Industria Textilă

ISSN 1222–5347

4/2018

Revistă **cotată ISI** și inclusă în **Master Journal List** a Institutului pentru Știința Informării din Philadelphia – S.U.A., începând cu vol. 58, nr. 1/2007/
***ISI rated** magazine, included in the **ISI Master Journal List** of the Institute of Science Information, Philadelphia, USA, starting with vol. 58, no. 1/2007*

Editată în 6 nr./an, indexată și recenzată în:
Edited in 6 issues per year, indexed and abstracted in:
Science Citation Index Expanded (SciSearch®), Materials Science Citation Index®, Journal Citation Reports/Science Edition, World Textile Abstracts, Chemical Abstracts, VINITI, Scopus, Toga FIZ technik ProQuest Central

Editată cu sprijinul Ministerului Cercetării și Inovării

Recunoscută în România, în domeniul Științelor inginerești, de către **Consiliul Național al Cercetării Științifice din Învățământul Superior** (C.N.C.S.I.S.), în **grupa A** /
*Aknowledged in Romania, in the engineering sciences domain, by the **National Council of the Scientific Research from the Higher Education** (CNCSIS), in **group A***

Suma r

Contents

EDITORIAL STAFF

Editor-in-chief: Dr. eng. Emilia Visileanu
Graphic designer: Florin Prisecaru
e-mail: industriatextila@certex.ro

Journal edited in colaboration with **Editura AGIR**, 118 Calea Victoriei, sector 1, Bucharest, tel./fax: 021-316.89.92; 021-316.89.93;
e-mail: editura@agir.ro, www.edituraagir.ro

The effect of process parameters on the electrospun polystyrene fibers

DOI: 10.35530/IT.069.04.1481

CRISTINA BANCIU
ADELA BĂRA
ELENA CHIȚANU
VIRGIL MARINESCU
GABRIELA SBÂRCEA
IOANA ION

REZUMAT – ABSTRACT

Efectul parametrilor de proces asupra fibrelor de polistiren electrofilate

Electrofilarea este una dintre metodele de obținere a nano/microfibrelor, utilizând soluții polimerice. Aceste membrane nanofibroase sunt foarte poroase, cu pori interconectați, o suprafață specifică ridicată și dimensiuni mici ale porilor, făcându-le un candidat adecvat pentru aplicațiile de filtrare. Proprietățile fibrelor electrofilate sunt influențate de soluția polimerică, solvent, concentrația soluției, viscozitate, conductivitatea electrică, tensiunea electrică, distanța dintre duza de filare și dispozitivul de colectare etc. Polistirenul expandat este un produs polimeric utilizat în mod obișnuit pentru izolare și ambalare. Reciclarea polistirenului expandat în nanofibre cu aplicații în filtrare ar putea fi utilă din punct de vedere economic. Scopul acestui studiu a fost investigarea influenței caracteristicilor soluției de polimer de polistiren expandat (concentrație, viscozitate) și a parametrilor de proces (tensiunea aplicată, distanța dintre vârful duzei și placa colectoare, debitul soluției polimerice) asupra morfologiei și proprietăților fibrelor electrofilate obținute. Trei soluții EPS cu o concentrație de 10, 15 și 20 procente masice au fost preparate și au fost electrofilate în condiții de procesare, cu o tensiune aplicată de 12, 15 și 18 kV, o distanță duza de filare-colector de 20 cm, un debit al soluției de 1,5 și 2 mL/oră, un diametru al duzei de filare de 0,8 mm și un substrat de cupru staționar. Morfologia fibrelor electrofilate a fost observată prin microscopia electronică de baleiaj. Proprietățile mecanice au fost evaluate prin teste de rezistență mecanică la tracțiune și alungire.

Cuvinte-cheie: polistiren expandat, electrofilare, fibre electrofilate, membrană, filtrare

The effect of process parameters on the electrospun polystyrene fibers

Electrospinning is one of the methods for obtaining nano/microfibers, using polymeric solutions. These nanofibrous membranes are highly porous with interconnected pores, having high specific surface area and small pore size, making them a suitable candidate for filtration applications. The properties of electrospun fibers are influenced by polymer solution, solvent, solution concentration, viscosity, electrical conductivity, electrical voltage, spinneret to collector distance etc. Expanded polystyrene is a polymeric product that is usually used for insulation and packaging. Recycling expanded polystyrene into nanofibers with applications in filtration could be useful from an economic point of view. The purpose of this study was to investigate the influence of expanded polystyrene polymer solution characteristics (concentration, viscosity) and the process parameters (applied voltage, distance between the tip and the collector plate, flow rate of the polymer solution) on the morphology and the properties of the obtained electrospun fibers. Therefore, three EPS solutions with 10, 15 and 20% wt. concentration were prepared and were electrospun under processing conditions with an applied voltage of 12, 15 and 18 kV, a spinneret-to-collector distance of 20 cm, a flow rate of solution of 1.5 and 2 mL/hour, a spinneret diameter of 0.8 mm and stationary copper substrate. The morphology of the electrospun fibers was observed by scanning electron microscopy. The mechanical properties were evaluated by tensile strength and elongation tests.

Keywords: expanded polystyrene, electrospinning, electrospun fibers, membrane, filtration

INTRODUCTION

Electrospinning is a process for developing non-woven membranes made of sub-micron to nano-scale fibers. These nano fibrous membranes are highly porous with interconnected pores, having high specific surface area and small pore size [1]. The structural properties of the Nano fibrous membranes make them a suitable candidate for filtration applications [2]. Electrospun nanofibers have many other applications in domains such as sensors, catalysis, drug delivery, tissue engineering, textiles, composite reinforcements, etc. [3–9].

Many polymers can be used in the electrospinning process, such as: polyacrylonitrile, polystyrene, polymethyl methacrylate, polyvinylchloride, polyamide, polyethylene terephthalate, cellulose acetate, polyvinyl alcohol, polyether imide, polyethylene glycol, nylon 6, polyethylene, polypropylene, etc. [9–12].

The polystyrene (PS) beads have been studied as a possible filter element in water treatment plants. In addition, the superhydrophobic PS nanofiber membrane was electrospun and it was found to be highly efficient at oil-water separation [13].

Expanded polystyrene (EPS) is a polymeric product that is usually used for insulation and packaging. Recycling EPS into nanofibers with applications in filtration could be useful from an economic point of view [14].

The properties of the obtained electrospun nanofibers are influenced by many parameters such as structural properties of polymers, polymer solution

parameters, processing conditions and the ambient parameters [15].
The purpose of this study was to investigate the influence of EPS polymer solution characteristics (concentration, viscosity) and the process parameters (applied voltage, distance between the tip and the collector plate, polymer solution flow rate) on the morphology and the properties of the obtained electrospun fibers.
The morphology of the electrospun fibers was observed by scanning electron microscopy (SEM). The mechanical properties were evaluated by tensile strength and elongation tests.

EXPERIMENTAL WORK

Materials

In this study, recycled expanded polystyrene (EPS) foam, waste from commercial insulating material used in constructions, was used as polymer source without further purification. The solvent used for dissolving EPS was dimethylformamide (DMF) with 0.94 g/cm^3 density, purchased from Alfa Aesar.

Preparation of electrospinning solutions

Three EPS solutions in DMF with concentrations of 10, 15 and 20 % wt. were prepared by dissolving EPS foam in DMF.
A good dissolution of the EPS in DMF is very important in achieving good morphological properties of the electrospun fibers. Thus, EPS was dissolved in DMF by magnetic stirring at room temperature for 1 hour, at a rotational speed of 420 rpm (table 1). The solutions were electrospun immediately after preparation.

Table 1

EPS/DMF solution	EPS10	EPS15	EPS20
EPS concentration in DMF, % wt.	10	15	20
Rotational speed, rpm	420		
Homogenization time, minutes	60		
Temperature, °C	Room temperature		

The prepared EPS solutions were electrospun using NaBond unit under processing conditions with an applied voltage of 12, 15 and 18 kV, a spinneret-to-collector distance of 20 cm, a solution flow rate of 1.5 and 2 mL/h, a spinneret with a nozzle size of 0.8 mm and stationary substrate. Aluminium foil served as the substrate for fiber collecting.

Characterization

Electrical conductivity of EPS solutions was measured with a VARIO COND portable conductivity meter model 340i with the cell constant K = 0.469 cm^{-1}.
The rheological behaviour of EPS solutions was studied using a rotational viscometer BROOKFIELD DV-II+ Pro, by measuring viscosity, shear rate and shear stress, at room temperature.
Morphological characterization of the EPS electrospun fibers by scanning electron microscopy (SEM) was performed by a FESEM/FIB/EDS Workstation Auriga produced by Carl Zeiss Germany, with an acceleration voltage of 2 kV, using the SESI detector.
Wettability testing of the polymeric membranes was carried out using the sessile drop method. The process of determining the contact angle of the polymeric membranes with distilled water was performed using an optical microscope equipped with a camera for images acquisition on the computer and the images were processed using the software Image J, Drop Analysis - Drop Snake.
The tensile strength and the elongation of the EPS electrospun fibers were determined by using a mechanical testing machine, model LFM 30 kN, Walter & Sai AG Switzerland.

RESULTS AND DISCUSIONS

EPS solutions electrical conductivity

The results regarding the electrical conductivity of EPS/DMF solutions (EPS10, EPS15 and EPS20) are presented in table 2.

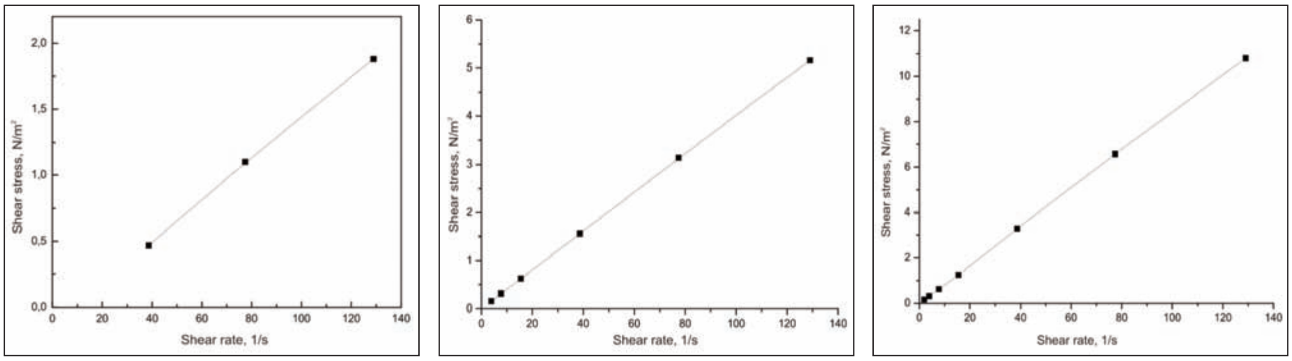
Table 2

EPS/DMF solutions	Electrical conductivity [S/m]	Electrical resistivity [Ω × m]
EPS10	4.0×10^{-4}	2.50×10^{3}
EPS15	4.8×10^{-4}	2.08×10^{3}
EPS20	5.1×10^{-4}	1.96×10^{2}

From the data presented above, it can be seen that the electrical conductivity values of the EPS solutions are low, their electrical resistivity being in the semiconductor range ($10^{-5} \div 10^{8}$ Ω×m). Increasing the EPS concentration determines an increase in the electrical conductivity of corresponding solution.

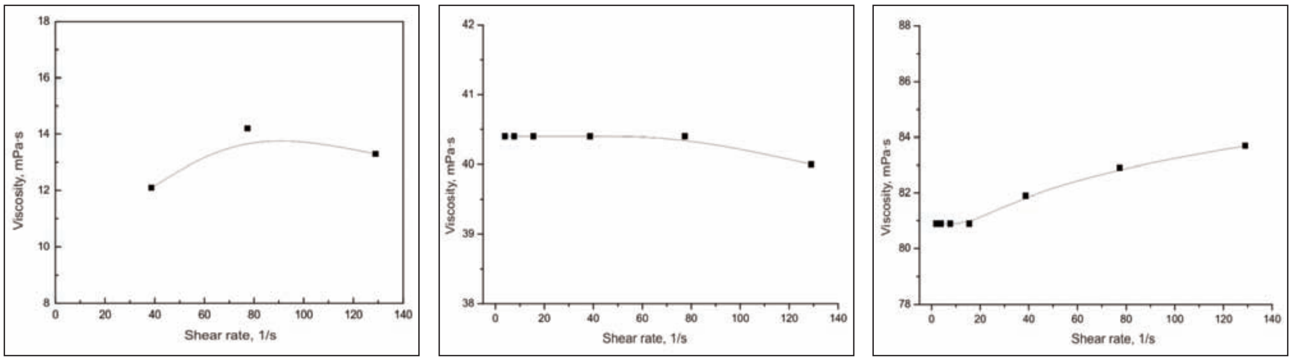
EPS solutions rheological behaviour

The viscosity of polymer systems is one of the parameters that determine their behaviour under external electric fields applied. The rheology of polymeric systems is influenced by the molecular weight of the dissolved polymers, the shape and rearrangement of macromolecules, and polymer-solvent interactions. The viscosity of the solution increases monotonically with concentration up to a critical value for a given polymer molecular weight. These observations reflect the consequences of macromolecular associations and are valid for studying polymer solutions to a range of low to high shear rates.
The experimental results regarding the rheological behaviour of EPS/DMF solutions are presented in figures 1 and 2. We can see that the viscosity of EPS solutions increases with increasing shear rate, indicating that they have pseudoplastic non-Newtonian fluid characteristics. Also, the viscosity of EPS solutions increases with the increasing of the polymer concentration in DMF.



a b c

Fig. 1. Rheological profile of solutions, shear stress–shear rate model: *a* – EPS10; *b* – EPS15; *c* – EPS20



a b c

Fig. 2. Rheological profile of solutions, viscosity–shear rate model: *a* – EPS10; *b* – EPS15; *c* – EPS20

Morphological characterization of the electrospun EPS fibers by SEM

The figures below show the SEM micrographs of the EPS fibers. The values of the EPS fibers diameters determined from the SEM analysis are presented in table 3.

Analysing the SEM micrographs we find that the fibers morphology is influenced by the parameters of

Table 3

Sample	Flow rate [ml/h]	Applied voltage [kV]	Fibers diameter [nm]		
			average	min	max
EPS10	1.5	12	324.6	232.3	431.6
	2		366.2	325.7	390.2
	1.5	15	398.9	275.1	485.2
	2		487.0	289.5	664.1
	1.5	18	385.7	294.0	447.7
	2		440.1	323.7	514.4
EPS15	1.5	12	629.0	435.3	969.6
	2		883.4	748.3	1091
	1.5	15	791.4	784.4	796.6
	2		813.2	346.9	1276
	1.5	18	810.6	648.2	983.9
	2		611.9	392.2	847.8
EPS20	1.5	12	696.0	553.5	861.3
	2		719.8	428.0	908.5
	1.5	15	795.4	699.6	852.2
	2		699.6	563.3	791.5
	1.5	18	602.5	534.6	731.3
	2		690.2	596.1	832.9

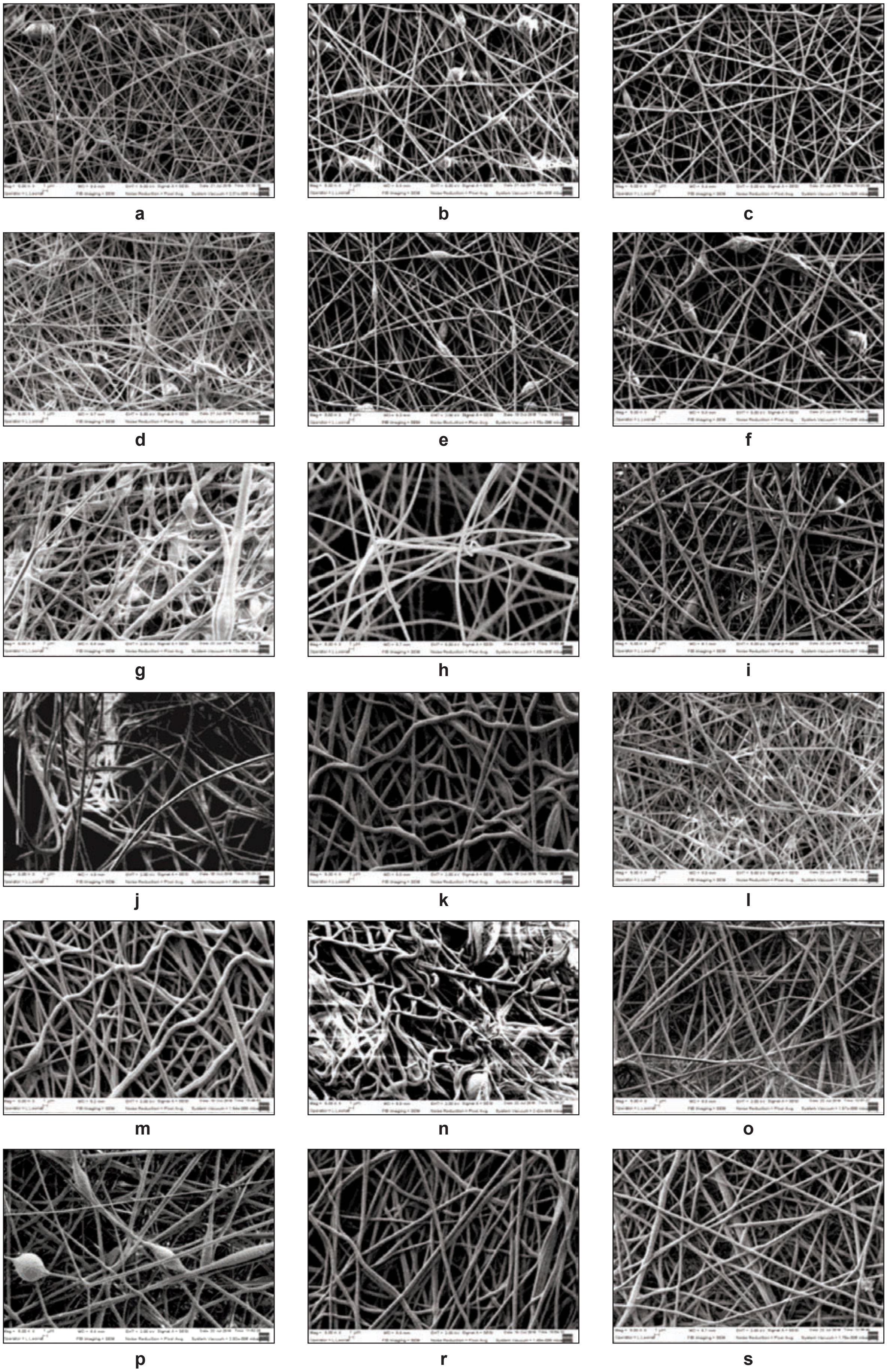


Fig. 3. SEM micrographs of samples electrospun on aluminum foil substrate:
EPS10: *a* – 1.5 ml/h, 12 kV; *b* – 1.5 ml/h, 15 kV; *c* – 1.5 ml/h, 18 kV; *d* – 2 ml/h, 12 kV; *e* – 2 ml/h, 15 kV; *f* – 2 ml/h, 18 kV;
EPS15: *g* – 1.5 ml/h, 12 kV; *h* – 1.5 ml/h, 15 kV; *i* – 1.5 ml/h, 18 kV; *j* – 2 ml/h, 12 kV; *k* – 2 ml/h, 15 kV; *l* – 2 ml/h, 18 kV;
EPS20: *m* – 1.5 ml/h, 12 kV; *n* – 1.5 ml/h, 15 kV; *o* – 1.5 ml/h, 18 kV; *p* – 2 ml/h, 12 kV; *r* – 2 ml/h, 15 kV; *s* – 2 ml/h, 18 kV

electrospinning process (concentration of polymer solution, flow rate, voltage).

Increasing the concentration of EPS in the solution from 10% to 20% leads to uniform fibers without defects (beads). At the same time, there is an increase in the average diameter of the electrospun fibers from 300 nm to 900 nm.

Increasing the flow rate of the polymer solution from 1.5 to 2 mL/h leads to an increase in the average diameter of the electrospun fibers by approximately 50–100 nm.

Increasing the applied voltage from 12 to 18 kV also causes an increase in the average diameter of the electrospun fibers. Uniform and faultless fibers are obtained at an applied voltage of 18 kV and solution concentrations of 15% and 20%.

Wettability testing of the electrospun EPS fibers

For static contact-angle measurements, small strips of the samples were cut and placed onto a planar stage to ensure a flat viewing surface. A drop of water was dropped on the polymeric layer's surface from a micro syringe at room temperature (~28°C). The drop was allowed to reach equilibrium before the measurement was recorded and before evaporation occurred. Figure 4 displays the contact angle of distilled water with the EPS fibers.

The data presented above shows that the membranes obtained from EPS exhibit hydrophobic behaviour, due to the fact that the contact angle has high values of about 125–133° for all the polymer concentrations used.

Mechanical properties of the electrospun EPS fibers

In order to conduct tensile strength and elongation tests, the EPS fibers were deposited on a textile substrate (gauze fabric) for 6 hours. The samples were prepared with the following dimensions: length of 100 mm and width of 20 mm. The tests were carried out with a drawing speed of 50 mm/minute. Five tests were carried out for each type of material and then an average value of the parameters was calculated. Figures 5 (a–d) display the tensile strength curves of the EPS15 and EPS20 fibers. Table 4 contains the mechanical properties of the EPS fibers electrospun on the gauze fabric.

From the data presented above, it is found that the tensile strength has values in the range of 3.73-6.11 MPa, the average elongation is between 1.45 and

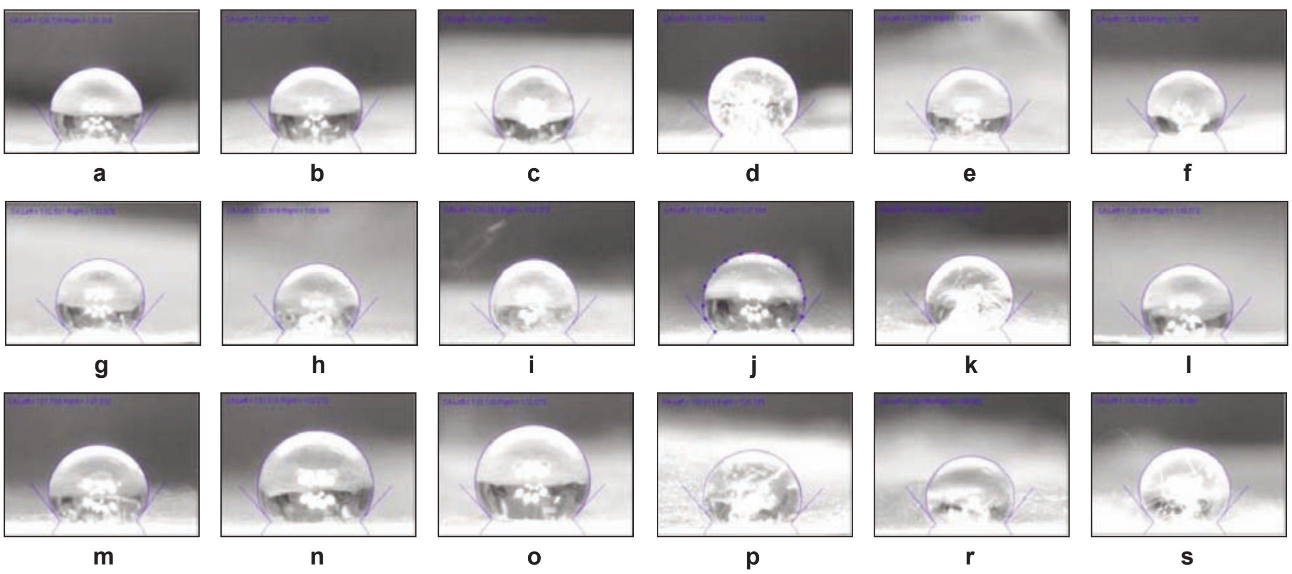


Fig. 4. Images of the water contact angle with the fibers surface:
EPS10: *a* – 1.5 ml/h, 12 kV; *b* – 1.5 ml/h, 15 kV; *c* – 1.5 ml/h, 18 kV; *d* – 2 ml/h, 12 kV; *e* – 2 ml/h, 15 kV; *f* – 2 ml/h, 18 kV;
EPS15: *g* – 1.5 ml/h, 12 kV; *h* – 1.5 ml/h, 15 kV; *i* – 1.5 ml/h, 18 kV; *j* – 2 ml/h, 12 kV; *k* – 2 ml/h, 15 kV; *l* – 2 ml/h, 18 kV;
EPS20: *m* – 1.5 ml/h, 12 kV; *n* – 1.5 ml/h, 15 kV; *o* – 1.5 ml/h, 18 kV; *p* – 2 ml/h, 12 kV; *r* – 2 ml/h, 15 kV; *s* – 2 ml/h, 18 kV

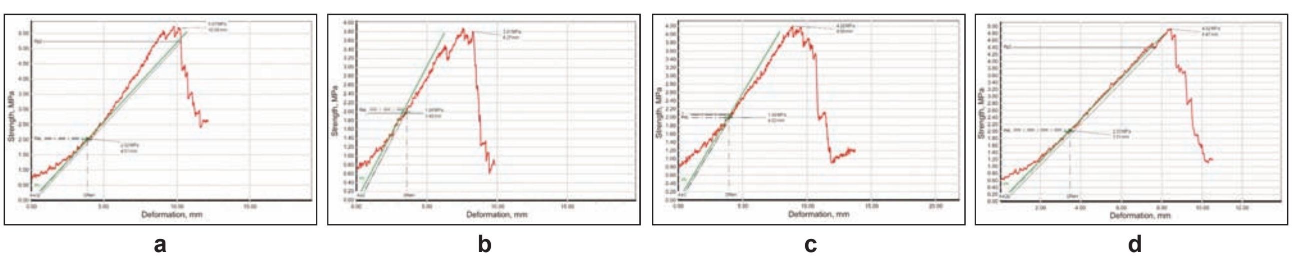


Fig. 5. Tensile stregth curves of the samples: *a* – EPS15 1.5 ml/h, 15 kV; *b* – EPS15 1.5 ml/h, 18 kV; *c* – EPS20 1.5 ml/h, 15 kV; *d* – EPS20 1.5 ml/h, 18 kV

Table 4

Sample	Membrane thikness [μm]	Average tensile strength [MPa]	Average elongation [%]	Average elastic modulus [GPa]
EPS15 1.5 mL/h 15 kV	280	5.41	2.94	0.06
EPS15 1.5 mL/h 18 kV	320	3.84	1.45	0.07
EPS20 1.5 mL/h 15 kV	340	4.16	1.70	0.06
EPS20 1.5 mL/h 18 kV	400	4.86	2.69	0.08

2.94%, and the average elastic modulus is between 0.06 and 0.08 GPa for all analysed samples. EPS20 samples exhibit a slight increase of the mechanical characteristics with the increase of the thickness of the electrospun layer.

