothing. Examples of sport equipment are: sails, trampolines, camping gear, leisure bags, bikes, and rackets. Examples of sport footwear are: athletic shoes, football boots, gym shoes, tenis shoes, and walking boots [2].

In the original Olympic games, male athletes performed naked. The skin is still the best fabric available, with regard to human physiological concerns such as breathability, thermal regulation, movement, fit, agility, sensitivity and grip. For modesty as well as climatic and environmental reasons, clothing has been adopted and modified over the centuries in an attempt to achieve the neutral state of comfort. Designers must have knowledge of textile properties and constructions in tandem with a basic understanding of human physiology and issues to do with survival. Discomfort only becomes apparent when the body feels too hot or too cold, where clothing impedes or restricts movement or visibility and lacks the desired fit, especially in the case of performence clothing for female athletes. Clothing can be abrasive and chaffing, can permit damp or wet to penetrate, be noisy, smell bad or look unattractive and generally fail to have the feelgood factor.

2. FIBRES AND FABRICS IN SPORT

The evolution of fibre developments has gone through the phases of conventional fibres, highly functional fibres and high performence fibres. Polyester is the single most common fibre used for sportswear and active wear. Other fibres suitable for active wear are polyamide, polypropylene, acrylics, and elastanes. Wool and cotton fibres are still finding applications in leisurewear. Synthetic can either be modified during manufacture, e.g. by producing hollow fibres and bibres with irregular cross-section, or be optimally blended with natural fibres to improve their thermo-physiological and sensory properties[2] .

In the past years, new fibres, yarns, constructions and coatings for the sport and functional textile market have been developed and introduced to the market. Beside the already known materials, microfibres made from different polymers offer innovations for new functional textiles. In addition, the finishing of fibres to incorporate, for example, anti-microbial behaviour, drug delivery systems temparature- storing capability, opens new markets.

Special high performance fibres used in sport textiles and in many other applicatipons must have a number of properties to fulfil the demands of the sport. The combination of properties is different, just as the applications are. The main properties are [2]:

- *Mechanical-physical*. Tensile strength, elongation at break, tensile modulus, compressive modulus, elastic recovery, relaxion under static loading, torsional modulus, torsional brittleness, specific weight, shrinkage, moisture absorption, loop strength, knot strength.
- *Chemical*. Glass transition temparature, melting point, heat stability, ironing temparature, specific electrical resistance, adhesion, resistance against environment (hmidity, chemical, biological, radiation), combustibility LOI (limited oxygen index), dyeability, solubility, fastness.
- *Surface-related.* Hydrophilic and hydrophobic, wettability, oil repellence, soil repellence, barrier to water penetration, improving aesthetics, antibacterial and other types of surface treatments, friction, softness.

Beside the natural fibres such as cotton and wool, there is a wide range of man-made fibres.

Fibres from natural polymers

The most common fibre, based on natural polymer is viscose, which is made from the polymer cellulose obtained mostly from farmed trees. Other modified cellulose-based fibres are cupro, acetate and triacetate, lyocell and modal. Less common natural polymer fibres are made from rubber, alginic acid and regenerated protein.

Fibres from synthetic polymers

There are many synthetic fibres, i.e. organic fibres based on petrochemicals. The most common are: polyester, polyamide (Nylon or Perlon), acrylic and modacrylic, polypropylene, the segmented polyurethanes which are high-elastic fibres known as elastanes (or spandex in the USA), and speciality fibres such as the high performance meta-aramids or para-apamids, polybenzinidazole (PBI), polyolefin, saran, polyphenylenesulfide (PPS) (or sulfar in the USA), chlorid fibre CLF (vinyon).

Fibres from inorganic materials

The in-organic man-made fibres are fibres such as glass, metal, carbon and ceramic. These fibres are very often used to reinforce plastics to form composites.

High-functional fibres and textiles

Alarge variety of properties, which are important for application, can be engineered by finishing and coating textiles. For sports clothing, in particular, the following demands arise which vary according to application and which stil have to be completed for special applications:

- Low maintenance/good washability
- Dirt repellence/easy dirt seperation
- Oil repellence
- Wearing comfort due to watertightness and climatic compensations (breath-ability due to vapour permeability connected with humidity transport), windblocking for good heat insulation
- UV protection
- Quick drying
- Flame retardance
- Antistatic behaviour
- Antibacterial/odour absorption
- Tensile strength, abrasion resistance
- Protection against mechanical influences
- Low degree of shrinkage
- Smooth handle.

3. COMFORT IN SPORT

The wear comfort of sportswear is an important quality criterion. In affects not only the well-being of the wearer but also their performance and efficiency. If, for example, an active sportsperson wears a clothing system with only poor breathability, heart rate and rectal temperatures will increase much more rapidly than while wearing breathable sportswear.

After recognising the importance of wear comfort and the physiological function of sportswear, one should define in more detail what wear comfort entails. In fact, wear comfort is a complex phenomenon, but in general it can be devided into four different main aspects [3].

- The first aspect is denoted as thermophysiological wear comfort, as it directly influences a person's thermoregulation. It comprises heat and moisture transport processes through the clothing. Key notions inclued thermal insulation, breathability, and moisture management.
- The skin sensorial wear comfort characterises the mechanical sensations, which a textile causes at direct contact with a skin. These perceptions may be pleasent such as smoothness or softness, but they may also be unpleasent, if a textile is scratchy, too stiff, or clings to sweat-wetted skin.
- The ergonomic wear comfort deals with the fit of the clothing and the freedom of movement in allows. The ergonomic wear comfort is mainly depentet on the garment's pattern and the elasticity of the materials.
- Last but naot least the psychological wear comfort is of importance. It is affected by fasion, personal preferences, ideology, etc.

For many outdoor sports such as cycling, running, sailing, climbing, ect.,foul weather protection is required. For these applications, waterproof and yet water-vapour-permeable (breathable) textiles are state of the art. Because of the high market potantial, today numerous constructions are available. They can be devided into two main groups:

- Laminates, in which a ready-made membrane is glued to a textile carrier.

- Coatings, in which the polymer melt is directly applied to the textile carrier [2].

Clothing may get wet from precipitation or contacts from outside. Wetting from the outside should be prevented by selection of water-repellent or waterproof fabrics for the outermost clothing layer. A number of materials on the market are absolutely impermeable to water. Different treatments of fabrics render them more or less waterproof.

Clothing may also get wet from absorption and accumulation of sweat. This is likely to occur at hifh activity levels. In such circumstances the selection of outer layer must be a compromise between the need for wind protection and the need for additional evaporative cooling.

Although most people prefer to enjoy water sports in temperate and warm weather conditions, some sporting events take place in waters at temperatures well below 20 °C and sometimes as low as 5 °C.

In the cold there is a steep temperature gradient from skin, across clothing layers to ambient air. The dew point temperature and eventually also the freezing temperature may be reached inside the clothing by the moist air passing from the skin. Condensation occurs and moisture builds up in discrete layers. Wetting of cloting reduces the effective thermal insulation [2].

Prevention of injuries is one of the primary concerns of participants in many types of sports and games and has lately attracted greater research attention. For impact protection to be provided by the clothing or sporting equipment such as protective helmets, it is necessary to use textiles and textile-based materials which possess high strength and durability as well as a high level of energy absorption. These materials are attached to the clothing in appropriate places depending on the sporting activity and the information available from injury risk analyses of different sports and games. A variety of textiles and textile composite structures are commercially available with the required mechanical properties of strength, impact resistance, abrasion resistance and tear strength for rugged outdoor and performance sports and games.

4. APPLICATIONS IN SPORT

The sports industry has driven much research within the textile industry to help improve athletic performance, personal comfort, and protection from the elements. Synthetics that were once thought to be inferior to natural fabrics now boast high performance characteristics [4].

Prevention of injuries is one of the primary concerns of participants in many types of sports and games and has lately attracted greater research attention. For impact protection to be provided by the clothing or sporting equipment such as protective helmets, it is necessary to use textiles and textile-based materials which possess high strength and durability as well as a high level of energy absorption. These materials are attached to the clothing in appropriate places depending on the sporting activity and the information available from injury risk analyses of different sports and games. A variety of textiles and textile composite structures are commercially available with the required mechanical properties of strength, impact resistance, abrasion resistance and tear strength for rugged outdoor and performance sports and games.

Figure 1. (a) Carbon-loaded elastomer-sensorized garment for kinesthetic monitoring developed at the University of Pisa.

Figure1. (b) The Intelligent Knee Sleeve is a biofeedback device using PPy sensors that monitors the wearer's knee joint motion. (Courtesy of CSIRO Textile and Fiber Technology.)

5. CONCLUSIONS

Textiles in sport is divided into five parts. Part One explores the current sportswear market, starting with a market overview then going on to look at current design, material requirements and functional footwear. In Part Two the innovative fibres and fabrics available are outlined, including high performance and high functional fibres, smart and intelligent textiles and coated and laminated textiles. Part Three focuses on the need for comfort in sportswear. The physiological comfort of sportswear can affect not only a wearer's wellbeing but also his performance. The role of elastic can also play a part in providing comfort, through minimising the garment's resistance to the wearer's movements. The important issue of protection is looked at in the next section, with chapters on impact protection, protection against the cold and water resistance and water vapour transfer. Finally, part Five offers outlines of specific applications, with case studies of textile composites, textiles in sailing and textile use in sports shoes [2].

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PHOTOCHROMIC TEXTILE GRAFTED BY ETHYLCELLULOSE-SPIROOXAZINE NANOCAPSULES

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ABSTRACT

Photochromism is the phenomenon whereby the absorption spectrum of a molecule or crystal changes reversibly when the sample is irradiated by UV or visible light. The use of photochromism provides new opportunities to develop smart textiles. In this work 5-Chloro-1,3-dihydro-1,3,3-trimethylspiro[2*H*-indole-2,3′-(3*H*)naphth[2,1-*b*](1,4)oxazine] photochromic dye was encapsulated by eco-friendly ethylcellulose into nanocapsules, and they were grafted to textile. The preparation of durable nanocapsules for textile finishing compositions was performed based on an oil-in-water emulsion process. The size of the capsules determined by dynamic light scattering method was optimized (216 nm, volume mean diameter) by varying the encapsulating polymer concentration. The photochromic property of nanocapsules, proportional to the dye concentration, was certified by UV/VIS spectrophotometry. 1,2,3,4-butanetetracarboxilic acid and citric acid were used as crosslinking agents in binding nanocapsules to textile. The grafting of nanoparticles to textile was investigated by FTIR spectroscopy. The main advantage of this method was the use of biocompatible encapsulating polymer and non-toxic crosslinking agents.

Key Words: photochromism, ethylcellulose, spirooxazine, non-toxic materials, crosslinking to cotton

1. INTRODUCTION

Photochromism can be defined as a reversible transformation of chemical species, induced in one or both directions by electromagnetic radiation, between two states having observable light absorptions in different regions.

Spirooxazines are one of the most popular classes of photochromic materials, and have shown to possess high fatigue resistance and excellent photostability [1]. The photochromism of spirooxazines is attributable to the photochemical cleavage of the spiro-C–O bond, which results in the extension of π-conjugation in the colored photomerocyanine conformer and thus, shifts the absorption to the visible region [2].

For all investigations and applications of organic photochromic dyes a suitable matrix is indispensable. In order to overcome the aggregation and improve the stability of the dyes solid matrices are preferred. The use of organic polymers alleviates the commonly arising problems with dye solutions, concentration quenching and low photostability, but at the same time leads to a deep suppression on both fading speed and photochromic response of the dye [3]. The photochemical as well as thermal behaviour of organic photochromic molecules is influenced in various ways by the characteristics of the polymer media in which they are incorporated. More importantly, the interaction between the photochromic and polymeric entities can lead to novel photoinduced properties beyond the obvious colour changes. Polymeric materials play a very crucial role in studies on photochromism, in particular from a practical viewpoint, since various applications require photochromic materials in the form of films, sheets, plates, fibers, beads and so on. Photochromic molecules have usually been incorporated into polymer matrices by binding them covalently to polymer backbones or by dissolving or suspending them in polymer solids [4].

The application of photochromism in textiles will create new opportunities to develop smart garments capable of blocking UV radiation and/or sensing environmental changes, as well as displaying fancy colour-changing effects [5,6].

The use of natural polymers has received considerable attention, especially from the viewpoint of safety. Ethylcellulose (EC) is frequently used as a hydrophobic polymeric coating material for extended drug release applications [7] and other sustained delivery material, e.g. for controlled herbicide release [8]; nowadays it has also been used in encapsulating experiments for textile application [9].

There are numerous coating methods to fix capsules on textile. However, the surface coating of photochromic capsules usually imparts harsh handle to the fabrics which adversely affects the comfort characteristics of garments made from the fabric [5]. By grafting capsules to textile the palpability of particles can be decreased substantially. Polycarboxylic acids such as 1,2,3,4-butanetetracarboxylic acid (BTCA) and citric acid (CA) are well-known non-formaldehyde, environmental friendly polyfunctional crosslinking reagents, which are appropriate to link capsules covalently by means of ester bonds to the surface of textiles containing hydroxyl groups [10].

The aim of this work was to encapsulate a spirooxazine photochromic dye into ethylcellulose nanocapsules. The nanoparticles were formed by an oil-in-water emulsion process, and bound to cotton fibres using BTCA and CA crosslinkers. The size of nanocapsules was influenced by the polymer concentration of organic phase and by the volume of phases. The photochromic behaviour of capsules was checked by a UV-VIS spectrophotometer, and the effectiveness of crosslinking was determined by FTIR-ATR (Fourier Transform Infrared - Attenuated Total Reflectance) method.

2. PREPARATION OF PHOTOCHROMIC NANOCAPSULES

2.1. Materials

Dichloromethane, polyvinyl alcohol (M_w=30,000-70,000, 87-90 % hydrolized), ethylcellulose (46 mPa s, 5 wt% in 80:20 toluene/ethyl alcohol, 25 °C), sodium dihydrogen hypophosphite, citric acid monohydrate and 5-Chloro-1,3-dihydro-1,3,3-trimethylspiro[2*H*-indole-2,3′-(3*H*)naphth[2,1-*b*](1,4)oxazine] were obtained from Sigma Aldrich. 1,2,3,4-butane tetracarboxylic acid was provided by Merck.

2.2. Synthesis and crosslinking of photochromic ethylcellulose nanocapsules

The nanocapsules were synthesized by an oil-in-water emulsion, solvent evaporation method. Briefly, 100-250 mg ethylcellulose (EC) and 2-14 mg 5-Chloro-1,3-dihydro-1,3,3-trimethylspiro[2*H*-indole-2,3′-(3*H*)naphth[2,1-*b*](1,4)oxazine] were dissolved in 8 ml dichloromethane (DCM) using magnetic stirring. The oil-in-water emulsion was formulated by adding the organic phase into 20 ml distilled water including 1 % polyvinyl alcohol (PVA) then, sonicating the two phases for 2 minutes in an ice bath. The dichloromethane was removed from the droplets by evaporation during magnetic stirring for 4 h under atmospheric pressure at room temperature, while the nanocapsules formed.

Particles were ultracentrifuged (Beckman Optima Max-E) with 30,000 rpm for 25 min, and redispersed in 20 times volume of distilled water. To the suspension BTCA or CA (5 % or 10 %) and constant 5 % sodium dihydrogen hypophosphite as a catalyst was added. Cotton fabrics were impregnated by the nanocapsule suspension that contained the reactants, roll-squeezed, dried and thermofixed at 170 °C for 3 minutes, and finally washed several times with distilled water, until water was clear. Raw and treated samples were dried 30 min at 104 °C before being weighted [11].

2.3. Investigation of nanocapsules

The size of nanoparticles was measured by dynamic laser scattering using a Zetasizer 3600 (Malvern Instruments, Malvern, UK). The average particle size was expressed in volume mean diameter.

The photochromic property of nanocapsules was monitored by UV-VIS spectrophotometry (Tecan Infinite M200). The UV-VIS spectra were drawn after diluting 60 μl nanocapsule suspension (0.5 w/v %), formed in the emulsion process, to 3 ml with distilled water.

The crosslinking of nanoparticles to textile was investigated by weight measurement and Fourier Transform Infrared spectroscopy (FT-IR) using a Perkin-Elmer spectrophotometer including a Golden Gate attenuated total reflection (ATR) attachment with a diamante crystal.

3. CHARACTERIZATION OF PHOTOCHROMIC NANOCAPSULES

3.1. Size of nanocapsules

The size of nanocapsules synthesized in an emulsion process can be affected by numerous parameters. The most important step is to find a suitable emulsifier and adjust its concentration. In our previous study [12] we have found that PVA is a very effective surfactant to emulsify organic droplets in a water phase. According to our former experiences we applied 1 w/v % PVA, thus, fine

nanoparticles were formulated, while the other parameters were appropriate (see in the next paragraph). The increase of the PVA concentration did not influence the size of particles significantly.

After preliminary experiments the organic phase volume was fixed to 40 % related to the aqueous phase (8 ml DCM and 20 ml water containing 1 w/v % PVA). The duration of sonication was 2 minutes, which was found to be sufficient for emulsifying small volume of emulsion. Nevertheless, enhancing the volumes of phases (both organic and aqueous), that is scale-up resulted in increasing size of particles (Table 1), since the sonication time and consequently the emulsifying energy was not elevated simultaneously.

Table 1: Photochromic nanoparticle size (nm) as a function of aqueous phase volume (ml).

Aqueous volume (ml)	Organic volume (ml)	Volume mean diameter (nm)
20	8	216
40	16	242
80	32	335

One of the most important factors on nanocapsule size was the ethylcellulose polymer concentration in the organic solvent. It is obvious that increasing the polymer concentration enhances the viscosity of the oil phase, and the more viscous organic droplets can be dispersed less with the same energy. Figure 1 shows the shift of size distribution to the higher size ranges due to enlarging the EC concentration. Adding 1.25 % ethylcellulose into the organic solution gave a monomodal size distribution with an average size of 216 nm, while homogenizing the organic phase involving 3.13 % polymer resulted in a bimodal size distribution with 612 nm mean diameter.

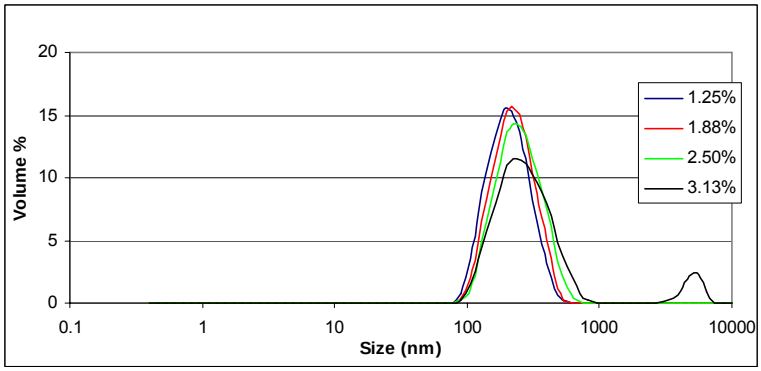

Figure 1: Effect of ethylcellulose concentration in the organic phase on the size distribution of photochromic nanoparticles.

It is noted that the the concentration of photochromic dye did not influence the size of particles substantially.

3.2. Photochromism of ethylcellulose-spirooxazine nanocapsules

The nanocapsules formed in the emulsion-solvent evaporation method showed significant reversible photochromic activity. In order to study their absorbance, the UV-VIS spectra of the investigated spirooxazine and its composite nanocapsules with ethylcellulose were recorded (Figure 2).

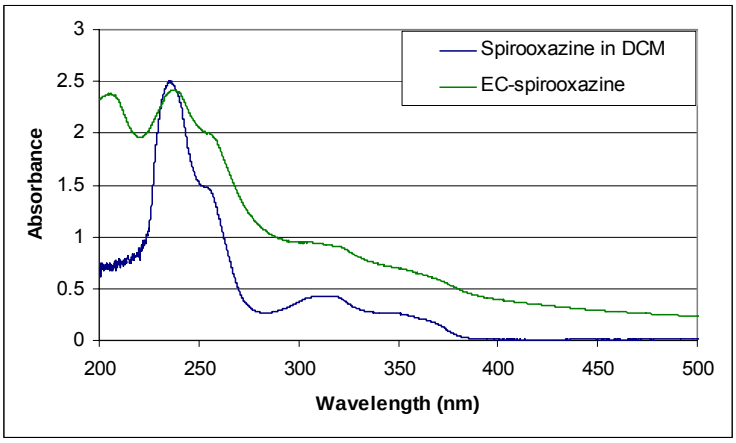

Figure 2: UV-VIS spectra of spirooxazine in dichloromethane and ethylcellulose-spirooxazine capsules dispersed in water.