CONCLUSIONS

In the present work, polymeric membranes of EPS were prepared under various conditions through an electrospinning process. Experiments were conducted to identify the influence of the process parameters on the morphology and properties of the electrospun EPS fibers.

Increasing the concentration of EPS in the solution from 10% to 20% and the applied voltage from 12 to 18 kV, leads to the obtaining of uniform fibers without defects (beads).

Increasing the concentration of EPS and increasing the flow rate of the polymer solution from 1.5 to 2 mL/h leads to an increase in the average diameter of the electrospun EPS fibers.

The EPS fibers exhibit a hydrophobic behaviour, the contact angle having values of about 125–133°.

EPS20 fibers, compared to EPS15 fibers, exhibit a slight increase of the mechanical characteristics with the increase of the thickness of the electrospun layer.

ACKNOWLEDGMENT

This work was supported by the project PN 16110205/2016 (CORE Program) and the project 113PED/2017.

BIBLIOGRAPHY

[1] Homaeigohara, S. Sh., Buhra, K., Ebertb, K. *Polyethersulfone electrospun nanofibrous composite membrane for liquid filtration*, In: Journal of Membrane Science, 2010, vol. 365, pp. 68–77

[2] Wertz, J., Schneiders, I. *Filtration media: Advantages of nanofibre coating technology*, In: Filtration & Separation, 2009, vol. 46, no. 4, pp. 18-20

[3] Wang, X., Kim, Y.-G., et al. *Electrostatic assembly of conjugated polymer thin layers on electrospun nanofibrous membranes for biosensors*, In: Nano Letters, 2004, vol. 4, no. 2, pp. 331–334

[4] Cui, W., Zhou, Y., Chang, J. *Electrospun nanofibrous materials for tissue engineering and drug delivery*, In: Sci. Technol. Adv. Mater., 2010, vol. 11, 014108 (11 pp.)

[5] Demir, M. M., Gulgun, M. A., et al. *Palladium nanoparticles by electrospinning from poly(acrylonitrile-co-acrylic acid)-$PdCl_2$ solutions. Relations between preparation conditions, particle size, and catalytic activity*, In: Macromolecules, 2004, vol. 37, no. 5, pp. 1787–1792

[6] Kenawy, E.-R., Bowlin, G. L., et al. *Release of tetracycline hydrochloride from electrospun poly(ethylene-co-vinylacetate), poly(lactic acid), and a blend*, In: Journal of Controlled Release, 2002, vol. 81, no. 1–2, pp. 57–64

[7] Luong-Van, E., Grondahl, L., et al. *Controlled release of heparin from poly(epsilon-caprolactone) electrospun fibers*, In: Biomaterials, 2006, vol. 27, no. 9, pp. 2042–2050

[8] Xu, C., Inai, R., Kotaki, M., Ramakrishna, S. *Aligned biodegradable nanofibrous structure: A potential scaffold for blood vessel engineering*, In: Biomaterials, 2004, vol. 25, pp. 877–886

[9] Huang, Z.-M., Zhang, Y.-Z., Kotaki, M., Ramakrishna, S. *A review on polymer nanofibers by electrospinning and their applications in nanocomposites*, In: Compos. Sci. Technol., 2003, vol. 63, pp. 2223–2253

[10] Bara, A., Marinescu, V., Chitanu, E., Banciu, C., Clicinschi, F. *Influence of process parameters on the morphology of polyacrylonitrile electrospun fibers*, In: Industria Textila, 2015, vol. 66, nr. 4, pp. 232–239

[11] Banciu, C., Bara, A., Chitanu, E., Lungulescu, M., Ion, I., Leonat, L. *Filtering membranes based on electrospun expanded polystyrene/β-cyclodextrin fibers*, In: 10th International Symposium on Advanced Topics in Electrical Engineering (ATEE), March 23-25, 2017, Bucharest, Romania, IEEE, pp. 223-226, DOI: 10.1109/ATEE.2017.7905084

[12] Chitanu, E., Bara, A., Patroi, D., Marinescu, V., Codescu, M.M., Banciu, C. *PAN/ZnO composite electrospun fibers for UV shielding applications*, In: 10th International Symposium on Advanced Topics in Electrical Engineering (ATEE), March 23-25, 2017, Bucharest, Romania, IEEE, pp. 227–230, DOI: 10.1109/ATEE.2017.7905098

[13] Lee, M. W., An, S., et al. *Electrospun polystyrene nanofiber membrane with superhydrophobicity and superoleophilicity for selective separation of water and low viscous oil,* ACS, In: Appl. Mater. Interfaces, 2013, vol. 5, no. 21, pp. 10597–10604

[14] Shin, C., Chase, G.G., Reneker, D.H. *Recycled expanded polystyrene nanofibers applied in filter media*, In: Colloids and Surfaces A: Physicochem. Eng. Aspects, 2005, vol. 262, pp. 211–215

[15] Qavamnia, S. S., Nasouri, K., Haji, A. *A new insight into controlling the morphology of polystyrene nanofibers in electrospinning process*, In: International Conference of Applied Research on Textile, CIRAT-7, November 10–12, 2016, Hammamet, Tunisia, ISSN 2286-5659

Authors:

CRISTINA BANCIU
ADELA BĂRA
ELENA CHIȚANU
VIRGIL MARINESCU
GABRIELA SBÂRCEA
IOANA ION

National Institute for Research and Development in Electrical Engineering ICPE-CA
313 Spl. Unirii, 030138, Bucharest, Romania

e-mail: cristina.banciu@icpe-ca.ro, adela.bara@icpe-ca.ro, elena.chitanu@icpe-ca.ro, virgil.marinescu@icpe-ca.ro, gabriela.sbarcea@icpe-ca.ro, ioana.ion@icpe-ca.ro

Corresponding author:

ADELA BĂRA
e-mail: adela.bara@icpe-ca.ro

An investigation on the properties of polyester textured yarns produced with different fiber cross-sectional shapes

DOI: 10.35530/IT.069.04.1281

SELCEN ÖZKAN HACIOĞULLARI OSMAN BABAARSLAN

REZUMAT – ABSTRACT

Studiu asupra proprietăților firelor texturate de poliester cu diverse forme de secțiune transversală a fibrei

În acest studiu, s-au examinat efectele diferitelor forme de secțiune transversală a fibrei și ale valorilor densității liniare asupra caracteristicilor firelor parțial orientate (POY) și firelor texturate. În cadrul experimentului, au fost utilizate cinci forme diferite de secțiune transversală, și anume: rotunde, trilobale, tetralobale, hexalobale și octolobale, și două densități liniare diferite și au fost aplicate testele de tenacitate-alungire, ondulare și contracție a firelor. Ca rezultat, formele de secțiune transversală rotunde și octolobale au condus la formarea firelor cu tenacitate și alungire la rupere ridicată, iar pe de altă parte cele cu forme trilobale și hexalobale au determinat o tenacitate și alungire la rupere scăzută. Secțiunea transversală rotundă a condus la formarea firelor cu grad ridicat de ondulare și contracție scăzută, iar formele hexalobale și tetralobale ale secțiunii transversale au determinat o ondulare mai scăzută și o contracție ridicată. De asemenea, s-a observat că o creșterea a densității liniare determină o scădere a tenacității firelor, care conduce la un comportament de ondulare și o contracție ridicată a firelor.

Cuvinte-cheie: polyester POY, fir texturat, secțiune transversală a fibrei, proprietățile firului

An investigation on the properties of polyester textured yarns produced with different fiber cross-sectional shapes

In this study, the effects of different fiber cross-sectional shapes and yarn linear density values on Partially Oriented Yarn (POY) and textured yarn characteristics have been examined. In experiment, five different cross-sectional shapes, namely round, trilobal, tetra, hexsa and octolobal and two different linear densities have been used and tenacity-elongation, crimp and shrinkage tests have been applied to the yarns. As a result, the round and octolobal cross-sectional shapes lead to yarn formation with high tenacity and breaking elongation, on the other hand trilobal and hexsa cause low tenacity and breaking elongation. The round cross-section has provided yarn formation with high crimp and low shrinkage, the hexsa and tetra cross-sectional shapes have caused lower crimp and high shrinkage. It was also observed that the increase in the linear density has caused a decrease in yarn tenacity, however this has increased the crimp and shrinkage behaviours of the yarns.

Keywords: polyester POY, textured yarn, fiber cross-section, yarn properties

INTRODUCTION

Filament yarns can be produced with the melt spinning process and these yarns have flat and unbulked structure, low tenacity and highly breaking elongation, high-luster properties, etc. Generally, these properties are developed with texturizing process. Besides, there are various structural parameters (number of filament, cross-sectional shape, linear density, etc.) determined during the production of filament yarns and these parameters influence these product features. Among these parameters, cross-sectional shape of fibers has a significant importance.

Currently, it is known that a change in fiber cross-sectional shape has an important effect on the features of fabric such as feel, mechanical feature, comfort, etc. Several studies were carried out on the effect of fiber cross-sectional shapes on yarn and fabric properties [1–4]. For instance, Varshney et. al. have carried out detailed studies on this subject in 2010 and 2011 [5, 6].

The texturing process is applied on flat, non-bulk synthetic filament yarns with a rather brighter structure. With this process, it is also aimed to have the natural appearance and the feel of yarn which are obtained from natural fibers. Moreover, filament yarn properties such as higher cover factor, higher thermal insulation, higher water vapour permeability and higher tenacity and lower breaking elongation can also be obtained with the texturing process. Thus, a big majority of filament yarns are used after texturing process. False twist and air jet texturing processes are the most frequently used methods among various techniques. Also, when different texturing techniques are applied on the same filament yarn groups, these textured yarn properties can be different from each other. Moreover, with changing production parameters of the same texturing technique, the filament yarn properties are also changing. Thus, texturing process is complicated and contains many production parameters. When the previous studies on textured yarn are examined, it is seen that these studies mostly focus on the changing of textured yarn production parameters (temperature, D/Y ratio, etc.) and the effects of these parameters on yarn properties [7–12]. Besides, the studies examining the effect

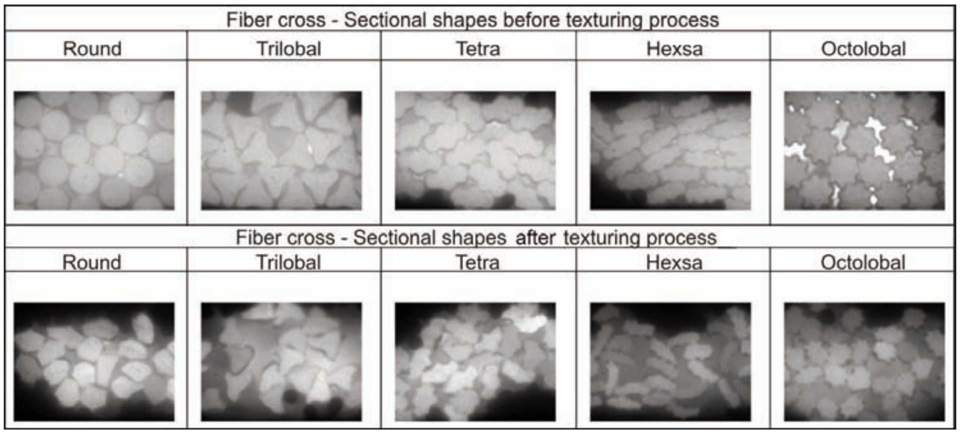


Fig. 1. Fiber cross-sectional shapes used in the study (X500 magnification) [14]

of different yarn structural parameters on product properties are rather oriented towards staple fiber and/or knitted/woven fabric performances [1–5, 13]. This paper examined the effect of different fiber cross-sectional shapes on the properties of flat and textured yarns.

EXPERIMENTAL WORK

Materials and method

Polyester (PES) flat and textured yarns, which have an important place and an extensive area of use among synthetic yarns, have been used as materials in this study. Also, two different yarn groups have been used in the study with 34 and 47 filaments because there were spinneret of 34 filaments for tetra cross-sectional shapes and 47 filaments for hexsa cross-sectional shapes under the process condition of the study. Hence, cross sectional shapes have been grouped according to their number of filaments. The first yarn group has round, trilobal, tetra and octolobal cross-sectional shapes while the second yarn group has round, hexsa and octolobal cross-sectional shapes. The images of fiber cross-sectional shapes before and after the texturing process have been provided in figure 1.

It is seen in the pictures that the distinct cross-sectional shapes of the individual filaments constituting the yarn at the beginning have partially been deformed after the texturizing process. PES flat yarns have been produced according to melt spinning principle. Production parameters of these yarns have been provided in table 1.

False twist texturing technique was used and 1.6 drawing ratio applied on the flat yarns with the texturizing process. During the flat and textured yarns production process, all other parameters except for the factors whose effects were aimed to be investigated were kept constant. False-twist texturing process and production parameters of textured yarns are given in figure 2 and table 2 respectively.

The shape of the filament cross-section slightly changes the level of heat transfer during the contact

Table 1

PRODUCTION PARAMETERS OF PES FLAT YARN [15]		
Spinneret configuration	Cross-sectional shape	Round, trilobal, tetra, hexsa and octolobal
	Number of filament	34 and 47
	Diameter of spinneret	9 cm
Flow speed of air-quench (m/s)		60
The amount of lubricant (%)		0,3
Godet 1 speed (m/min)		2900
Pressure at intermingling (bar)		4
Godet 2 speed (m/min)		2880
DT (Draw Tension) value-cN		96 (283 dtex) 50 (133 dtex)

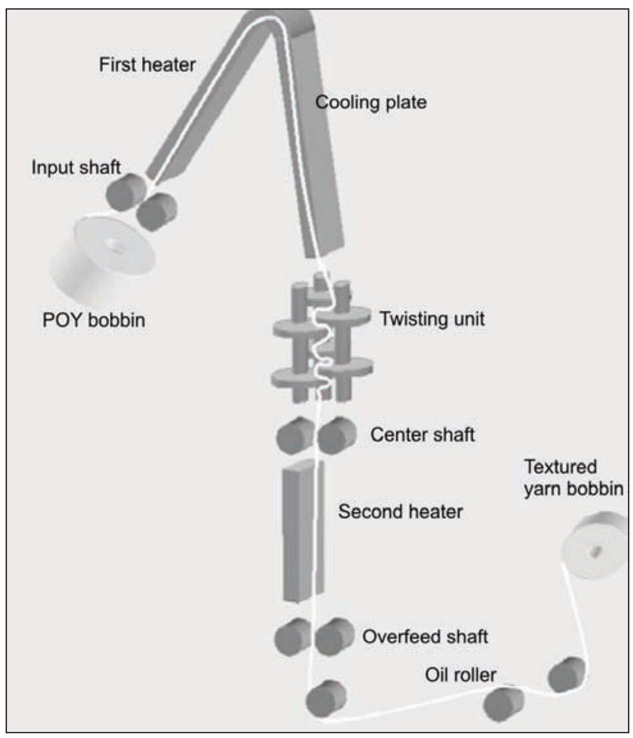


Fig. 2. False-twist texturing process [13]

Table 2

PRODUCTION PARAMETERS OF TEXTURED YARNS	
Feed Roller Speed (m/min.)	364
Delivery Roller Speed (m/min.)	600
Take-up Roller Speed (m/min.)	573
Winding Roller Speed (m/min.)	576
Disc Speed (m/min.)	1711
Yarn Speed (m/min.)	900
D/Y Ratio	1,90
First Heater Temp. (°C)	180
Second Heater Temp. (°C)	130
Disc Fineness (mm)	6
Disc Material	Ceramic Polyurethane
Lubricant	Spreiton 1384
Winding Angle (°)	27
Conical Angle (°)	80

heating of the rotating yarn in the first heater (figure 2). Thus, the maximum yarn temperature in the end of the heater can depends on the particular filament cross-section. Hence, the observed differences in mechanical properties of the yarns might be the influenced by the very crucial maximum yarn temperature during the texturing [16].

To determine the effect of fiber cross-sectional shape and linear density parameters on the yarn properties such as tenacity and elongation at break for flat and textured yarns were carried out. Crimp and shrinkage tests were also applied only on textured yarns which were taken as basis of the study. Tenacity and elongation tests were carried out with Uster Tensorapid-3 test device according to BS EN ISO 2062, 1995 test standard. Crimp and Shrinkage tests were carried out with Texturmat-ME test device according to DIN 53840-2; 1983 test standard [17, 18]. Before starting the tests, yarn samples were conditioned for 24 hours at 20°C ± 2 temperature and 65% ± 2 relative humidity, which are the standard environment conditions. The tenacity and breaking elongation tests repeated thirty times for each yarn and the average values were obtained. Eighteen tests for each yarn sample were performed during experimental studies of crimp and shrinkage tests. While tenacity and breaking elongation tests were applied to flat yarns at 200 mm length and textured yarns at 500 mm, crimp and shrinkage tests were applied to hank of textured yarns. Information of these test conditions have been given in table 3.

The effects of cross-sectional shape factor on the characteristics of textured yarns were statistically analyzed by using the general linear model-univariety method. The statistical study was carried out at a reliability level of α = 0,05.

RESULTS AND DISCUSSION

Yarn tenacity and breaking elongation

Tenacity and breaking elongation tests applied on the yarns which have 34 filaments and round, trilobal, tetra and octolobal cross-sectional shaped that constituted the first group of the study have been provided in figures 3 and 4. When the graphics are examined, one of the remarkable results is that after the texturizing process, the tenacity values increased but the breaking elongation values decreased. The high tenacity of the textured yarn compared to flat yarn can be explained that the texturizing process with drawing increased the orientation factor in the filament structure and that ultimately the textured yarn tenacity increased. Because of drawing on texturizing process for the yarns resulted that textured yarns have lower breaking elongation compared to the flat yarns. It can also be seen that the tenacity and breaking elongation of flat and textured yarns with trilobal cross-sectional structure are lower than those with other cross-sectional shapes, and that the highest values lie with the round cross-sectionally shaped yarns.

It can be also seen that the flat yarns with 283 and 133 dtex linear densities are lowered 178 and 84 dtex linear densities respectively because of drawing at a certain amount during texturizing process. With the

Table 3

INFORMATION OF TEST CONDITIONS OF FLAT AND TEXTURED YARNS [17, 18]

Test name \ Test condition	Test speed (mm/min.)	Principle	Clamp pressure-Pcl (N/cm^2)	Hank length (cm)	Pretension (cN/tex)	Time
Tenacity and breaking elongation	POY: 750; Tex.: 380	CRE	POY: 225; Tex.: 338	—	POY: 8,9; Tex.: 27,6	*
Crimp	5000 (loading speed)	—	—	84 dtex: 1400; 178 dtex: 700	L_g: 2; L_f: 0.1; L_b: 10	10 min. (recovering period)
Shrinkage	150 (loading speed)	—	—	84 dtex: 2800; 178 dtex: 6000	2.0	10 sec. (loading period)

* Time has changed depending on breaking time of yarns

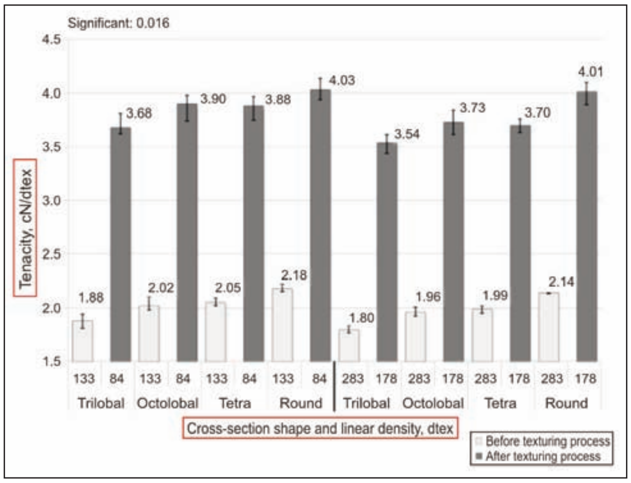


Fig. 3. Effect of fiber cross-sectional shape and yarn linear density on yarn's tenacity-34 filaments

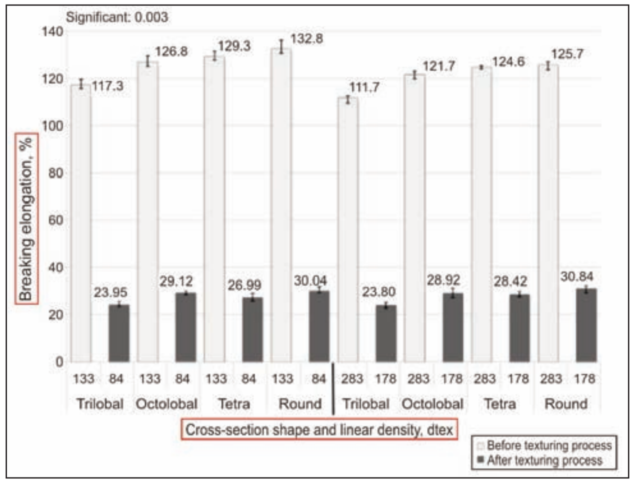


Fig. 4. Effect of fiber cross-sectional shape and yarn linear density on yarn's breaking elongation-34 filaments

drawing effect on the yarns the tenacity values of these yarns are increased. As the significance level of the tenacity results was found as 0,016 and that of the breaking elongation results was found as 0,003 at a reliability level of α = 0,05, meaning that the effect of cross-sectional shape variable on the tenacity and breaking elongation of textured yarns are statistically significant.

The second group of the study is composed of 47 filaments with round, hexsa and octolobal cross-sectional shaped of flat and textured yarns. The effect of the cross-sectional shape and linear density values of these yarns on tenacity and breaking elongation have been examined and the results have been interpreted in figures 5 and 6. It is observed that after the texturizing process the tenacity values of the yarns increased and the breaking elongation values decreased. In addition to this for flat and textured yarns, the yarns produced with hexsa cross-sectional shape had the lowest tenacity and breaking elongation compared to other cross-sectional shapes. This result can be explained that the adherence features because of hexsa cross-section compared with the other cross-sectional shaped yarns. Examining previous studies like this topic in the literature we can see that round cross-sectional shape shows ideal mechanical properties according to lobed and channeled cross-sectional shapes [14–15, 19].

According to the statistical analysis, the significance level of the tenacity results was found as 0,057 and that of the breaking elongation results was found as 0,043 at a reliability level of α = 0,05. Although there is a difference in the tenacity test results of textured yarns, the finding was not significant statistically but breaking elongation results found to be significant.

Textured yarn crimp and shrinkage properties

"Crimp Contraction" property is essentially assessed on false-twist textured yarns and is defined as the contraction of a textured yarn due to crimp development, expressed as percentage rate (CC%) on the stretched out (uncrimped) yarn length [20]. When the CC% values of the yarns consisting of both groups the highest crimp value was on round cross-section and the lowest crimp value was on tetra and hexsa cross-sectional shapes (figures 7, 8). This result can

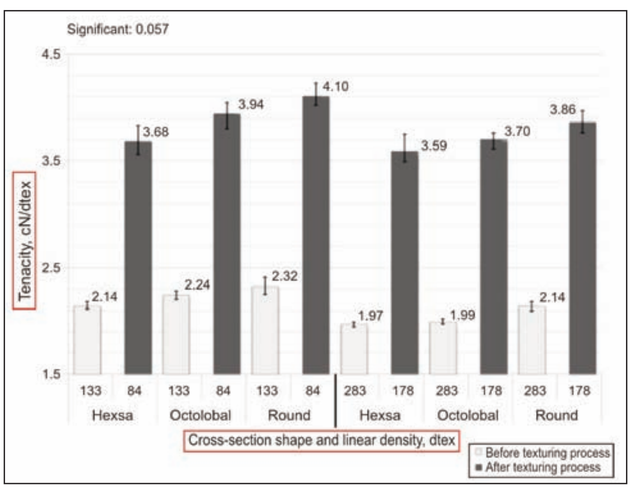


Fig. 5. Effect of fiber cross-sectional shape and yarn linear density on yarn's tenacity-47 filaments

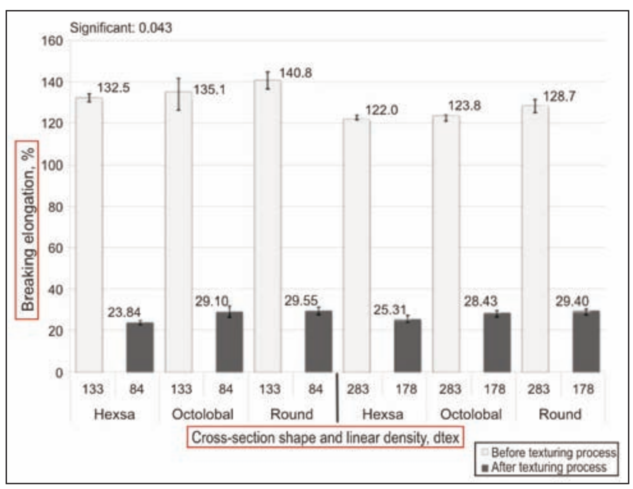


Fig. 6. Effect of fiber cross-sectional shape and yarn linear density on yarn's breaking elongation-47 filaments

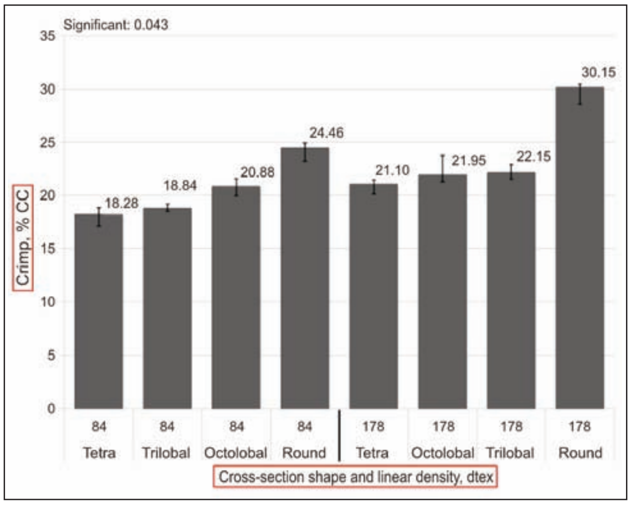


Fig. 7. Effect of fiber cross-sectional shape and yarn linear density on yarn's crimp-34 filaments

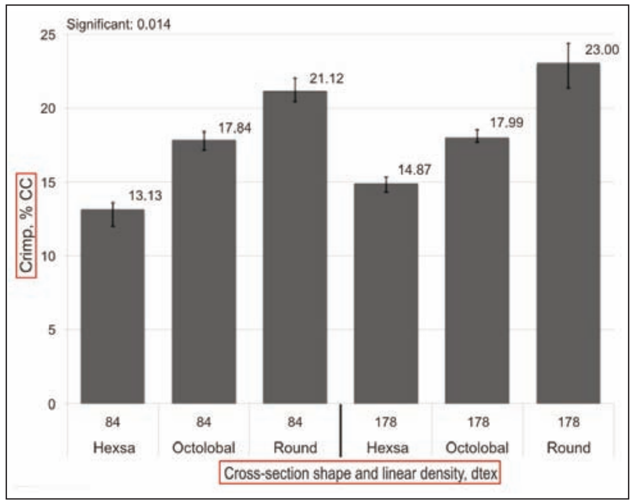


Fig. 8. Effect of fiber cross-sectional shape and yarn linear density on yarn's crimp-47 filaments [21]

be explained that round cross-sectional shaped filaments with a more bulky structure combine and provide formation of more bulked yarns. On the other hand, because of channelled structures of tetra and hexsa cross-sectional shapes, they were deformed more easily while texturing and as a result they caused more flat, thin and unbulked filaments (figure 1). In addition to the increase in linear density provided that the yarns had a more bulky structure as expected. As also seen in figure 7 and figure 8, the first group of yarns with 34 filaments possesses higher %CC values than second group of yarns with 47 filaments. It was also found that the significance level of the crimp test results of the first group yarns with reliability level α = 0,05 was 0,043 and that of the second group yarns was 0,014. Thus, the impact of the cross-sectional shape variable on the textured yarn was statistically significant in both groups. Consequently, structural parameters of filament yarns (cross-sectional shape, linear density, number of filament, etc.) have affected crimp properties of textured yarns.

Shrinkage in fibers, yarns and fabrics can be determined by a great number of different methods in which the changes in length after contraction are measured under defined conditions [22]. In this study, hot-air shrinkage test has been applied on textured filament yarns according to DIN 53840-2; 1983 test standard with Texturmat-ME test device. Figures 9 and 10 display the effects of cross-section and linear density on the shrinkage of textured yarns with 34 and 47 filaments in yarn cross-section. It is observed that the textured yarns have different shrinkage peculiarities according to their cross-section and linear density. Textured yarns with 34 filaments and with 84 dtex linear density the highest shrinkage was in the tetra cross-sectional shape and the lowest shrinkage was in the round and octolobal cross-sectional shapes. Among the yarns with 178 dtex linear density the highest shrinkage value was in the round and the lowest shrinkage value was in the octolobal

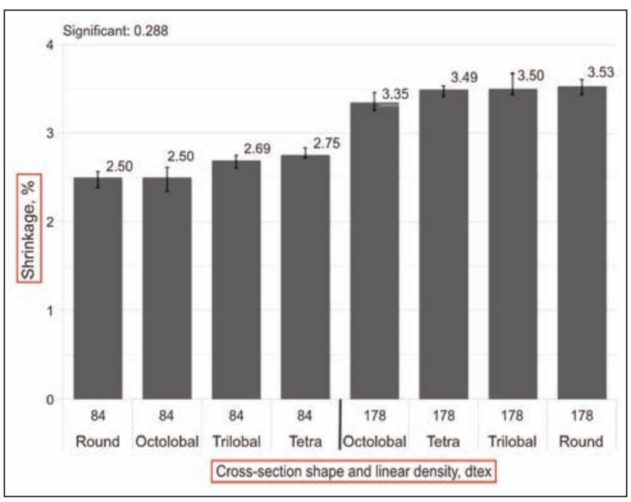


Fig. 9. Effect of fiber cross-sectional shape and yarn linear density on yarn's shrinkage-34 filaments

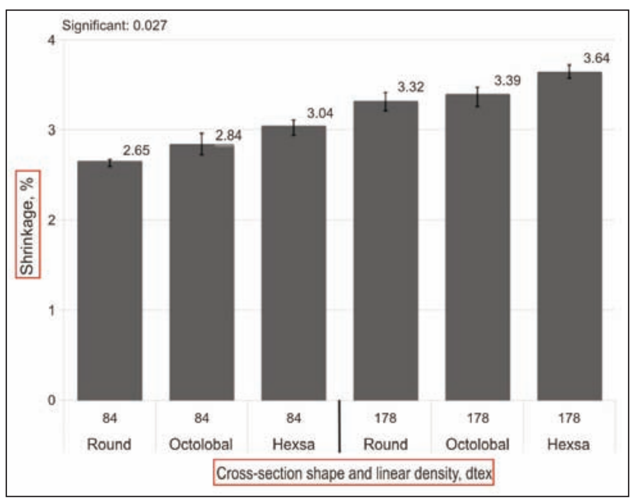


Fig. 10. Effect of fiber cross-sectional shape and yarn linear density on yarn's shrinkage-47 filaments [21]

cross-sectional shapes (figure 9). As a result, the shrinkage values when compared with cross-sectional shapes display neither a certain increase nor a decline.

The shrinkage test results of the second group textured yarns with 47 filaments have been shown in figure 10. As seen in figure, the highest shrinkage value is at the hexsa cross-sectional shaped yarns and the lowest shrinkage value is at the round cross-sectionally shaped yarns. Textured yarns produced with round cross-sectional shapes possess more resistance to temperature compared to hexsa and octolobal cross-sectional shapes. This result can be explained that due to the good cohesion and bulky structure of the round cross-sectional shape filaments and they display a more resistance towards the heat. Because of deep channel cross-sectional shape of hexsa textured yarns, more heat has penetrated to their structure. According to the statistical analysis results, the significance value of the shrinkage tests of the first group yarns with reliability level $\alpha = 0,05$ was found to be 0,288 and that of the second group yarns was 0,027. It has been understood that the effect of the cross-sectional shape on the shrinkage of the first group textured yarns was not statistically significant but that its impact on the second group yarns was statistically significant.

CONCLUSIONS

In the study, the effects of selected cross-sectional shapes and two different linear density values on PES flat and textured yarn features have been examined. Consequently, there was a tendency for increase in the tenacity values of the yarns and for decrease in the breaking elongation values after the texturizing process. Furthermore, round cross-sectional shaped yarn has resulted positive effects on high tenacity, high breaking elongation, high crimp value and low shrinkage on textured yarn. The first yarn group of this study, the tenacity and breaking elongation values of trilobal cross-sectional shape are lower than those with other cross-sectional shapes (round, tetra and octolobal) and that the highest values lie with the round cross-sectionally shaped yarns in the same group. In the second group of this study, the yarns produced with hexsa cross-sectional shape had lower tenacity and breaking elongation values compared to other cross-sectional shapes. Yarns with channeled and lobed cross-sectional shape gave the results of lower tenacity and breaking elongation values. It was also observed that the increase in the linear density value decreased the tenacity and breaking elongation values of the yarns. When the CC% values of the yarns consisting of both groups of the study are examined, the highest crimp value was in the round cross-section and the lowest crimp value was in the tetra and hexsa cross-sectional shapes. The shrinkage values of yarns when compared with cross-sectional shapes display neither a certain increase nor a decline. Also, the increase in linear density value increased the shrinkage values as expected.

ACKNOWLEDGEMENTS

We extend our thanks to SASA Polyester San. A.Ş. Management and employees of related departments, who provided all the necessary opportunities for the carrying out of the tests and the production of the basic materials of this study, which was conducted with the cooperation of Çukurova University and SASA Polyester San. A.Ş. within the scope of "Academic Support Project".

BIBLIOGRAPHY

[1] Matsudaira, M., Tan, Y., Kondo, Y. *The Effect of fibre cross-sectional shape on fabric mechanical properties and handle*, In: The Journal of the Textile Institute, 1993, vol. 84, no 3, pp. 376–386

[2] Bozdoğan, F. *Effect of fiber cross-sectional shape on aesthetic properties of textile product*, In: Textile&Technical, 2000, 184, pp. 136–140

[3] Bueno, M., Aneja, A.P., Renner, M. *Influence of the shape of fiber cross-section on fabric surface characteristics*, In: Journal of Materials Science, 2004, 39, pp. 557–564

[4] Tascan, M., Vaughn, E. *Effects of fiber denier, fiber cross-sectional shape and fabric density on acoustical behavior of vertically lapped nonwoven fabrics*, In: Journal of Engineered Fibers and Fabrics, 2008, 3, pp. 32–38.

[5] Varshney, RK., Kothari, VK., Dhamija, S. *A study on thermophysiological comfort properties of fabrics in relation to constituent fibre fineness and cross-sectional shapes*, In: The Journal of the Textile Institute, 2010, vol. 101, no. 6, pp. 495–505

[6] Varshney, RK., Kothari, V.K., Dhamija, S. *Influence of polyester fibre fineness and cross-sectional shape on low-stress characteristics of fabrics*, In: The Journal of the Textile Institute, 2011, vol. 102, no. 1, pp. 31–40

[7] Karakaş, C., Dayıoğlu, H. *Influence of major false-twist texturing parameters on the structural properties of polyamide 6.6 yarn*, In: Fibers&Textiles in Eastern Europe, 2004, 12, pp. 23–28

[8] Vitkauskas, A., Miglinaite, R., Vesa, P., Puolakka, A. *Mechanical properties of polypropylene multifilament yarns in dependence of their drawing ratio*, In: Materials Science, 2004, vol. 11, no. 4, pp. 407–410

[9] Çirkin, S. *Effect of texturing variables on the yarn properties during false-twist texturing process*, In: MSc Thesis, 2006, University of Çukurova, Turkey

[10] Yıldırım, K., Altun, Ş., Ulcay, Y. *The effect of first heater temperature on the properties of false-twist textured poly (ethylene terapthalate) yarn*, In: Journal of Textile and Apparel, 2009, vol. 19, no. 4, pp. 286–290

[11] Koç, S., Hockenberger, A. *Investigation of air-jet texturing of technical polyester yarns*, In: Journal of Textile and Apparel, 2010, vol. 20, no. 4, pp. 299–305

[12] Tehran, M., Azimi, B., Mojtahedi, M. *Investigating the effect of false twist texturing process on the color coordinates variation of spun-dyed polyester filament yarns*, In: Journal of Engineered Fibers and Fabrics, 2011, 6(4), pp. 54–62

[13] Yıldırım, K., Altun, Ş., Ulcay, Y. *Relationship between yarn properties and process parameters in false-twist textured yarn*, In: Journal of Engineered Fibers and Fabrics, 2009, vol. 4, no. 2, pp. 26–32

[14] Özkan, S. *Effect of filament cross-section shape, number of filaments and filament linear density on the properties of POY and textured yarn*, MSc Thesis, 2008, University of Çukurova, Turkey

[15] Babaarslan, O., Hacıoğulları, SO. *Effect of fibre cross-sectional shape on the properties of POY continuous filament yarns*, In: Fibers and Polymers, 2013, vol. 14, no. 1, pp. 146–151

[16] Hes, L., Ursiny, P. *Yarn Texturing Technology*, In: Comett Eurotex, EUROTEX Head Office: Universidade do Minho, 1994, p. 149

[17] BS EN ISO 2062: Textile-Yarns From Packages: *Determination of single-end breaking force and elongation at break*, 1995

[18] DIN 53840-2: Testing of Textiles: *Determination of parameters for the crimp of textured filament yarns*, 1983

[19] Karaca, E., Özçelik, F. *Influence of the cross-sectional shape on the structure and properties of polyester fibers*, In: Journal of Applied Polymer Science, 2007, 10, pp. 2615–2621

[20] Andreoli, C., Freti, F. Textile Process, In: *Man-Made Fibres*, Edited by Fondazione Azimit, Milano-Italy, 2006, pp. 35–36

[21] Babaarslan, O., Hacıoğulları, SO. P*roperties of POY and textured yarn with different cross-sectional shapes,* In: The Fiber Society Spring 2012 Conference-Fibers Research for Tomorrow's Applications, Empa, St. Gallen, Switzerland, 2012, pp. 87–88

[22] Militky, J., Kremanakova, D., Kosatkova-Huskova, M. *Shrinkage rate of polyester for membrane applications, 2010*, In: 7th International ConferenceTEXSCI-2010

Authors:

SELCEN ÖZKAN HACIOĞULLARI
OSMAN BABAARSLAN

Çukurova University
Faculty of Engineering and Architecture, Department of Textile Engineering
Saricam-01330, Adana-TURKEY

e-mail: selcenozkan@gmail.com, teksob@cu.edu.tr

Corresponding author:

SELCEN ÖZKAN HACIOĞULLARI
e-mail: selcenozkan@gmail.com

Influencing factors analysis of tensile properties of wool yarns with different proportions of polyamide blend

DOI: 10.35530/IT.069.04.1437

IOAN PAVEL OANA
DORINA OANA
SIMONA TRIPA

REZUMAT – ABSTRACT

Analiza factorilor care influențează proprietățile de rezistență la tracțiune a firelor de lână în amestec cu poliamida, în diferite proporții

Această lucrare prezintă o analiză comparativă a trei loturi de fire din lână cu diferite densitati de lungime, torsiuni și compoziții privind modul în care aceste caracteristici influențează proprietățile de rezistență la tracțiune a firelor. Au fost efectuate teste de rezistență la tracțiune, determinându-se valorile pentru următoarele caracteristici ale rezistenței la tracțiune: forța de rupere, alungirea la rupere, tenacitatea și ruperea mecanică și au fost realizate diagramele eferente. Rezistența la rupere și alungirea la rupere – aceste diagrame prezintă distribuirea de secțiuni slabe de-a lungul firului testat. Pentru a realiza această analiză a fost utilizat echipamentul USTER® TENSOJET 4. Principalele concluzii ale acestei analize sunt următoarele: forța de rupere a firelor este determinată în principal de valoarea densității de lungime, procentul de poliamidă și valoarea torsiunii, iar alungirea la rupere este în primul rând influențată de procentul de poliamidă din compoziția firelor și apoi de gradul de torsiune a firelor, cele mai dure fire fiind cele cu cea mai mică finețe; ruperea mecanică la întinderea firelor depinde în principal de procentul de poliamidă din compoziția firelor, de finețea firelor și în final de gradul de torsiune al acestora.

Cuvinte-cheie: alungirea la rupere, finețe, poliamidă, forța de rupere, torsiune, fire

Influencing factors analysis of tensile properties of wool yarns with different proportions of polyamide blend

This paper presents a comparative analysis of three batches of wool yarns with different fineness, twists and compositions and the way in which these characteristics influence the tensile properties of the yarns. We performed the tensile strength tests and the values for the following tensile characteristics were determined: breaking force, elongation at break, tenacity and the mechanical breaking work and were made the diagrams. Stroke for strength and elongation at break – the diagrams give us an idea on the distribution of weak sections along the yarn tested. In order to make this analysis we used the machine USTER® TENSOJET 4. The main conclusions drawn from this analysis are following: the breaking force of the yarns is mainly determined by the value of length density and only after that by the percentage of polyamide and the twisting value, elongation at break is primarily influenced by the percentage of polyamide from the yarns composition and only then by the yarns twisting degree, the toughest yarns are the ones with the smallest fineness, the mechanical work created when stretching the yarns depends mainly by the percentage of polyamide from the yarns composition, by the yarns fineness and only then by their twisting.

Keywords: elongation at break, fineness, polyamide, breaking force*, twisting, yarns*

INTRODUCTION

The yarns, in all their forms, are products that are sold thus they are in direct contact with the market economy. In order to meet the requirements imposed by this market, the yarns should comply from a qualitative point of view and this depends both on the technology of obtaining them and also on the way the yarns behave during processing. In the present competitive age, quality of the all kinds of the textile product is the most desirable factor at purchase counter for the consumer [1].

The quality of the yarns seen as an objective of increasing the profit represents the consequence of correlating the characteristics of the yarns with the technology of their processing and their structure. The yarns breakage is caused by the unfavourable equilibrium between tensile strength and the yarns resistance which are variable during the technological process of production and processing and these breakages are produced only when the tensile strength exceeds its resistance. That is why the tensile properties of the yarns are accepted as one of the most important parameters for the assessment of yarn quality. Tensile properties contribute to the performance of post spinning operations; warping, weaving and knitting, hence their accurate technical evaluations very important in industrial applications [2].

Yarn quality is an essential concept defined by customer which requests the satisfaction of several properties simultaneously [3]. Among the decisive features for estimating the yarns usage value are: fineness, twisting, tensile strength, tensile elongation, the non-uniformity. Twisting the yarns is done in order to produce them and consequently to increase their tensile strength [4]. A fairly high degree of twist produces strong yarn; a low twist produces softer, more lustrous yarn; and a very tight twist produces crepe yarn [5].

Frequently used to assess the quality and value of using textile products, the tensile strength shows their ability to take over the axial efforts during products exploitation [6]. Tensile strength of yarns is influenced by characteristics by the raw material (length, length density and tensile strength of yarn components) and the level of twisting and it is calculated using the following indexes: breaking force, specific resistance, tenacity, the mechanical breaking work and tear length [7].

A physical-mechanical characteristic closely correlated with breaking force is the elongation at break of textile yarns [8]. During tensile stress of textile products they tend to elongate with a size dependent on the amount of effort applied and also on their own characteristics. After suppressing the tensile force we notice the tendency of the product to get back to initial length [9]. For the textile processing it is important that the fibres and yarns to be solicited with forces that would produce only elastic elongation, thus keeping the proportionality between effort and deformation, to spare their tensile properties [10].

Textile products in general have a certain non-uniformity of their own characteristics, which is manifested by the variation of specific parameters such as: the number of yarns in the cross section, the length density, tensile strength, etc. [11]. The unevenness of the textile products characteristics on the one hand is caused by the unevenness of the constituent yarns and on the other the imperfections of the technological processes of their processing. The unevenness of the yarns greatly influences their processing and the products appearance made of them [12].

Another influential factor of products quality is the yarn breakage (both during technological process of production and in their processing), breakages which are determined by the unfavourable balance of tension and yarns resistance [13]. This is the main reason why in this paper we are doing a comparative study of tensile properties for three batches of wool yarn mixed with polyamide in different percentages of different fineness and different twists.

MATERIALS AND METHODS

The tensile properties for the 3 batches of yarns were studied, performing tensile strength tests on 10 samples from each yarn batch with the help of the device USTER® TENSOJET 4. The three yarns batches have the following features:

- Batch I is formed 80% of woollen yarns mixed with 20% polyamide, with length density of Ttex = 31.25 and twist of 412 spins/m.
- Batch II is formed 90% of woollen yarns mixed with 10 % polyamide, with length density of Ttex = 33.33 and twist of 412 spins/m.
- Batch III is formed 80% of woollen yarns mixed with 20 % polyamide, with length density of Ttex = 25 and twist of 498 spins/m.

RESULTS AND DISCUTION

After performing these tensile strength tests the values for the following tensile characteristics were determined: breaking force, elongation at break, tenacity and the mechanical breaking work and were made the diagrams Stroke for strength and elongation at break – the diagrams give us an idea on the distribution of weak sections along the yarn tested. For each yarn batch were determined the minimum, maximum, average values and the variation coefficient for all 4 analysed tensile characteristics. The values obtained are presented in the following centralized tables (1–4).

Table 1

B-Force (cN)	Batch I	Batch II	Batch III
Mean	259,6	269,0	224,7
Cv	12,4	12,5	12,8
Min	75,26	111,1	119,5
Max	385,9	391,8	357,1

Table 2

ELONGATION AT BREAK, FOR THREE YARNS BATCHES			
Elongation (%)	Batch I	Batch II	Batch III
Mean	14,93	8,69	13,11
Cv	27,3	32,3	31,4
Min	2,36	1,66	3,36
Max	27,03	21,58	25,85

Table 3

TMECHANICAL BREAKING WORK, FOR THREE YARNS BATCHES			
Tenacity (cN/Tex)	Batch I	Batch II	Batch III
Mean	8,31	8,07	8,99
Cv	12,4	12,5	12,8
Min	2,41	3,33	4,78
Max	12,35	11,76	14,29

Table 4

ELONGATION AT BREAK, FOR THREE YARNS BATCHES			
B-Work (cN*cm)	Batch I	Batch II	Batch III
Mean	1554	885,1	1171
Cv	36,9	46,2	42,2
Min	78,67	64,44	151,7
Max	3483	2785	2918

In order to get a more accurate picture regarding the distribution of weak sections along the tested yarns, there were also made the Stroke diagrams for breaking force and elongation at break. Figures 1 and 2 show these diagrams obtained for yarn batch I.