There are important absorption peaks of spirooxazine in the UV region, and all of them can also be observed in the spectrum of ethylcellulose-spirooxazine nanocapsules, moreover, another peak appears around 210 nm, which is likely the consequence of the scattering of the nanocapsules having comparable size. Figure 3 demonstrates the absorbance is proportional to the concentration of spirooxazine in the nanocapsules. The absorbance of blank nanocapsules must be the result of their scattering, as the absorption of ethylcellulose is negligible.

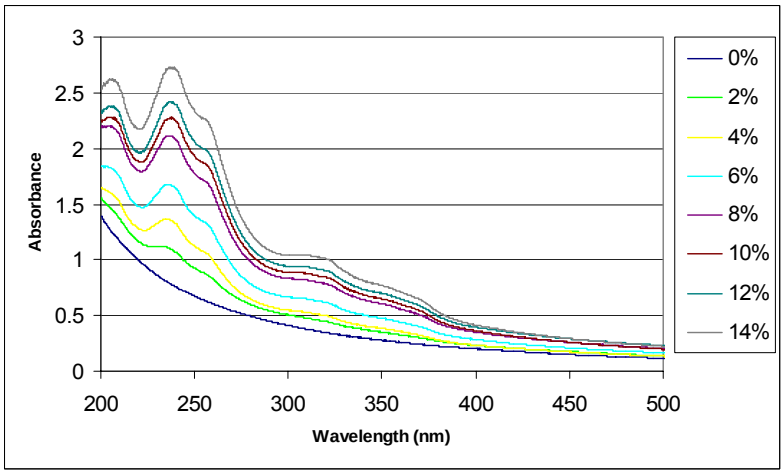

Figure 3: UV-VIS spectra of ethylcellulose nanocapsules containing increasing concentration (0-14 %) of spirooxazine photochromic dye.

The proportionality of spirooxazine concentration and absorbance change can be displayed more spectacularly by correcting the absorbance of photochromic nanocapsules with that of blank nanocapsules. Figure 4 indicates that the corrected absorbances change linearly as a function of the concentration of photochromic dye.

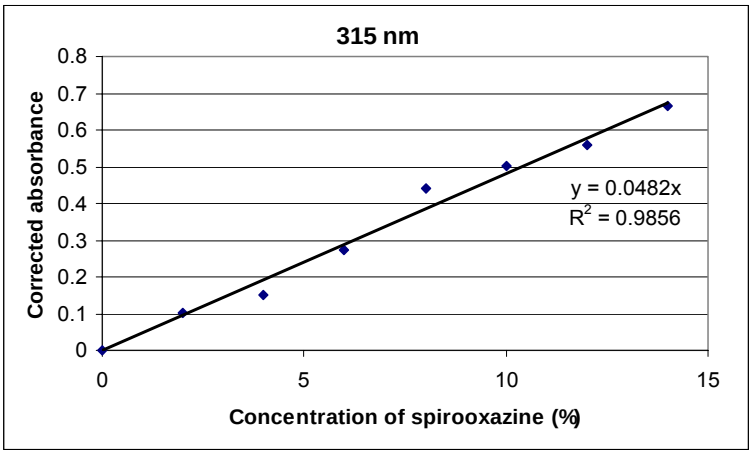

Figure 4: Absorbance of photochromic nanocapsules corrected by that of blank nanocapsules as a function of spirooxazine concentration (%) at 315 nm.

3.3. Binding of photochromic nanocapsules to cotton

Photochromic nanocapsules were linked to cotton by means of BTCA or CA crosslinker. Cotton was impregnated by 200 m/m % (related to textile mass) suspension containing 5 w/v % nanocapsules, sodium dihydrogen hypophosphite catalyst (5 w/v %) and one of the crosslinking reagents (5 or 10 w/v %). This means the total ratio of nanocapsules reacted was 10 m/m % of textile mass. Table 2 shows the crosslinked mass related to the added nanocapsule volume. Since by using 10 % of crosslinking reagents the mass crosslinked was much higher (201 % and 166 % at BTCA and CA, respectively) than the mass of added nanocapsules, it can be concluded that significant amount of the crosslinker was also bound to the surface of cotton. When 5 % crosslinker was applied, the bound mass was approximately equal to the mass of nanocapsules, however, assuming that also the crosslinker weighed substantial part, nanoparticle grafting was likely not so efficient.

Table 2: Crosslinked mass (%) related to added nanocapsule mass due to different concentration of 1,2,3,4-butane tetracarboxylic acid and citric acid.

Crosslinker	Crosslinked mass (%)
BTCA, 5 %	106
BTCA, 10 %	201
CA, 5 %	95
CA, 10 %	166

FTIR spectroscopy can give information about the efficacy of the ester forming during crosslinking. The ester carbonyl band appears around 1735 cm^{-1}, however, carboxyl carbonyl band can be found at 1710 cm^{-1}, hence, the peaks can overlap in this region, and it is difficult to differentiate them. The post-treatment of textile containing bound nanocapsules by an alkaline solution (0.1 M NaOH) converts the acid to carboxylate anion, which absorbs at 1550-1610 cm^{-1}. Figure 5 shows that in all of the four different crosslinking process ester bonds were formed, however, as it was expected 10 % of BTCA or CA (Fig. 5 B and D, respectively) resulted in higher amount of ester bonds. In the cases of 5 % crosslinkers usage (Fig. 5 A and C), the anyway smaller absorption peaks around 1735 cm^{-1} decreased more substantially after alkaline treatment, that might have been caused by the cleavage of some portion of ester bonds.

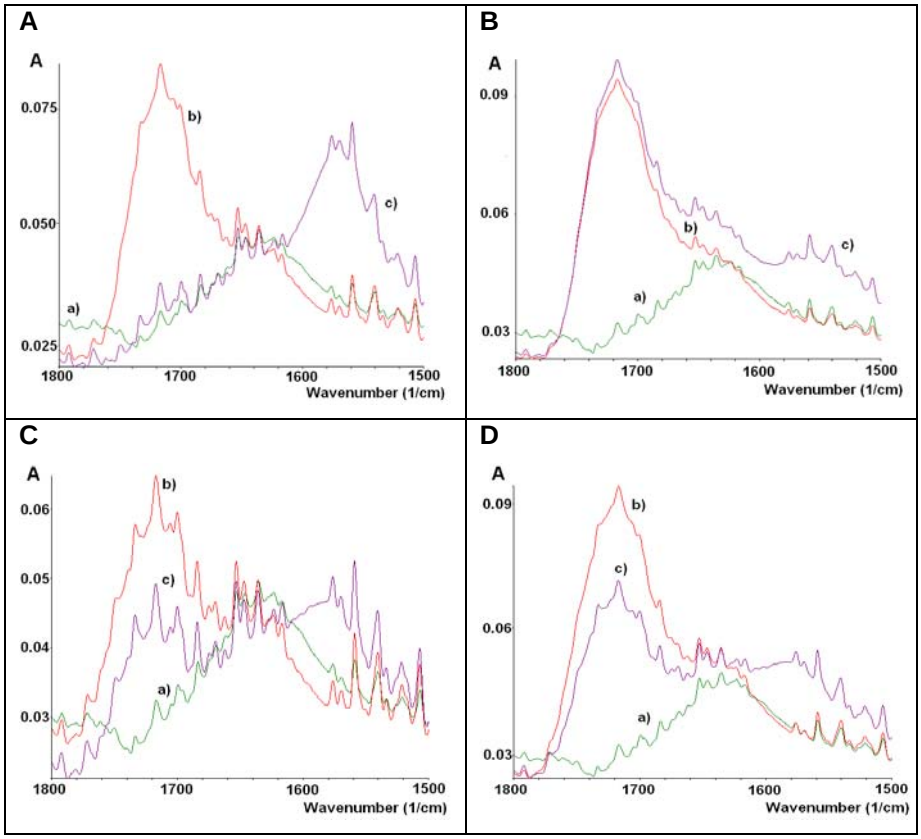

Figure 5: FTIR spectra of cotton consisting of crosslinked nanocapsules, crosslinkers: A: 5 % BTCA, B: 10 % BTCA, C: 5 % CA, D: 10 % CA, spectra: a) pure cotton, b) cotton with crosslinked nanocapsules, c) cotton with crosslinked nanocapsules after alkaline (0.1 N NaOH) treatment.

4. CONCLUSIONS

Photochromic spirooxazine was encapsulated into ethylcellulose nanoparticles, and the photochromism of particles was proportional to the dye concentration in a wide range, as was shown by UV-VIS measurements. The nanocapsules were attached effectively to cotton by polycarboxylic acid crosslinkers. The main advantage of this method was the use of biocompatible encapsulating polymer and non-toxic crosslinking agents. However, it must be mentioned that the nanocapsules lost most of their photochromic activity during the grafting due to the high temperature (170 °C) applied. In order to eliminate this problem, other catalyst (e.g. cyanamide) could be used in the crosslinking process, that enable much lower reaction temperature, or another photochromic dye with higher termostability might be encapsulated.

ACKNOWLEDGMENTS

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PROPERTIES OF RECYCLED PET NON-WOVEN FABRICS FOR BUILDINGS

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Abstract

In our world, plastics waste has more than 10% share of all solid waste. Although developed countries have been searching biodegradable or environmentally-friendly plastics, existing production and usage of common plastics are still too much. The relatively low costs of production combined with large design flexibility make plastics favourable. PET offers mechanical strength and clarity, and has been particularly successful in taking a major share of carbonated drinks market.

PET bottles have been recycled for more than thirty years and usage of recycled PET fibres is very popular in felting industry during last ten years. Recycled PET fibres find applications in technical areas such as composites, floor coverings and thermal insulation products for building constructions.

In this research, non-woven fabrics with different recycled PET fibre ratio were produced. These types of fabrics are commonly used for building constructions especially for floor protections and thermal insulations. Five different non-woven fabrics with three different weights were produced in needle-punching machine. Some properties of these fabrics such as thickness, weight, drape, bending rigidity, breaking load, and air, thermal and water vapour permeability were evaluated. Apparently, blending ratios of recycled PET fibres and production weights have affected properties of these non-woven fabrics.

Key words: Virgin polyester, r-PET, PET bottles, recycling, needle-punching

1. INTRODUCTION

New advances as a result of the changing needs emerging since the existence of man have been continuing increasingly. The technology which has developed parallel to the protection, shelter, food and covering oneself has brought advantages and disadvantages. The effort to eliminate these disadvantages has been the biggest challenge of the 21st century. That the world population has increased rapidly and the eco-systems and living being have to be protected have give rise to socio-economic and political conflicts among the countries.

The natural sources have been depleted and the idea to eradicate the waste resulting from technology or to keep the waste away from the residential zones has been an issue in home politics. People, with their desire to get rid these wastes, have thought that they have gotten rid of these by just releasing them to the air, the water or the soil. Being aware of this misconception, man has started to try to keep the waste at the minimum even during the production process by building filters on the chimneys, by building water treatment plants and processing contaminated water in these plants and getting to a level which is not harmful for the water organisms, by building special areas for the solid wastes and producing energy through burning these, which are a few examples of the efforts. A survey carried out in the USA has shown that the waste amount between 1960 and 1990 was twice as much as the

waste amount between 1990 and 2005 [1]. However, in the second period the recycling is five times more than the first period, which indicates that recycling has gained a considerable importance.

The relatively low costs of production combined with large design flexibility make all plastics agreeable. PET offers mechanical strength and clarity, and has been particularly successful in taking a major share of carbonated drinks market. PET bottles have been recycled for more than thirty years and usage of recycled PET fibres is very popular in felting industry during last ten years. Recycled PET fibres find applications in technical areas such as composites, floor coverings and thermal insulation products for building constructions.

2. RECYCLING OF PET BOTTLES

PET is the abbreviation for polyethylene terephthalate. It is a polyester which is formed by polycondensation of two monomers called ethylene glycol and purified terephthalic acid. Water is released during polycondensation process of polyester. During recycling PET, water should been stayed away because the process is reversible. Contacting water leads the decomposing or weakening of polymer. PET is produced from either crude oil or natural gas. PET is thermoplastic material which liquidize at higher temperatures. Depending on the production temperature PET can be amorphous or crystalline. This results in an opaque or glass clear appearance of the material. Since PET is clear, flexible but tough, neutral in taste, has low weight, good at gas and moisture preventing and recyclable, PET is a very suitable material for beverage bottles. Recycling circle of PET bottles is shown in Figure 1[2].

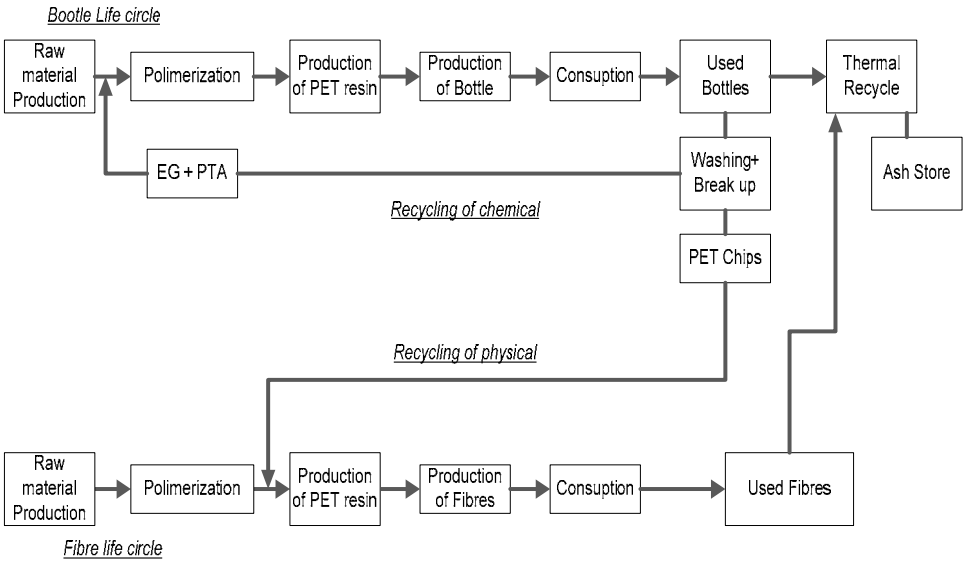

Figure 1 Recycling of PET Bottles [2]

PET bottles can be recycled by mechanical and chemical processes.

a) Mechanical or material recycling of plastics involves a number of treatments and operations: sorting and separation, washing to remove dirt and contaminants, grinding and crushing to

reduce the plastic particle size, rinsing and drying, cutting into required sizes. In separation, different materials and coloured bottles are separated. Removing dirt, dust and labels is performed by water grinding machine. Small pieces then are dried at 140-170˚C during 3-7 hours [3]. PET granules then are sent to extrusion unit. Mechanical recycling circle of PET bottles is schematized in Figure 2 [4].

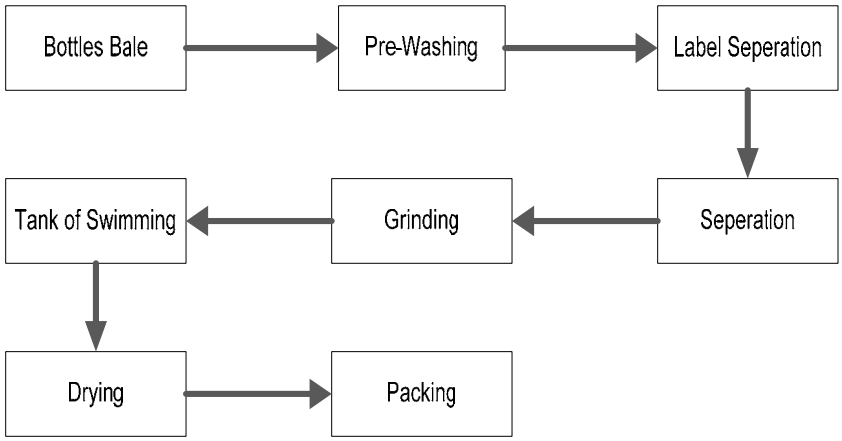

Figure 2 Mechanical Recycling of PET Bottles [4]

b) Chemical recycling consist of the breakdown of the polymer by reaction with certain chemical agents, leading back to initial monomers. These monomers are identical to those used in the preparation of virgin polymers hence the plastics prepared from both depolymerization and fresh monomers are used. Ammonolysis, aminolysis hydrolysis, and methanolysis are the methods of PET depolymerization. Chemical recycling circle of PET bottles is shown in Figure 3 [4].

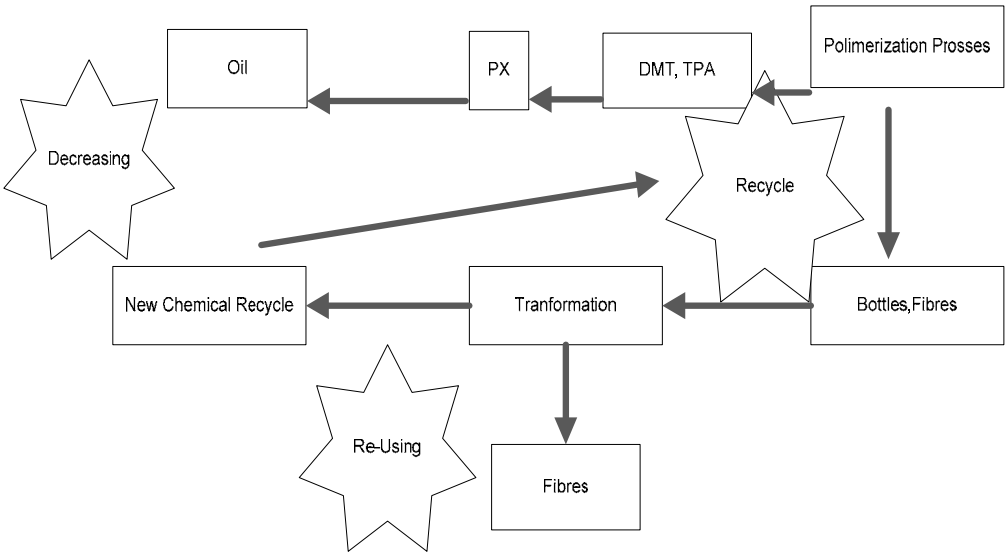

Figure 3 Chemical Recycling of PET Bottles [4]

Many researchers have been focused on plastic production, plastic waste usage and recycling of PET. Sahajwalla used plastic waste instead of cocking coal during steel production [5]. Kotov has produced a type of plastic thin like paper and strong like steel. This material is biodegradable [5]. İyim has hydrolyzed PET in phenol [6]. Masaiko has reported that 1 kg PET flake and 1.133 kg PET polymer by mechanical recycling and by chemical recycling respectively can be reproduced from 1.246 kg PET bottle bale [7]. Hassani and his colleagues used PET waste instead of metal in asphalt composition. New material has less weight and helps less usage of natural sources [8]. Anabal developed a method to separate PET and PVC electrostaticly [3].

3. TECHNICAL USAGE OF RECYCLED PET

Recycled products have created new sources of raw materials, especially in the production of technical textile areas. In the last two decades, the rapid increase in the use of technical textile applications has been reported. These application areas have been categorized into twelve groups according to Techtextil, Messe Gmbh Frankurt [9]. These are agrotech (agriculture, horticulture, forestry and fishery products), buildtech (textiles used in buildings and constructions), clothtech (clothing and technical components of the shoes), geotech (geological and civil engineering materials), hometech (furniture, home textiles and technical components of the coatings), indutech (filtration, transport, cleaning textiles for industrial applications), medtech (hygienic and medical products), mobiltech (automotive, ship, rail and air transport textiles), oekotech (textiles for environmental protection), packtech (packaging materials), protech (textiles for personal protection), sportech (sport and leisure clothing).

As seen from this classification textiles used in building constructions is a separate class. Textiles used in building can be classified into three groups which are architecture, geotextile and buildings. Textiles used in architecture are cheap and versatile resources especially for roof construction and design. Geotextiles is used in earth applications such as drainage, road construction, and dams. Textile surfaces except from composite materials are used in buildings to fulfil heat and sound insulation functions.

Technical performances of construction textiles used for insulating function should fulfil some standards. Physical and mechanical properties such as tensile strength, elongation, bending strength, thickness, weight, drape, water vapour permeability, and thermal resistance are important.

In recent years, General Electric and Mrc Polymers have used 50-60% waste PET in automobile bumpers, wind shield, and wheel cover production [6]. Hon and Buhion has researched the productiblety of different blending ratio of PET and HDPE [10]. Kawamura and his colleagues have produced powder coating resin from recycled PET. They have found out similar properties of coating

resins produced both recycled and virgin PET [11]. Abbasi and Mojtahedi have studied the effects of structural and physical properties of recycled PET Filament yarns on spinning speed [12].

4. OUR RESEARCH

In the study we have performed virgin PET and r-PET fibres have obtained. Then, five different blends of these fibres have formed as follows: 100 % PET; 70% PET and 30 % r-PET; 50% PET and 50 % r-PET; 30 % PET and 70 % r-PET; 100 % r-PET. Since blends consisted of synthetic fibres, they were laid to rest for 24 hours after anti static materials were applied to prevent electrification. Then non-woven fabrics using these blends have been produced in three different weights 150g/m^2, 250g/m^2, and 500 g/m^2. Throughout production fibre feeding direction, machine calibration, needle direction, needle shape and size and all the conditions have been kept stable. Before the production, the length and finesse of the fibres have been examined together with cross-sections and no differences have been found. Only virgin PET fibres have two times more crimp than r-PET fibres. Air permeability, thickness, weight, drape, bending resistance and tensile strength tests have been carried out to evaluate these 15 fabrics. Data obtained from the different blends with same weights and same blend with different weight have been examined. The average of results has been shown in table 1.

	Fabrics	Air Permeability (l/m^2/s)	Weight (g/m^2)	Thickness (mm)	Drape (%)	Bending Resistance (Mac. Dir) (mg.cm)	Bending Resistance (Opp. Mac. Dir) (mg. cm)	Tensile Strength (Mac. Dir.) (N)	Tensile Strength (Opp .Mac. Dir.) (N)	Thermal Concudtivity (W/mK)	Thermal Absorption (Ws$^{1/2}$/m^2 K)	Thermal Resistance (m^2 K/W)	Relative Water Vapour Permeability (%)
First Group	100% RPET	2973,0	165,075	0,250	92,9385	257,517	289,8717	70,139	142,689	0,0318	31,9567	0,1268	24,8300
	70% RPET 30% PET	3716,0	112,425	0,218	89,4786	77,573	136,7088	42,768	57,775	0,0317	36,1633	0,1044	25,8700
	50%RPET 50% PET	3655,0	117,625	0,253	91,9590	81,161	162,55775	25,155	39,347	0,0312	35,8000	0,1068	27,3700
	30% PRET 70% PET	3602,0	116,275	0,223	88,6756	80,230	123,2515	29,029	35,128	0,0315	38,1433	0,1034	25,3700
	100% PET	2941,0	136,400	0,353	95,8032	165,862	268,4352	27,112	46,103	0,0312	31,9567	0,1268	24,8300
Second Group	100% RPET	1454,0	308,825	1,353	97,5982	919,990	1439,1245	177,995	448,543	0,0361	51,8300	0,1117	20,6000
	70% RPET 30% PET	1843,0	244,850	0,738	96,1966	542,604	1354,656	142,220	339,152	0,0322	50,9633	0,1090	25,4700
	50%RPET 50% PET	1764,0	243,900	0,955	96,5484	526,824	876,3327	120,848	248,341	0,0319	55,3267	0,1143	25,8700
	30% PRET 70% PET	1646,0	246,550	0,945	95,9230	433,188	433,188	108,409	221,950	0,0349	56,5000	0,1038	24,0000
	100% PET	1261,0	306,900	1,648	97,4347	1206,117	1430,154	146,728	363,488	0,0321	50,3067	0,1342	23,8000
Third Group	100% RPET	806,7	540,100	2,848	98,7639	5162,701	4513,704	495,957	967,249	0,0332	68,4033	0,1624	19,5000
	70% RPET 30% PET	945,8	395,650	1,385	96,1944	2170,932	5246,319	397,449	803,170	0,0351	68,3467	0,1151	24,4000
	50%RPET 50% PET	1075,6	400,625	1,940	97,8471	1838,869	4158,4875	301,704	514,946	0,0316	62,6000	0,1481	22,4300
	30% PRET 70% PET	864,7	477,800	2,123	97,7479	2420,057	4357,536	247,002	465,523	0,0332	59,0433	0,1702	20,2000
	100% PET	751,20	635,73	2,82	97,86	9464,04	5797,81	296,91	380,77	0,03	58,93	0,18	18,93

While the production weight increases from 150 g/m^2 to 500 g/m^2 it was observed that the air permeability of fabrics has decreased. Increasing the production weight results in more weight and thickness thus less space between fibres allows less air transmission. Air permeability values of fabrics produced 100% PET and 100% r-PET are quite similar and more than that blended fabrics. However, when air permeability values of blended fabrics have been examined increasing virgin PET ratio causes slight decrease on air permeability vales. This is because either blending two types of fabric may cause more orientation between fibres or higher crimp values of virgin PET may cause more firmness.

Increasing production weight from 150 g/m^2 to 500 g/m^2 under constant production circumstances also has raised reasonably weight and thickness values of fabrics. Thickness and weight values of 100% PET and 100% R-PET fabrics are fairly close. Nonetheless, increasing virgin PET ratio in blended fabrics has resulted in small raise in weight and thickness values of blending fabrics.

Although higher weight and thickness of fabrics have created higher drapeability, different blending ratios have no important effects statistically on drape properties. Bending rigidity has tested on both machine direction and opposite of machine direction. Higher weight and thickness have caused higher bending rigidity in both directions. Different blending ratios have no significant effects on bending rigidity.

Tensile strength of all type of fabrics has examined on both machine and opposite machine direction. Increasing production weight from 150 g/m^2 to 500 g/m^2 has raised tensile strength of all type of fabrics. However, increasing blending ratio of r-PET has resulted in higher tensile strength. This may be because of higher individual fibre strength of r-PET.

The effects of different production weights and blending ratios on thermal conductivity and thermal resistance are not statistically significant. Increasing production weight has caused higher thermal absorbency. Relative water vapour permeability results have decreased with higher production weights.

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PROTECTIVE TEXTILES

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ABSTRACT

For millions of years man had struggled against environmental conditions and had made an effort to protect himself from the hazards. At the beginning the hazards were consisted of main subjects like cold and rain. But as the technology improved to supply new requirements and the style of life changed, so the range of hazards became ever more complex and specific species of them obtained such as fire, chemical and mechanical impact.

In 21. century developing technology, globalization, changes in climates, improvements in industry and cold warms that have been still between countries enforces human beings to be protected from hazardous conditions. Among the equipments that supply protection, textile products come first. There are a lot of specialties to be cared about the process that will be implemented on the textiles from the choice of raw material to the finished product in protective textiles. Nonetheless, the external impacts that have to be protected by the finished product displays differences from each other. When these impacts are looked over by the main titles, protective clothing can be divided into the groups such as protective clothing against heat and flame, protective clothing against mechanical impacts , firemen's protective clothing , protective clothing against cold, protective clothing against foul weather (moisture, wind, cold), protective clothing against chemical substances (gases, liquids, particles), protective clothing against radioactive contamination, protective clothing against electrostatic charges and high visible warning clothing.

Textile materials for protective clothing have to meet a wide range of technical and, in most cases, complex requirements and functions as a protection against the hazards such as thermal (fire, heat, electrical arcs, extreme cold), mechanical (cut, abrasion, ballistic and impact resistance), chemical (liquid, gas, dust), microbiological (biological and nuclear protection), electrostatic, absorbent (UV, energized radiation) and electrically insulating. In this study, information was given about the groups of protective textiles and the hazards that have been mentioned above.

1. INTRODUCTION

Scientific advancements made in various fields have undoubtedly increased the quality and value of human life. It should however be recognized that the technological developments have also exposed us to greater risks and danger of being affected by unknown physical, chemical and biological attacks. For example in the past main objective of military protective clothing was to protect the soldier from environmental effects such as rain, snow, cold, heat and wind as well as to give him freedom maneuver. With the development of chemical, biological, thermonuclear and more effective fragmentation weapons, small arms surveillance and sensor systems the requirements for military protective clothing have increased dramatically. One such currently relevant danger is from bioterrorism and weapons of mass destruction. In addition, we continue to be exposed to hazards from fire, chemicals, radiation and biological organisms such as bacteria and viruses. Fortunately, simple and effective means of protection from most of these hazards are available. Textiles are an integral part of most protective equipment. Protective clothing is manufactured using traditional textile manufacturing technologies such as weaving, knitting and non-wovens and also by specialized techniques such as 3D weaving and braiding using natural and man-made fibers [1, 41].

The driving force for the changes in the textile industry is mainly the shift from developing and producing textiles purely for clothing purposes to more advanced applications such as heating, cooling and protection (shielding, anti-radar, flame-retardant properties, sensing and actuating amongst other applications) [16]. The U.S. market for advanced personal protective equipment (PPE) was valued in 2005 at ~2 300 million USD per year [26]. According to a study from IFAI (the Industrial Fabrics Association International) the research on the state of the industry shows that in 2007 the world market for technical textiles/specialty fabrics was estimated to be around 21 million tons, accounted for a value of around US$115 billion [21].

The variety of protective functions that needs to be provided by different textile products is considerable and diverse. It includes protection against cuts, abrasion, ballistic and other types of severe impact including stab wounds and explosions, fire and extreme heat, hazardous dust and particles, nuclear, biological and chemical hazards, high voltages and static electricity, foul weather, extreme cold and poor visibility [2].

In textile terms, protection and defence can be a passive response in which the textile product receives and absorbs the impending impact or energy in order to protect the underlying structure. Ballistic garments are obvious examples, where the assembled fibrous material is deliberately designed to slow down and reduce the penetration of an incoming projectile. But they may also have a more active role, where the fibres show positive response by generating char or protective gases, shrinking or expanding to prevent penetration of moisture or vapour and so on. In each scenario, the protection of the underlying structure is the common objective [2].

There are in principle three types of protective suits: air and water vapor impervious protective suits which are equipped with layer of rubber impervious to chemical poisons, and which very rapidly lead to a buildup of heat; air and water vapor pervious protective suits, which offer the highest wear comfort; and finally protective suits which are equipped with a membrane which is pervious to water vapor but not to the poisons mentioned [11].

Protective clothing is now a major part of textiles classified as technical or industrial textiles. Protective clothing refers to garments and other fabric-related items designed to protect the wearer from harsh environmental effects that may result in injuries or death. Today, the hazards that we are exposed to are often so specialized that no single type of clothing will be adequate for protection. Extensive research is being done to develop protective clothing for various regular and specialized civilian and military occupations. Providing protection for the common population has also been taken seriously considering the anticipated disaster due to terrorism or biochemical attacks [1].

In addition, most situations generally involve a combination of several types of hazards, thus requiring a multirisk approach. In the absence of appropriate protection, this may eventually lead to the need for superimposed layers of protective clothing, each corresponding to a certain type of risk, with all the

drawbacks this implies in terms of loss of dexterity and motion freedom, among others. Indeed, in addition to protection requirements, functionality and comfort must be carefully considered during PPE (Personal Protective Equipment) selection since it controls the impact of PPE on task performance and even the wearer's health. Unsatisfactory PPE functionality and comfort may also lead people to decide not to wear necessary PPE [26].

2. CLASSIFICATION

Classifying personal protective textiles is complicated because no single classification can clearly summarize all kinds of protection. Overlap of the definitions is common since there are so many occupations and applications that even the same class of protective clothing often has different requirements in technique and protection. Depending on the end use, personal protective textiles can be classified as industrial protective textiles, agricultural protective textiles military protective textiles, civilian protective textiles, medical protective textiles, sports protective textiles and space protective textiles. Personal protective textiles can be further classified according to the end-use functions such as thermal (cold) protection, flame protection, chemical protection, mechanical impact protection, radiation protection, biological protection, electrical protection and wearer visibility. Their relationship is illustrated in Fig. 2 [1].

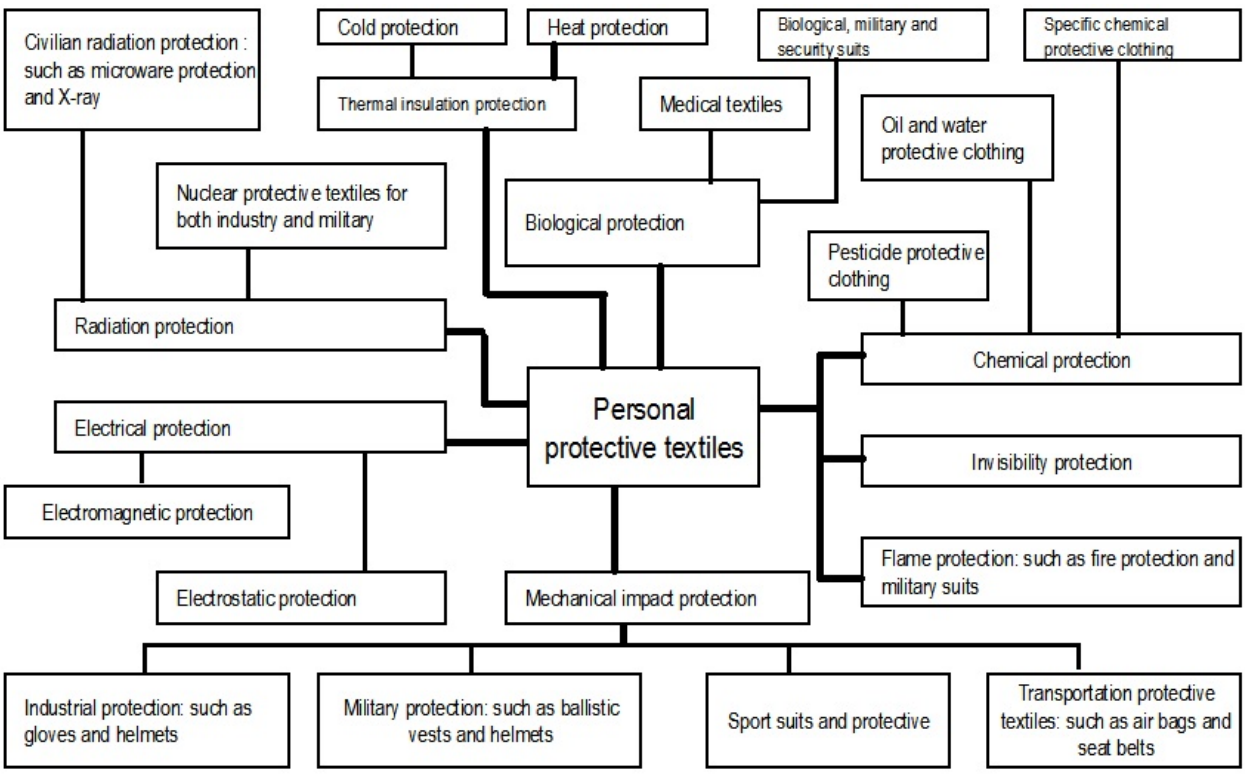

Figure 2. Schematic classification of protective textiles [1]

2.1. Fire Protection

All the fires including textile, furnishings and clothing have the common feature that the textiles present at each scene functioned as the material first ignited by the relevant igniting source. Secondly and subsequently, the speed with which this caused the fire to grow and spread to adjacent materials was a significant feature in the inability of victims to escape or the fire fighters to bring the fires under

control. Therefore, these catastrophic fires serve to demonstrate more obviously the ignitability of textiles in the first place followed by the associated speed with which the resulting fire can grow. It is rarely the direct causes of the fire, such as burn severity which are the prime causes of death, however, but the effects of the smoke and emitted fire gases which cause disorientation and impede escape initially followed by subsequent incapacitation asphyxiation and death. Only in clothing related fires are injury and death caused primarily by burns, especially when garments are loose-fitting and worn directly over the body as are nightwear and summer dresses [3].

Human tissue (skin) is very sensitive to heat. It is reported that, at 45 °C, the sensation of pain is experienced, and at 72 °C the skin is completely burnt [1]. No textile-based material can withstand the power and ferocity of a fire for sustained periods of greater than 10 min or so [2]. The purpose of fire-protective clothing is to reduce the rate of heating of human skin in order to provide the wearer enough time to react and escape. The time that a wearer stays in flame circumstances and the amount of heat flux produced are important factors for designing the protective stratagem. Under normal conditions, only 3-10 seconds are available for a person to escape from a place of fire with a heat flux of about 130-330 kW/m^2 . Fibers commonly used for textiles are easily burnt. Untreated cotton will either burn (flaming combustion) or smolder (smolder combustion), whenever it is in the presence of oxygen and the temperature is high enough to initiate combustion [1].

Original firefighters' protective clothing against heat and flame used natural materials such as cotton, wool and leather, with possible treatment with fire retardant agents. Over the last 40 years, new synthetic fibers with better thermal, chemical and mechanical resistance have been developed [8]. Their application to firefighters' protective clothing was driven by the improved protection they offer as well as the reduction in physical constraints associated with wearing the bulky suits. The current firefighters' protective clothing technology is based on six synthetic fibers, Nomex® (meta-aramide, DuPont), Kevlar® (para-aramide, DuPont), PBI (polybenzimidazole, Performance Products), Basofil® (melamine, Basofil LLC), Zylon® (polyphenylene benzobisoxazole, Toyobo) and PI (polyimide, Inspec Fibres GmbH). Polyurethane and polytetrafluoroethylene (PTFE) are used as the moisture barrier semipermeable coating [26].

Protective clothing designed for flame protection must have two functions, i.e., be flame-resistant and form a heat barrier. The latter is a very important factor if the wearer needs to stay near flames for a fairly long time. In fact, the danger of burning lies with the parts of the body not covered by clothing, confirmed by statistics showing that 75% of all firefighter burn injuries in the USA are to the hands and face. Flame-retardant clothing is generally used for occupation uniforms. Increasing government regulations and safety concerns necessitate that certain classes of garments and home textiles such as children's sleepwear, carpets, upholstery fabrics and bedding be made flame-retardant or resistant. Using inherently flame-retardant materials such as Kevlar and Nomex, applying a flame-retardant finish or a combination of these methods are commonly used to make clothing and textiles flame retardant [1].

Flame-retardant finishes provide textiles with an important performance characteristic. Protection of consumers from unsafe apparel is only one area where flame retardancy is needed. Firefighters and emergency personnel require protection from flames as they go about their duties. Floor coverings, upholstery and drapery also need protection, especially when used in public buildings. The military and the airline industry have multiple needs for flame-retardant textiles. The requirements for a commercially successful flame-retardant textile product have been given as meeting flammability requirements: having little or no adverse effect on the textile's physical properties; retaining the textile's aesthetics and physiological properties; being produced by a simple process with conventional equipment and inexpensive chemicals; and being durable to repeated home launderings, tumble dryings and dry cleaning [4].

New materials and designs have been developed for heat protective clothing. For example, improved thermal insulation can be provided by nonwovens made with thin hollowed fibers and can be made thermo-adaptive with two-way shape memory alloys like nickel-titanium. Better thermoregulation inside the garment is sought with phase change materials, either encapsulated or incorporated in a matrix. Other solutions use external power, e.g., for liquid coolant circulation or with Peltier cells embedded in the textile [26].

In addition, coated textile materials are common applications for protection against flame and are based on the synergy between antimony and bromine, usually decabromodiphenyl ether. This construction is common in furniture and other similar seating and bedding products, but also in other technical textile items [19].

2.2. Heat and Cold Protection

An ideal clothing fabric, in terms of thermal comfort, should have the following attributes: (1) high thermal resistance for protection from the cold; (2) low water vapour resistance for efficient heat transfer under a mild thermal stress conditions; and (3) rapid liquid transport characteristics for transferring heat efficiently and eliminating unpleasant tactile sensations due to perspiration under high thermal stress conditions [14].

Extremely cold weather protective clothing refers to garments that are used in extreme climates such as in skiwear, mountaineering and for army personnel posted in hilly areas at high altitudes. For this purpose, clothing that provides a high degree of insulation with the least amount of bulk is most desirable. For such applications, breathable membranes and coatings, and high-loft battings of special fibres in conjunction with reflective materials have been suggested. The protection of an individual in a cold environment would depend on the following main factors: (1) metabolic heat, (2) wind chill, (3) thermal insulation, (4) air permeability and (5) moisture vapour transmission. Survival depends on the balance of heat losses due to (2)—(5) and heat output due to metabolic heat [14].

Basic metabolisms occurring inside our body generate heat that can be life saving or fatal depending on the atmosphere and circumstances that we are in. Normally, human bodies are comfortable to heat in a very narrow temperature range of 28-30 °C (82-86 °F). In summer, we need the heat from our metabolic activity to be transferred outside as soon as possible, while in winter, especially in extremely cold conditions, we must find ways to prevent the loss of heat from our body. Heat stress, defined as the situation where the body cannot dissipate its excess heat to the environment is a serious problem especially during physical working [1].