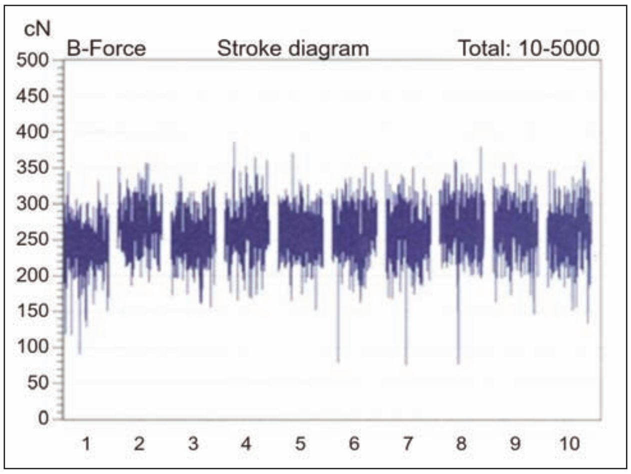


Fig. 1. Variation diagram for breaking force of yarns from batch I

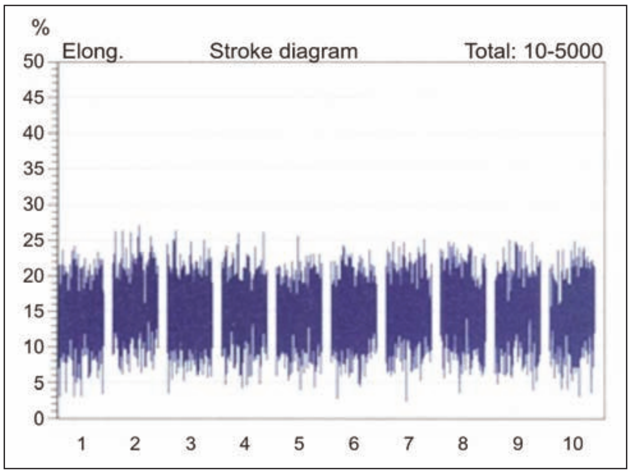


Fig. 2. Variation diagram for elongation at break for yarns from batch I

Breaking force of the first batch of yarns varies between 75.26 and 385.9 cN and has a breaking force average value for this type of yarns of 259.6 cN. For batch II the breaking force average value is 269 cN, minimum and maximum limits being 111.1 and 391.8 cN, respectively. It was found that the yarns made of 80% wool + 20% polyamide, and with tex fineness 25 have the lowest breaking force, their average value being 224.7 cN.

Comparing the fibrous composition, twist and fineness of the yarns in the three batches the conclusions were the following:

– The thicker yarns in batch II have a better resistance compared to yarns in batch I, although their polyamide synthetic component is of only 10% compared to 20% polyamide of yarns in batch I, a component that should improve these properties.
– The yarns in batch II have better resistance compared to the yarns in batch III although the proportion of polyamide is half compared to that of the yarns in batch III and moreover the yarns in batch II have a smaller twist than the ones in batch III.
– The yarns in batches I and III which have the same polyamide percentage in their composition but the yarns twist is different (is higher in batch III compared to that of the yarns in batch I) but have a different breaking force, it is higher for the yarns in batch I because they are thicker than those in batch III.

From the facts presented above we can conclude that the breaking force of the yarns is mainly determined by the value of length density and only then by the polyamide percentage and twist value (which is known to improve the yarns resistance).

Regarding the elongation at break – as it was expected, the highest values were recorded in the batches in whose component the polyamide percentage is higher – i.e. the batches I and III. Even if the fibrous composition of the two groups is identical we notice that different values of elongation at break were obtained – i.e. 14.93% (batch I) and 13.11% respectively (batch II) the main difference being given by their different degree of twisting (much higher in batch III).

Comparing the three yarns batches tenacity we noticed that even though the breaking force is the lowest for yarns in batch III, their tenacity has the highest value since its value is inversely proportional to the yarns finesse.

By comparing the values obtained for the mechanical work created when stretching the yarns in the three batches we noticed that:

– The highest values – in 1554 and 1171 respectively cN*cm – are recorded in the batches I and III, batches which are composed of the highest percentage of synthetic fibre
– The mechanical work created when stretching the yarns in batch II register the lowest value 885.1 cN*cm – is consistent with the percentage of synthetic fibre.
– The yarns in batch I even though have a lower twist than those in batch III, they tear hardly and in order to be broken a higher mechanical work must be created due to the fact that their thickness is greater.

CONCLUSIONS

As a result of these comparative analyses of yarns tensile properties in the 3 batches the following conclusions are drawn:

- The breaking force of yarns is mainly determined by the value of length density and only then by the percentage of polyamide and twist value (which is known to improve the yarns resistance);
- Elongation at break – is primarily influenced by the percentage of polyamide from the yarns composition (the greater this is, the higher the value of elongation at break) and only then by the degree of yarns twisting (the higher the twisting the lower the elongation at break);

- The highest tenacity is obtained by the yarns with the lowest fineness;
- The mechanical work created when stretching the yarns depends mainly by the percentage of polyamide from the yarns composition (the higher the percentage the bigger the mechanical work value). Yarn fineness is the next factor influencing the mechanical work necessary for yarns breakage and only then the yarns twisting.

The results of these analyses are successfully applied in textile industry, weaving mills and knitwear, where choosing the yarns with high tensile strength is highly important in obtaining high quality products.

BIBLIOGRAPHY

[1] Kotb, N. A. *Predicting yarn quality performance based on fibers types and yarn structure,* In: Life Science J 9(3), (2012), pp. 1009–1015.

[2] Das, B. R., Ishtiaque, S. M. and Rengasamy, R. S. *Static and dynamic tensile behaviour of spun yarns: A critical review*, In: Breaking force, for three yarns batches Research Journal of Textile & Apparel, Vol. 15 Issue 4, (Nov 2011), pp. 70–83.

[3] Souid, H. & Cheikhrouhou, M. Slup *Yarn quality optimization by using desirability function and neural networks*, In: Journal of Applied Science 11(17), (2011), pp. 3204–3208.

[4] Gribincea, V. & Bordeianu, L. *Fibre textile – Proprietăţi generale*, In: Editura Performantica, Iaşi, (2002).

[5] Neha Gupta, *Analysis on the defects in yarn manufacturing process & its prevention in textile industry*, In: International Journal of Engineering Inventions, e-ISSN: 2278-7461, p-ISSN: 2319-6491, Volume 2, Issue 7, (2013), pp. 45–67.

[6] Abhijit, M. *Assessment of tensile properties of cotton yams*, In: Indian Journal of Fibre&Textile Research, Vol. 26, (2001), pp. 354–357.

[7] Avram, M., Avram, D. and Bahu, L. *Structura firelor*, Editura Gh. Asachi, Iaşi, 2002.

[8] Cioară, I. & Onofrei, E. *Inginerie generală în textile-pielărie. Îndrumar de laborator,* Editura Performantica, Iaşi, 2006.

[9] Cioară, I. & Onofrei, E. *Inginerie generală în textile-pielărie*, Editura Performantica, Iaşi, 2007.

[10] Oana, D., Suteu, M., and Oana, I. *The study of irregularity elongation of yarns of wool in mixture with silk using the Uster® Tensojet 4 Machine*, In: Annals of the University of Oradea, Fascicle of Textiles-Leatherwork, Oradea, vol. XVI, nr. 2, (2015), pp. 51–56.

[11] Avram, M. & Avram, D. *Structura și proprietățile firelor*, Editura CERMI, Iaşi, 1998.

[12] Antoniu, Gh. & Arnăutu, I. *Fibre textile. Aplicaţii,* Vol. 2, Editura Dosoftei, Iaşi, 2002.

[13] Oana, D., Oana, I. P., Suteu, M. *The thinness degree study of wool yarns of different origins using the Uster machine/Studiul gradului de subtirime a firelor de lâna de provenienta diferita cu ajutorul aparatului Uster*. In: *Industria Textila*, 66.6: 329, 2015.

Authors:

Lecturer PAVEL OANA IOAN

Lecturer DORINA OANA

Lecturer SIMONA TRIPA

Department of Engineering and Industrial Management in Textiles and Leatherwork
University of Oradea, Ro- 410041, Oradea, str. Universitatii nr. 1, Oradea, Romania

e-mail: oanaioanpavel@yahoo.com, tripasimona@yahoo.com

Corresponding author:

IOAN PAVEL OANA

e-mail: oanaioanpavel@yahoo.com

The influence of texturing process parameters on yield points and breaking forces of pes filament yarns

DOI: 10.35530/IT.069.04.1466

PETAR STOJANOVIĆ
DUŠAN TRAJKOVIĆ
JOVANA STEPANOVIĆ
NATAŠA RADMANOVAC
JOVAN STEPANOVIĆ

REZUMAT – ABSTRACT

Influența parametrilor procesului de texturare asupra punctelor limită de elasticitate și forțelor de rupere ale firelor filamentare Pes

O analiză a proprietăților mecanice ale firelor PES texturate arată că viteza de texturare are un efect semnificativ asupra acestor proprietăți. Rezultatele au arătat că, odată cu creșterea vitezei de texturare, s-a observat o tendință descrescătoare a forțelor de rupere ale firelor PES texturate analizate, la grade de întindere de 1,665 și 1,685. Unele deviații ale rezultatelor au fost găsite în cazul firelor PES texturate cu gradul de întindere aplicat de 1,675. De asemenea, rezultatele au arătat că, la un grad de întindere de 1,685, firele analizate au în general valori mai mari ale forțelor de rupere. Aplicarea unui grad mai mare de întindere a firelor filamentare PES îmbunătățește orientarea lanțurilor moleculare în direcția forței de întindere, ceea ce contribuie la îmbunătățirea caracteristicilor mecanice ale firelor PES texturate. În plus, rezultatele analizei influenței temperaturii arată că, la temperaturi mai ridicate, se produc fire PES texturate cu valori mai mari ale forțelor de rupere. Rezultatele obținute au fost utilizate pentru a determina ecuațiile pentru estimarea punctelor limită de elasticitate și a forțelor de rupere ale firelor filamentare PES texturate în funcție de parametrii de proces ai producției.

Cuvinte-cheie: fir texturat, viteză de texturare, forța de rupere, punct limită de elasticitate

The influence of texturing process parameters on yield points and breaking forces of pes filament yarns

An analysis of the mechanical properties of textured PES yarns shows that the texturing speed has a significant effect on these properties. The results showed that with the increase in the texturing speed, a decreasing trend was observed in the breaking forces of the analyzed textured PES yarns at stretching degrees of 1.665 and 1.685. Some deviations of the results were found in the textured PES yarns with the applied stretching degree of 1.675. Also, the results showed that at a stretching degree of 1.685, the analyzed yarns generally have higher values of breaking forces. Applying a higher degree of stretching of PES filament yarns improves the orientation of molecular chains in the direction of the stretching force, which contributes to better mechanical characteristics of textured PES yarn. In addition, the results of the analysis of the influence of the first heater temperature show that, at higher temperatures, the textured PES yarns with higher values of breaking forces are produced. The results obtained were used to suggest the equations for predicting the yield points and breaking forces of textured PES filament yarns depending on the process parameters of production.

Keywords: textured yarn, texturing speed, breaking force, yield point

INTRODUCTION

During the development and production of textured PES fibers, great attention in the research was devoted to finding and explaining the dependence between the parameters of the texturing process and the structure of the textured filament, that is, the dependence between structure and properties. Texturing is a process with numerous parameters and the polyester filament texturing parameters significantly influence its behavior during further processing, and all the errors and irregularities created in the texturing process become easily visible in finished products. This problem is particularly pronounced when texturing a partially oriented PES filament (POY – Partially Oriented Yarn), on which there is not much data in the reference works. They mainly refer to the texturing process in laboratory conditions [1–3]. A significantly higher number of papers is devoted to texturing of extruded polyester filaments (FOY – Fully Oriented Yarn) that is characterized by a stable structure and lower sensitiveness to parameter changes in the texturing process, but also the use of different texturing processes [4–7].

The modern texturing machines use contactless high temperature heaters (HT heaters) [8–10]. Although heater temperatures (usually 380°C to 420°C for texturing PET filament of 167 dtex at texturing speed of 1000 m/min) are considerably above polymer softening (about 230–240°C) and melting (about 260°C) temperatures, yarn retention time in the heater is short so the yarn temperature at heater exit is in the range of normal operating temperatures (about 210°C) [9]. Due to such high operating temperatures retention time in the heating zone ranges, depending on the yarn speed and heater length, from 0.12 to 0.072 s. During such short retention time yarn must be heated above glass transition temperature, where temperature distribution across the cross section of multifilament yarn must be uniform, in order to obtain textured yarn of uniform properties. Increasing the temperature of the heater results in a more intense heating of the yarn, the retention time of the yarn in the heater is reduced and therefore the temperature drop over the cross-section of yarn [10–11]. It was noted that the temperature difference between the surface and the core of the yarn is increased with increasing heater temperature, texturing speed and reducing yarn fineness while the temperature difference is decreased with increasing the length of the heater [10].

Since the textured filament POY PES yarns, produced on machines with HT heaters, are insufficiently studied, in the scope of this work presented are the investigations of the influence of some texturing process parameters on the yield points and breaking forces of textured PES filaments.

The results obtained can be used for the selection of optimum production parameters of the yarns in industrial conditions. Moreover, the results contributed to suggest equations for predicting the yield points and breaking forces of PES filament yarns at various process parameters.

EXPERIMENTAL WORK

Materials and methods

Experimental part of the work includes the analysis of breaking forces of POY multifilament polyester yarn of fineness 167f3×1dtex. The textured PES yarn of fineness 167f36×1 dtex, was produced under industrial conditions from POY PES multifilament of fineness 278f36×1 dtex, and obtained from TWD Fibers, Germany. The texturing was made on a stretching friction texturing machine with high temperature heater: FTF-15 (ICBT, France).

The texturing of yarn was performed using varying temperatures of the first heater (350°C, 400°C and 450°C) maintaining the constant temperature of the second heater (180°C), then with varying values of surface speed of disks to yarn speed ratios (2.15, 2.20 and 2.25) and by changing stretching degrees in texturing zoone (1.665, 1.675 and 1.685), at texturing speeds of 500 m/min, 600 m/min, 700 m/min, 900 m/min, 1000 m/min and 1100 m/min.

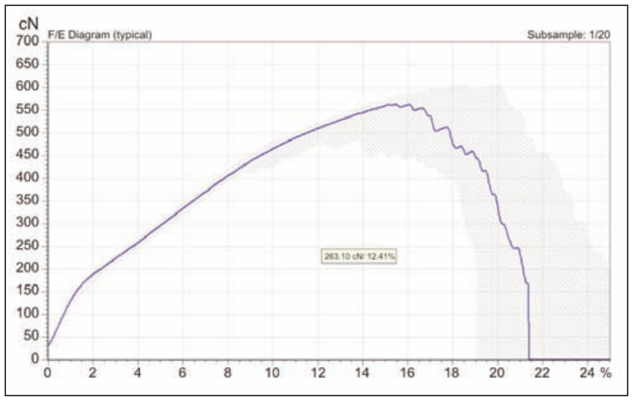


Fig. 1. Typical curve *F*-e textured PES yarn

For determination of breaking characteristics of experimental material automatic dynamometer USTER TENSORAPID 4 was used. The breaknig force of yarn was determined according to DIN 53384. Further, based on funcion *F*-e (figure 1) it was determinated the value of the force in the yiled point, which was numerically determined in the maximum of the first derivative of the curve *F*(e), where is $F''(e) = 0$. Up to this point, textured PES filament yarns exhibits higher resistance to stretching forces. Then, a faster deformation is set in, up to material destruction.

RESULTS AND DISCUSSION

The influence of texturing speed on the breaking force of PES filament yarn

The texturing speed causes the changes in the structure of filament yarns, which affect the mechanical characteristics of these yarns. Changing the texturing speed affects the time of contact between the yarn and heaters, the cooling and stabilization time of the textured PES yarn.

In figures 2 to 10 shown there are the changes of breaking characteristics of textured filament PES yarns at various texturing speeds, temperatures of the first heater and D/Y ratios.

The results show that, as the texturing speed increases, a decreasing trend is observed in the value of the breaking forces of the analyzed yarns. By applying a stretching degree of 1.675, the tendency of reducing the breaking force with an increase in the texture speed to 900 m/min is observed in most cases, and then a growth trend of the breaking force is observed.

At the same time, in figures 1 through 9, histograms are shown illustrating the effect of the change of the individual texturing parameters on the values of the breaking forces of textured PES filament yarn. The results show that at a stretching degree of 1.685 the analyzed yarns generally have higher values of breaking forces, at higher texturing speeds, i.e., at speeds of 900 m/min, 1000 m/min, and 1100 m/min. This is explained by the fact that the stretching of filament PES yarns improves the orientation of the macromolecules in the direction of the stretching force, which contributes to better mechanical characteristics of these yarns.

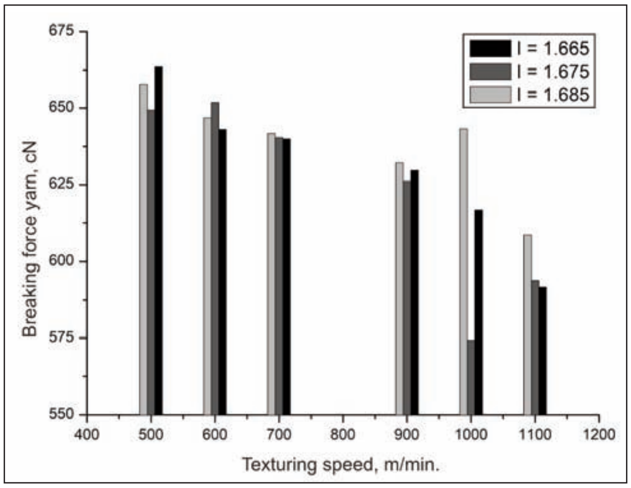


Fig. 2. The influence of the texturing speed on the breaking force of yarn (Samples 1-18; T = 350°C; D/Y = 2.15)

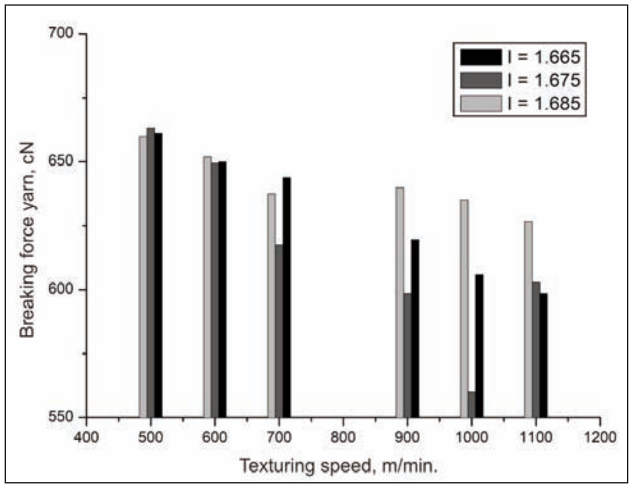


Fig. 3. The influence of the texturing speed on the breaking force of yarn (Samples 19-36; T = 350°C; D/Y = 2.20)

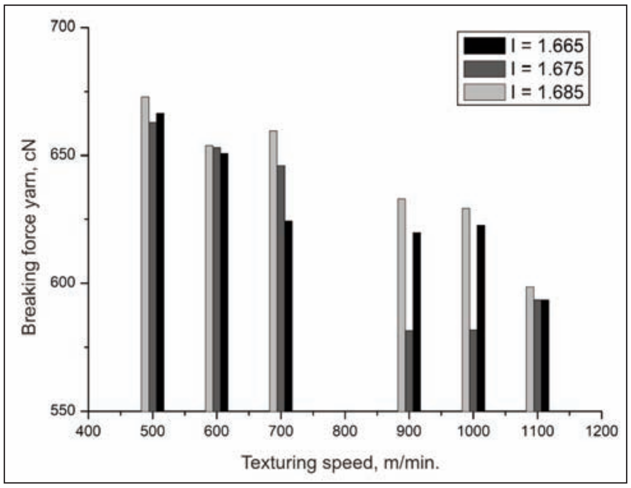


Fig. 4. The influence of the texturing speed on the breaking force of yarn (Samples 37-54; T = 350°C; D/Y = 2.25)

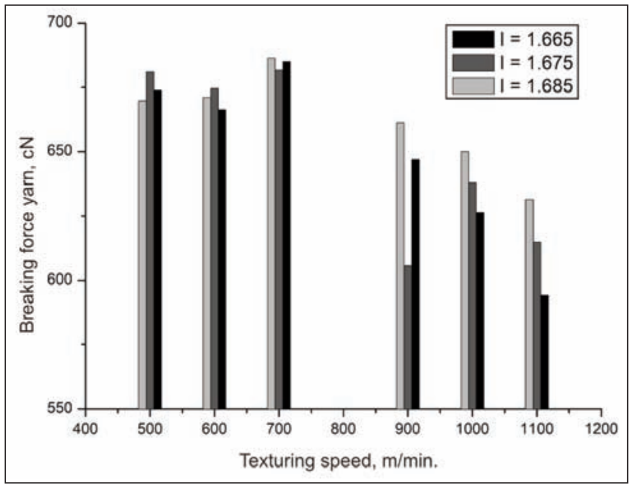


Fig. 5. The influence of the texturing speed on the breaking force of yarn (Samples 55-72; T = 400°C; D/Y = 2.15)

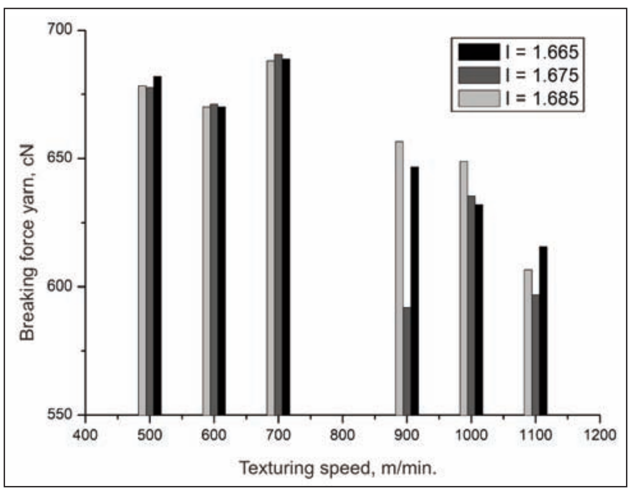


Fig. 6. The influence of the texturing speed on the breaking force of yarn (Samples 73-90; T = 400°C; D/Y = 2.20)

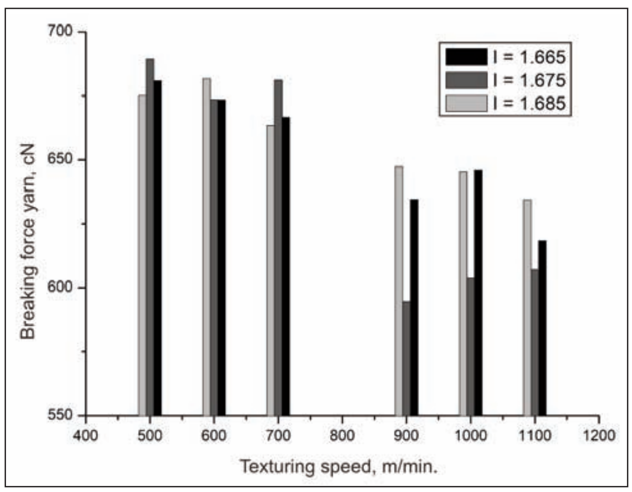


Fig. 7. The influence of the texturing speed on the breaking force of yarn (Samples 91-108; T = 400°C; D/Y = 2.25)

The influence of the first heater temperature on the breaking force of PES filament yarn

In figure 11 given there are the total graphs of the variations of the breaking force of the textured PES yarn as dependent on the temperature of the first heater and the texturing speed.