Basically, heat is transferred either as conductive, convective, radiant heat or a combination of these modes depending on the source of heat, the atmosphere the heat-absorbing material is in and the protection available against heat. Any heat transfer will have at least one of these modes and heat protection is the method to decrease or increase the rate of heat transfer. For protection from conductive heat, fabric thickness and density are the major considerations, since air trapped between fibers has the lowest thermal conductivity of all materials. For protection from convective heat (flame hazard in particular), the flame-retardant properties of the fabric are important. As for radiant heat protection, metalized fabrics such as aluminized fabrics are preferred, since metalized fabrics have high surface reflection and also electrical conductivity. Ideal clothing for protection from heat transfer are fabrics with thermo-regulating or temperature-adaptable properties. Phase change materials (PCM) are one such example that can absorb heat and change to a high-energy phase in a hot environment, but can reverse the process to release heat in cold situations [1]. More than 500 different phase change materials have been documented by NASA [14]. The impact of phase-change materials (PCM) on intelligent thermal-protective clothing has been investigated by researchers. Phase change materials possess the ability to change their state with a certain temperature range. These materials absorb energy during the heating process as phase change takes place, otherwise this energy can be transferred to the environment in the phase change range during a reverse cooling process. Textiles containing phase change materials react immediately with changes in environmental temperatures, and the temperatures in different areas of the body. When a rise in temperature occurs, the PCM microcapsules react by absorbing heat and storing this energy in the liquefied phase change materials. When the temperature falls again, the microcapsules release this stored heat energy and the phase change materials solidify again. The thermal insulation capabilities of cold protective clothing materials may be significantly improved by the incorporation of Micro- PCM, these capsules containing small amounts of PCM [36]. Comparing heat absorption during the melting process of a phase-change material (PCM) with those in a normal heating process, a much larger amount of heat is absorbed if a PCM melts. A paraffin-PCM, for example, absorbs approximately 200 kilojoules per kilogram of heat if it undergoes a melting process. In order for a textile to absorb the same amount of heat, its temperature would need to be raised by 200K [16].

Specifically designed protective clothing is necessary to survive and operate in temperatures below -30 °C. Such low-temperature conditions are aggravated in the presence of wind, rain or snow leading to cold stress that may be fatal. The most effective method of cold protection is to avoid or

decrease conductive heat loss. Clothing designed to protect from cold is usually multi-layered, consisting of a non-absorbent inner layer, a middle insulating layer capable of trapping air but transferring moisture, and an outer layer that is impermeable to wind and water. Temperature-adaptable clothing that can protect from both heat and cold has been developed by fixing poly-ethylene glycol to cotton at different curing temperatures [1].

In addition to basic protection against weather conditions are clothes, including fur. The aesthetic and practical advantages of animal fur are the reasons why this material has always been in wide use in spite of the progress in the textile industry. Due to environmental premises, textiles imitating natural fur – so called knitted fur fabrics - have been introduced into production. The main aim of the production of such textiles is give them all the properties of natural fur – the so-called “naturalisation” of knitted fur fabrics [15].

2.3. Chemical Protection

Chemical protective clothing (CPC) should be considered the last line of defense in any chemical-handling operation and every effort should be made to use less hazardous chemicals where possible, or to develop and implement engineering controls that minimize or eliminate human contact with chemical hazards [1]. On other hand, the design of nuclear, biological, and chemical (NBC) protective clothing is focused on protection against external threats and not on environmental weather conditions [5]. Such clothing is widely used by for example soldiers, fire fighters and rescue workers [6]. Chemical agents are used in warfare to attack the organs of the human body in such a way that they prevent organs from functioning normally. The result is usually disabling to a varying degree or fatal [7]. NBC protective apparel is thus traditionally produced either from completely impermeable systems (suits composed of butly rubber, for example) or permeable, adsorptive filter systems based on activated carbon (powders, fibers or spherocarbon) [11].

Obligations of the countries ensuing from the convention for the prohibition of chemical weapons do not reduce the actuality of the protection. Terrorist acts during last decades with use of chemical and biological weapons enforce not only elaboration of new more efficient protection means, but permanent development and improvement of methods and means for consequence management [12].

In spite of numerous researches devoted to improve methods and means for special treatment efficiency of decontamination in a number of instances does not correspond to the new requirements. An explanation for this from one side is the higher level of toxicity of the new chemical warfare agents small quantities of which could be very dangerous to humans and, from the other side, the process of decontamination is dependent both on methods and decontamination ability and specific properties of the contaminated object [12].

The United States Military has a high need for rapidly deployable, lightweight, soft-walled structures that are capable of providing rugged protection from chemical and biological (CB) warfare agents. The versatility of these structures serve command and control, medical, and rest and relief functions with minimal time and effort. Speed and ease of deployment are critical due to the time constraints involved in a contaminated environment. The theory of rapidly deployable structures for collective protection has existed for decades, but the design challenges, logistics, and cost associated with such a structure have been a tremendous burden to overcome [8].
Important considerations in designing chemical protective clothing are the amount of chemical permeation, breakthrough time for penetration, liquid repellency, and physical properties of the CPC in specific chemical conditions. Chemical protective clothing can be categorized as encapsulating or non-encapsulating based on the style of wearing the clothing. The encapsulating system covers the whole body and includes respiratory protection equipment and is generally used where high chemical protection is required. The non-encapsulating clothing is assembled from separate components and the respiratory system is not a part of the CPC. Traditionally, used disposable clothing also offers resistance to a wide range of chemicals and some disposable clothing can be repaired using adhesive patches and reused before being disposed. Chemicals that are in liquid form are more often used than solid chemicals. Therefore, chemical protective clothing should be repellent or impermeable to liquids [1].

Three new orientations of research for protective clothing against chemicals are currently being investigated: selective blocking of toxic chemicals, chemical destruction of toxic materials that contact the fabric and detection of hazardous agents [26].

Developing pesticide-resistant clothing has received considerable attention from researchers since exposure of skin to pesticide is a major health hazard to farmers. Clothing currently used for pesticide protection does not give adequate protection, especially to the hands and thighs, even if farmers use tractor-mounted boom sprayers with a closed cabin and wear protective clothing with gloves and rubber boots. Other important functions of chemical protective clothing are to protect from chemicals present in the air such as toxic and noxious gases or fumes from automobiles, dust and microorganisms present in the air. Safety masks containing activated carbon particles which can absorb the dust present in the atmosphere are commonly used against air pollution [1].

2.4. Mechanical Impact Protection

2.4.1. Ballistic Protection

Ballistic protection is generally required for soldiers, policemen and general security personnel. Ballistic protection involves protection of body and eyes against projectiles of various shapes, sizes, and impact velocities [1]. The bulletproof vest is a functional clothing item. Its major capability is protecting life. Specialized materials must be used in bulletproof vests to enhance their performance; therefore, the bulletproof vest is heavy and uncomfortable. If a bulletproof vest is uncomfortable, it is inconvenient and reduces mobility. This not only reduces work efficiency, but also allows the wearers'

lives to be threatened as they are in a dangerous situation. Thus, the manufacturer must ensure that bulletproof vests are comfortable in order to improve the inclination of police officers to wear them [38]. In the early days, leather and metal mesh garments were used to protect the body against sword and spear attacks, but with the passage of time development of new materials occurred and, for example, early in the 1940s, nylon-based flack jackets48 were introduced. They were a considerable improvement on the leather and metal garments but were still rather heavy and uncomfortable to wear. With the advent of *para*-aramids in the early 1970s, advanced fibres were for the first time used to make much more acceptable protective gear. In these garments, Kevlar or Twaron continuous filament yarns are woven into tight structures and assembled in a multilayer form to provide maximum protection. Their high tenacity and good energy absorption combined with high thermal stability enables these garments to receive and neutralise a range of projectiles from low calibre handguns, that is 0.22 to 0.44 inch (5.6–11.2 mm) to military bullets within the 5.56–7.62mm range.In the latter case, the fabric will require facing with ceramic tiles or other hard materials to blunt the tips of metal-jacket spitzer-pointed bullets [2].

Textile materials provide the same level of ballistic protection as metals but have relatively low weight and are therefore comfortable to wear. Most of the casualties during military combat or during unintended explosions are from the fragments of matter caused by the explosion hitting the body [1].

High-performance clothing designed for ballistic protection dissipates the energy of the fragment/shrapnel by stretching and breaking the yams and transferring the energy from the impact at the crossover points of yarns. The ballistic protection of a material depends on its ability to absorb energy locally and on the efficiency and speed of transferring the absorbed energy. One of the earliest materials used for ballistic protection was woven silk that was later replaced by high-modulus fibers based on aliphatic nylon 6,6 having a high degree of crystallinity and low elongation. Since the 1970s, aromatic polyamide fibers, such as Kevlar® (Du Pont) and Twaron (B(Enka) and ultra-high-modiilus polyethylene (UHMPE) have been used for ballistic protection [1]. Ballistic-resistant materials generally are unable to respond rapidly to the impact stress under high-velocity impact. Structural design offers a useful means of overcoming this problem. In certain special cases, the structure of nonwoven fabric is used as a fragment-resistant device [23].

It has been reported that using a nonwoven facing on a woven fabric provides increased protection against handgun threats (the velocity being between 350 m/s and 430 m/s) compared to Spectra shield alone. The flexible layer can also transmit the impact stress to the fibers [23].

2.4.2. Other Impact Protection

According to the US Labor Department, each year, more than one million workers suffer job-related injuries and 25% of these injuries are to the hands and arms. Gloves, helmets and chain-saw clothing are the main protective accessories used by personnel working in the chemical, construction and other industries [1]. To strike a better balance between garment weight, comfort and protection an

even stronger and lighter fibre based on ultra-high molecular weight polyethylene was developed and used in the early 1990s, which immediately reduced average garment weight by 15% UHMWPE, commercially known as Dyneema (DSM) and in composite form as Spectra Shield by Allied Signal, is now used to make cut-resistant gloves and helmets, as well as a wide range of protective garments [2]. These high modulus fibers (Spectra® produced by Honeywell (USA) and Dyneema® by DSM are based on ultra high molecular weight polyethylene combined with patented gel spinning processes. They offer a specific strength 40% higher than that of aramid fibers and a large resistance to various aging agents [26].However, unlike Kevlar, with a fairly low melting temperature of 150°C, it is best suited to low temperature applications [2].

Some examples of non-combat impact protection are the seat belts and air bags used in automobiles. Air bags have reduced the death rate in accidents by 28%, serious injuries by 29% and hospitalization by 24% and seat belts can reduce fatal and serious injuries by 50%. A typical seat belt is required to restrain a passenger weighing 90 kg in collision with a fixed object at 50km/h (about 30mph). The tensile strength of a seat belt should be at least 30 kN/50mm [1].

With a technology called SuperFabric® based on tiny hard guard plates embedded in a base fabric, HDM (USA) is offering engineering solutions for high resistance to cutting, abrasion and puncture while retaining a good level of flexibility. For resistance to impact, a new technology based on intelligent molecules has been developed. It has several potential applications in protective clothing, e.g., for bulletproof vests. At low rate of movement, the molecules simply flow past each other. If subjected to an impact, they instantly lock together, and then unlock when the impact is over. Other new energy absorbing Technologies include tridimensional mesh knitted fabrics and deformable pouches filled with elastic capsules immersed in a liquid or grease matrix [26].

Although sports and recreational injuries account for relatively few deaths (0-6% of deaths to those under age 20), these activities are associated with 17% of all hospitalized injuries and 19% of emergency room visits to hospitals. More than half of the total sports and recreational injuries are attributed to eight activities: ice hockey, baseball, basketball, soccer, jogging, cycling, football and volleyball. Modern sports clothing uses high-performance fabrics that are designed to operate at high speed but are still safe and comfortable to wear. The most common protective textiles used in sports are in knee braces, wrist braces, ankle braces, helmets and guards [1].

Active Protection System can be given as an outstanding example for impact protection. A “smart” impact protection textile with superior defense and comfort won the 2008 ASM International Engineering Materials Achievement Award for Dow Corning Corp. The Dow Corning Active Protection System is a unique “smart” technical textile. It is an alternative to hard, rigid armor systems for protection against high-energy impacts. The system is comprised of innovative materials that instantly become rigid upon impact, but flex with body movements when protection is not required. Because the system is a textile, it can easily be integrated into protective garments by traditional cutting and sewing

techniques. It can be built up in layers to maximize protection where needed, without compromising design or appearance [27].

Another example for the impact protection is improvement of design of vehicles. The bumper of a vehicle is a first element, which perceives the front impact in the most common cases of automobile accidents. Thus, the problem of optimization and improvement of design of a bumper with the purpose of increasing the safety level of the vehicle is an important topic. Researchers solved the problem and the dependences allowing to define a zone of optimum increase of mass and rigidity of a bumper were found earlier, and the design of the bumper's protecting device was developed [28].

2.5. Biological protection

Most natural textile fibers such as wool, silk and cellulosics are subject to biological degradation by bacteria, dermatophytic fungi, etc. Fortunately, various chemicals and finishing techniques are available that can protect the textile and the wearer from biological attacks. Textiles designed for biological protection have two functions: first, protecting the wearer from being attacked by bacteria, yeast, dermatophytic fungi, and other related microorganisms which cause aesthetic, hygienic, or medical problems; secondly, protecting the textile itself from biodeterioration caused by mold, mildew, and rot-producing fungi and from being digested by insects and other pests [1].

The antimicrobial properties of silk have been used for many years in medical applications. Natural fibers contain lignin and other substances that have inherent antimicrobial properties. Generally, textiles made from natural fibers have better anti-microbial properties than man-made fibers due to the presence of substances such as lignin and pectin. Chemical finishing is most commonly used for imparting anti-microbial properties to natural and man-made textiles by applying functional finishes onto the surface of the fabric or by making fibers inherently resistant to microorganisms [1]. Slow release of copper ions can be given as an example for making anti-bacterial fibres. Similarly, slow release of silver ions makes anti-bacterial agents in fibres and textiles [20]. Another example relates to antimicrobial capabilities imparted to fabrics coated with nanosized silver salt crystals. The resulting product displays a high antibacterial activity while maintaining a wide of range biocidal properties [26].

In addition, textiles materials used in filtration can be given as an example for biological protection. Typical respirators are uncomfortable when worn for long periods. A Washington University environmental engineer has developed a nanofiber material for a mask that would be comprised of just less than 2 percent material, more than 98 percent of air, making for a more comfortable and efficient fit [17].

Fabrics designed for microbial protection should act as barriers to bacteria and other microorganisms that are believed to be transported from one location to another by carriers such as dust or liquids. Films generally have high barrier properties against microbes and chemicals. However, films when used with fabrics to provide antimicrobial properties make fabrics impermeable to airflow leading to

heat stress and other physiological problems that may be fatal. New membrane structures called 'perm-selective' or 'breathable' membranes have been developed that can prevent airflow through the fabric layer but have high water-vapor permeability. Using these membranes with fabrics provides effective protection from hazardous materials or microbes without causing heat stress (HAZMAT) [1].

Numerous civilian and military occupations, including first response teams, fire fighting, and hazardous materials (HAZMAT) clean-up, require personnel to work in contaminated environments wearing environmental protective clothing. The protective clothing required for these situations ranges from semi-permeable chemical protective uniforms to fully encapsulating impermeable level A HAZMAT systems providing protection from contamination through the skin and/or the respiratory tract. The microenvironment created by protective clothing has minimal capability for heat dissipation through conduction, radiation, convection and, most importantly, evaporation of sweat. The end result is reduced work due to elevated heat strain [9].

In addition, nerve agents are chemicals that attack the central nervous system. A release of a nerve agent has the potential to rapidly affect a large number of people. The majority of nerve agents belong to a class of compounds called organophosphates. The development of an early warning system, based on detection of toxic materials, is now an important topic for research and development. Fiber optic sensor systems provide with numerous advantages over conventional systems which include immunity to electromagnetic interference, small and compact size, sensitivity, ability to be multiplexed, remote sensing and to be embedded into textile structure . An optical fiber forms an effective medium to sense chemical species. The presence of chemical species can modulate light property such as intensity, phase or polarization in the optical fiber. These changes can be detected at the fiber output and can be related to the concentration of the chemical species present at the point. Sensing of chemical agents using fiber optic sensor systems has been reported in literature for 50 – 60 years. These include sensors for toxic chemicals such as ammonia, hydrazine, hydrogen peroxide, organophosphate nerve agents. Developments on the chip level sensors illustrates the potential for nanotechnology based approaches to detection of and protection from chemical, biological, radiological, and explosives threats [10].

Biological warfare involves the use of living organisms to attack normal functioning of the human body to render the opponent ineffective. Man has used knowledge of toxicity of plant and animal venom since ancient times for hunting, warfare removal of undesired individuals and executions [1]. The use of protective ensemble is therefore unavoidable especially in chemical and biological warfare [7].

2.6. Radiation Protection

2.6.1. Nuclear Radiation Protection

Special clothing to prevent exposure to radiation is needed for people working in radioactive environments. Alpha-, beta- and gamma-radiation are the major modes of nuclear radiation. Irradiation

injuries by alpha- and some beta-radiation can be prevented by keeping the radioactive dirt off the skin and out of the eyes, nose and mouth. Goggles, respiratory masks, gloves and lightweight protective clothing may be adequate for protection from some alpha- and beta-radiation which have weak penetration. However, gamma- and some beta-radiation have sufficient energy to penetrate through textiles and can affect the human tissue even if the radioactive substance does not contact the human skin.

Woven cotton, polyester/cotton or nylon/polyester fabrics with a twill and sateen weave are the major types of fabric forms used for nuclear protective clothing. Non-woven fabrics used as over- and transit garments in nuclear radiation protection act as a barrier against dangerous particles, shields the main garment against contamination and are disposable when contaminated [1].

Demron™ can be given as an example for nuclear radiation protection. Miami-based Radiation Shield Technologies (RST) reports its Demron™-W High Energy Nuclear/Ballistic IED RDD RED Shield offers complete protection against ballistics, improvised explosive devices (IEDs), radiological dispersive devices (RDDs), radiological emission devices (REDs), fragmentation bombs and nuclear spills. Demron Shield provides unsurpassed nuclear suppression and outperforms all current soft-body armor in anti-frangment and ballistic protection. Its effectiveness in blocking gamma rays, X-rays and nuclear emissions has been proven by the Lawrence Livermore National Laboratory, Georgia Institute of Technology and Columbia University College of Physicians and Surgeons. Demron-W fabrics are flame and acid-resistant and have received National Fire Protection Association Class 2 Certification for the 1994-2007 Standard on Protective Ensembles for First Responders to CBRN (chemical, biological, radiological and nuclear) Terrorism Incidents. In tests conducted by H.P. White Laboratory Inc., the Demron-W Nuclear/Ballistic Shield also has been proven to provide National Institute of Justice Level IIIA ballistic protection and unmatched protection against fragmentation. RST's Demron™ radiation-blocking products are a nontoxic, flexible, lightweight alternative to traditional lead-based aprons and other radiation-shielding products [39].

2.6.2. UV Radiation Protection

In the recent years, consumers have become increasingly aware of the need for sun protection, which is related to the incidence of sun induced skin damage and its relationship with increased exposures to UV light. UV radiation can lead to acute and chronic reactions and damage, such as acceleration of skin ageing and sunburn. Billions of people live on the earth and each has his or her own color of the skin. In human body the skin color depends on the quantities of melanin, carotene and oxygenated or reduced hemoglobin combined in the skin, as well as the thickness, water content etc. Among other factors, the quantity of melanin that is distributed in the skin determines its fairness or darkness and greatly influences the human complexion, at the same time melanin plays an important role in minimizing the damage that UV rays cause in the skin [33].

The wavelength of solar radiation reaching the Earth's surface spans from 280 to 3,000 nm. Ultraviolet (UV) light has the highest energy radiation consisting of UV-A and UV-B, whose radiation is from 320-

340 nm and 280-320 nm, respectively. Excessive exposure of the skin to UV-A radiation can be carcinogenic resulting in chronic reactions and injury, accelerated ageing of the skin, promotion of photodermatosis (acne) etc. An overdose of UV-B can lead to acute and chronic reactions, skin reddening (erythema) or sunburn, increasing the risk factor of persons susceptible to melanoma and skin cancer. In the last decade, attempts to reduce the incidence of skin cancer were mainly focused on decreasing solar UVR exposure [1].

Table 1. Main factors affecting UVR protection [1]

FACTORS	**EFFECTIVENESS**
Fiber	Cotton has high permeability to UVR, Wool has high absorption, Polyester has high absorption to UV- B, polyamides are fairly permeable to UVR.
Weave	Fabric construction, which determines the porosity and type of weave, is the most important factor affecting UV protection. Tighter the weave, lesser the UVR transmitted.
Color	Dark colors absorb UVR more strongly and therefore have high UPFs
Weight	Thicker and heavier fabrics transmit less UVR.
Stretch	Greater the stretch, lower the UPF rating.
Water	Depends on the moisture absorption capabilities of the fibers/fabrics. Generally, fabrics provide less UVR protection when wet.
Finishing	UVR absorbing additives can be used to increase the protection of lightweight summer garments.

The UV protection factor states how long someone using sun protective textiles wearing UV protective clothing can stay out in the sun without suffering damage to their health (skin damage). The UPF protection factor is comparable to the sun protection factor of sunscreen. In both cases, the basis for calculations is what is known as the intrinsic protection time of the skin, which can vary considerably depending on the individual skin type [31].

Although many terms such as SPF (sun protection factor), and CPF (clothing protection factor) which are generally used in the UK have been used to designate the amount of solar UVR protection of fabrics, UPF (ultraviolet protection factor) is the most commonly used index . The UPF for clothing with an excellent UV protection should be 40 to 50+. But from a clinical viewpoint, a UPF greater than 50 is entirely unnecessary. Sunscreens, sunglasses, hats and clothing are the main accessories used to protect from UVR. Textiles are excellent materials for UVR protection and most UV can be blocked by common clothing. As shown in Table 1, the UVR protection of a fabric depends on fiber content, weave, fabric color, finishing processes, the presence of additives, and laundering [1].