The obtained results show that, generally, at higher temperatures of the first heater, textured PES yarns with the higher breaking force are produced. In the

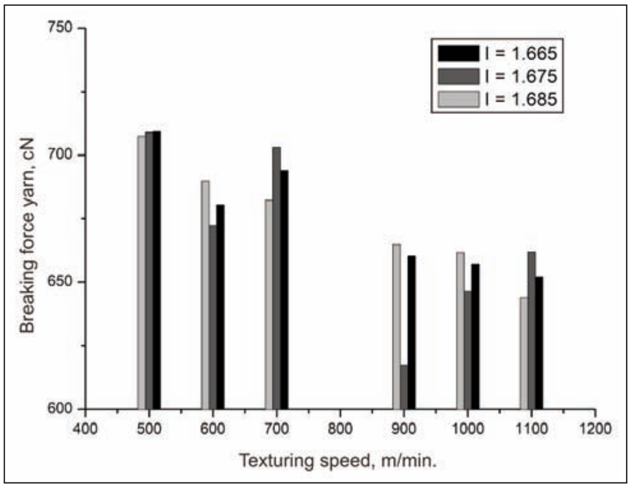


Fig. 8. The influence of the texturing speed on the breaking force of yarn (Samples 109-126; T = 450°C; D/Y = 2.15)

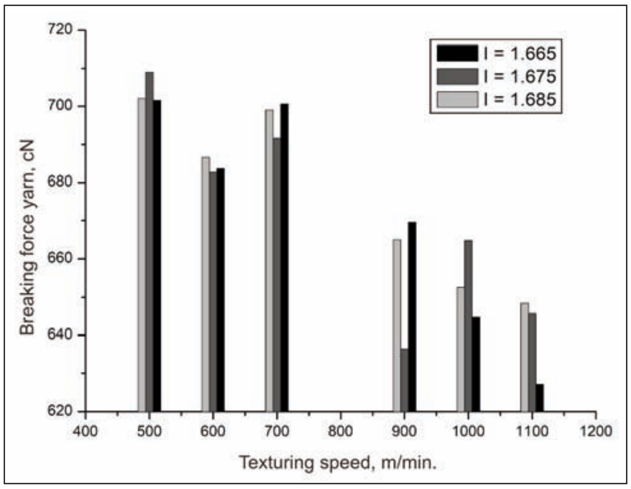


Fig. 9. The influence of the texturing speed on the breaking force of yarn (Samples 127-144; T = 450°C; D/Y = 2.20)

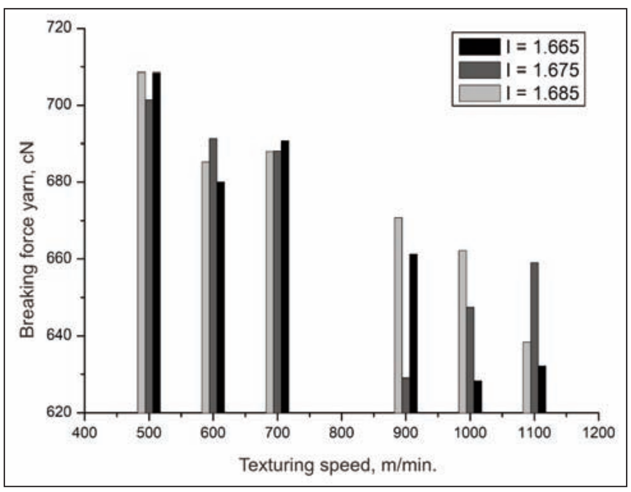
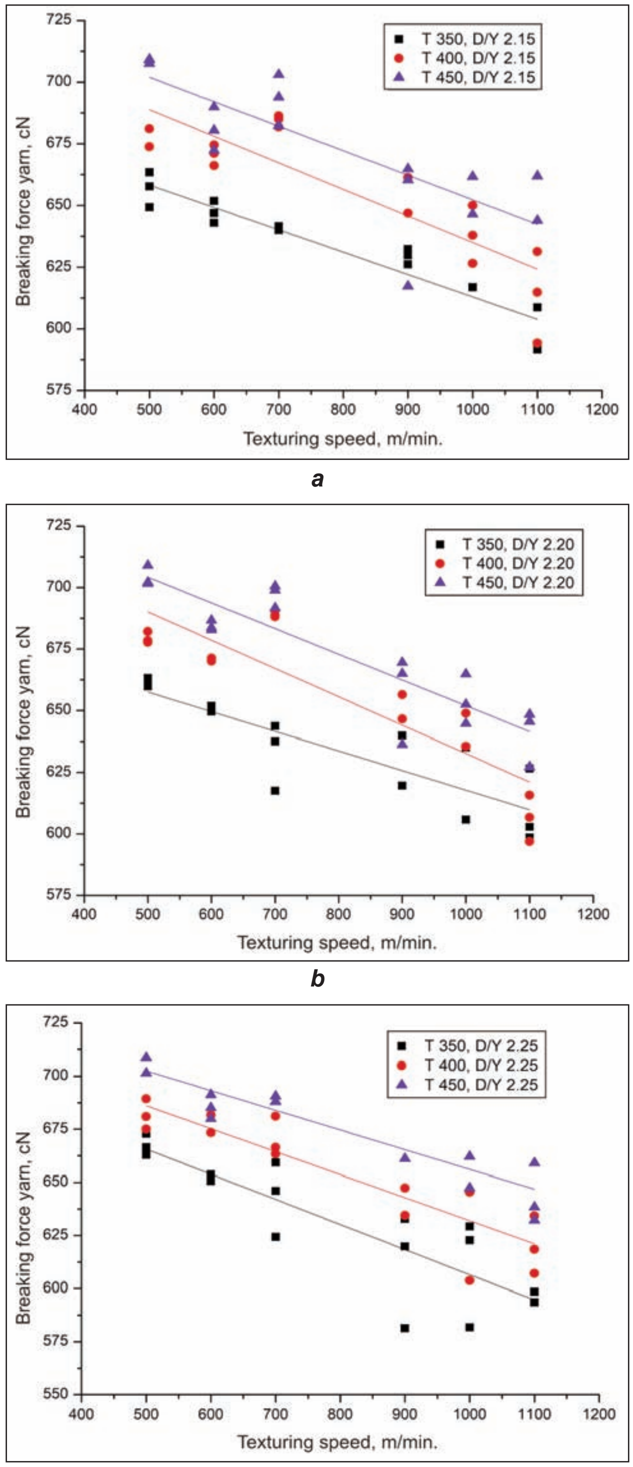


Fig. 10. The influence of the texturing speed on the breaking force of yarn (Samples 145-162; T = 450°C; D/Y = 2.25)



c

Fig. 11. The influence of the texturing temperature on the breaking force of yarn:
a – D/Y = 2.15; *b* – D/Y = 2.20; *c* – D/Y = 2.25

texturing process, the mobility and flexibility of molecular chains increases at higher temperatures, which is reflected in their orientation in the direction of the tensile force, and consequently in the values of the breaking forces of textured PES filament yarns.

Prediction of the yield points and breaking forces of the textured PES filament yarns

Table 1 shows the parameters of the regression equation that can be used for the prediction of the breaking forces of the textured yarns with the stretching degree of 1.665 depending on the texturing speed for given first heater temperatures and D/Y ratios, while table 2 contains the corresponding equation parameters for the stretching degree of 1.685 in the texturing process.

Table 1

REGRESSION EQUATION PARAMETERS (STRETCHING DEGRE 1.665)					
Samples	$F_b = a + bv$ [cN]				
	R^2	***a***	**Standard error**	***b***	**Standard error**
1-18	0.88872	710.29762	12.87334	–0.09939	0.01554
19-36	0.99206	715.62857	3.55359	–0.10729	0.00429
37-54	0.81143	709.42143	17.41356	–0.09971	0.02101
55-72	0.74076	750.56667	26.96918	–0.12725	0.03255
73-90	0.81100	746.62619	19.83547	–0.11343	0.02394
91-108	0.88242	731.64762	13.0696	–0.09789	0.01577
109-126	0.83114	747.61429	14.76029	–0.09014	0.01781
127-144	0.82490	766.11905	19.83444	–0.11861	0.02394
145-162	0.87527	770.14762	17.81412	–0.12914	0.0215

Table 2

REGRESSION EQUATION PARAMETERS (STRETCHING DEGRE 1.685)					
Samples	$F_b = a + bv$ [cN]				
	R^2	***a***	**Standard error**	***b***	**Standard error**
1-18	0.60616	685.17143	16.42928	–0.05846	0.01983
19-36	0.80488	679.17143	8.32408	–0.04671	0.01005
37-54	0.87879	726.47619	14.48376	–0.10668	0.01748
55-72	0.56666	713.73095	19.66077	–0.06514	0.02373
73-90	0.64151	740.71667	27.12734	–0.10325	0.03274
91-108	0.90723	718.24286	8.84859	–0.07543	0.01068
109-126	0.96253	750.64524	6.88545	–0.09454	0.00831
127-144	0.87354	750.90238	13.08121	–0.09411	0.01579
145-162	0.89561	753.7619	12.22992	–0.09779	0.01476

Where: F_b is breaking force of the yarn [cN]; v – texturing speed [m/min]

Table 3

REGRESSION EQUATION PARAMETERS (FORCE IN THE YIELD POINT)					
Samples	$F_y = a + bF_b$ [cN]				
	R^2	***a***	**Standard error**	***b***	**Standard error**
1-18	0.87923	–329.21577	63.55562	1.05289	0.1003
19-36	0.67407	–174.73434	90.82439	0.80875	0.14292
37-54	0.91199	–215.92297	41.60487	0.87777	0.06595
55-72	0.82824	–433.89132	90.25481	1.17869	0.13764
73-90	0.94363	–323.32638	42.15543	1.01664	0.06403
91-108	0.84042	–391.62645	79.92019	1.12700	0.12205
109-126	0.64126	–4.05184	67.87856	0.52975	0.10045
127-144	0.60221	–164.7482	99.04516	0.76062	0.1471
145-162	0.60263	–114.60364	99.90673	0.69625	0.14767

Where: F_y is force in the yield point [cN]; F_b – breaking force of the yarn [cN]

The force value at the yield point depending on the temperature of the first heater and the D/Y ratio, they can be predicted by using the regression equations whose parameters are shown in table 3.
The results shown can be used for the selection of the optimal parameters for PES filament yarns texturing.

CONCLUSIONS

The false twist texturing of POY polyester yarn is a process which includes close interactions between process parameters and the structure and properties of textured yarn. The most significant texturing process parameters are texturing speed and temperature of the heater, because both parameters affect the properties of textured yarn.

Analyzing the mechanical properties of textured PES yarns it can be concluded that texturing speed shows a significant impact on these properties. The results showed that with the increase of the texture speed, a decreasing trend in the value of the breaking forces of the analyzed textured PES yarns is observed. In addition, the results showed that at a higher degree of stretching, the analyzed yarns generally have higher values of breaking forces, which is explained by correction of the orientation of molecular chains due to stretching. Also, the results show that, at higher temperatures of the first heater, the textured PES yarns with higher values of breaking forces are produced. At higher temperatures in the texturing process mobility and flexibility of molecular chains are increased contributing to their better orientation in the direction of tensile forces, which reflects on the mechanical properties of textured PES filament yarns.

BIBLIOGRAPHY

[1] Yildirim, K., Altun, S., Ulcay, Y. *Relationship between yarn properties and process parameters in false-twist textured yarn*, In: J. Engineered Fibers and Fabrics, 2009, vol. 4, nr. 2, pp. 26–32.

[2] Tehran, M.A., Azimi, B., Mojtahedi, M.R.M. *Investigating the effect of false twist texturing process on the color coordinates variation of spun-dyed polyester filament yarns*, In: J. Engineered Fibers and Fabrics, 2011, vol. 6, nr. 4, pp. 54–62.

[3] Canbaz Karakaşa, H., Dayıoğlu, H. *Influence of false-twist texturing parameters on the structural properties of polyester yarn*, In: Indian Journal of Fibre & Textile Research, 2005, vol. 30, pp. 37–41.

[4] Celik, P., Ozdil, N., Supure, G., *Experimental investigation on the static and dynamic strength of false twist textured polyester yarns*, In: Industria Textila, 2011, vol. 62, nr. 1, pp. 38–43.

[5] Bhattacharya, S.S., Shaikh, T.N., Pratap, A. *An investigation of thermal characteristic of mechanical crimp textured polyester yarn by Differential Scanning Calorimeter (DSC)*, In: AIP Conf. Proc. 1249, 2010, pp. 67–74.

[6] Shaikh, T.N., Bhattacharya, S.S. *Deriving an empirical formula to determine the optimum level of false-twist in mechanically-crimped textured polyester yarn*, In: Textile Research Journal, 2011, vol. 81, nr. 19, pp. 1995–2005.

[7] Mahish, S.S., Punj, S.K., Kothari, V.K. *Comfort and handle related properties of P/V blended air-jet textured yarn fabrics,* In: Fibers and Polymers, 2010, vol. 11, nr. 6, pp. 932–940.

[8] Demir, A., Behery, H.M. *Synthetic filament yarn texturing technology*, Prentice Hall, Upper Saddle River, USA, 1997.

[9] Atkinson, C. *False twist textured yarns: Principles, processing and applications*, Woodhead Publishing Limited, Cambridge, 2012.

[10] Eskin, N. *Analysis of a high temperature heater in a false twist texturing process*, In: Energy Conversion and Management, 2003, vol. 44, nr. 16, pp. 2531–2547.

[11] Dupeuble, J.C., *Texturing performance of polyamide yarn on high temperature heaters*, In: Chemiefasern Textilindustrie, 1993, vol. 43, nr. 11, E145–E152.

Authors:

PETAR STOJANOVIĆ[1]

DUŠAN TRAJKOVIĆ[2]

JOVANA STEPANOVIĆ[2]

NATAŠA RADMANOVAC[2]

JOVAN STEPANOVIĆ[2]

[1] Dunav a.d. Grocka, Bulevar revolucije 15, 11306 Grocka, Serbia

[2] Faculty of Technology, University of Niš/Bulevar oslobođenja 124, 16000 Leskovac, Serbia

e-mail: p.stojanovic@dunavgrocka.rs, dusan@ tf.ni.ac.rs, stepanovicjovana@yahoo.com, radmanovac@tf.ni.ac.rs, jovan@tf.ni.ac.rs

Corresponding author:

JOVAN STEPANOVIĆ
e-mail: jovan@tf.ni.ac.rs

Evaluating compressive behavior of general fibrous assemblies

DOI: 10.35530/IT.069.04.1507

JING HUI YU WEIDONG

REZUMAT – ABSTRACT

Evaluarea comportamentului la compresiune al structurilor fibroase

În general structurile fibroase sunt realizate din fibre cu o dispunere întâmplătoare și aerul din porii formați din aceste fibre. O caracteristică importantă a acestor compoziții este comportamentul lor mecanic la presiune și relaxare. În această lucrare, a fost utilizat un studiu experimental unificat și sistematic pentru cuantificarea și caracterizarea comportamentului la compresiune și revenire al mai multor compoziții fibroase orientate aleatoriu prin intermediul unui sistem de măsurare integrat mecanic și conductiv in situ. Au fost caracterizate curbele de forță, modulul, efortul și pierderea de energie în timpul ciclurilor de compresiune și de revenire. O histereză considerabilă a apărut între operațiile de compresiune și relaxare, ceea ce reprezintă o dovadă a existenței efectelor fenomenelor de alunecare și frecare ale fibrei. Efortul, pierderea de energie și rata de revenire au demonstrat o relație exponențială neliniară în raport cu ciclurile.

Cuvinte-cheie: compresiune, revenire, compoziție fibroasă, ciclu, histereză

Evaluating compressive behavior of general fibrous assemblies

General fibrous assemblies are made of loose fibers and air filling in the pores formed by these fibers. An important characteristic of these assemblies is their mechanical behavior under compression and release. In this paper, a unified and systematic experimental investigation was used to quantify and characterize the compressional and recovery behavior of several randomly oriented fibrous assemblies via mechanical and conductive in situ integrated measurement system. An attempt was made to characterize the curves of force, modulus, work and energy loss during compressional and recovery cycles. Considerable hysteresis occurred between the compression and release operations which is an evidence for the existence of fiber slippage and frictional effects. Work, energy loss and recovery rate of work turned out to have a nonlinear exponential relationship with cycles.

Keywords: compression, recovery, fibrous assembly, cycle, hysteresis

INTRODUCTION

General fibrous assemblies are made of loose fibers and air filling in the pores formed by these fibers. These fibrous assemblies are of the first hierarchical level, otherwise known as simple or primary fibrous assemblies. An important characteristic of these assemblies is their mechanical behavior under compression. In most end-uses of textile products, such as carpet, pillows and nonwoven fabrics, fibrous assemblies are subjected to repeated compressional forces followed by recovery. Mechanical behavior under compressional forces has a significant value adding effect to the end-use products. Many of these materials used in these applications fail because of the loss of ability to recover from deformation due to fiber failure and slippage. Products lose their liveliness due to repeated compressional forces and changes in the fiber architecture of the assemblies [1].

Extensive works have been done in the field of compression properties of general fiber assemblies. However, nearly all have been of an empirical analysis in the fiber compression and release characteristics fitting a series of equations, or parameters have been derived from these characteristics. The pioneered work done by Van Wyk over sixty years ago provided the only theoretical basis on which to explain the relationship between the pressure and volume of a fibrous assembly during compression [2]. Theoretical derivation was based on the bending behavior of a rigid beam with equally spaced supports and by neglecting fiber slippage, friction and time dependent behavior. Dunlop showed that fiber friction and slippage have a major effect on the compressive behavior [3]. Neglect of fiber slippage and friction effect may be one of the major reasons causing the Van Wyk's results to deviate from the experimental values. Neckář derived a bi-dimensional deformation equation based on the Van Wyk's theory by taking the effect of uncompressed areas between contacting fibers into consideration [4]. Sebestyen and Hickie reported the compressional behavior of wool fiber mass at pressures ranging from medium to high and a relationship between fiber mass density and applied pressure was given in a power law form [5]. Komori, T. introduced a formula for compressional mechanics of a fiber mass treated as the assembly of the fiber elements whose individual bending behaviors are combined into the overall response of the mass [6]. Carnaby, G. A. and Pan, N. predicted the compressional behavior of fibrous assembly at large deformations, especially the compression hysteresis [7].

Works have been in progress for decades, but a detailed insight into the compressive behavior of fibrous assemblies still remains elusive. There is a lack of well-established knowledgebase to characterize the compressional and release behavior of these systems, although these behaviors are of considerable importance. Having a systematic and thorough insight of the compressive behavior will aid us to design fiber assemblies with better resilience. In this work, the focus will be on a systematic analysis of the compressional and recovery behavior of fibrous assemblies. Experimental studies have been undertaken to characterize these behaviors. This work extends to several natural fibrous assemblies since many natural fibrous assemblies have unparalleled compression recovery properties. We are attempting to find the basic mechanisms of compression and recovery for these systems and particularly interested in work and energy loss during repeated successive compression and release cycles and to understand the reason for compression hysteresis.

EXPERIMENTAL DETAILS

Materials and preparation

Compression experiments were conducted on three different randomly oriented fibrous assemblies. The materials used as test specimen were cotton, kapok and cashmere fibrous assemblies. The corresponding average length, diameter and density of constituent fibers are respectively presented in table 1. The specimens were pre-conditioned at specific climatic conditions (20 ± 2 °C, 65% ± 5% relative humidity) for more than 24 hours until equilibrium temperature and moisture content was reached.

Table 1

Material	Average fiber length [mm]	Average fiber diameter [μm]	Fiber density [g/cm^3]
Cotton	23.56	23.56	1.54
Kapok	34.64	34.64	0.30
Cashmere	40.00	15.00	1.32

Experimental setup and measurement

The apparatus testing the compressional and recovery properties of general fibrous assemblies is shown in figure 1 and described in detail in Ref [8]. The apparatus designed to measure the macroscopic and microscopic compressive and recovery properties consists mainly of three parts. The first part is a cylinder (the upper chamber) which is connected to a force sensor and boosted by a stepping motor. The second part is a CCD camera moving up and down to capture changes of microstructure in situ during compression and release state. The third part is a cylindrical vessel equipped with another force sensor in the bottom of the lower chamber to record the passive force during compression and recovery state.

This upper chamber compresses the fibrous assemblies in the lower chamber into different thicknesses and densities with uniform velocities, similar to the principle of syringe. Due to the application of the force, the fibrous assembly undergoes compressive

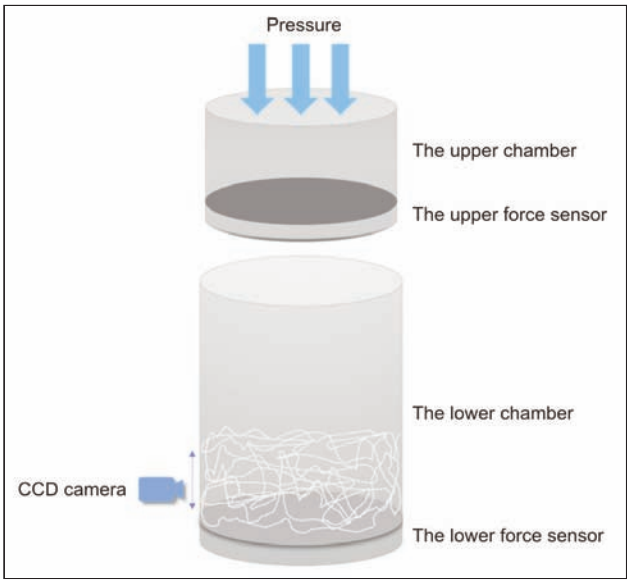


Fig. 1. Principle diagram of compressional apparatus

deformation. Trapped air will be removed quickly through the holes on the surface of the cylinder, thus the time dependent effect of consolidation of fibrous assembly due to removal of trapped air from the system can be eliminated. The system is connected to an Instron that measures the force and the deformation, from which the stresses and the strains can be measured. The compressive cycle is then followed by a recovery phase, where the applied load is removed at a chosen rate and the fibrous assembly is allowed to expand naturally. The recovery could be tested by relaxing (reducing the force or stains) at a certain rate or by suddenly removing the force and measuring the time dependent displacement recovery of the assembly. In our measurements, we applied the required compressive displacements and measured corresponding force, and then slowly removed the displacements and measured corresponding forces. The fibrous assembly went through several successive cycles of compression and recovery in order to separate the effect of fiber slippage, friction and even damage in the fibrous assembly. Compression resulting from fiber slippage is not fully recoverable, thus the loss of resilience in the fibrous assembly may be a direct measure of fiber slippage and damage, which may be an undesirable effect for many of the end uses. We have completed our experiments on three different natural fibrous assemblies as mentioned above to understand the macroscopic force displacement relations.

RESULTS AND DISCUSSION

Characteristic curves of active and passive force

A series of compressional experiments were completed to understand the macroscopic force-displacement behaviors during compressive state. Figure 2, *a–c* shows force and displacement curves of cotton, kapok and cashmere fibrous assemblies that provided us with non-linear constitutive relationships for fibrous assemblies. Small differences were found

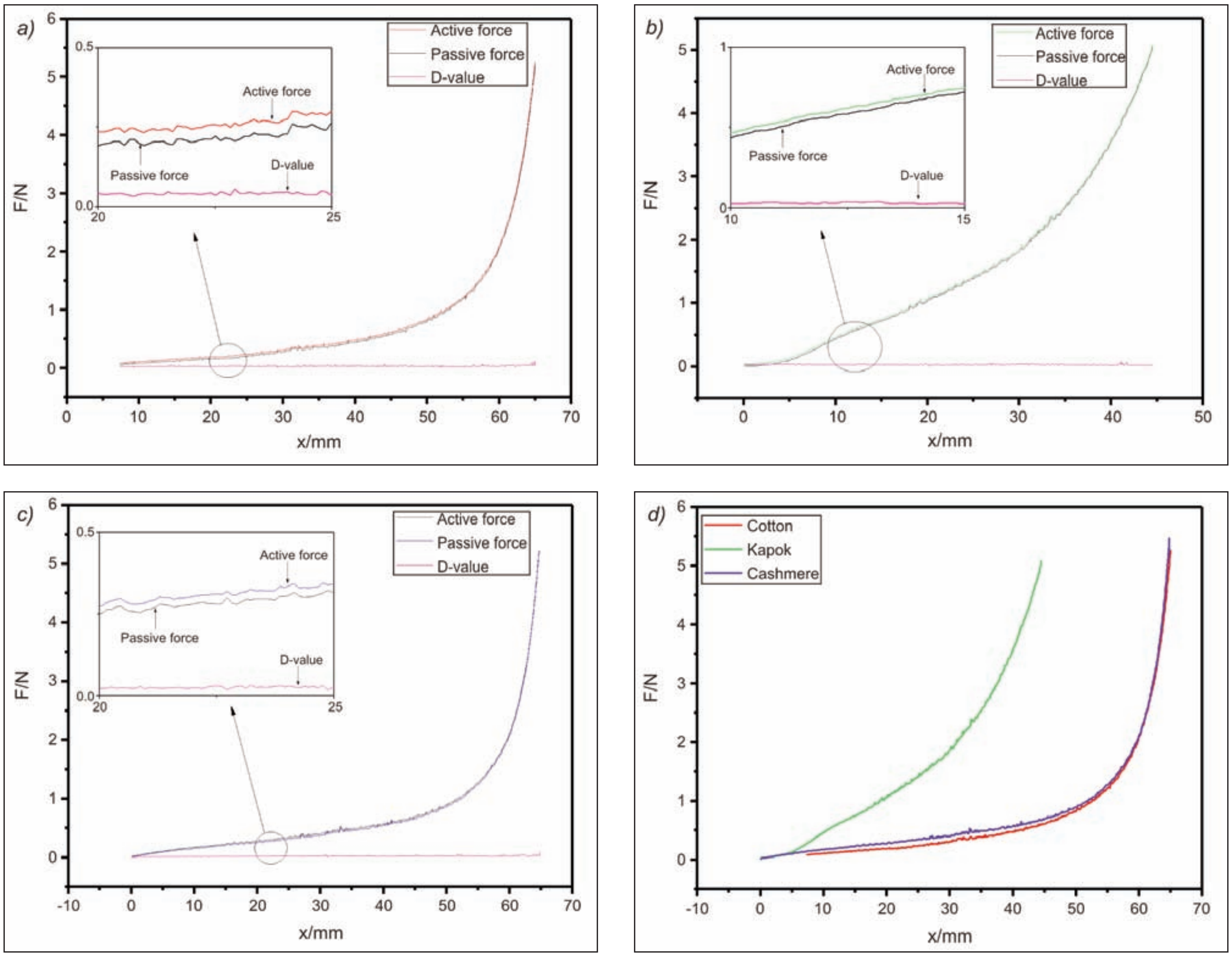


Fig. 2. Force-displacement curves of general fibrous assemblies

between active and passive force, and active forces are slightly larger than passive forces resulting in a nearly zero D-values (the difference between active force and passive force). This is mainly because of the time-dependent of force transmission. Active force-displacement curves of cotton and cashmere are similar with only small difference while Kapok is quite different because the original weight of three different fibrous assemblies are same and the density of kapok is much smaller than the other two fibers leading to a larger packing density of kapok fibrous assembly (figure 2, *d* as an illustration).

Packing density is a physical quality which is often used to describe the compactness of loose fibrous assembly. It is defined as the ratio of the volume of fibers to the volume of fibrous assembly (including pores between fibers and within fibers). Active force and packing density curves of cotton, kapok and cashmere fibrous assemblies are illustrated in figure 3. The force increases with the increase of packing density. The notable differences in force and packing density curves of three fibrous assemblies are mainly due to the differences of single fibers in stiffness and elasticity.

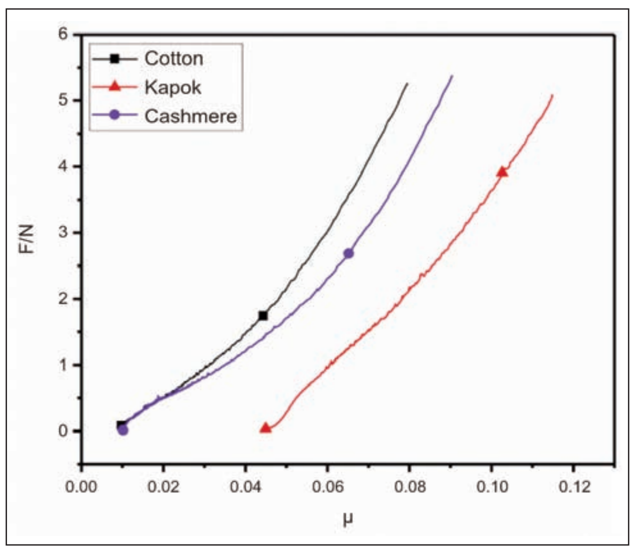
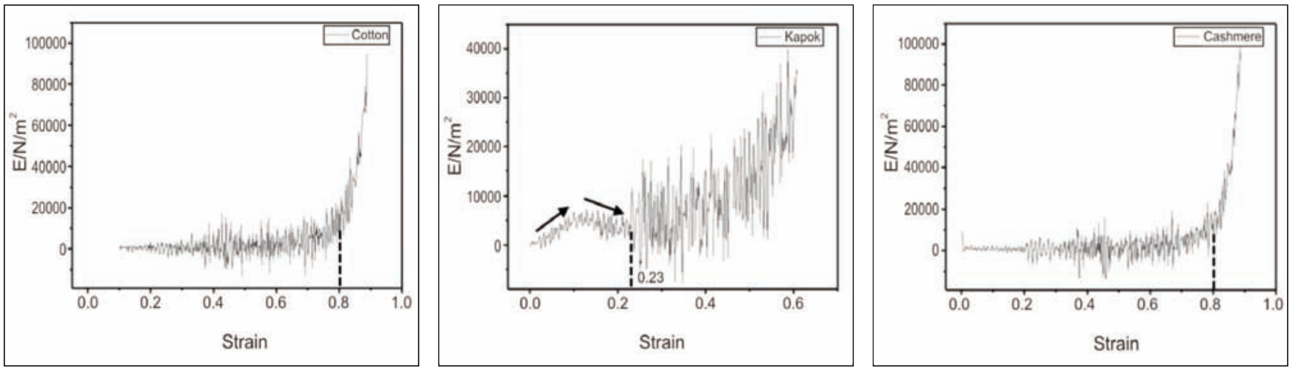


Fig. 3. Active force-packing density curves of general fibrous assemblies

Bulk modulus analysis

A series of modulus and strain curves of cotton, kapok and cashmere fibrous assemblies are plotted in figure 4, *a–c*. Similar modulus curves can be observed in cotton and cashmere fibrous assemblies, and modulus keep steady in the range of 0 to 0.8



a b c

Fig. 4. *a* – Modulus and strain curve of cotton; *b* – Modulus and strain curve of kapok; *c* – Modulus and strain curve of cashmere

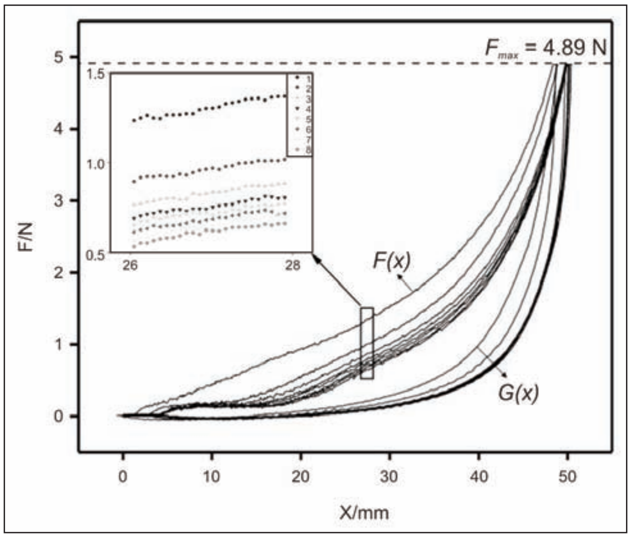


Fig. 5. Compression and release cycles of cashmere fibrous assemblies for eight successive cycles, plotted as compression force against displacement

while a sharp increase can be observed when the strain reaches the maximum value. The modulus characteristic curve of kapok fibrous assembly shows a different tendency with cotton and cashmere fibrous assemblies. Modulus increases and then decreases within the range of 0 to 0.23, and presents a reciprocating morphology and the overall trend is continuing to increase. The values of the bulk modulus of fibrous assemblies determined here are in excellent agreement with Liu, Q.'s [9] results.

Compression and recovery cycle curves

Compression force against displacement curves of cashmere fibrous assemblies for eight successive compressional and release cycles are illustrated in figure 5. It will suffice here to mention that the curves shift with each successive cycle of compression and release, but finally attain a steady position. The experimental results show that the compression and recovery curves of the fibrous assemblies are in a monotone downward curve, and the compression curve and the recovery curve do not coincide due to the coexistence of viscosity and elasticity of the textile fibers. In addition, a considerable hysteresis occurs between the compression and release operations, which is an evidence for the existence of fiber slippage and friction effects.

Compression work W_C, recovery work W_R, energy loss E_L and recovery rate of work r_W can be calculated from a series of compression and release curves showed above. The corresponding formulas are showed below:

$$W_C = \int F(x)\,dx \qquad (1)$$

$$W_R = \int G(x)\,dx \qquad (2)$$

$$E_L = W_C - W_R \qquad (3)$$

$$R_W = \frac{W_R}{W_C} \qquad (4)$$

Where $F(x)$ and $G(x)$ are compressional and recovery characteristic functions of each successive circle.

Calculations of works and energy loss of eight successive circles are presented in table 2 and a histogram is illustrated in figure 6. As the cycling continues, a palpable decrease can be observed in compression work and energy loss resulting in a stable recovery work. An important factor neglected in the theory of Van Wyk is the part played by slippage and fiber friction effects that may occur during the compression of a general fibrous assembly. There is now substantial evidence to support the concept that such slippages and fiber friction occur and that they may

Table 2

n	W_C / 10^{-2}J	W_R /10^{-2}J	E_L /10^{-2}J	r_W
1	7.254	2.031	5.223	0.27998
2	6.262	2.011	4.251	0.32114
3	5.615	1.973	3.642	0.35138
4	5.420	1.971	3.449	0.36365
5	5.243	1.969	3.274	0.37555
6	5.086	1.915	3.171	0.37652
7	4.781	1.845	2.936	0.38590
8	4.576	1.775	2.801	0.38789

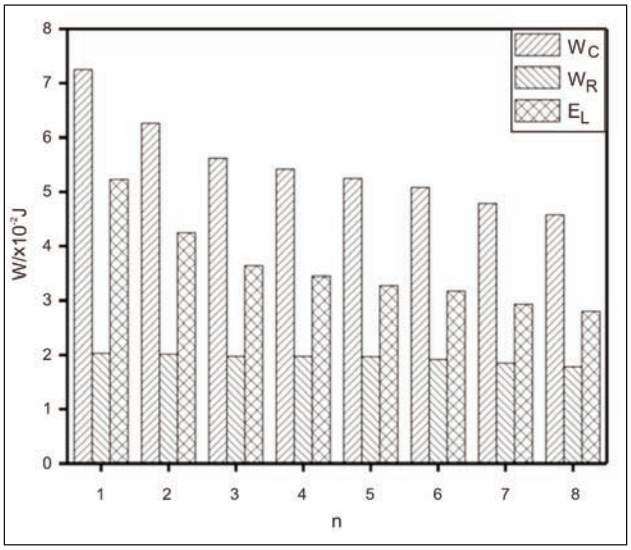


Fig. 6. Histogram of compression work, recovery work and energy loss during eight successive compression and recovery curves

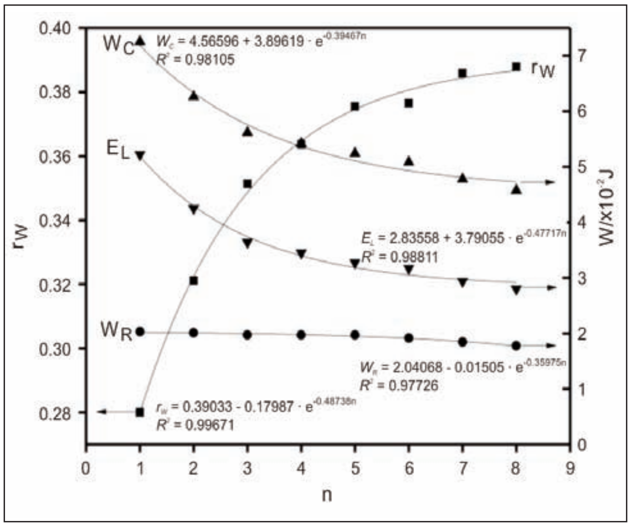


Fig. 7. Fitting curves of compression, recovery work, energy loss and recovery rate of work

have a considerable influence on the compression properties of fibrous assemblies.

The exponential model based on least square method was adopted for nonlinear fitting of experimental data, and a series of correlation coefficient R^2 excelling 0.97 was obtained (figure 7). It is obvious that there exist approximate nonlinear relationships between work and cycles as well as recovery rate of work.

CONCLUSIONS

A unified and systematic experimental investigation was used to quantify and characterize the compressional and recovery behaviours of randomly oriented fibrous assemblies via mechanical and conductive in situ integrated measurement system for variable density fibrous assemblies. Results show that small differences were found between active and passive force within three fibrous assemblies, and active forces are slightly larger than passive forces resulting in a nearly zero D-values because of the time-dependent of force transmission. Notable difference in active force and packing density curves of three fibrous assemblies mainly due to the differences of single fibers in stiffness and elasticity. Similar modulus and strain curves can be observed in cotton and cashmere fibrous assemblies while kapok fibrous assembly shows a quite different tendency.

Compressional and release curves shift with successive cycles and finally attain a steady position. The compressional and recovery curve do not coincide with each other due to the coexistence of viscosity and elasticity in the textile fibers. In addition, a considerable hysteresis occurs between the compression and release operations, which is an evidence for the existence of fiber slippage effects. As the cycling continues, a palpable decrease can be observed in compression work and energy loss resulting in a stable recovery work. Work, energy loss and recovery rate of work turned out to have a nonlinear exponential relationship with cycles.

ACKNOWLEDGEMENTS

This work was financially supported by National Key Research and Development Program of China (2016YFC0802802).

BIBLIOGRAPHY

[1] Karl I. Jacob, David McDowell, Georgia Tech. *Compressive behavior of fiber assemblies*, In: National Textile Center Annual Report, 2003, pp. 1–10

[2] Van Wyk, C.M. *Note on the compressibility of wool*, In: Journal of the Textile Institute Transactions, 1946, vol. 37, no. 12, pp. 285–292

[3] Dunlop, J.I. *On the compression characteristics of fibre masses*, In: Journal of the Textile Institute, 1983, vol. 74, no. 2, pp. 92–97

[4] Neckář, B. *Compression and packing density of fibrous assemblies*, In: Textile Research Journal, 1997, vol. 67, no. 2, pp. 123–130

[5] Sebestyen, E., Hickie, T. S. *Effect of certain fibre parameters on the compressibility of wool*, In: Textile Inst J, 1971, pp. 545ꞔ560

[6] Komori, T., Itoh, M. *A new approach to the theory of the compression of fiber assemblies*, In: Textile Research Journal, 1991, vol. 61, no. 7, pp. 420–428.

[7] Carnaby, G.A., Pan, N. *Theory of the compression hysteresis of fibrous assemblies*, In: Textile Research Journal,1989, vol. 59, no. 5, pp. 275–284

[8] Song, W., Chan, A.P.C., Yu, W. *Experimental and theoretical study on heat-insulating properties of fibrous assemblies in natural state using a new apparatus*, In: Journal of Thermal Analysis & Calorimetry, 2014, vol. 115, no. 2, pp. 1183–1193

[9] Liu, Q., Yu, W. *Discussion on the compression properties and permeability of fiber assemblies*, In: Proceedings of The Textile Institute 83rd World Conference, 2004, vol. 1, pp. 349–353

Authors:

JING HUI

YU WEIDONG

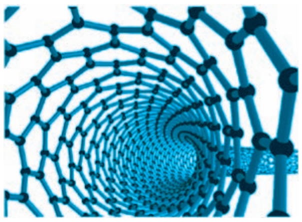
Donghua University, College of Textiles, Key Laboratory of Textile Science & Technology, Ministry of Education, 2999 North Renmin Road, Songjiang District, 201620, Shanghai, P.R.China

e-mail: 1125132@mail.dhu.edu.com, wdyu@ dhu.edu.cn

Corresponding author:

YU WEIDONG

e-mail: wdyu@ dhu.edu.cn



The analysis of dimensional stability of 1x1 RIB CO and CO/LY knitwear

DOI: 10.35530/IT.069.04.1434

MARIJA PEŠIĆ
VASILIJE PETROVIĆ
JOVAN STEPANOVIĆ
CARIŠA BEŠIĆ

REZUMAT – ABSTRACT

Analiza stabilității dimensionale a tricoturilor patent 1x1 CO și CO/LY

Această lucrare analizează impactul compoziției fibroase, a densității liniare și finisajului firelor asupra stabilității dimensionale a tricotului patent 1x1 realizat pe mașina de tricotat circulară. Stabilitatea dimensională a fost analizată prin metoda FAST 4. Diferite probe au fost comparate prin intermediul mai multor indicatori. Rezultatele arată că cea mai stabilă variantă tricotată, vopsită este din: 96% CO / 4% Lycra și fire cu densitate liniară 19,14 tex. Valorile factorului de etanșeitate în stare uscată de relaxare s-au situat la 17,90, în cea umedă la 18,45, în total 18,73 și 18,59 în condiții de climatizare standard. Tricoturile cu cele mai ridicate valori ale instabilității dimensionale sunt tricoturile crude din 100% CO și fire cu densitate liniară de 13,39 tex. Valoarea factorului de etanșeitate în stare uscată de relaxarea a fost de 12,16, în cea umedă la 12,36, în total 13,26 și 13,35 în condiții de climatizare standard.

Cuvinte-cheie: constante dimensionale, factor de etanșeitate, metoda FAST 4, lungimea firului

The analysis of dimensional stability of 1x1 RIB CO and CO/LY knitwear

This paper analyzes the impact of knitwear's fiber composition, linear density and finishing of yarn used in the dimensional stability of the 1x1 RIB knitwear made on the same circular knitting machine. Dimensional stability of these samples was analysed by FAST 4 method. Different samples were compared across multiple indicators. The results show that the most stable dyed knitted fabric are made of cotton 96% and 4% of Lycra and of yarn with linear density 19.14 tex. Tightness factor's values in the dry relaxation stood at 17.90, in the wet 18.45, in total 18.73 and 18.59 in air conditioned terms. Knitwear with the highest values of dimensional instability are raw knitted fabric made of 100% CO, and yarn with linear density of 13.39 tex. Tightness factor's values in the dry relaxation stood at 12.16, in the wet 12.36, in total 13.26 and 13.35 in air conditioned terms.

Keywords: dimensional constants, the tightness factor, FAST 4 method, yarn length

INTRODUCTION

Knitted products are clasified as unstable products in dimensional stability point of view. This is due to the fact that, a variety of different loads affect knitwear's production process and also nature of knitwear structure itself. Therefore in the yarn, which has formed a loop, a certain amount of potential energy is accumulated and causes a certain pressure yarn against yarn in places where these yarns intersect in knitwear. On these places, between the yarns frictional forces appear which prevent their displacement. Yarn tends to free of deformations that have occurred in the shaping of the loop which causes a shrinkage. Knitwear's shrinkage stops when these deformation and friction forces are in balance [1].

Due the fact that several external factors simultaneously influence on the shrinking of knitwear, their individual impact is difficult to measure. Therefore, analisys conducts impact of raw materials selection, knitting machine, knitting conditions and the impact of knitwear's finishing [2].

Characteristics of fiber significantly affect knitwear's shrinkage. For example, natural cellulose fibers have a small area of elastic deformation while synthetic fibers are more elastic and much faster occupy steady state [2].

The impact of treatment is also significant. Wet finishing method leads to the relaxation of knitwear. The water molecules during penetration into intermicellar spaces cellulose fibers, lead to swelling of fibers and as result yarn's diameter in the loop increases by 20 to 30 % [3]. Wet processing usually is accompanied by increasing temperature of processing agents [4]. All this leads to shrinkage knitwear.

When designing clothing products nig issue is the prediction of dimensional stability of knitwear. This problem is expressed during the exploitation of knitted products as well as during their washing, because very often there are significant dimensional changes in clothing products that reduce their quality.

MATERIAL AND METHODS

Experimental part of this paper analyses the dimensional stability of the 1x1 RIB knitted fabric made of 100% CO yarns and CO yarns in combination with LY (96% CO/4 % LY). Linear density of LY which was used is 44 dtex. CO yarn was used in two linear densities: 19.14 tex and 13.39 tex. Samples in the raw state and stained samples were examined (table 1).

Knitwear are made on a circular knitting machine type Fv 2.0 of company Mayer & Cie. Characteristics of the machine are as follows: cylinder diameter 19" (inch), the gauge is E18 and with 40 feeders, the

Table 1

Samples	A_1	A_2	A_3	A_4	B_1	B_2	B_3	B_4
Structure	1x1 RIB	1x1 RIB	1x1 RIB	1x1 RIB	1x1 RIB	1x1 RIB	1x1 RIB	1x1 RIB
Fiber composition	100% CO	100% CO	96% CO / 4% LY	96% CO / 4% LY	100% CO	100% CO	96% CO / 4% LY	96% CO / 4% LY
Linear density (tex/dtex)	19,14	13,39	19,14/4,4	13,39/4,4	19,14	13,39	19,14/4,4	13,39/4,4
Twists (m–1)	565	693	565 / -	693 / -	565	693	565 / -	693 / -
Finishing	raw	raw	raw	raw	dyed	dyed	dyed	dyed

knitting speed is 1.7 m/s. All of the samples are knitted under the same conditions and same machine.
Dimensional stability of samples was analysed by FAST 4 method. Measurment was performed on 20 samples of the same type and in measurment result in the following, the arithmetic mean values of these 20 samples is represented.

Determination of the dimensional stability by the FAST 4 method

Sample's dimensions were 300 x 300 mm and they were taken with 5 cm minimum distance from the edges of a knitted fabric.
FAST 4 method consists of several stages [5]. First, the conditioned samples of knitted fabric has to be exposed to heat at a temperature of 105 °C in a dryer for 60 min period, after which dimension of samples have to be taken in the longitudinal and transverse direction for a period of 30 seconds (length L1). That is followed by immersion of a dry sample for 30 minutes in water at a temperature of 25 °C to 30 °C with the addition of 0.1% detergent. After that, sample has to be placed on smooth surface with gentle pressing in order to remove excess water, after which the sample should be measured again (length L2). The sample is then returned to the dryer to be exposed to heat at a temperature of 105 °C for 60 min. The dried sample is measured over a period of 30 seconds to obtain the length L3. At the end the sample is left for relaxation, and after conditioning in a room with standard atmospheric conditions according to ISO 139 the sample is measured (length L4).

According to the method FAST 4, relaxing shrinkage is defined as percentage change of knitwear sample's dimension after the heat and wet processing. It can be described as the ratio of the difference between the dry sample length after heat treatment (length L1) and the dimension of the dried sample after relaxation at a wet state (length L3) and dimension of dry sample after the heat treatment (length L1). Relaxational shrinkage of knitwear's sample can be represented by following expression 1 [5]:

$$RS = \frac{L_1 - L_3}{L_1} \cdot 100\ [\%] \tag{1}$$

FAST 4 method defines relaxing stretching in a wet condition as the percentage change of dimension of the knitwear's sample upon wet treatment and is calculated according to following expression 2 [5]:

$$HE = \frac{L_2 - L_3}{L_2} \cdot 100\ [\%] \tag{2}$$

RESULTS AND DISCUSSION

Figure 1 shows the values of shrinkage/stretch on horisontal axis for all samples shown in table 1, i.e. for all raw samples: A1, A2, A3 and A4 and stained samples B1, B2, B3 and B4. Figure 2 shows the same values but measured on vertical axis of knitted samples.
In figure 1 and 2, we can see that the raw samples of knitwear made from finer yarns have less shrinkage of the knitted fabric which are made of coarser and stronger yarn. Samples with Lycra show that Lycra contributes to greater stabilization of knitwear. Also it

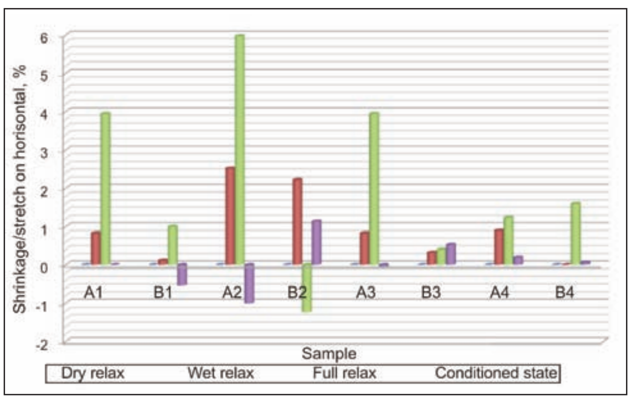


Fig. 1. Results of shrinkage/stretch of knittung material on horisontal

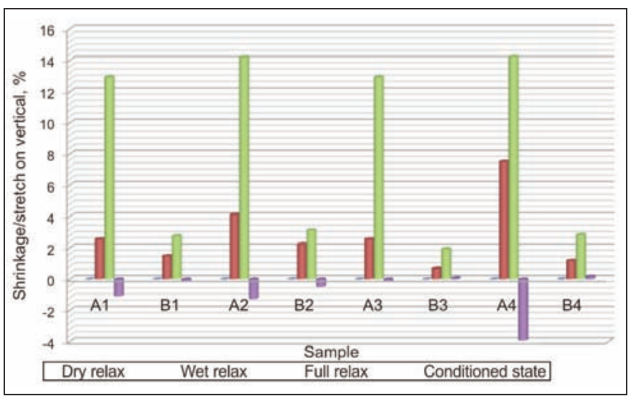


Fig. 2. Results of shrinkage/stretch of knittung material on vertical

can be seen that samples of colored knitwear have a significantly greater dimensional stability than the samples of raw knitwear. This is due to stabilization of knitwear in the technological stage of coloring. This stabilization is further increased when 4% Lycra is added into cotton knitwear. Figures also show that samples of the raw knitted fabric is woven from finer yarns have less vertical and horizontal shrinkage comparing with knitwear made from the coarser and stronger yarn.

Dimensional constants K-values

In order to monitor the stability of the knitted structure through different state of relaxation, dimensional constants can be used. Usually, following Munden's geometrical correlation are used [1] for calculating the dimensional constants of knitwear 4 relaxation conditions:

$$K_c = \frac{D_h}{l}; \quad K_w = \frac{D_v}{l}; \quad K_r = \frac{K_c}{K_w}; \quad K_s = S \cdot l^2 \quad (3)$$

l is the mean value of the yarn's length in a loop, K_c, K_w, K_r and K_s – dimensional constants.

K values are important for prediction of the structural behavior, to create a material with better stability, for determining the minimum/lower energy level of loops after treatment. K constants can interconnect values D_h, D_v and yarn's length in a loop. K_w and K_c are constants of D_v and D_h. K_r constant represents the ratio of the constants K_c/K_w. This is a direct measure of a loop's shape and it is called the shape factor of the loop. K_s is a constant overall density of loops. It is the product constants K_c and K_w [1]. Table 2 shows the value of dimensional constants for the test samples.