More and more people are utilizing textiles to provide extra protection from the sun, preferably in combination with conventional UV Protection. NanoArc® Zinc Oxide, a highly effective broad spectrum UV absorber is used to enhance the sun protection of these textiles. The NanoArc® Zinc Oxide particle can be firmly attached to the fibers of fabric for reliable UV protection. These nano Zinc Oxide particles are invisible to the human eye and the colors of the treated textiles remain clear and bright. The screening effect remains intact even if the fabric becomes wet as a result of perspiration or a soaking [32].

Additionally, ultra-violet absorbing fabric can absorb the ultraviolet wavelengths of the light spectrum and reflect the near-infrared rays 226 Analytical electrochemistry in textiles of this spectrum, resulting in a decrease in the inner temperature of the clothing and thus indirectly of the body temperature (cooling effect) [16].

2.6.3. Electromagnetic-Radiation Protection

With the development of modern society, people greatly benefit from the electrical and electronic devices used during work and everyday life. Electromagnetic interference effectiveness (EMI) remains a technical challenge given the rapid development of electronic devices such as laptop computer, medical instruments, and wireless communication devices that is run at high frequencies and in smaller packages. However, these devices are capable of emitting radio frequencies that are potential hazards to health concerns, such as the symptoms of languidness, insomnia, nervousness, headache, etc. on exposure to electromagnetic waves, although the controversy on the dangerousness of electromagnetic field on health and the lack of convincing biological evidence for such adverse health effects in humans. When electromagnetic waves enter an organism, they vibrate molecules producing heat that could obstruct a cell's capability for regeneration of DNA and RNA. Furthermore, electromagnetic waves can cause abnormal chemical activities that produce cancer cells leading to leukemia and other types of cancer. Thereof electrical and electronic components need to be shielded for the full range of the EMI frequency spectrum [1, 35].

Traditionally, sheet metals are used for shielding radio frequencies. In recent years, conductive fabrics have been used for shielding electromagnetic and static charges in defense, the electrical and electronic industries. Conductive fabrics are designed according to specific requirements using various techniques such as:

1. Laminating conductive layers onto the surface of the fabric by using conductive coatings, zinc arc sprays, ionic plating, vacuum metallized sputtering, and metal foil binding.
2. Adding conductive fillers such as conductive carbon black, carbon fibers, metal fibers (stainless steel, aluminum, copper) or metal powders and flakes (Al, Cu, Ag, Ni) to the insulating material.
3. Incorporating conductive fibers and yams into a fabric. This method provides flexibility in designing the conductive garments [1].

Multi-layer textiles or textile-polymeric materials designed for protection against electromagnetic radiation (EMR), which are relatively light, with low thickness and surface density, elastic, formable, and modified with electro-conductive as well as ferromagnetic substances, showing simultaneous EMR reflecting and absorbing effects. It was of great importance to make the individual component layers of the shielding systems using the techniques of direct or reversible thin-layer coating with pastes of non-conductive polymers and also interstitialy conductive polymers (ICP), including those filled with nano- and micro-metric particles of conductive and ferromagnetic substances, deposited on textile carriers with flat or specially developed spatial structures. Textile carries were made from various textile fibres including blends with metal or metallised fibres, creating conductive grids in the structures of such carriers. The basic assumption of the studies undertaken was to design such coating materials for the component layers and the textile carrier structures, including electro-conductive or EMR reflecting additives, which would make it possible to attenuate EMR by simultaneous absorption and reflection of this radiation. The final laminar products would have layers of different character, e.g. a top layer that absorbs EMR and an internal (bottom) layer that reflects residual incident radiation. Such a complementary way of using both types of shielding effects makes it possible to optimise the protective effect required, with a reduction in material consumption at the same time [34].

2.7. Electrical Protection

2.7.1. Electromagnetic Protection

Protection from electromagnetic sources is required because people who work close to power lines and electrical equipment have the possibility of being exposed to electric shocks and acute flammability hazards. Generally, rubber gloves, dielectric hard hats and boots, sleeve protectors, conductive Faraday-cage garments, rubber blankets and non-conductive sticks are used for electromagnetic protection. Conductive protective clothing with flame resistance, known as 'Live line' garments, is necessary for people who work in the vicinity of very high-voltage electrical equipment. A live-line garment which was introduced in the early 1970s is still in use [1].

Electrically conductive and semi-conductive fabrics have been used in applications such as electromagnetic interference and microwave attenuation. Electromagnetic interface shielding is the most common application. Conductive fibres braided into a shield or sock offer superior performance against electromagnetic interference [16].

Conductive yarns can be produced by coating with conductive polymers or by embedded conductive fillers like carbon nanotubes. Electrically active structures can then be formed, e.g., through specially patterned knitting. However, numerous challenges remain, in particular with contactless sensors, interconnects, electronic reliability, data and power transmission lines and shielding [26].

Radiation from electro-magnetic fields (EMF) generated by power lines is another potential risk to people working near power lines. There have been reports about the relation between exposure to electromagnetic fields and health hazards like leukemia and brain cancer. A typical electromagnetic

protective fabric is woven from conductive material such as spun yarns containing a mixture of fire-retardant textile fibers and stainless steel fibers (8--12 micron diameter). It has been shown that fabrics made of 25% stainless steel fiber/75% wool blend or 25% stainless steel fiber/75% aramid fiber blend can protect the wearer from electromagnetic fields generated by voltages of up to 400 kV. Protection at even higher voltages can be obtained by using a combination of these fabrics in two or more layers [1].

2.7.2. Electrostatic Protection

Static electricity poses a real threat to human life, health and material resources. This risk is present in many spheres of human activity, especially in working environments where electrostatic fields and discharges may cause fire or explosions, as well as disturbances in the production process. Personal protective equipment, which in substance is designed to protect people, may become a source of danger itself if it is made of an inappropriate material or used in an incorrect way. Among other items, this concerns protective clothing made of material that may become electrified, and especially, which could cause the dangerous charging of the human body. However, clothing material which charges itself, especially when it is worn, causes practically no risk, because the energy of the discharge from the material surface is relatively low [40].

Electrostatic charges accumulate easily on ordinary textile materials, especially in dry conditions. Charges once accumulated are difficult to dissipate. The dissipation of an electrostatic-charge occurs through shocks and sparks which can be hazardous in a flammable atmosphere. Therefore, the presence of a static charge in textiles can be a major hazard in explosives, paper, printing, electronics, plastics, and the photographic industry. Before the advent of nonflammable anaesthetics and anti-static rubber components in operating theatre equipment there was evidence of static electrically initiated explosions in hospitals. The charge present in a garment can probably be over 60 kV depending on the balance between the rate of generation and the rate of dissipation of the static charges and the body potential [1].

Conductive fibres have been used in several stitched applications for electrostatic charge dissipation, including large pharmaceutical containment enclosures where fine powders are being captured for transfer between manufacturing facilities, as well as impact-attenuation airbags used in landing spacecraft on the surface of Mars. They present the advantages such as more uniform coverage, improved high-frequency shielding, reduced weight, flexibility and compatibility [16].

The clinging of garments is a common problem caused due to the presence of electrostatic charges. Electrostatic attraction may impede the opening of parachutes and even lead to catastrophic failure under certain circumstances. Anti-electrostatic finishes are used for textiles both in civilian and non-civilian applications. The basic principle of making an antistatic garment is to decrease the electrical resistivity or the chance of electrostatic accumulation in a fabric. Examples of the former are spinning yams containing conductive materials, producing a composite fiber in which at least one element is a

conductive material or a fiber containing a conductive material such as metallic or carbon coatings. Examples of the latter are the addition of a mixture of lubricants and surfactants to the textiles, or anti-static finishing. It should, however, be noted that electrostatics can be very useful for practical industrial applications. In the textile industry, electrostatics are used as a means of spinning fibers and yams [1].

2.8. Reduced Visibility Protection

Studies have shown that reduced visibility contributes to fatal pedestrian accidents. It is reported that night-time vehicles hit and kill more than 4000 pedestrians and injure more than 30,000 pedestrians annually in the United States. High-visibility materials (HVM) are believed to be capable of assisting in avoiding worker and pedestrian deaths or serious injuries. HVMs are used by pedestrians, highway workers, cyclists, joggers, hikers, policemen, firemen and other professionals. Clothing is made highly visible by sewing high-visibility materials or by chemical finishing. There are three major types of high-visibility products:

1. Reflective materials which shine when struck by light; e.g., reflective microprism
2. Photoluminescent materials that can absorb daylight or artifical light, store the energy and emit a green yellow glow in darkness
3. Fluorescent materials (red-orange is visible during the day)

In some cases, combinations of these methods are used to provide optimum visibility during the night [1, 41].

3. FUTURE OF PERSONAL PROTECTION

3.1. Highly Functional Clothing with Physiological Comfort

Human cultures have adapted to climatic extremes ranging from frigid arctic cold to debilitating tropical heat. Even with in a culture circumstances may require that humans encounter wide variation in temperatures. Since thermal stress has clear effects on physiology and comfort, it's not suprising that it influences overt behaviour. Physiological effects of heat and cold are closely tied to the need to keep the core temperature of the body. A core temperature above 45 C or 25 C leads to death. The impact of thermal stress on a individual is not just a function of ambient temperature. Rather, the crucial factor is how well the body can maintain core temperture. Consequently,any factor that reduces the efficiency of homeothermic mechanismas will increase thermal stress, and any factor that increases this efficiency will reduce it [42].

Protective clothing guards the wearer against the vagaries of nature and against abnormal environment. In addition to protection, clothing must also be comfortable so that an energy balance can be maintained within the limits of tolerance for healing or cooling the body. When wearing protective clothing while doing hard physical work, metabolic heat is generated by the body that develops heat-stress in the wearer. Heat-stress or comfort problems have been of great interest to

scientists in recent years [1]. Comfort factors are the user physiology factor, psychology factor, external surroundings and other factors. The human heart rate is mainly affected by the position of the body, exercise, emotion and body temperature [38].

Heat-stress increases the rate of heartbeat, body (aural) temperature, blood pressure and fluid loss that are potential hazards for a wearer's health. Newer technologies and materials have made the production of protective clothing with high protective functions and good comfort a reality. The most typical example is the application of breathable membranes in protective clothing. Nanotechnology, biotechnology and electronic technology have contributed to developing protective clothing that is more comfortable to wear [1].

3.2. Nanotechnology

The concept of nanotechnology is not new; it was started over forty years ago. According to the National Nanotechnology Initiative (NNI), nanotechnology is defined as the utilisation of structures with at least one dimension of nanometre size for the construction of materials, devices or systems with novel or significantly improved properties due to their nano-size [22].

By nanotechnology, the electrical, thermal, mechanical and chemical properties of the fibres can be improved to enlarge the application fields of the fibres in the final use such as “breathable” laminates and super absorbency of fibres provided by the process of creating open-pore-structure in a variety of polymers. The properties imparted to textiles using nanotechnology include water repellence, soil resistance, wrinkle resistance, anti-bacteria, anti-static and UV protection, flame retardation, improvement of dye ability and so on [13].

Nanotechnology allows inexpensive control of the structure of matter by working with atoms. Nanomaterials, sometimes called nanopowders, when not compressed have grain sizes in the order of 1-100 nm in at least one coordinate and normally in three. Nanomaterials include nanopowder, nanofiber, nanotube and nanofilms. Carbon black is a natural nanomatcrial that is used in car tires to increase the life of the tire and provides the black color. Fumed silica, a component of silicon rubber, coatings, sealants and adhesives are also nanomaterials, commercially available since the 1940s. However, it was only in the last decade that people began to better understand the basic science of nanotechnology and tried to apply them in engineering. Nanomaterials can be made by plasma arcing, chemical vapor deposition, sol-gels, electrodeposition and ball milling [1].

Nanotechnology also has real commercial potential for the textile industry. This is mainly due to the fact that conventional methods used to impart different properties to fabrics often do not lead to permanent effects, and will lose their functions after laundering or wearing. Nanotechnology can provide high durability for fabrics, because nano-particles have a large surface area-to-volume ratio and high surface energy, thus presenting better affinity for fabrics and leading to an increase in

durability of the function. In addition, a coating of nano-particles on fabrics will not affect their breathability or hand feel [22].

Nanomaterials are so small in size that most atoms are at the surface. Such structures will exhibit completely different properties from the normal materials in which the atoms are buried in the bulk of the substance. Properties of materials change dramatically when made into nanosize. Silicon made into nanotubes will have conductivity similar to metals. A nanotube fibre made from carbon is tougher than any natural or synthetic organic fiber described so far. Nanomaterials such as nanotubes developed either from silicon or carbon would be very useful for producing highly functional protective clothing [1]. In terms of potential applications, nanocomposite fibers including nanoparticles or carbon nanotubes have displayed increased electric and mechanical properties. Yarns made of spun carbon nanotubes could be used in bulletproof vests thanks to their large resistance to impact. In addition, they can allow the easy incorporation of actuators and sensors into clothing [26].

Nanomaterials can be added to polymers to produce nano-modified polymer fiber or applied during finishing to make nano-finished textiles. Polymer-clay nanocomposites have emerged as a new class of materials that have superior properties such as higher tensile strength, heat resistance, and less permeability to gas compared with traditional composites. Poly-propylene (PP) fiber is one of the main fibers used for textiles but PP is highly hydrophobic and is inherently undyeable. Nanostructural materials such as nanofiber and films show great prospects for use in textiles. A lightweight multifunctional membrane made from electrospun nanofiber exhibits high breathability, elasticity and filtration efficiency [1]. Nano-clays are used to create dye sites into PP fibres with modified quatemary ammonium salt. To improve the dye sorption of PP, the sorbent can be added physically into the polymer matrix for making a composite. Because of good dye sorption ability of the sorbent made from nano-clay, textiles made from that composite will have good dye ability, good colour fastness, less cost in dying and less problems in waste water treatment. Also they have functionality to improve the properties of the textile material such as strength, modulus, UV absorbance and fire resistance. In a melting or dissolving process by using heat, organic sorbent and/or mechanical blending nano-clays can be added to the polypropylene matrix. This gives the polymer structure thermal and chemical stability and good mechanical properties [13].

Using sol-gel, one of the common methods for manufacturing nanomaterials, a nanolayer of titanium was deposited onto the surface of cotton fibers that gave excellent UV protection [1]. In addition nanostructured particules (such as ZrO_2 nanoparticles) are used to improve corrosion protective properties of sol–gel hybrid coatings [18].

Nanoparticle coatings are also very useful to produce textiles fabrics with special surface effects.Although nanotechnology has provided novel properties to polymers, practical applications in textiles are not yet well established. Nanomaterials have far higher surface-to-bulk ratio than normal materials. The high surface energy makes nanomaterials agglomerate, which could greatly reduce the

strength of composites. Also, the agglomeration decreases the surface-to-bulk ratio and nanomaterials will have reduced properties [1].

For increased thermal insulation, the use of nanoporous gels macroencapsulated in viscose based thin, light-weight nonwovens seems promising. Finally, application of nanoclay-reinforced resin coatings to textiles has been shown to improve flammability resistance [26].

The benefits of nanotechnology may be enormous on a theoretical basis. But nanoparticles can affect human health and well being in several unpredictable ways: Nanoparticles can enter the body through multiple routes of entry (inhaled, eaten or absorbed) and can accumulate in novel places. Accumulation of nanoparticles in novel places in the body (intracellular, intercellular, extracellular or in the cell membranes, receptors, organelles, inclusions, etc.) may disturb normal molecular, biochemical, physiological and anatomical functions leading to unpredictable conditions that may lead to cytotoxicity, necrosis, and cell death [24]. Research on humans and animals indicates that some nanoparticles are able to enter the body, and rapidly migrate to the organs via the circulatory and lymphatic systems. Subjects with pre-existing diseases (such as asthma, diabetes, among others) may be more prone to the toxic effects of nanoparticles [25]. Nanoparticles may interact with molecular structures, proteins, enzymes, DNA, RNA in a reversible or irreversible, predicted or unpredicted ways that may cause havoc in biological systems leading to the appearance of new diseases and symptoms never before seen [24].

3.3. Biotechnology

Animals have their own effective way of protecting themselves from predators and abnormal climatic conditions. An intriguing example of protection adopted by animals is the changing of color by chameleons to match the color of their surrounding environment. A chameleon has several layers of cells beneath its transparent skin, of which some layers contain pigments while others just reflect light to create new colors. The most often changed colors of chameleons are between green, brown and gray, which coincidently, often match the background colors of their habitat. Although we are yet to produce a fabric that can change its color with the changing background, camouflage-patterned clothing is an effective way to conceal soldiers in their surrounding environments.

Another interesting aspect of color in nature is the vivid and extraordinary fastness of color in the feathers of peacocks. Color production in nature is either due to structural coloration or pigmentation. The color of peacock feathers is due to the 2D photonic-crystal structure that has the same size as the wavelength of light. This crystal is arranged in lattices in a number of layers called periods that can reflect light to produce colors. The variations in the lattice constants or the number of periods produce the diversified colors. We are still unable to simulate either the chameleon or peacock color to perfection. Studies on dyes that can change color with changing conditions such as temperature and light have partially succeeded, but the change in the magnitude of color is very narrow.

Natural materials are renowned for their relatively higher strength and toughness. Spider dragline silk has a breaking energy per unit weight two orders of magnitude greater than that of high-tensile steel. Spider silk is stronger than Kevlar and stretches better than nylon, a combination of properties seen in no other fiber. Spider silk is considered an ideal material for protective ballistic materials. Spider silk has been artificially produced by using liquid crystalline spinning. By successfully copying the spider's internal processing mechanisms and with precise control over protein folding combined with knowledge of the gene sequences of its spinning dopes, industrial production of silk-based fibers with unique properties can be commercialized [1].

In addition, in many industries, enzymes are used as biological catalysts to replace harsh chemicals or perform reactions under milder conditions. The textile industry is no exception. Not only do enzymes make good economic sense by saving energy, water and chemicals or by improving quality, they also give valuable environmental benefits. These benefits are becoming more and more important at a time of increasing awareness about sustainable development and climate change. Enzymes are used in a broad range of processes in the textile industry: scouring, bleach clean-up, desizing, denim abrasion and polishing. Enzymes are specific and fast in action and small amounts of enzyme often save large amounts of raw materials, chemicals, energy and/or water [29].

Industrial biotechnology applications have led to cleaner processes with lower production of wastes and lower energy consumption. The aim of biotechnology is remediation of polluted air, soil, water and waste [30].

3.4. Electronic Technology

The electronics that facilitate our daily pursuits and interactions may soon be integrated into the textiles in all areas of our near environment. These “Interactive Electronic Textiles” (IETs) may find niches in many traditional textile applications.Opportunities exist for IETs in fashion and industrial apparel, residantal and commerical interior, military, medical and industrial textile markets. Textile keypads on integrated into the arm of a sofa, a light switch integrated in a curtain. IET s can also be developed to detect pressure and/or movement in sensitive medical textiles, engineering fabrics, active sportswear and automotive seats [43].

Wearable electronic systems are a promising area for textiles. Wearable electronics are part of the so called 'smart textiles' or 'smart clothing'. A smart material is that which will change its characteristics according to outside conditions or according to a predefined stimulus. Wearable electronics have been successfully used in some areas such as space suits and in military suits equipped with a GPS (global positioning system). Textiles integrated with sensory devices driven by a Global Positioning System (GPS) can detect a users exact location any time and in any weather. IETs with integrated GPS enhance safety by quickly locating the wearer and allowing the suit to be heated. Parents can easily keep track of a child’s location with garments containing integrated GPS. GPS can also provide added safety for emergency personnel by facilitating offsite monitoring of vitals.Wearable electronic systems are being designed to meet new and innovative applications in military, public safety, healthcare,

space exploration, sports and in fitness fields. Developments in electronic technology have made it possible to integrate innovation, intelligence and information into a wearable and comfortable infrastructure in a new generation of interactive textiles. An interactive garment called the wearable mother board, or smart shirt has been developed at Georgia Institute of Technology, Georgia, USA. The smart shirt provides an extremely versatile framework for incorporation of sensing, monitoring and information-processing devices. Application of electronic technology will surely make protective clothing more reliable, safe and comfortable in future [1, 43].

In addition, in wearable Computer Laboratories researchers have developed a three-part system to monitor heartbeat respiratory organs.

- Clothes combined with electrical engineering
- Connected wire combined with electrical engineering
- Computer built into clothes

The clothing collects data about the user's action. Also, it's possible to wash the clothes without affecting any data or electrical parts. Metal bonds of connected wires are built into the clothes, so the computer installed inside the clothes is connected with wires.

A touch screen is located on the surface of the clothes and each electrical material is able to transfer signals. The clothing will contain a cable for downloading any data stored on a computer. At the same time, this lead will be able to recaharge the clothing for use the following day.

According to researchers, such a technology could have a variety of uses in the monitoring services area. For example, a "monitoring service" makes it possible to check on Alzheimer patients staying at home. The new system also makes it possible to check the wearer's health. The wearer does not neeed to learn how to use the new machine but just needs to attach it on the clothes [37].

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TEXTILE BASED PERSONAL PROTECTIVE EQUIPMENTS

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ABSTRACT

Safety clothings and personal protective equipments (PPE) are special products that designed to protect the wearer's body from various dangerous cases, pollution, infection and injuries etc.. These items have wide application fields and they are used by various staff including; bicyclists, construction workers, emergency responders, paramedics and Emt's, firefighters, equestrians, search and rescue crew, first aid staff, fishermen, hunters, linemen, meter readers, motorcyclists, parking attendants, pedestrians, rail workers, surveyors, police, film and Tv crews (when needed), ground handling personnel on airside, pilots.

High-visibility clothing, work gloves, safety glasses, disposable coveralls, rainwear, respirators, hard hats, fall protection, ear plugs and muff are some of the common examples of this extensive usage of these special products. In addition to job-related occupational safety, PPE have lots of potential application possibilities for health purposes and for sports also.

The terms "protective gear" and "protective clothing" are, in many cases, interchangeable; "protective clothing" is applied to traditional categories of clothing, and "gear" is a more general term and preferably means uniquely protective categories, such as pads, guards, shields, masks, etc.

In this study, textile based PPE's and safety clothing products are reviewed.

Key words: personal protective equipments, safety clothing, protective textiles

1. INTRODUCTION

Technical textiles are textile products that manufactured for non-aesthetic purposes, where function is the primary criterion. It is a large and growing sector and supports a vast array of other industries.

Technical textiles include textiles for automotive applications, medical textiles (e.g., implants), geotextiles (reinforcement of embankments), agrotextiles (textiles for crop protection), and protective clothing (e.g., heat and radiation protection for fire fighter clothing, molten metal protection for welders, stab protection and bulletproof vests) etc.

Over all, global growth rates of technical textiles are about 4% per year greater than the growth of home and apparel textiles, which are growing at a rate of 1% per year [1]. In present market opportunities and in free quota system, the importance of technical textile materials is increasing to accommodate the needs of requirement. Nowadays the most widely technical textile materials are used in filter, furniture, hygiene medicals, construction materials and protective applications.

2. TEXTILE BASED PERSONAL PROTECTIVE EQUIPMENTS

Textile based PPE's are used to protect the wearer especially against dangerous cases, such as pollution, infection and injuries etc. Protection against heat and radiation for fire fighter clothing, against molten metals for welders, for bullet proof jackets etc, All these products are obtained by usage of technical textiles. When we examine the raw materials of the textile based PPE's, It's so clear that high performance fibers have a wide application possibilities for protective purpose [2]. For example, In bullet proof jackets, special fiber aramid are used which have high tenacity, high thermal resistance and low shrinkage. Glass fiber is also used in fire proof jackets due to its high strength, chemical and flame resistance. The special clothes that used by the astronauts during their studies in space, are covered with special chemicals including lead to protect them from suns heat, their suit not only made from special fibers but their airship was also lined with special fabrics [2].

2.1. Biological hazard protection

Biological hazards refer to organisms or organic matters produced by these organisms that are harmful to human health [3]. These include parasites, viruses, bacteria, fungi and protein. In general, there are three major of routes of entry for these micro-organisms into our body, i.e. through the respiratory system, transmission through contact with body fluids of the infected or contact with contaminated objects. Medical staff, cleaning staff, laboratory technicians, agriculture, fishery, veterinary services, manufacturing industries that use plant- or animal-based raw materials may come into contact with biological hazards. If the contact with biological hazards cannot be prevented, the employees must use personal protective equipment and adhere strictly to the practice of personal hygiene.

Protective equipment for biological hazards includes masks worn by medical personnel (especially in surgery to avoid infecting the patient but also to avoid exposing the personnel to infection from the patient.) Gloves, frequently changed, are used to prevent infection but also transfer between patients [3].

On the other hand, there are also overall protective clothes that protect the body from contamination by blood, droplets or other body fluids and prevent these contaminants from getting into the body through open wounds or contaminating the worker's own clothing [3]. Protective clothing is disposable in most cases though some can be reused after sterilization;

Figure 1. Protective clothes against biological hazard

2.2. Combat Protective Equipments (Ballistic, Riot and Protective Training Equipments)

Ballistic personal protective equipments (or Personal armor) are used in combat by soldiers and in lesser conflicts by law enforcement. Most common ballistic equipment called ballistic vest, bulletproof vest or bullet-resistant vest is an item of personal armor that helps absorb the impact from firearm-fired projectiles and shrapnel from explosions, and is worn on the torso. Soft vests are made from many layers of woven or laminated fibers and can be capable of protecting the wearer from small caliber handgun and shotgun projectiles, and small fragments from explosives such as hand grenades.

Metal or ceramic plates can be used with a soft textile surface, providing additional protection from rifle rounds, and metallic components or tightly-woven fiber layers can give soft armor resistance to stab and slash attacks from knives and similar close quarter weapons [4]. For instance, soft vests are commonly worn by police forces, private citizens, security guards, and bodyguards, whereas hard-plate reinforced vests are mainly worn by combat soldiers, police tactical units, and hostage rescue teams.

Fiber reinforced composite structures also have a wide application about ballistic and combat protection of military, paramilitary and civilian fields. Aramid, Kevlar, PBO and HPPE fibers are some of the most common materials that can be used in ballistic products [5].

Modern body armor may combine a ballistic vest with other items of protective clothing, such as a combat helmet. Vests intended for police and military use may also include ballistic shoulder and side protection armor components, and bomb disposal officers wear heavy armor and helmets with face visors and spine protection [5].

Figure 2. Ballistic shields, vests and related products about ballistic protection

2.3. Respiratory protection

Dusts, gases, fumes, mists and vapors are common hazards in workplace air. These can seriously affect the health of workers. For instance, breathing in asbestos fibers can lead to asbestosis and lung cancer while crippling lung diseases can be caused by the inhalation of certain dusts.

Inhaling some chemicals, such as solvents, can damage many parts of the body including the brain. Welding fumes, smoke, mists from spray painting are also serious respiratory hazards and workers should be adequately protected from exposure to any of them.

Respiratory protective equipments are designed to protect the wearer against breathing in hazardous substances in the workplace air.

- **Respirator (filtering device).** This uses filters to remove contaminants in the workplace air. They should never be used for protection in situations with reduced oxygen levels;
- **Breathing apparatus (BA).** This needs a supply of breathing quality air from an independent source (e.g. air cylinder or air compressor) [6].

Using the appropriate respiratory protective equipment is essential for the securing an adequate protection from biological hazard. Respirators such as "gas masks" and particulate respirators filter chemicals and gases or airborne particles. A second type of respirator protects users by providing clean, respirable air from another source. For air-supplying respirators, clean air is supplied by air compressor or high-pressure cylinder through a hose. This type includes airline respirators and self-contained breathing apparatus. In work environments, respirators are used when adequate ventilation is not available or other engineering control systems are not feasible [7].

Figure 3. Air-Purifying Respirator

Mechanical filter respirators retain particulate matter when contaminated air is passed through the filter material. Wool is still used today as a filter, along with other substances such as plastic, glass, cellulose, and combinations of two or more of these materials. Since the filters cannot be cleaned and reused and therefore have a limited lifespan, cost and disposability are the key factors. Single-use, disposable as well as replaceable cartridge models are common. Reusable elastomeric respirators are a type of respiratory protection that has a flexible, rubber-like facepiece with either permanent or removable filter cartridges. The facepiece can often be cleaned, repaired and reused, and the filter cartridges can be discarded and replaced when they become unsuitable for further use. Other elastomeric respirators with permanent filter cartridges are designed to be disposed of when the cartridges need to be replaced [8].

2.4. Foot Protection

Employees, who face possible foot or leg injuries from falling or rolling objects or from crushing or penetrating materials, should wear protective footwear. Also, employees whose work involves exposure to hot substances or corrosive or poisonous materials must have protective gear to cover exposed body parts, including legs and feet. The shoe material must be consistent to the type of work being done and the task to be conducted.

Wearing proper shoes, not sandals or open toed shoes, in work areas where chemicals are used or stored is a necessity. Perforated shoes, sandals or cloth sneakers should not be worn in areas where mechanical work is being done. If an employee's feet may be exposed to electrical hazards, non-conductive footwear should be worn. On the other hand, workplace exposure to static electricity may necessitate the use of conductive footwear. Penetration protected boots and shoes have been designed to protect against corrosive materials such as chemicals, oils, caustics, and petroleum products. Also for puncture protection, the protective shoes should be worn around areas that accumulate debris and sharp objects that the employee has the potential to step on.

Footwear is available in a range of styles, for example shoe, low ankle boot, high ankle boot, knee boot, thigh boot and even chest-high waders. The different types of protective footwear include the following [9]:

(a) **Safety boots or shoes** – These are the most common type of safety footwear. They normally have protective toecaps and may also have other safety features including slip-resistant soles, penetration-resistant midsoles and insulation against extremes of heat and cold.

(b) **Wellington boots** – These are usually made of rubber and used for working in wet conditions. They are also useful in jobs where the footwear needs to be washed and disinfected for hygiene reasons, e.g. in the food industry and the chemical industry.

(c) **Clogs** – These may also be used as safety footwear. They are traditionally made from beech wood and may be fitted with steel toecaps and thin rubber soles for quieter tread.

(d) **Footwear for specific tasks** – These protect against hazards in these areas, for example foundry boots and chainsaw boots.

Figure 4. Various types of protective boots.

2.5. Helmets

Today's armed services often use high-quality helmets made of ballistic materials such as Kevlar, which have excellent bullet and fragment stopping power. Military helmets can be worn with radio earmuffs, and other equipment such as night vision goggles can be added. Military helmets are often worn with a removable cotton-polyester helmet cover, which allows the user to change the pattern of the camouflage (e.g., from dark green forest camouflage to tan-colored desert camouflage) [10,11].

Military helmets were often made from lightweight plastics materials, to protect the head from bullets and shell fragments. In civilian life, helmets are used for recreational activities and sports (e.g., jockeys in horse racing, American football, ice hockey, cricket, and rock climbing); dangerous work activities (e.g., construction, mining, riot police); and transportation (e.g., Motorcycle helmets and bicycle helmets). Since the 1990s, most helmets are made from resin or plastic, which may be reinforced with fibers such as Aramids [10,11].

Helmets come in a variety of designs and it is important that the right type is provided for the work to be done. A properly fitting safety helmet should have the right shell size for the wearer and an easily adjustable headband, nape and chin strap. The range of size adjustments should be large enough to accommodate thermal liners used in cold weather.

Safety helmets that are used in cycling, military or sports fields should be as comfortable as possible. Comfort is improved by the following:

- A flexible headband of adequate width and contoured both vertically and horizontally to fit the forehead;
- An absorbent sweatband that is easy to clean or replace;
- Textile cradle straps;
- Chin straps (when fitted) which:
  - fit around the ears;
  - are fitted with smooth, quick-release buckles which don’t dig into the skin;
  - are made from non-irritant materials;
  - can be stowed on the helmet when not in use.

Figure 5. Helmet types for different usage purposes.

2.6. Knee & Elbow Pads

Knee pads are protective gear worn on knees to protect them against impact injury during, e.g., a fall or a strike, or to provide padding for extended kneeling. In other words, knee pads should be considered to reduce pressure on the knees

Kneepads are worn in many recreational and sporting activities such as cycling, roller-skating, skateboarding, volleyball, handball, basketball, American football, polo, dancing, etc. Kneepads are also used in various trades, for the home handyman, for police SWAT teams, are incorporated into military uniforms. These kneepads are generally designed differently than the general all round high impact kneepads made for sports [12].

Soft knee pads are designed to protect knees from hard, rough, wet, or cold surfaces, and area easily installed in double knee work-wear. They eliminate the problem of being unprepared for kneeling when on site, away from any source of knee protection. Hard shell kneepads are better for situations where there are hard or sharp protrusions that might impact the kneecap area [12].

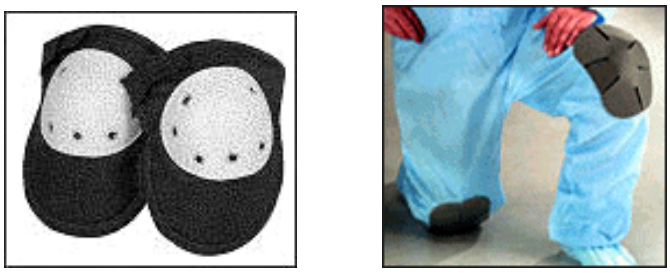

Figure 6. Protective knee pads

Elbow pads are protective padded gear worn on the elbows to protect them against injury during a fall or a strike. Elbow pads are worn by many athletes, especially cyclists, roller skaters, skateboarders, volleyball players, skiers and wrestlers. Just like knee pads, elbow pads reduce stress and fatigue, allowing wearer to work longer and more effectively.

2.7. Medical Protections

Medical textiles is one of the major growth areas within technical textiles and the use of textile materials for medical and healthcare products ranges from simple gauze or bandage materials to scaffolds for tissue culturing and a large variety of prostheses for permanent body implants [13, 14].

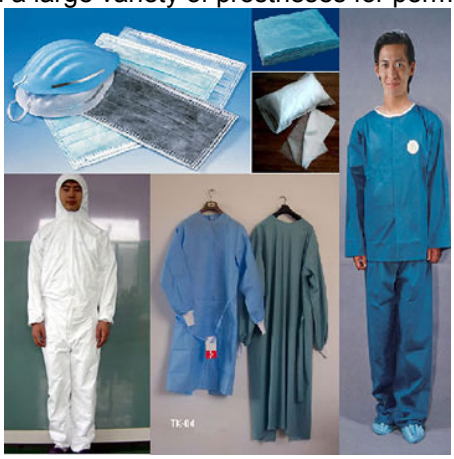

Figure 7. Medical, Healthcare & Hygienic Products

An important area of textile is the healthcare and hygiene sector among other medical applications. The range of products available for healthcare and hygiene is vast, but they are typically used either in the operating theatre or in the hospital wards for hygienic, care and safety of the staff and patients. They could be washable or disposable.

1. Surgical gown: It is essential that environment of operating theatre is clean and strict control of infection is maintained. A possible source of infection to the patient is the pollutant particle shed by the nursing staff, which carries bacteria. Surgical gowns should act as barrier to prevent release of pollutant particles into air. Traditional surgical gowns are woven cotton goods that not only allow the release of particles from the surgeons but also a source of contamination generating high levels of dust (lint). Disposable non woven surgical gowns have adopted to prevent these sources of contamination to patients and are often composite materials of nonwoven and polyethylene films [13, 14].

2. Surgical masks: They should have higher filter capacity, high level of air permeability, lightweight and non-allergic. Surgical mask generally consists of three layers of non-woven fabrics. It provides a barrier protection against large respiratory droplets [13, 14].

3. Surgical caps: These are made from nonwoven materials based on cellulose [13, 14].

4. Surgical drapes and cover-cloths: These are used to cover patients or to cover working areas around patients. It should be completely impermeable to bacterial and also absorbent to body perspiration and secretion from wound [13, 14].

2.8. Improved Visibility – Visual Protection

High-visibility clothing is any clothing worn that has highly reflective properties or a color that is easily discernible from any background. Yellow waistcoats worn by emergency services are a common example. In general, people who wear high-visibility clothing are those who need to be seen during poor lighting or weather conditions, or when working in environments where there is a lot of moving machinery. Examples include pedestrians, workers, cyclists, motorcyclist, hunters and hikers.

Part of the surface of the garment may have retroreflective stripes. By this way, they become much more visible in the dark for observers near a light source, such as the driver of a car with its headlights on. The pattern of the retroreflecting parts also helps to distinguish between objects and people.

For greater visibility during the daytime, very bright colors are used for the main body of the garment by means of fluorescent material

Reflective cords and cord-like trimming sewn along the edges of seams are used on safety vests to protect workers. It covers various products such as Reflective T-Shirts & Sweatshirts Safety Vests, Reflective Jackets and Coats, Reflective Rainwear, Reflective Hats and Gloves

There are three classes of high-visibility clothing. Each has minimum areas for the background and retroflective bands [15]:

(a) Class 1 – the least conspicuous (waistcoats and most trousers).
(b) Class 2 – more conspicuous than Class 1 (waistcoats, jackets and some trousers).
(c) Class 3 – the most conspicuous (jackets and coveralls

Figure 8. Examples of High-Vis Clothing

2.9. Gloves

Hazards to the hands include thermal hazards (contact with very hot or cold objects) mechanical hazards (the skin may be torn or cut by rough or sharp surfaces) chemical hazards (substances containing strong acids, alkalis, solvents or irritants) or vibration hazards (from using tools such as heavy drills). The handling of small components will require that the glove must be highly flexible and give good dexterity to the operator. Alternatively, a glove to give heat protection might place almost no emphasis on these properties. A range of protective gloves are available to meet all these needs [6].

There are various types of gloves that are being used in different industries such as Barbed wire handler's gloves, Chainsaw gloves, Fireman's gauntlets, Disposable gloves, Medical gloves, Welder's gloves, Aircrew gloves, Sandblasting gloves, Gardening gloves, Impact gloves, Rubber gloves, Clean room gloves, Chemical resistant gloves, Cold handling gloves etc. Gloves are made of materials including cloth, knitted or felted wool, leather, rubber, latex, neoprene, and metal (as in mail). Gloves of Kevlar protect the wearer from cuts [16].

Latex, nitrile rubber or vinyl disposable gloves are often worn by health care professionals as hygiene and contamination protection measures. Gloves protect the hands from contacting blood, droplets, body fluids and other body tissue of the infected, or pathogen-contaminated objects and can avoid infection when touching the eyes, mouth or nose afterwards. Gloves can also protect open wounds from contamination by pathogen. Gloves should fit the hands snugly but they should not hamper movement or affect sensibility

Rubber gloves are best worn with a skin tight fit which, while still allowing for the hands to breathe, makes it easier to hold objects and manipulate them. Gloves are frequently used to keep the hands warm, a function that is particularly necessary when cycling in cold weather. The design of most modern bicycles is such that the rider's hands remain on the handlebars while cycling, a position that leaves them exposed to weather. Motorcycling gloves are typically gloves made of leather. They may have gauntlets to protect the rider's wrists from injury, and help reduce drafts while riding in colder climates [16].

2.10. Personnel Protection in Hot or Cold Environments

There are several occupational circumstances that employees exposed to hot environments i.e. Outdoor operations in hot weather, including surface mining, roofing, road repair and construction, dam building, and other construction, Farming operations, Iron, steel and nonferrous foundries, Brick-firing and ceramics operations, Glass products manufacturing plants, Rubber products manufacturing plants, Electrical utilities (particularly boiler rooms), Bakeries, Restaurant kitchens, Laundries, Chemical manufacturing facilities, Mines, Smelters, Steam tunnels etc.

Working in a hot environment induces a physiological strain on workers. Heat stress disorders include heat stroke, heat exhaustion, and heat rash. They adversely affect worker safety and productivity because they can cause distraction, reduce concentration, and lead to fatigue. There are ways to control exposure to heat stress in the work environment: (1) decreasing the temperature, (2) reducing the humidity, (3) increasing the air velocity, (4) reducing the work load, (5) adjusting the clothing, (6) providing shields against radiant heat, and (7) implementing work practices such as suitable work-rest intervals, fluid replenishment, acclimatization, and worker training

Clothing inhibits the transfer of heat between the body and the surrounding environment. Therefore, in hot jobs where the air temperature is lower than skin temperature, wearing clothing reduces the body's ability to lose heat into the air. When air temperature is higher than skin temperature, clothing helps to prevent the transfer of heat from the air to the body. However, this advantage may be nullified if the clothes interfere with the evaporation of sweat. In dry climates, adequate evaporation of sweat is seldom a problem. In a dry work environment with very high air temperatures, protective clothing could be an advantage to the worker. The proper type of clothing depends on the specific circumstance. Certain work in hot environments may require insulated gloves, insulated suits, reflective clothing, or infrared reflecting face shields. For extremely hot conditions, thermally conditioned clothing is available. One such garment carries a self-contained air conditioner in a backpack, while another is connected a compressed air source which feeds cool air into the jacket or coveralls through a vortex tube. Another type of garment is a plastic jacket which has pockets that can be filled with dry ice or containers of ice [17, 18, 19].