The results shown in table 2, indicate that the values of the dimensional constants increase with increasing relaxation, except for the conditioned samples where the values decrease. Knitwear made of 96% CO and 4% LY give different values of knitwear made of 100% CO, because they have a greater angle of recovery and this is due to their more elastic properties.
The difference can be seen between raw and dyed knitwear. Constants K_w, K_c and K_s are significantly lower with raw knitwear. Values of the constants rise with the knitted fabric which is made of thicker cotton yarns, comparing with ones made by thinner cotton yarn. Also with the change of the relaxation condition, it can be seen that K_r constant or a loop's shape factor is significantly reduced as a result of achieving a stable condition.
According to the results shown in table 2, knitted fabrics which are made of a mixture of 100% CO and 4% LY faster reach stable condition. It can also be noted that colored knitwear attain stable condition quicker than raw samples.

Tightness factor variations

Tightness factor represents a measure of fabric density and it can be calculated by the following equation 4 [1]:

$$\textit{tightness factor}\ (\mathrm{TF}) = \frac{\sqrt{Tt}}{l} \quad [\mathrm{tex}^{1/2}\mathrm{cm}^{-1}] \quad (4)$$

Or, it can be represented as structural tightness factor [1]:

$$(\mathrm{STF}) = TF \cdot K_s \quad [\mathrm{tex}^{1/2}\mathrm{cm}^{-1}] \quad (5)$$

where: TF is tightness factor, $\mathrm{tex}^{1/2}\mathrm{cm}^{-1}$; Tt – linear density, tex; l – yarn's length in a loop, cm.

Table 2

		A_1	A_2	A_3	A_4	B_1	B_2	B_3	B_4
l	cm	0.280±0.0111	0.289±0.0121	0.0272±0.0122	0.269±0.0079	0.270±0.0048	0.274±0.0063	0.264±0.0046	0.0262±0.0038
Kw	D	3.09±0.0344	3.61±0.0437	4.72±0.0572	4.84±0.0384	3.28±0.0156	3.68±0.0233	5.07±0.0231	5.49±0.0209
	W	3.22±0.0357	3.67±0.0444	4.84±0.0585	5.07±0.0403	3.39±0.0162	3.87±0.0245	5.19±0.0237	5.54±0.0211
	F	3.30±0.0367	4.11±0.0497	5.15±0.0623	5.37±0.0427	3.43±0.0164	4.05±0.0257	5.49±0.0250	5.67±0.0216
	C	3.22±0.0358	4.08±0.0495	5.03±0.0609	5.30±0.0422	3.40±0.0162	4.01±0.0245	5.46±0.0249	5.68±0.0216
Kc	D	6.10±0.0678	6.7±0.0812	6.48±0.0785	6.86±0.0546	6.55±0.0312	7.42±0.0471	7.07±0.0322	7.87±0.0300
	W	6.14±0.0682	6.9±0.0835	6.54±0.0791	6.95±0.0552	6.58±0.0314	7.56±0.0479	7.12±0.0325	7.89±0.0301
	F	6.34±0.0705	7.12±0.0863	7.03±0.0850	6.98±0.0555	6.69±0.0319	7.35±0.0466	7.20±0.0328	8.02±0.0306
	C	6.31±0.0701	7.01±0.0849	7.01±0.0846	6.96±0.0554	6.66±0.0318	7.32±0.0464	7.13±0.0325	8.01±0.0305
Kr	D	1.97±0.0219	1.86±0.0225	1.37±0.0166	1.42±0.0113	2.00±0.0095	2.02±0.0128	1.39±0.0064	1.43±0.0055
	W	1.91±0.0212	1.88±0.0228	1.35±0.0164	1.37±0.0109	1.94±0.0093	1.95±0.0124	1.37±0.0063	1.43±0.0054
	F	1.92±0.0213	1.73±0.0210	1.36±0.0165	1.30±0.0103	1.95±0.0093	1.80±0.0115	1.31±0.0060	1.42±0.0054
	C	1.96±0.0218	1.72±0.0208	1.39±0.0168	1.31±0.0104	1.96±0.0093	1.82±0.0116	1.31±0.060	1.41±0.0054
Ks	D	18.89±0.2099	24.18±0.2929	30.62±0.3706	33.2±0.2639	21.47±0.1024	27.28±0.1731	35.84±0.1632	43.24±0.1647
	W	19.75±0.2195	25.3±0.3064	31.62±0.3826	35.2±0.2798	22.32±0.1065	29.25±0.1854	36.92±0.1684	43.69±0.1665
	F	20.94±0.2326	29.26±0.3543	36.18±0.4377	37.47±0.2979	22.97±0.1096	29.78±0.1888	39.49±0.1801	45.48±0.1733
	C	20.35±0.2261	28.62±0.3466	35.20±0.4260	36.94±0.2937	22.64±0.1080	29.39±0.1863	38.93±0.1775	45.49±0.1733

Legend: D – dry relaxation, W – wet relaxation, F – full relaxation, C – conditioned sample, l – the mean value of the yarn's length in a loop (cm).

Table 3

	TF				STF			
	D	W	F	C	D	W	F	C
A_1	14.93	15.14	16.32	16.20	281.99	299.05	341.77	329.72
A_2	12.16	12.36	13.26	13.35	293.98	312.76	387.87	382.20
A_3	16.96	17.20	18.73	18.59	519.43	544.07	677.67	654.40
A_4	15.01	15.51	16.04	16.16	498.38	545.83	600.85	597.02
B_1	15.79	16.14	16.51	16.45	339.10	360.37	379.21	372.40
B_2	12.88	13.21	13.65	13.55	351.54	386.37	406.64	398.29
B_3	17.90	18.45	18.73	18.59	641.58	681.14	739.85	723.68
B_4	15.80	15.98	16.41	16.22	683.08	698.09	746.37	738.02

Legend: D – dry relaxation, W – wet relaxation, F – full relaxation, C – conditioned sample.

Table 4

Sample		A_1	A_2	A_3	A_4	B_1	B_2	B_3	B_4
Coefficients TF	a_0	78.0925	62.9388	89.2732	78.4514	80.9362	66.7810	91.6991	80.5603
	a_1	–557.9346	–435.0830	–655.7698	–582.9026	–600.1090	–487.4101	–696.0883	–614.4097
	a_2	1992.9112	1500.3595	2410.9583	2166.8203	2222.6825	1778.8273	2637.8772	2345.1497
	a_3	–3558.7856	–2586.8595	–4431.9287	–4027.6379	–4116.1078	–3246.0707	–4994.1072	–4475.1907
	a_4	2542.0085	1784.0234	3258.8111	2994.5252	3048.9752	2369.3912	3783.3881	3416.4758

Table 3 shows that the value of the *TF* decreases from full, through a wet to dry relaxation. Knitwear made of 96% CO and 4% LY mixture faster returns to its original state due to Lycra effect compared to knitwear made from 100% cotton. This contributes to the rapid establishment of a stable condition in these knitwear. It is also reducing the length of the yarn loops is more evident in knitted fabric containing Lycra which gives a higher values of *TF*. Table 4 also shows that thicker knitwear provides greater value of *TF* comparing with knitwear made of thinner yarn. Also, colored knitwear have higher *TF*, because during coloring process kneatwear was exposed to temperature tratment and wet processing.

Mathematical model for describing relation between TF and value of the yarn's length (l_0) in knitwear's loop

To determine TF dependencies from yarn's length in the knitwear's loop, specific mathetmatical model is introduced. In order to represent method of nonlinear regression, polynomial model is used. For a given set of data pairs (x_1,y_1), (x_2,y_2), K, (x_n,y_n), the following relation should be found, $y = a_0 + a_1x + K + a_mx^m$, whereby $m \leq n - 2$, so experimental data can be the best represented.

The results of experimental research have been approximated by a non-linear model fitting data which has a form of polynomial of degree 4:

$$TF = a_0 + a_1 l + a_2 l^2 + a_3 l^3 + a_4 l^4 \quad (6)$$

wherein a_0, a_1, a_2, a_3, a_4 are constants, l_0 independant variable i.e. length of yarn in the loop twists. As l_0 changes in knitwear depending on relaxation, that's *TF* value changes according to the previous formula. Table 4 gives an overview of the calculated coefficients of the empirical formula for the *TF* value changes depending on the length of yarn in the loop.

CONCLUSIONS

This paper analyzes the impact of raw material composition of knitwear, finishing method and fineness of used yarn on dimensional stability of the 1x1 ribbed knitwear made on the same circular knitting machines. The results obtained show that the most stable are dyed knitwear made of CO 96% and 4% of LY and yarn fineness 19.14 tex. According to the results, the knitted fabric with the highest degree of dimensional instability are raw knitted fabric of 100% CO, yarn made of fineness 13.39 tex.

It can be concluded that values *Kc* and *Kw* increase at knitwear which have LY in their structure, as well as at those which are dyed and those which are made of thinner yarn. *Kr* decreases with an increase of relaxation which means that the loop reaches its stable state and it has minimal ability to change shape. *Ks* factor raises significantly with the increase of relaxation and with increase of the *TF*.

It can be concluded that knitwears which show the most stable condition are dyed knitwears made of CO and LY and of thicker yarns. Knitwears with the highest degree of dimensional instability are made of raw knitted fabric of 100% CO, and of thinner yarn. In complete relaxation, all samples have recorded the largest dimensional change.

BIBLIOGRAPHY

[1] Antônio Augusto Ulson de Souza, Luiz Felipe Cabral Cherem and Selene M. A. Guelli U. Souza, *Prediction of dimensional changes in circular knitted CO fabrics,* In: Textile Research Journal, Vol. 80(3), pp. 236–252, (2011)

[2] Chathura N. Herath and Bok Choon Kang, *Dimensional stability of core spun CO/spandex single jersey fabrics under relaxation,* In: Textile Research Journal, Vol. 78(3), pp. 209–216, (2008)

[3] Munden, D. L., *The geometry and dimensional properties of single jersey-knit fabrics*, In: Textile Research Journal, Vol. 50, pp. T448-T471 (1959)

[4] Petrovic, V. *Tehnologija pletenja, Tehnicki fakultet "Mihajlo Pupin",* Zrenjanin, Serbia (2000)

[5] Gersak, J. *Objektivno vrednovanje plošnih tekstilija i odjeće*, Faculty of Textile Technology, Zagreb (2014)

[6] Bayazit Marmarali, A. *Dimensional and physical properties of CO/spandex single jersey fabrics*, In: Textile Research Journal, Vol. 73, pp. 11–14, (2003)

[7] Anand, S.C., Brown, K.S.M., Higgins, L.G., Holmes, D.A., Hall M.E. and Conrad, D. *Effect of laundering on the dimensional stability and distortion of knitted fabric*, In: AUTEX Research Journal, Vol. 2, No. 2, pp. 85–100 (2002)

[8] Knopten, J.J.F., Ahrens, F.J., Ingenthron, W.W. and Fong, W. *The dimensional properties of knitted wool fabrics, Part 1: The single jersey structure,* In: Textile Research Journal, Vol. 38, pp. 999–1012 (1986)

[9] Mukherjee, Sandip, Ray, Sadhan Chandra, Punj, S.K. *Dimensional parameters of 1x1 rib fabric produced on a circular bed double jersey knitting machine using ultrasonic technique,* In: Indian Journal of Fibre & Textile Research, Vol. 39, pp. 230–237, (2014)

[10] Prakash, C., Thangamani, K. *Establishing the effect of a loop lenght on dimensional stability of single jersey knitted fabric made from CO/LY core spun yarn*, In: Indian Journal of Science and Technology, Vol. 3, No. 3, pp. 287–289, (2010)

[11] Stojiljkovic, D.T., Petrovic, V., Stojiljkovic, S.T., Ujevic, D. *Defining of memory function for tension and deformation of linear textile products on the basis of their rheological models,* In: Industria Textila, No. 6, 2009; ISSN 1222-5347.

[12] Stepanovic, J., Milutinovic, Z., Petrovic, V., Pavlovic, M. *Influence of relative density on deformation characteristics of fabrics in plain weave,* In: Indian Journal of Fibre and Textile Research, No. 1 Vol. 34, 2009. 69-75; ISSN 0971-0426.

[13] Radivojevic, D., Stepanovic, J., Stamenkovic, M., Petrovic, V. *Analysis of deformation characteristics of twisted woolen yarns*, In: Tekstil, No. 11, 2008, pp. 563–568; ISSN 0492-5882.

[14] Stojiljkovic, D.T., Petrovic, V., Dj-Petrovic, M. *Rheological modelling of yarn extension*, In: Tekstil, No. 9, 2007, pp. 554–561; ISSN 0492-5882.

[15] Salopek, I., Skenderi, Y., Gersak, J. *Investigation of knitted fabric dimensional characteristics*, In: Tekstil, Vol. 56, No.7, 2007, pp. 391–406; ISSN 0492-5882.

[16] Fatkic, E., Gersak, J., Ujevic, D. *Influence of knitting parameters on the mechanical properties of plain jersey weft knitted fabrics*, In: Fibres Text. East. Europ., vol. 19, no. 5 (88), 2011, pp. 87–91.

Authors:

MARIJA PEŠIĆ [1]
VASILIJE PETROVIĆ [1]
JOVAN STEPANOVIĆ [2]
CARIŠA BEŠIĆ [3]

[1] Technical Faculty "Mihajlo Pupin", University of Novi Sad, Djure Djakovica nn, 23000 Zrenjanin, Serbia
[2] Faculty of Technology, University of Nis, Bulevar Oslobođenja 124, 16000 Leskovac, Serbia
[3] Faculty of Technical Sciences, University of Kragujevac, Svetog Save 65, 32000 Čačak, Serbia

e-mail: marija.stankovic.986@gmail.com; vlp@eunet.rs; jovan@tf.ni.ac.rs; carisa.besic@ftn.kg.ac.rs

Corresponding author:

MARIJA PEŠIĆ
e-mail: marija.stankovic.986@gmail.com

Thermo-physiological properties of woven structures in wet state

DOI: 10.35530/IT.069.04.1452

AMAL BOUGHATTAS
SOFIEN BENLTOUFA
LUBOS HES
MUSADDAQ AZEEM
FATEN FAYALA

REZUMAT – ABSTRACT

Proprietățile termofiziologice ale structurilor țesute în stare umedă

Parametrii cei mai performanți care măsoară confortul termofiziologic al articolelor de îmbrăcăminte sunt conductivitatea termică, absorbția termică și permeabilitatea la vaporii de apă. În această lucrare, confortul termofiziologic a fost studiat pentru diferite structuri de țesături și grade de umiditate. Proprietățile termice și permeabilitatea la vapori de apă în stare uscată și umedă a tuturor probelor de țesătură au fost determinate de către ALAMBETA și, respectiv, Permetest. Rezultatele au arătat că structura țesăturii și compoziția firelor în bătătură influențează puternic proprietățile termice și permeabilitatea la vaporii de apă în prezența umidității. Probele de țesătură au fost proiectate prin modificarea tipului de legătură și a compoziției fibroase a bătăturii. În stare umedă, cu un conținut de umiditate de până la 20%, structurile de țesătură au prezentat un comportament nesemnificativ pentru proprietățile termice datorită fracției de oxigen. Pe măsură ce conținutul de umiditate crește, țesătura cu fire de bătătură din poliester a oferit o senzație mai mare de rece la contactul cu pielea.

Cuvinte-cheie: model de legătură, conductivitate termică, absorbție termică, permeabilitate la vapori de apă, conținut de umiditate (stare umedă)

Thermo-physiological properties of woven structures in wet state

The utmost parameters that measure the thermo-physiological comfort of garments are thermal conductivity, thermal absorptivity and water vapor permeability. In this paper, thermo-physiological comfort was studied with different weave design and moisture content. Thermal properties and water vapor permeability in dry and wet state of all fabric samples were determined by ALAMBETA and Permetest respectively. Results showed that the weaving structure and yarn composition in weft were closely related to the thermal properties and water vapor permeability in presence of moisture. Woven fabric samples were constructed by varying the weave design and weft composition. In wet state, moisture content up to 20%, weave structures exhibited non-significant behavior for thermal properties due to air fraction. As the moisture content enhanced, woven structure made with polyester weft yarn provided cooler feeling with skin contact.

Keywords: weaving design, thermal conductivity, thermal absorptivity, water vapor permeability, moisture content (wet state)

INTRODUCTION

Thermo-physiological comfort of clothing is an important issue for everyday body wear, protective garments, sportswear and varying end of use application. It concerns the psychological, physiological and physical harmony between human body and the external environment conditions [1]. Nowadays, consumers require clothes which provide comfort and protection of the body against environmental conditions while performing different physical activities [2]. During high activities and/or high atmospheric temperature, sweat glands get activated and produce perspiration in its liquid and vapour form. Clothes should allow the passage of perspiration through it, otherwise it leads to discomfort. Discomfort principally results from the build-up of sweat on the skin [3].

The main role of clothing is the protection of human body against the harmful effects of external environment and to promote the own thermoregulatory function in different environmental conditions, while performing various physical activities. The fabric as a protection layer creates and regulates the appropriate microclimate around the skin, which is strongly influenced by the wearer physiological comfort [4]. Contrary to a commonly accepted theory garments, due to sweat sorption or because of humid, rainy climate are often used in wet state, which has influence on their comfort properties. The thermo-physiological comfort of wet fabrics is given by the active cooling resulting produce from the moisture evaporation of the skin and passing through the garment and from direct evaporation of sweat from the fabric surface [5–6].

Many studies on water vapor permeability of textile fabrics have been conducted [7–9], but there is a warm/cool feeling still no taken into consideration due to the moisture content. This follows from the fact that current measuring instruments for the evaluation of the properties usually require more than 30 minutes for full reading, avoiding the precise determination of humidity effect on their cooling heat flow [W/m^2], which decrease during the measurement.

Thermal properties of textiles such as thermal conductivity and thermal absorptivity are important parameters that influence thermal comfort of fabrics and continue to be the subject of many studies

[10–12]. The knowledge of thermal properties of fabrics in dry state is important but the most important is to know the effect in wet state to simulate the real feeling of the wearer especially when a fabric is designed for people working under moist conditions [10]. With the increasing in moisture regain thermal properties of fabrics changes and affects adversely thermo-physiological comfort of wearer. Theories characterizing thermal properties of fabrics in wet state are not sufficient in the literature. To understand the mechanism, it was further studied the effect of moisture regain on thermal conductivity of woven fabrics [11]. The thermal conductivity grows up with the increase of percentage of moisture in the fabric [12]. Thermal conductivity indicates the ability of a material to allow the passage of heat through due to change in temperature. Thermal conductivity is anisotropic in nature and largely depends upon the structure of the material. A fabric is composed of polymers (fibers), air trapped inside the fabric, and moisture present in voids [13–14]. In clothing comfort, there is a thermal property relates warm/cool feeling, called thermal absorptivity (*b*) [$Ws^{1/2}/(m^2 \cdot K)$] which was firstly introduced by Lubos Hes. This parameter allows the assessment of fabric's character in the aspect of its "warm /cool" feeling [15].

WVP (water vapor permeability) in dry state is easy to understand and measure but in wet condition it is difficult to measure. A water film is produced on the surfaces which lessen the flow of permeability in fabric [9, 16]. Simultaneously, wet skin can greatly increase the cooling effect can be created by wet body skin results in formation of drop compared to the dry fabric. Water vapor permeability measurements by WVP testers has a drawback of long time period therefore Skin Model Type (Permetest Sensora Skin Model) is suitable for WVP evaluation of fabric along within wet state [17].

MATERIAL AND METHODS

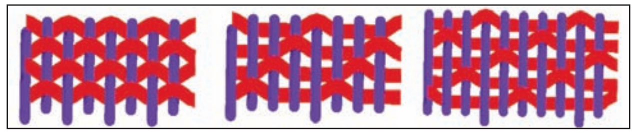
Material

Woven fabric used for the study consists of three basic weave structures (plain, twill and satin) as shown in figure 1.

The detail of fabrication is listed in table 1. Warp density is 24 ends/cm and weft density is 21 picks per cm.

Table 1

Sample number	Weave structure	Warp	Weft	Weight (g/m²)	Thickness (mm)
1	Plain	PC (50:50) 30 tex	PC (50:50) 30 tex	165	0.43
2	Twill 3/1			166	0.52
3	Satin 4/1			167	0.51
4	Plain		20 tex 100% Polyester	131	0.34
5	Twill 3/1			134	0.44
6	Satin 4/1			135	0.43



a *b* *c*

Fig. 1. Weave structure of three basic designs: *a* – plain; *b* – twill; *c* – satin

Rapier weaving machine (GamMax Picanol) was used to make all woven sample.

Methods

After pretreatments, all samples were tested for thermal properties and water vapor permeability in standard environmental conditions at 20–22 °C temperature and 50–55 % relative humidity.

Thermal conductivity

Thermal conductivity coefficient "λ" presents the amount of heat, which passes from one square meter area of material through the distance one meter within one second and create the temperature difference of one Kelvin. Thermal conductivity of textile structures generally reaches levels from 0.033 to 0.01 W/m/K. Thermal conductivity of steady air by 20 °C is 0.026 W/m/K, while thermal conductivity of water is 0.6 W/m/K, which is 25 times more. Therefore, the water presence in textile materials is undesirable [12].

Thermal absorptivity

Thermal absorptivity (*b*) of fabrics was firstly proposed by Lubos Hes to characterize thermal feeling (heat flow level) during short contact of human skin with the fabric surface [15]. Providing that the time of heat contact (τ) between the human skin and the textile is shorter then several seconds, the measured fabric can be simplified into semi-infinite homogenous mass with certain thermal capacity ρc [J/m^3] and initial temperature t_2. Unsteady temperature field between the human skin (with constant temperature t_1) and fabric with respect to boundary conditions offers a relationship, which enables to determine the heat flow q [W/m^2] course passing through the fabric:

$$q = \frac{b(t_1 - t_2)}{(\pi\tau)^{1/2}}, \quad b = (\lambda\rho c)^{1/2} \qquad (1)$$

Where ρc [J/m^3] is thermal capacity of the fabric and the term *b* presents thermal absorptivity of fabrics. The higher is thermal absorptivity of the fabric, the cooler is its feeling.

Relative water vapor permeability

Relative water vapor permeability was measured on a Permetest instrument by a similar procedure to that given by Standard ISO 11092 [18]

Principle of ALAMBETA instrument – A tester for thermal properties of fabrics

ALAMBETA instrument was used to measure thermal conductivity and thermal absorptivity of fabrics. The

Alambeta simulates the dry human skin and its principle depends in mathematical processing of time course of heat flow passing through the tested fabric due to different temperatures of bottom measuring plate (22 °C) and measuring head (32 °C). When the specimen is inserted, the measuring head drops down, touches the fabrics and the heat flow levels are processed in the computer and thermo-physical properties of the measured specimen are evaluated [15]. The contact pressure fixed at 200 Pa, and the CV values for all the samples were lower than 5%.

PERMETEST

In wet state, the samples were first dried in an oven at 110 °C, in order to remove the moisture and weighted immediately to record the dry weight of the fabrics. To increase the humidity, the samples were immersed in their full volume with water containing a surfactant to lower the surface tension. After taking out, fabrics specimen were weighed again to check the amount of moisture gained. Samples were experimented by Alambeta and then placed horizontally on a net made of nylon string stand. This procedure was carried out to allow free evaporation of water molecule from the fabric.

Moisture regain calculation

The moisture content or the mass increase M_n (%) due to absorbed moisture was calculated as follow [6]

$$M_n\,(\%) = \frac{W_{Wet} - W_{dry}}{W_{dry}} \cdot 100 \qquad (2)$$

Where:

M_n (%) is fabric relative moisture content;
W_{Wet} – fabric weight in wet state;
W_{dry} – fabric weight in dry state.

RESULTS AND DISCUSSION

Thermal conductivity

Thermal conductivity (λ) is an intensive and specific property of materials. Thermal conductivity of water is approximately 25 times higher than that of dry textile fabrics therefore thermal conductivity of wet fabrics enhanced with the increase in moisture content. In figure 2, graphical presentation showed that the thermal conductivity of samples increased favorably with the increase of fabric moisture content because water molecule substituted the entrapped air in the fabric structure.

Moreover, according to figure 2, there were two stages of moisture sorption:

1) Moisture content up to 20%, thermal conductivity varies significantly with the fabric water content. As water droplet replaced the entrapped air in the pores, it became humidified rapidly. Weave structure appeared non-significant for this moisture content level as displayed in figure 2.

2) Higher moisture content (≥ 20%), thermal conductivity increased gradually with the moisture uptake. It was also observed a significant difference between the plain structure and other structures (twill and satin). In fact, the plain weaving structure revealed lower thermal conductivity. This phenomenon could be explained by the cover factor of this structure which was more compact leading to an entrapped air fraction in micro-pores more important than twill and satin weave design [19]. It was also noticed that twill and satin fabric design had the same cover factor apart from the plain weave.