Figure 9. Occupational Safety In Hot Environment

Workers who are exposed to extreme cold or work in cold environments may be at risk of cold stress. Extreme cold weather is a dangerous situation that can bring on health emergencies in susceptible people, such as those without shelter, outdoor workers, and those who work in an area that is poorly insulated or without heat. Clothing should be worn in multiple layers which provide better protection than a single thick garment. The air between layers of clothing provides better insulation than the clothing itself. The inner layer should provide insulation and be able to "wick" moisture away from the skin to help keep it dry. Thermal underwear made from polyesters or polypropylene is suitable for this purpose. "Fishnet" underwear made from polypropylene wicks perspiration away from the skin and is significantly thicker than regular underwear. It also keeps the second layer away from the skin. The open mesh pattern enables the moisture to evaporate and be captured on the next layer away from the skin. The second layer covers the "holes" in the fishnet underwear which contributes to the insulation properties of the clothing. The additional layers of clothing should provide adequate insulation for the weather conditions under which the work being done [20].

Figure Various cold weather clothing products

2.11. Protection of Electro-Magnetic Field Effects

The use of electrical and electronic devices is expanding rapidly. Electromagnetic interference (EMI) is the result of electrical or magnetic emissions through radiated or conducted path with unwanted electromagnetic noises.

Metal is considered the best electromagnetic shielding material; however, metal is expensive and heavy and may be subject to thermal expansion and metal oxidation or corrosion problems associated with its use. In contrast, most synthetic fabrics are used as electrical insulation and are transparent to electro magnetic radiation, i.e. their inherent electromagnetic shielding effectiveness (EMSE) is practically zero. To shield against EMI, the technical approach of textile processing, which has been considered extensively, incorporates electrically conductive fillers in to synthetic fabrics. The conductivity, permeability and EMSE of synthetic fabrics have been improved using the following methods [21]:

- Lamination of conductive layers on to the fabric surface; conductive coating, zinc arc spraying; ionic plating; vacuum metallization; sputtering and metal foil binding

- Adding conductive fillers, such as conductive carbon black, carbon fiber, metalized fiber, metal fiber (stainless steel, aluminum, copper), metal powder (Al,Cu,Ag,Ni) to the insulating material for EMI shielding purpose.

- Incorporation of conductive fibers or yarns in to the fabric is to achieve the function of EMI shielding. As metallic fibers are closely spaced, continuous conductive paths can be established easily

In recent years, conductive fabrics have been considered for Electromagnetic shielding and anti-electrostatic applications in the defense, electrical, and electronics industries. Such fabrics have desirable properties such as flexibility, electrostatic discharge, EMI protection, radio frequency interference protection, thermal expansion matching and lightweight.

Textile-based electromagnetic protective materials can be covered to surfaces and walls as wallboards, wall papers and upholstery, also can be used as other textiles such as curtains, EM protective garments, drapes, bedding, RF shielding-canopies and EM shielding-chambers, fly screens.

3. CONCLUSION

In terms of occupational safety, some or all of the following points should need to be taken into account:

- The risks in the workplace;
- The parts of the body which may be affected;
- The nature of the task;
- The degree of physical effort involved;
- Methods of work;
- How long “Personal Protective Equipments” must be worn;
- Any special requirements e.g. ease of use with prescription spectacles, or with other Personnel Protective Equipments (PPE).

Proper PPE’s should be selected by considering following criterias;
(i) Adequate control of any risks identified, without in itself adding to the risk (e.g. the use of powdered latex gloves may present a risk to the wearer or to others in the vicinity);
(ii) Compatibility with other items of PPE (e.g. ear defenders worn with a safety helmet must still provide the necessary degree of attenuation);
(iii) Minimum discomfort to the wearer.

It is usually necessary to have more than one type or size of PPE available, so as to maximize the chances of obtaining good fit and comfort. Uncomfortable or unsuitable PPE is unlikely to be worn and involvement of the user in the selection or specification is often useful in ensuring the best results.

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THE FORMULATION OF INKJET INKS FROM SOLUBILISED VAT DYES FOR DIGITAL DYEING AND PRINTING OF HIGH PERFORMANCE CELLULOSIC FABRICS

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Digital inkjet printing is growing in importance in textile coloration, especially using reactive dyes for cellulosics, acid dyes for protein fibres and disperse dyes for polyester. Cellulosic fibres are commonly dyed and screen printed with vat dyes for high performance and technical applications, but inkjet printing with vat dyes remains problematic. One option is to print as finely-dispersed pigments, followed by the reduction/oxidation fixation process as a fabric pre-treatment or post-treatment. Alternatively, a process whereby the water-soluble reduced (leuco) form is delivered would expose the printhead to the aggressive alkaline reduction medium and invoke significant issues with ink stability because of ease of air oxidation of the leuco dye.

Within EC Framework 6 integrated project DIGITEX, Digital Fast Patterned Microdisposal of Fluids for Multifunctional Protective Textiles, we have developed an inkjet system for digital dyeing and printing using solubilised vat dyes, water-soluble sulphate esters derived from the leuco vat dyes, which are applied to cellulosic fabrics and subsequently converted to the vat dye by acid hydrolysis and oxidation. This paper describes the development of aqueous inkjet inks from solubilised vat dyes with appropriate physical and rheological characteristics providing good jettability on to cellulosic fibres. Purification techniques were required to produce the dye in a form sufficiently salt-free to minimise printhead kogation. The formulation required judicious additive selection to minimise premature formation of the vat dye and consequent reduced ink storage stability. High quality inkjet inks have been developed which, with appropriate optimised fabric pre-treatment and post-treatment, provide inkjet printed vat dye images on cellulosic fibres with high technical performance and image quality.

THE PLACE AND THE IMPORTANCE OF TECHNICAL TEXTILES APPLICATIONS IN ENTERPRISES DURING THE TEXTILE BRANDING PROCESS

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ABSTRACT

Trademarking is an important essential to provide the sectoral leadership. This essential may be responded by giving priority to country presentation, education, design, production input and providing logistic supports. For building the fashion mark, the important of the areas such as the productivity which is one of the important elements, innovation, quality, creating the difference, Research development, design, technological development have been increasing every new day. For defining the competitive power, product range and its properties, the changeable of the consumers, expectations of quality increasement and performance have caused an obligation to give priority to non price factors such as variety, invention and innovation. With the decision of World Trade Organization in 2005, the western countries having the part of their industry based on Textile sector started to produce new and modern textile products for being the market creators by creating trademarks. And as a result of this, it has been focused on the new innovations providing different usages and restatement of the daily used textile products according to the people's consuming trends. Because of being textile materials produced for their technical performance and functional properties, apart from the esthetic properties, the, high added valued technical textiles will provide a privilege and one step forward in the trademarking process for the countries having the success of this focusing. The Technical Textile studies carried out by the Research & Development - Production & Development Departments will provide important advantages for revival of our textile sector, for the solutions of the problem during the global competition and taking some precaution for the future. The process of the fashion products' production starts from the raw material and ends with the finishing treatment to the structure provided by using various production technologies (weaving, knitting, non-woven technologies). Especially the variation in finishing technology creates marketing preference by facilitating the supplement of technical textile aimed product with the modification of the product appearance, touching and its performance. The Technical Textile concept should be regarded during the process of fashion products' production technology and their target group. In our study, some of the technical textiles studies of our country companies' Research & Development – Production & Development Departments will be analyzed. It will be examined whether if technical textile is a chance of Turkey computing with the trademarking process in a Global World and the opportunity of the utilizing from the advantages and privileges provided from the trademarking with Technical Textiles will be analyzed.

Key Words: Technical Textile, Trademark, Technology

1. INTRODUCTION

Textile was the first industrial branch in the Turkish Republic to be established in 1933. Textile treatment, cotton yarn and weaving facilities and factories were initially established by the public sector and which later on was launched by private enterprises. With the institution of Sümerbank, initial steps were taken towards modernization in the Textile sector. Thus, while the job opportunities increased in factories that were opened in Anatolia, and the workers, technical personal and permanent staff were trained accordingly; the social life, on the other hand, also flourished around these factories. The textile sector was not able to adapt to present market conditions as the result of the insufficient conduct of R&D studies over the years and the textile industry, which lay across a vast area, focusing solely on production. The sector especially faced difficulties after 2005. According to the decision of the World Trade Organization all quotas on the Textile sector were abolished in 2005. For this reason, western countries whose industries were based on the textile sector started to concentrate on matters as producing new and modern fabrics in order to create trademarks, that is, to be market creators as well as shaping daily worn clothes according to people's consuming trends. In Turkey, the gravity of the matter, unfortunately, is just being registered. In accordance with the plan to restructure textile, it is believed appropriate for a sector which is still producing on a fairly average and above average ground to turn into a structure consisting of top grade, high quality fashion trademark products. Hence, textile was to reduce in quantity while its turnover increased as the results of the progress made in production and products. Our Textile and Readymade businesses' insufficient consideration over matters as following fashion trends, new production techniques, research development and relevant education activities, prevented the sector to enforce qualified and competent work force as well as the production of high value added products. While industrialized countries advanced in technology and took full advantage of being a manufacturing country, they were able to produce high value added as well as high-quality textile and readymade products and technical

textiles. Turkey developing in technical efficiency within the area of intelligent textiles of concentrated information and of high value added is quite significant for our textile sector in respect to competing with others [1]. In order to attain the goals of the study conducted by the European Technology Platform for Textile which Turkey was a part of and which is indexed to 2020; transition from standard products to specific product, new applications in textile and the transition from mass production to private production were the designated plan as the three main method determine the priorities and the collaboration possibilities of the required R&D and P&D studies. Subjected to change, the functions will persist in this context and the sector will now be able to determine the market target more rather than just being a supplier [2].

Hence, the significance of Technical Textiles; the products manufacture with the usage of this technology will surely be beneficial for Turkey within the foreign market. This paper will initially study the conceptions of trademark, fashion and design. It will provide general information on technical textile and evaluate Turkey's stand within this area and contemplate on the chances of competing in a globalizing world.

2. CONCEPTS OF DESIGN, FASHION AND TRADEMARK

2.1 Design

Design is a notion that shows the intention of a person, the reflection of the intended occurrence or accomplishment formed in one's mind. And in order for a design to take shape; a subject matter needs to be established, it also requires the determination of a main idea, creation and execution of a plan, the supervision of it and establishing further progressive studies. The essence of design should be rooted in fashion and the market; at the same time the designed product should be functional as well as original [3].

The process of design involves all actions in general, steps beginning from generation of ideas to views on the developed prototype of the last product. It is a multidisciplinary science which requires teamwork and collaboration between various common operations. Design is essential for material and process data, other phases and finally in the creation of new products [4]. Multidisciplinary studies are also indispensable where technical textile applications are concerned.

While the word textile literally means woven fabric or weaving/knitting, today it corresponds to a vast area. On the whole, it constitutes of the aesthetic element of the woven fabric, a mixture of composition, color and material within the context of Textile Design which in turn can be categorized together with Textile Raw Materials, Weaving, Print, Fashion and Accessory. In the present day there are methodical and theoretical studies involving all fields of design. Aside from the production of fiber, thread and fabric in Turkey and in the rest of the World; textile dyeing and après/finishing, knitted products and clothes, carpets, all home textiles and technical textiles are considered all to be Textile Design Products [5].

It is possible to manufacture two and three dimensional textures and fabrics on a universal level with a contemporary approach with the developing technical facilities, taking full advantage of the rich cultural accumulation and early production techniques of the historical process of Textile Design.

2.2 Fashion

Fashion corresponds to the entire characteristics of a combined and prevalent attitude and expression of a society or at least a vast section of the society in many areas as manner of dressing, conduct, household furniture, make up, etc which has been the main basis that nourishes the changes in fashion. It enables change through designs which satisfies the feeling regarding the human instinct of change.

Owing to the environmental activities and factors that make up a community, fashion is no longer a necessity but has transformed into a phenomenon of fashion itself. Fashion has become one of the biggest economic forces in present day living and a new competitive environment has arisen with this new force. The importance of fashion marketing increased within this competitive atmosphere, all the while manufacturing fashion products, quality, trademark, distribution channel, cost and promotion have become an element of competition. However, the effective and collective usage of all these has

increased one's chances of survival in such an environment. The effort of designing a product in the most fashionable sense, its relation to high quality, a well planned promotion and low cost will definitely contribute to the introduction of a product ready to compete [6].

Making of fashion products are determined by the textile industry and as a result, the production process of these goods is achieved through acquiring and production of fiber and thread. Textile factories produce fabric by interweaving threads and fibers using different techniques, which is then followed by the appearance of the fabric, its hold, performance or treatments on the material's surface. Even the act of concluding the treatments conducted over the fabric, can create a marketing preference within the industry; surface treatments are applied on the thread and fiber, before it is made into the actual fabric. From an industrial perspective, the next phase involves the design and production of the finished goods. All these fashion products are considered throughout the processes of design and production of which are carried out according to the industry and the targeted consumers [7]. (Watkins, 1988) Production of these fashion goods by making use of conventional as well as technical textiles and with the materialization of different products will all give grounds for competitiveness.

In the last years we see a serious amount of interest of world famous designers towards applications of technical textile, the main subject of our study. The Japanese designers in particular took the lead on the matter. The different applications they made have been felt throughout the fashion world, in a sense, making a place for them selves by becoming a label. In the east, fashion and textile designers work hand in hand and the artists manufacture designs that research the prospect of new materials over the human body.

Issey Miyake, Yohji Yamamato, Junichi Arai, Rei Kawakubo and Junya Watanabe are all chief designers that make use of technique and intelligent textiles. Moreover, leading fashion designers work with materials and technologies from Japan. In the west, however, Helmut Lang shows his close interest towards technology through the sophisticated Synthetics he uses and the textile treatments he applies. On the other hand, the New York fashion designer Donna Karan says technology is the future of fashion [8].

Figure1: Dancers in Issey Miyake clothes: the movement of the fabric, their relationship with the body and the way the clothes were used have all been beautifully displayed.

2.3 Trademark

Trademark is marks of all sorts that can be published and reproduced by means of printing and which also be displayed and expressed by sketches of wrappings, shape of the products, words, symbols, letters, numbers or even a person's names so that it will create a distinction between the products and services of a certain business ventures from the rest of the products and serves of other business. The Turkish Patent Institute is the sole legitimate authority on patenting/registry in Turkey.
The most significant step of all enterprises which have made the notion to become a 'trademark' their venture's vision is to leave a permanent mark in consumers' minds and thus creating customer loyalty, securing steady sale and last, but not least, gaining grounds for rivalry.

Marketing is as important as fashion itself in the fashion industry. The label product is distinct from such others and creates an emotional bond between the consumer and product. With his clothes, Versace wants to reflect a deluxe, romantic life style for his customers while Calvin Klein consumers side with minimal and clean cut aesthetics. Aside from their products, successful fashion designers also market their identity and way of life. This expands to all corners of life, extending from Ralph Lauren selling art pictures to Christian Lacroix's sale of espresso coffee cups.

All trademarks are prepared such that they target a certain group of consumers of the market. As design labels which have a price range and which target high income groups face difficulty in reaching a wide range of consumers, trademarks of the middle income group do not give place to expensive designs in their collections. Each and every trademark has a certain style, strategy and product range. And the important thing here is to create a difference and technical textiles are amongst the most important opportunities in creating such differences.

3. TECHNICAL TEXTILES

When considering the conception of Technical Textiles, one clearly sees that it is more functional and requires qualities as technical performance rather that just rely on looks and aesthetics and which also firmly entails the know-how's and R&D as well as interdisciplinary studies and which is generally exercised on textile products used within the industrial, military, medical, safety, construction and many other areas [9]. Whether it be an increase in the variety of fibers in recent years or an increase in new technologies of production, the demand for technical textiles is on a rapid increase. Technical textiles mainly concentrate on mechanical and chemical advantages rather than depending on looks and aesthetics, and the processes of raw material and production are considered accordingly to these expectations.

Products characterized as technical textile are generally of high value added goods. For these products, the market is less sensitive on pricing in general. However, their products do require technical efficiency and experience, investment capital, particular knowledge, materials, dealings and equipment. Moreover, technical textiles materials initially require research & development as well as a well-rounded knowledge on its appliances, engineering capacity, high capacity production and quality control standards. Sometimes it may take years for a product to own any kind of market value [10].

Appropriate to the demands of the changing market structure, the ageing population, healthy life styles, environmental factors and protection from harm, too much free time and increasing sport/hobby activities, the need for new functional textiles, Technical Textile can be counted amongst the reasons why Market development. In resent years many different functional special textural structures developed as perspiration control, protection from weather conditions, antibacterial, inflammable, antistatic and protection from detrimental electromagnetic, protection from UV rays, strengthening of UV resistance, intelligent textiles with censoring ability, textiles with filtrations, self-cleaning textile and conductive textile.

Aside from the fashion conceptions, the textile industry put forth the development necessitated from worldwide global changes. Within the context of this development, the textile industry had quickly turned towards high value added products amongst which technical textile has drawn attention with its raid growth during the last years and was conceived as products that promised a future [11].

The concept of technical textile was solely used for industrial textile materials (side from clothes and home textile) when it first appeared. However, through the years, with developments in technology, there was significant amount of increase within the areas of technical textile production and application; for synthetic fibers of very different characteristics were beginning to be produced. Technical/intelligent textiles were initially used in military and sportive clothing; shortly after fashion designers carried these materials to their collections and thus high technical textiles were begun to be adapted to daily wear. With the integration of computers with clothes after the 90s the capacities of technical textiles and clothes were increased. Today it is possible to produce on micro-level and re-structure fibers through nanotechnology. Such technological innovations and facilities have increased the need and demand for these high-performance and high- functional materials. And with the developments in production techniques and methods, aesthetics has also become a required criterion in technical/intelligent textile products. Industrial textile materials were brought together with the

technical/intelligent material designs of people expert in their fields ranging from producers to textile designers, from textile artists to scientists, thus new products came to being as a result of interdisciplinary studies.

Technical textiles is a concept which most of us do not use or recognize in our lives, however which is quite established in every section of it, presently used from construction sites to clothing, from transportations to health-care; the outdated former definition of the concept consisted as “textile materials and products excluding non preserving clothes, home textile products, upholstery and carpeting”. Its present definition however sets out from the performance and decorative characteristics of textile products which are at a rapid increase and the combining makeup of their functions, and is as “Textile materials and products produced initially for their technical performance and functional traits rather than for aesthetic and decorative reasons” [12].

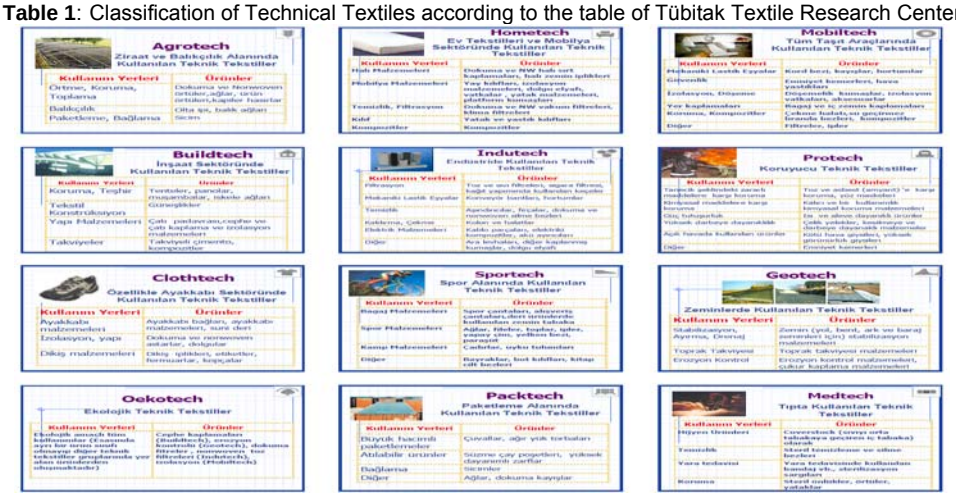
The ever-growing process of technical textiles continue to display rapid growth thanks to the third world countries as they manufacture at very low costs which has pushed the West and Japan to seek new solutions in order to sustain the presence of their textile industries. The introduction of High Performance Textile facilities has increased the importance of the applications of electronic, computer and nanotechnology appliances as well as the technical textile structure.

The United States, India, China, Japan, England, Germany, France and Italy are leading countries in world technical textile production. The European Union slightly behind in the race with the United States and Japan, is drawing up plans in order to become the most competitive rivalry on informative economy in the world in 2010.

When classifying the subject matter in general we see applications and technologies as Bicomponent Fibers, Biotechnology, Coating and Lamination Technologies, Composite Materials, Computer Aided Design (CAD), Computer Aided Manufacturing (CAM) Information Technologies and Computing, Spinning of Fibers through Electro spinning, Nanotechnology, Plasma Applications and Intelligent Textiles played a great significance in the production of technical textiles [13].

According to the table prepared by TÜBİTAK (the Scientific and Technological Research Council of Turkey) Textile Research Center, the general classification of technical textiles is as shown below.

Table 1: Classification of Technical Textiles according to the table of Tübitak Textile Research Center



3.1 Technical Textile Sector in the World

The business scoop of the technical textile industry generally seems smaller than it really is. Whereas technical textiles of most countries consist of more that 40 % of the consumption of the textile industry’s latest products. World technical textile Industry and statistical data on marketing do not reflect the sector in the true sense due to such enormity and extent range of application of technical textile products. On the other hand, when we analyze the sector in terms of country and based on the data especially attained from developed countries as the United States, Western Europe and Japan, we clearly see that the technical textiles industries in North America are the largest industries in the world [14]. Technical Textile Market is becoming a valuable asset with current developments and with the significance of the market the applications are also on the increase. Technical textile becoming

more and more important is closely connected to the advances in artificial fibers in general. Thus, the Market is prospered due to the efficiency in the use of sound and high-performance synthetic fibers which over 30 % of all fibers used in technical textiles. Bearing in mind all fiber consumption in technical textiles we see that it is under the domination of textile itself. In terms of regional production of technical textiles, we also see that West Europe, America and Japan are leading productions centers [15]. Looking at the table below, we can distinguish the present condition of technical textiles worldwide.

Table 2: Estimation of technical textile consumption worldwide in terms of regions [16]

	2005 (*)	2010 (*)	Variation %
North America	4.774,00	5.591,00	17
South America	1.004,00	1.230,00	23
West Europe	4.107,00	4.760,00	16
East Europe	666,00	817,00	23
Asia (Except for China)	5.220,00	6.348,00	22
China	2.871,00	3.808,00	33
Other Regions	1.041,00	1.219,00	17
Totally	19.683,00	23.773,00	21

Unit : 1000 Ton
(*) Prediction

Table 3: Ratings of world technical textile consumption according to regions and 2010 estimations [17]

	2005 (*)	2010 (*)	Variation %
North America	4.774,00	5.591,00	17
South America	1.004,00	1.230,00	23
West Europe	4.107,00	4.760,00	16
East Europe	666,00	817,00	23
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China	2.871,00	3.808,00	33
Other Regions	1.041,00	1.219,00	17
Totally	19.683,00	23.773,00	21

Unit : 1000 Ton
(*) Prediction

Table 4: Estimations of technical textile consumption according to places used worldwide [16]

	2005 (*)	2010 (*)	Variation %
Agrotech	1.615	1.958	21
Buildtech	2.033	2.591	27
Clothtech	1.413	1.656	17
Geotech	319	413	29
Hometech	2.499	2.853	14
Indutech	2.624	3.257	24
Medtech	1.928	2.380	23
Mobiltech	2.828	3.338	18
Packtech	2.990	3.606	21
Protech	281	359	28
Sportech	1.153	1.362	18
TOTALLY	19.683	23.773	21

Unit : 1000 Ton
(*) : Prediction

3.2. Technical Textile Sector and Its Condition in Turkey

As Technical Textile Investments are new in Turkey and as productions are kept private and the lack of data inventories within the sector, it was quite difficult for us to obtain the exact numbers on production capacities and product varieties of enterprises. However, it is a fact that business do exist, whether big or small, and are in operation. Businesses as Moğul Spunbonded Nonwovens, KordSA, Penta Tekstil, Bezci Tekstil, Vateks Tekstil, Teksis, Flokser, and Beteks-bodurlar have all become international firms within their branch. In recent years, firms as Korteks, Karsu and Hassan Group have stood out within technical textile production and their products shed new light which will enable for Turkey to move forward within the sector. For instance, the TAÇ antimikrobiyel thread, developed by Korteks provides a wide spectrum and permanent antimicrobiyel feature in textile fabrics [18]. When examining the tables below, it is obvious that before long technical textiles will, no doubt, receive the attention it deserves.

Table 5: Turkey's technical textile export according to years[19]

YEARS	AMOUNT	VARIATION %
2000	425.701.333	
2001	495.402.697	16
2002	562.203.183	13
2003	675.371.434	20
2004	824.846.748	22
2005	903.737.293	10
2006	943.174.079	4
2007	1.091.572.258	16

Unit: ABD $

Table 6: Countries which Turkey exports technical textile the most

COUNTRIES	2000	2007	VARIATION %
GERMANY	94.431.236	172.482.088	83
FRANCE	40.095.573	119.272.700	197
ITALIAN	22.435.215	62.070.682	177
SPAIN	21.046.103	59.846.537	184
ENGLAND	24.853.673	58.157.941	134
RUSSIA	10.246.010	51.789.415	405
RUMANIA	3.632.177	42.326.000	1.065
U.S.A	25.409.541	40.950.803	61
POLAND	3.371.910	39.122.316	1.060
HOLLAND	22.447.340	33.307.336	48
REPUBLIC OF SLOVAK	2.295.079	25.833.929	1.026
ISRAEL	12.882.513	23.637.104	83
IRAN	20.319.900	21.462.187	6
UKRAIN	21.754.865	18.945.432	-13
SERBIA	-	17.864.005	-
SUM OF 15 COUNTRIES	325.221.135	787.068.475	142
SUM OF TECHNICAL TEXTILES EXPORTATION	425.701.333	1.091.572.258	156
THE PORTION OF 15 COUNTRIES TOTALLY %	76,4	72,1	

Unit: ABD $

4. The Branding Process in Turkey and Relations of Technical Textile

If we were to examine the Condition of the Turkish Textile Industry and the Conception of the Branding Process within the Process of Globalization, we would easily see that world competitive elements changed as a natural result of globalization. As the “traditional competitive elements” in the world is lagging behind; well-trained man power, a well-functioning market mechanism, a wide scope of information that will stimulate a way to the final market destination, an extensive developed transportation and communication network which will enable the delivery of products to their final market destinations [20].

Branding is the most important norm of the globalizing world, a conception of competitiveness. Local rivalry is no longer valid, for it is now inevitable for business to avoid engaging in a rivalry with businesses located at the other side of the world. In a sense they will be playing in the world league, that is to say, they are now faced with the difficulty of competing in the global market. In order to survive in such an intense competitive environment, enterprises were forced to attach great importance four strategic leverages; Quality, Cost, Product Innovations and the Time to Market. These four factors are the prerequisite for concurrent management to compete in the global market. (Yönetim, 1995) Applications are the initial product innovation which came about as a result of R&D studies conducted in the area of technical textile which we have also analyze the statistical data of. Following the year 2000, the Turkish Textile Sector is undergoing a new era of chance. Through the tendency towards active marketing strategy, the enterprise has started to manufacture its own original designs and collections; and the subsistence of Turkish designers have rapidly developed with chain stores and process becoming a trademark within Turkey as well as in foreign countries. Production quantity has also shown rapid increase thought this process, tending towards a more moderate group production. There was also an increase in exports until 2005. The expression of ‘must create a Fashion Trademark’ has become a catch phrase which indicates an image of a glorified country. This

no doubt refers to the image of a country which is powerful enough to enforce a safe environment not only over a few fashion – trademarked enterprises but over all of textile. Hence, it is necessary for such efficient conditions to prosper. The condition efficiency consists of focusing on opportunities or the state to contemplate multi-dimensionally and globally over matters as statutes of production factors, demand or the condition of creating such demand for produced products/goods, the existence of an associate and supplement industries and the competitive conditions of a business [21].

Becoming a trademark in technical textiles and creating a difference in today's fashion enterprises is something which is desire, however a goal which is yet to be fully attained. It is quite clear that with technical textiles products which contribute positively over people in context of comfort and hygiene in clothes, will easily appeal to Turkish consumers. In this context, the produced goods are quite beneficial as they are products which instantly appeal to people;which make consumers fell better; and which are beneficial in health wise. Making use of microcapsule methods, natural medication, perfumes, product that protect from radiation can be relayed to the consumer during consumption. In addition to these structures which are currently only used in the sock and underwear sectors, the development of fabrics which consist cream capsules that prevent aging (as indented in Japanese studies) will shed important light on the process of branding in Turkey.

Each enterprise needs to reserve capital for R&D but this does not mean that every business needs to establish a R&D department. It aims to accomplish what is unknown by others and for this reason, it is a very risky study based on possibilities. R&D directors should be prepared for great number of failures. Thus, it is more appropriate to for Research Foundations (Universities, freelance R&D laboratories) to assume on R&D activities in exchange for money. Unfortunately the basis of such service has not yet been established in Turkey [18]. It seems that in order to find/make a place in such a competitive market, the produced good would stimulate a larger denominator by applying technical textiles in textile enterprises.

5. CONCLUSION

The basis of the Turkish readymade/textile sector consists of custom manufacturing for established labels that have made a place within the global platform through the price and cost policies founded mainly on low labor costs. In a medium term this system can not possibly sustain the Turkish readymade sector. Setting out from the fact that Turkey is a significant textile producing geography from archeological times, we need to establish the conception of fashion – trademark as well as accept its existence and importance of textile within/for Turkey in order to eradicate the predicaments the textile sector - which is known to be a significant export unit since and especially during the Seljuk and Ottoman Eras - found itself in the present years and which have been brought about by the casual connection of the global economy. Technical textiles are the most important concession of this construction process. One can clearly see a gradual increase and variation of technological textile products. There is sufficient/efficient basis for the matter in question and increase in investments. In the fast-consuming world that we inhabit, it is very important to effectively correspond/meet to expectations of consumers, however, which can only be made possible by the wide range of quality and innovative products. And this only can be made possible by technical textiles. R&D departments need emphasis and support. Constituting a significant percentage of Turkey's economy, the weakest point of the textile sector involves the insufficient investments to R&D departments. If one wants to transform from a custom manufacturing country into a "Made in Turkey" conception, Turkey needs to speed R&D studies with the support and investment from both public and private enterprises as those countries that have an advanced or at least a developing industry. Stipulating that our Textile basis is sufficiently facilitated and its work-force employs experience personnel, this will certainly be an advantage and stimulate efficient and qualified production output within the applications of technical textiles. This, no doubt, will come to mean that Turkey will be a creator of a trademark within the world market and be a country in demand.

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USE OF FIBER REINFORCED POLYMERS IN SEISMIC ISOLATION BEARINGS

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ABSTRACT

Seismic isolation technique is a recently developed earthquake resistant technique in which flexible and dissipative elements are inserted at the base of a structure so that the devastating effects of earthquakes on the structure can be reduced significantly. Seismic isolation bearings used for this purpose can be grouped into two main types: sliding bearings and rubber-based bearings. Until recently, most of the rubber-based seismic isolation bearings are steel-reinforced. In other words, they are composed of several thin rubber layers bonded to and interleaved by interior steel shim plates under high pressure and temperature. While interior reinforcing sheets do not affect the horizontal behavior of soft rubber layers, which is necessary for isolation of the superstructure from horizontal earthquake forces, they increase the stiffness of the composite bearing system under compression and flexure, which is essential to support heavy weight of the superstructure safely. Since steel (with elasticity modulus of about 200 GPa) is much stiffer than rubber (with shear modulus in the range of 1.0 MPa), it is usually considered as an ideal reinforcing material for such a purpose. However, steel-reinforced rubber bearings are both expensive and heavy, for this reason, they are suitable mostly for large buildings with sensitive equipment and/or historical value and/or post-earthquake importance. In an attempt to develop low-cost and low-weight bearings to be used in conventional buildings or in structures to be built in developing countries, Kelly (1999) have recently proposed the use of fiber reinforcing sheets instead of steel reinforcing plates. Although the idea is very new, the viability of this proposal has already been investigated and verified through several experimental and analytical studies. This paper attempts to provide a review on these studies and discuss the possible future work on fiber-reinforced seismic isolation bearings.

USING THE BODY MESH FOR GARMENT PRODUCT SIMULATION

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Abstract

This paper presents aspects of 3D simulation of apparel products using that support different types of human bodies created in the virtual environment.

The paper presents for achieving this goal using of the finite element mesh. Mesh is done both in body and clothing to the product. It follows the correspondence points that define the perimeters of the main body and body product level.

The objective of this method is to model various clothing products to highlight their behavior under static and dynamic. Static or dynamic behavior can be predicted by knowing the forces acting on the surface of the textile product, taking into account the constraints imposed by the type and combination of parts of clothing. Textile material can be described by its geometry and physical properties and can be perceived as a two-dimensional surface is moving in a three-dimensional space. In clothing product textile material suffer some deformation due to multiple requests (bending, stretching, shearing) in multiple directions.

For accurate modeling of the textile material is required in advance of setting physical and mechanical properties emphasized by Kawabata evaluation system. With the evaluation results available, the textile material can be modeled as a continuous or as a particle-system model. Always, the continuous and the particle-system model were in competition. Although the two models are different they lead to similar results.

Continues technique is based on elasticity theory and the textile material is considered has a homogeneous structure. Modeling of the textile material in clothing product is done numerically using finite element method. The finite element method divide the surface or textile in a representative set of triangles and find the appropriate functions that satisfy the balance elements equations. Particle-system based model is due to gaps existing in a continuous model, which couldn't play the complex behavior of the textile surface to extension or bending tension[1].

Keywords : finite element, garment, simulation, body mesh, virtual.

1. Introduction

A cloth object is a 3D mesh composed of vertices, indices, and polygon faces. While they are understandably important for rendering, those vertices do double−duty when it comes to cloth simulation because they are affected by its physics. A cloth's vertices are therefore referred to as cloth points (or points, for short). By manipulating the coordinates of the cloth's points over time (with forces such as gravity, wind, or anything else you can throw at it), you can create the appearance of a flowing, elegant piece of material.

To closely emulate a real piece of cloth, these cloth points have a specific mass value associated with them that determines how the point moves according to how much external force is applied. Points with a higher mass require more force to accelerate them, whereas points with a lower mass tend to accelerate more due to external forces being applied. This is a factor of momentum, which states that the force required to move an object is equal to the mass times the acceleration you wish to achieve (F=ma).
The mass - spring system that has been used for the 3D simulation of cloth enables the parametrization of internal forces such as bending, stretching or damping of the fabric[1].

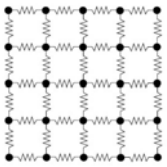

Figure 1. Mass-spring system

This provides us with the ability to implement different types of fabric by just modifying these parameters (parameters of the springs).

The cloth mesh's polygon edges also have an important role−they hold together the cloth's points. Well, the polygon edges really don't hold the points together−rather, those edges represent a bunch of tiny little springs that hold together the points. As the points in your cloth move, each spring tries to maintain a state of static equilibrium by pushing and pulling the points until the forces are balanced. Visually, this makes it look like the points are being kept at a certain distance from one another.
For a successful design product is required a 3D simulation of the garment product. The simulation of the clothing product starts from 3D modeling, that can be done by drape the textile surface on the industrial body mannequin, or in the virtual environment.
The textile surface drape in virtual environment can be made by :

- using a parameterized body type using the data obtained with a 3D scanner;

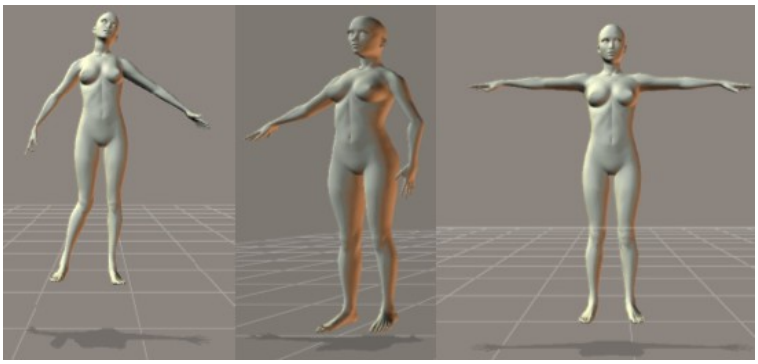

Figure 2. 3D Body obtained by using graphic software

- using a body type model done in 3D graphics software (figure 2).

In order to achieve this goal it is using the following data : body type, the textile material in the virtual environment and patterns productmade in a 2D graphics software. The result of the 3D modeling in virual environment is to obtain the 3D appearance of the clothing product modeled in static way.

2. Experimental simulation of the garment product using virual body

The simulating behavior of the garment in virtual environment involves the using of the parametrized virtual model .

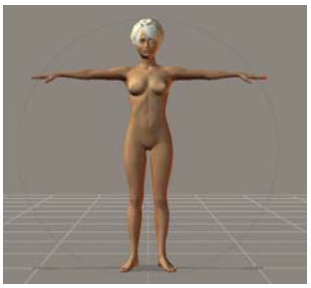

Figure 3. Virtual body parametrized

It must consider the fit zone of a garment that is in direct contact with the body surface and is responsible for the comfort of a garment that it must be designed to correctly reflect the shape of underlying body.

To achieve the dress pattern we start from a basic block showing:

- the pattern for bust pensions transferred to the shoulder line;
- the back side pattern to the pattern don't have any darts.

Product adjustment will be made through the side stitch.

The clothing products simulation require:

- virtual body, 2D pattern in .dxf file format (figure 4);

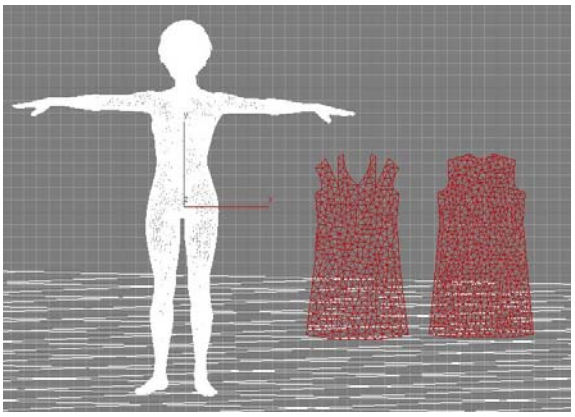

Figure 4. Virtual body, pattern mesh

- defining of the seam lines;
- defining ➔ the cloth type object – cloth ,garment product;
  ➔ collision object – bodies.

Garment simulation is performed on a virtual parametrized mannequin type by modeling or resizing the patterns surfaces.

Pattern are made and imported like surface obj.file from Autocad in 3D simulation software (figure 5).

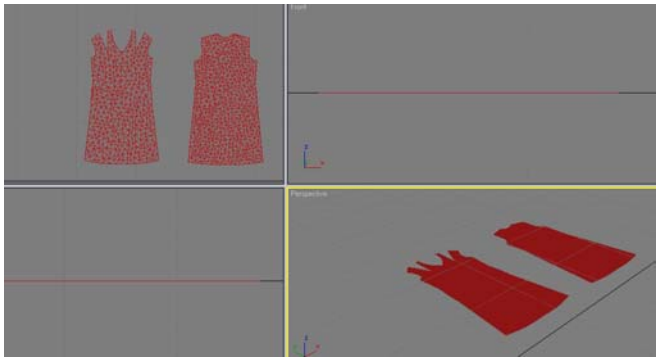

Figure 5. 2D Pattern dxf. file

The virtual body can be resize virtually for every sized and that is possibly to use for non-standard configurations bodies.

The surface mesh elements is to obtain representative simulation considered the type pattern drapery cloth on the body surface regarded as support - Collision object, for the determination of collisions that may occur.

Assembly patterns is done using function and simulated seams, stitching is accomplished by overwriting points defining the border areas to assemble (figure 6 ,7).

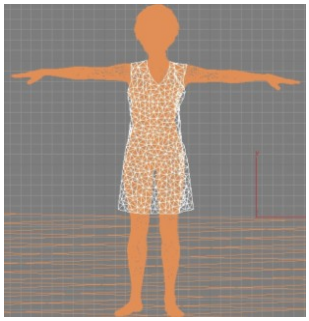

Fig. 6 Virtual body front view

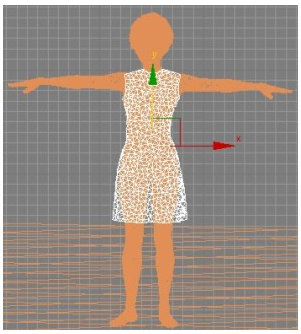

Fig.7 Virtual body back view

Cutting products requires a careful study of surface textiles, garment design to be made, but also on how to achieve 2D patterns.

3. Results

The spatial form of garment products is influenced by the interdependence of the features of extensibility, flexibility, material drape and by the morphological indices that characterize the human body.

Clothing products modeling arises from the need to simplify the process of design and product design. Simulation is necessary to visualize the shape and appearance of product design, and its behavior and response to various demands.

3D simulation for clothing products is to define the geometric parts of the product and objects that will interact with the product (ex. parts of product or the human body). It is necessary to simulate the constraints and the impact of body - product, product - parts of the product. The study of the constraints consists to find the limits of movement of the product, such as those caused by the seamless of coat parts or product mount in a fixed point.

4. Conclusions

By using the body mesh for gament product simulation we can :

- checking the correspondence between product characteristics and destination of its use;
- time economy;
- quickly choose the best fit textile material;
- achieving optimal physical prototype;
- economy of raw materials and materials;
- effective in assessing patterns and products can be made from textile surfaces with specific physical and mechanical parameters.

References

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