Figure 2 also intimated the graphical trend of fiber composition in weft yarn. Thermal conductivity of fabrics made of PC (50:50) yarn in weft was perceived higher than the fabric made of 100% polyester fabric. This phenomena occurred by the water absorption and swelling of the cotton fibers in fabric samples [20].

Thermal absorptivity

Thermal absorptivity (*b*) is expressed in equation 1. An important aspect of evaluating the warm–cool feeling is the change of this feeling when textile products get wet. Since the thermal conductivity and thermal capacity of water in cotton is much higher than synthetic polymer fiber. The air entrapped in the textile structure, fabrics attains moisture by sweat; give a greatly changed warm–cool feeling when compared with the dry state.

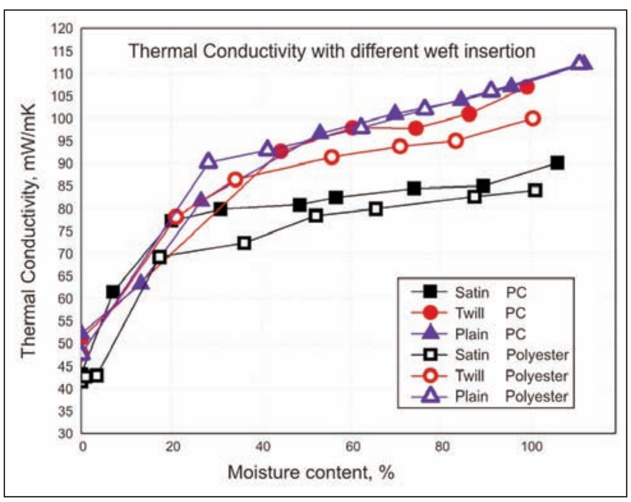


Fig. 2. Thermal conductivity of woven fabrics in wet state

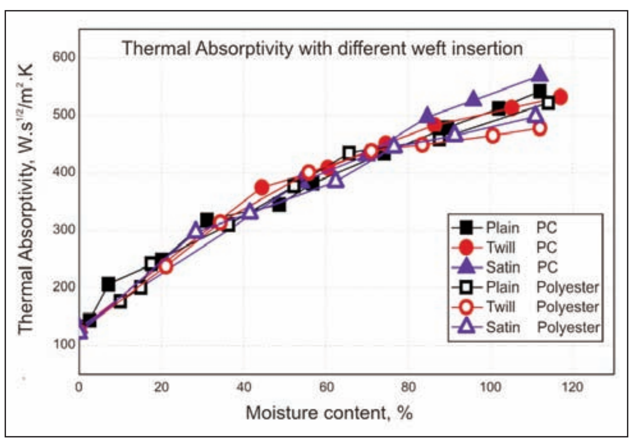


Fig. 3. Thermal absorptivity of woven fabrics in wet state

When the human skin touches a garment with temperature difference, heat exchange occurs between the hand and the fabric, and the warm–cool feeling is the first sensation. Fabric with low value of thermal absorptivity gives a warmer feeling. The better feelings depend on the customer mind satisfaction; for summer garments a cool hand feel is demanded, whereas a warmer feeling is preferred for winter [15]. Thermal absorptivity increases with the increasing of thermal conductivity as given in equation 1.

According to figure 3, there was no effect of weaving structures up to 75% moisture content. However, over 75% it was observed that twill and satin fabrics disclosed minor thermal absorptivity resulted in warm feeling.

The fabrics made of polyester weft yarn expressed warmer feeling, whereas fabric with PC yarn in weft direction demonstrated comparatively cool feeling. This could be explained that fibers of higher equilibrium humidity provided a cooler feeling because thermal conductivity and thermal capacity of water was much higher than those of polymer fiber and the air entrapped in the textile structure [21].

Water vapour permeability in wet state

The heat loss by the body creates the cooling effect due to the heat flow generated by the sweat evaporation. However, cool felling also affects the heat flow evaporates from the surface of fabric due to moisture as drawn in figure 4 [22].

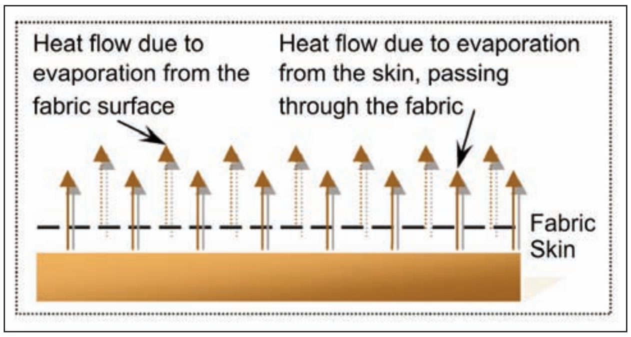


Fig. 4. Heat flow generation due to sweat evaporation from the skin surface and moisture evaporation from the fabric surface

The effective relative water vapour permeability (RWVP) of wet fabrics was also determined. The total relative cooling flow (q_{total}) transferred through the boundary layer of the wet fabric surface is given by the sum of relative heat (cooling) flow passing from the skin through the permeable fabric (q_{fabric}) and relative heat flow ($q_{\Delta t}$) caused by temperature gradient between skin and fabric surface, which is cooled by evaporation of water from the fabric surface

$$q_{total} = q_{fabric} + q_{\Delta t} \quad (3)$$

$$q_{fabric} = q_{total} - q_{\Delta t} \quad (4)$$

Equations 3 and 4 relates the heat flow passing through the free wet porous surface of the measuring head (q_0) which simulates the sweating of human skin. Therefore, the term "relative" was introduced in this equation. Relative water vapour permeability (RWVP) of dry fabric is then defined as:

$$RWVP = 100 \cdot \frac{q_{fabric}}{q_0} \quad (5)$$

Where, q_{fabic} is the heat flow measured by the PERMETEST.

When the measuring head was covered by a dry fabric, *RWVP* of dry fabric was in fact the relative cooling flow passing through the dry fabric multiplied by 100. Similarly, the effective relative water vapour permeability (*ERWVP*) is defined as "100 times the relative heat flow passing from the skin through the permeable fabric (q_{fabric})" (equation 4).

In order to determine the ERWVP by means of the PERMETEST instrument, two different measurements were necessary on the same wet sample. In the first step, the relative cooling heat flow (q_{total}) (equation 3) passing through the wet sample and also the cooling flow generated by the wet sample surface were measured. In the second step, the measuring head of the PERMETEST instrument was covered by an impermeable foil, which restricted the effective relative cooling flow (q_{fabric}) through the wet fabric. Thus, in the second step, it was only measured the relative cooling flow (q_{fabric}) of wet fabric surface. The difference between both the mentioned measurements yields the required relative cooling flow (q_{fabric}), which after multiplying by 100 also presents the *ERWVP* as shown below (figure 5):

$$ERWVP = 100 \cdot q_{fabric} = 100 \cdot (q_{total} - q_{\Delta t})$$

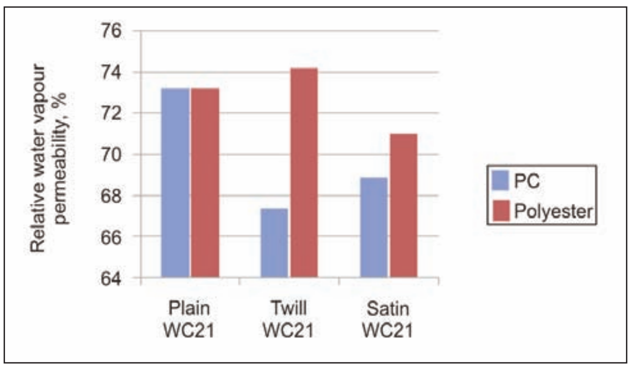


Fig. 5. RWVP of different woven fabric in dry state

Water vapor permeability gives the ability to transmit vapor from the body. Higher moisture resistance with high thermal resistance of the textile layers produces more heat storage on body skin causes uncomfortable sensation. RWVP of both PC and polyester weft inserted fabric samples (plain weave) manifested same behavior as displayed in figure 6. Difference in WVP of twill and satin weave as compared to plain was the consequence of variation in thickness of the fabric and composition of yarn used for weft lodging.

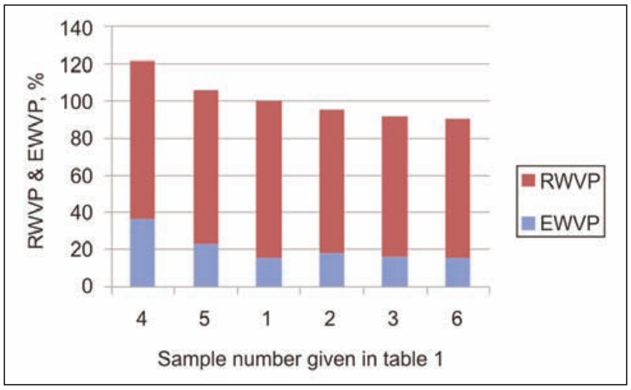


Fig. 6. Relative WVP or relative cooling heat flow of all tested fabrics at the 50% fabric moisture content consisting of real vapor transfer through the wet fabric (bottom level) and of evaporation from the fabric surface (upper level)

CONCLUSIONS

In this work, ALAMBETA and PERME tester (skin model) were utilized to simulate the complex thermal feelings in wet sate felt by wearers. Satin weave structure offered lower thermal conductivity because of its less yarn interlacing as compared to plain and twill and fabrics made from polyester weft inserted yarn offered cool feeling when get in contact with the skin.

Woven fabric samples were constructed by varying the weave design and weft composition. In wet state, moisture content up to 20%, weave structures exhibited non-significant behavior for thermal properties due to air fraction. As the moisture content enhanced, woven structure made with polyester weft yarn provided cooler feeling with skin contact.The thermal properties for moisture content up to 20% exhibited non-significant effect with weave design variable. This occurred due to air fraction which was almost the same for all samples. Whereas the moisture content greater than 20% reported the non-significant trend concerning thermal absorptivity. Furthermore it was also observed non-significant effect of fibre composition used in filling for fabrication of samples.

In wet state if the fabric, total relative cooling heat flow comprised not only flow transferred through the fabrics, but also involved moisture evaporation flow from the fabric surface. The liquid water in wet fabric structure created a partial continuous film, which limited the transfer of water vapor. The obtained results of WVP measurement in wet state confirmed the direct relation of fabric moisture and WVP. Experimental study proved a correlation between WVP and physiological properties of the fabric in wet state followed by the adverse outcome of fabric quality with continuous wet condition. Knowledge of these phenomena can be exploited in clothing comfort technology in severe weather conditions with high humidity.

BIBLIOGRAPHY

[1] Watkins, D.A., Slater, K. *The moisture vapor permeability of textile fabrics*. In: Journal of Textile Institute, 1981, vol. 72, pp. 11–18

[2] Mallikarjunan, K., Ramachandran, T., Manohari, B.G. *Comfort and thermo physiological characteristics of multilayered fabrics for medical textiles*. In: Journal of Textile and Apparel, Technology and Management, 2011, vol. 7, pp. 1–15

[3] Li, Y. *The science of clothing comfort.* In: Textile Progress, 2011, vol. 31 p.1/2, pp. 1–135

[4] Chakraborty, S., Kothari, V.K. *Effect of moisture and water on thermal protective performance of multilayered fabric assemblies for firefighters*. In: Indian Journal of Fibre & Textile Research, 2017, vol. 42, pp. 94–99

[5] Unal, P.G., Ureyen, M.E. *Mechanical and permeability properties of sportech fabrics*. In: Industria Textila, 2016, vol. 67, no. 3, pp. 151–156

[6] Baczek, M., Hes, L. *Effective water vapour permeability of wet wool fabric and blended fabrics*. In: Fibres & Textiles in Eastern Europe, 2013, vol. 21, no. 1(97), pp. 67–71

[7] Hes, L., Sluka, P. *Introduction into clothing comfort*. Textbook of Technical University of Liberec, 2005

[8] Gibson, P.W. *Factors influencing steady-state heat and water-vapour transfer measure for clothing materials*. In: Textile Research Journal 1993, vol. 63, no. 12, pp. 749–764

[9] Ren, Y., Ruckman, J.E. *Water vapour transfer in wet waterproof breathable fabrics*. In: Journal of Industrial Textiles, 2003, vol. 32, no. 3, pp. 165–175

[10] Özdemir, H. *Thermal comfort properties of clothing fabrics woven with polyester/cotton blend yarns*. In: AUTEX Research Journal, 2017, vol. 17, no. 2, pp. 135–141

[11] Schneider, A.M., Hoschke, B.N., Goldsmid, H.J. *Heat transfer through moist fabrics.* In: Textile Research Journal, 1992, vol. 62, no. 2, pp. 61–66

[12] Hes, L., Loghin, C. *Heat, moisture and air transfer properties of selected woven fabrics in wet state*. In: Journal of Fiber Bioengineering and Informatics, 2009, vol. 2, no. 3, pp. 141–149

[13] Chen, Q., Zhao, T. *The thermal decomposition and heat release properties of the nylon/cotton, polyester/cotton and Nomex/cotton blend fabrics*. In: Textile Research Journal, 2015, vol. 86, no. 17, pp. 1859–1868

[14] Ahmad, S., Ahmad, F., Afzal, A., Rasheed, A., Mohsin, M., Ahmad, N. *Effect of weave structure on thermo-physiological properties of cotton fabrics*. In: AUTEX Research Journal, 2015, vol. 15, no. 1, pp. 30–34
[15] Hes, L. *Thermal properties of nonwovens*. In: Proceedings of Congress Index, 1987, vol. 87, Geneva.
[16] Hes, L., Araujo, I. *Simulation of the effect of air gaps between the skin and a wet fabric on resulting cooling flow*. In: Textile Research Journal, 2010, vol. 80, no. 14, pp. 1488–1490
[17] Hes, L., Dolezal, I. *A new portable computer controlled skin model for fast determination of water vapour and thermal resistance of fabrics*. In: Asian Textile Conference, 2003, ATC 7, New Delhi
[18] ISO 11092 Standard, *Textiles – Physiological effects – Measurement of the thermal and water vapor resistance*
[19] Benltoufa, S., Fayala, F., BenNasrallah, S. *Capillary rise in macro and micro pores of jersey knitting structure*. In: Journal of Engineered Fibers and Fabrics, 2008, vol. 3, no. 3, pp. 47–54
[20] Benltoufa, S., Fayala, F., BenNasrallah, S. *Determination of yarn and fiber diameters after swelling using a capillary rise method*. In: Journal of the Textile Institute, 2012, vol. 103 no. 5, pp. 517–522
[21] Özdil, N., Marmaralı, A., Kretzschmar, S.D. *Effect of yarn properties on thermal comfort of knitted fabrics*. In: International journal of Thermal sciences, 2007, vol. 46, no. 12, pp. 1318–1322
[22] Bączek, M., Hes, L. *The effect of moisture on thermal resistance and water vapour permeability of Nomex fabrics*. In: Journal of Materials Science and Engineering 2011, vol. 1, no. 3, pp. 358–366

Authors:

AMAL BOUGHATTAS[1]
SOFIEN BENLTOUFA[1]
LUBOS HES[2]
MUSADDAQ AZEEM[2]
FATEN FAYALA[1]

[1]Monastir University, National School of Engineers, Department of Textile Engineering, Laboratoire d'Etudes des Systèmes Thermiques et Energétiques (LESTE Laboratory), Avenue Ibn Eljazzar-5019 Monastir, Tunisia

[2]Technical University of Liberec, Faculty of Textile Engineering,
Studentska 1402/2, 461 17, Liberec 1, Czech Republic

Corresponding author:

AMAL BOUGHATTAS
e-mail: boughattasamal@gmail.com

Quality of the household ozone laundering

BRANKO NERAL

DOI: 10.35530/IT.069.04.1454

REZUMAT – ABSTRACT

Calitatea spălării casnice cu ozon

În cadrul acestui studiu au fost investigate diferite proceduri de spălare casnică. După efectuarea procedurilor combinate clasice și cu ozon, au fost evaluate efectele de spălare primară și secundară, cum ar fi performanța de spălare, eficiența eliminării murdăriei, modificarea dimensională, scăderea rezistenței la rupere, reziduurile de incinerare și caracteristicile de culoare. Rezultatele finale au indicat faptul că spălarea casnică cu ozon oferă o calitate superioară a spălării în comparație cu procedura clasică și asigură reducerea consumului de apă și de energie.

Cuvinte-cheie: ozon, spălarea materialelor textile, mașină de spălat de uz casnic, generator de ozon, efecte de spălare

Quality of the household ozone laundering

Different household laundering procedures were investigated in this research. After performing classical and with ozone combined procedures, the primary and secondary laundering effects were evaluated, as washing performance, soil removal efficiency, dimensional change, decrease in breaking strength, incineration residue and colour characteristics. The end results indicate that household ozone laundering provides higher laundering quality compared to the classical procedure, and ensures reduction of water and energy consumption.

Keywords: ozone, textile laundering, household washing machine, ozone generator, laundering effects

INTRODUCTION

The main purpose for textile laundering is the removal of impurities, unpleasant odours and microorganisms, but with consideration that, at the same time, the fabric surface or structure must remain undamaged as much as possible. Household laundering is a complex process, where the synergy of physical and chemical factors in the aqueous medium influence the final results of textile cleaning. According to Sinner, the factors which determine the laundering quality are: chemical action, mechanical action, temperature and time. There is also a fifth quality parameter, water, which was added by Stamminger later, in order to expose its significance [1]. Water enables wetting with superseding air from fibres; it is a transportation system for heat and kinetic energy, a dispersing agent which, with help of detergent, absorbs inorganic and organic impurities and micro-organisms, thus preventing their re-deposition onto a textile's surface or onto parts of the washing machine [2–3].

Textile laundering is the most frequent household occupation, important to assure hygiene, reduce infection risk and, thus, protect the health and safety of household members. In the last decade, significant improvements in energy efficiency and also energy consumption have been achieved in home appliances. But, annual statistics and studies reveal a further wasteful consumption of water and energy in the EU27 household sector, where, amongst the largest energy consumers are washing machines [4–7].

Heightened environmental legislation demands producers to focus on the application and development of new textile care technologies and processes for household laundering machines. The introduction of ozone in the industrial laundries has increased significantly in the last decades. Yet, on the other hand, the use of ozone for textile washing is still almost unknown. In the past, rare research reports have been published referring to industrial ozone laundering. Reports expose mainly the economic benefits, such as water, energy, chemicals and detergents reduction and the disinfection effects [8–11]. At the same time, in published reports, there have been no results referring to primary and secondary laundering effects and related laundering quality.

This paper evaluates the influences of classical and newly developed household ozone laundering procedures on the laundering quality using a household washing machine and ozone-generator. The first goal was to examine and evaluate the soil removal efficiency of each laundering procedure. After analysing the acquired results, there followed a selection of the most appropriate ozone procedure based on the efficiency and environmental impact factors. The next goal was to carry out and evaluate the influence of laundering repetitions on the properties of fabrics. After 25 laundering cycles (classical or with addition of ozone) of standard cotton fabrics, the secondary laundering effects were determined: Dimensional change, decrease in breaking strength, incineration residue and colour characteristics. All parameters (duration, water, electricity) were collected and analysed of each examined laundering procedure.

EXPERIMENTAL PART

The one-bath household classical and two-bath ozone laundering procedures were performed with the aim of evaluating the soil removal efficiency and the impacts on the fabric's properties. The primary and secondary effects were determined under laboratory conditions. A household washing machine, ozone-generator, ballast fabrics, stain test strips, standard fabrics and detergent were used. The laundering effects were measured and evaluated in accordance with ISO, EN, SIST or CIE requirements, specifications or guidelines. All experiments were repeated three times.

Materials

In the research of primary laundering effects, we used 4.5 kg of ballast load (consisting of cotton sheets IEC T11, pillow cases IEC T13 and towels IEC T12), and stain strips. The characteristics of the stains used for evaluation of soil removal efficiency are presented in table 1. When secondary laundering effects were determined, two pieces of standard cotton fabrics (SC) [12] (100% cotton, 295 dtex in warp and weft direction, 170 g/m^2, plain wave) and ballast load were laundered 25 times.

In the main-washing phases of all laundering procedures the IEC 60456 standard detergent A* was added, composed of 77% basic powder, 20% bleaching agent Sodium Perborate Tetrahydrate (SPT) and 3% bleach activator (TAED). The main ingredients of the basic powder are: Surfactants for soil removal (linear sodium alkyl benzene sulfonate, ethoxylated fatty alcohol $C_{12/14}$ (7 EO), sodium soap), scale inhibitors (phosphonate Dequest 2066 (diethylenetriamine penta (methylenephosphonic) acid, sodium salt, sodium chloride), sodium aluminium silicate zeolite 4A), sodium carbonate, sodium sulphate, carboxymethyl cellulose and anti-redeposition agent, coagulant sodium silicate, enzyme protease (hydrolysing insoluble protein stains into soluble peptides and amino acids, which can be removed from fabrics easily already at 20–40 °C) and stilbene type optical whitener.

All used textile materials and laundering detergents were supplied from WFK Testgewebe GmbH (D).

The characteristics of the ballast load, SC fabrics, stain strips and amounts of added laundering detergent meet the Standards [12–13].

Laundry equipment and procedures

In our research, five different laundering procedures were carried out. Their structure, regarding laundering phases' sequences, laundering temperatures, amounts of detergent and added ozone, are shown in table 2. The first procedure was a classical (CL) laundering procedure consisting of main-washing at 40 °C, two phases of rinsing with cold water, and final spinning (1200 rpm^{-1}). It followed two procedures where ozone was added to the inlet water. During the latter procedure (CO_{MR}), ozone was added in the main-washing and rinsing phases, and in the third performed laundering procedure CO_{RI} ozone was added only in two rinsing phases. The laundering temperatures (40°) and spinning conditions (1200 rpm^{-1}) were equal in both cases.

Two-bath ozone procedures were also performed in the scope of the first part of the research. They con-

Table 1

Soil type	Composition of soil [13]	Colour Characteristics CIELAB (D65/10)				
		R_{460}	*Y*	*L**	*C**	*h*
Unsoiled	100% cotton, 200 g·m^2, desized, scoured, calandered	80.90	81.46	92.34	1.17	111.16
Sebum	Cows` and wool fat, free fatty acid, cholesterol, squalen, coconut oil, hard paraffin, carbon black, kaoline, iron oxide	47.21	49.35	75.56	2.99	97.60
Carbon	Carbon black, paraffin oil	20.81	22.01	53.98	2.53	74.47
Blood	Fresh pig's blood, stabilised with ammonium citrate	16.65	21.88	53.88	17.99	57.06
Cocoa	Unsweet. cocoa (22 % fat), sugar, full-cream cow's milk, water	22.81	33.75	64.76	21.05	58.05
Red wine	Red wine, treated with hot air	39.23	40.74	69.99	12.18	11.37

Table 2

Proc. code	Pre-washing		Main-washing			Rinsing 1		Rinsing 2	
	Oz	T	Det	Oz	T	Oz	T	Oz	T
CL	—	—	94	—	40	—	Col	—	Col
CO_{MR}	—	—	94	1	40	1	Col	1	Col
CO_{RI}	—	—	94	—	40	1	Col	1	Col
PO_{30}	1	30	94	—	30	1	Col	—	—
PO_{40}	1	30	94	—	40	1	Col	—	—

Note: Det – Laundering detergent IEC A (94g/cycle), Oz – Ozone (1 mg/L), T – Laundering temperature (°C), Col – Rinsing with a cold water sisted of four phases: Pre-washing in a laundering bath heated to 30° with the addition of ozone, main-washing, cold rinsing with added ozone and final spinning (1200 rpm^{-1}). In the case of a two-bath ozone procedure, PO_{30}, the main-washing laundering bath was heated to 30 °C, and, in case of the PO_{40} procedure, it was heated to 40 °C.

During the second part of the research, evaluation of secondary laundering effects was carried out only on two laundering procedures. Initially, 25 cycles of the classical procedure CL were performed, followed by 25 cycles of the two-bath ozone procedure PO_{40}. The structures and the conditions of 25 times performed washing procedures CL and PO_{40} were identical to those in the first part of the research (table 2).

All laundering procedures were performed in a household washing machine SensoCare W8665K Gorenje d.d. (SLO), with a capacity of 9.0 kg and a drum volume of 64 L. The inlet water characteristics met the Standard [13]: conductivity < 10 μS/cm, total water hardness 2.5 ± 0.2 mmol/L, pH = 7.3–7.7, T = 15 ± 2 °C.

Ozone was generated with a commercial ozone-generator OVK-W01 Eco Laundry (CN) at room atmosphere. In the laundering procedures, a concentration of 1.0 mg/L of ozone was used with a water flow rate of 4.5 L/min. Ozone is produced under the corona discharge principle. The surrounding air is pumped through the filter into the oxidizing module with a very strong electric field. That splits the molecules of oxygen into highly excited negatively charged oxygen atoms which react with other unstable oxygen molecules and, thus, form highly reactive and chemically unstable ozone gas [14–15]. The produced ozone is injected into water under negative pressure, which is generated in a venture injector, pulling the ozone into the inlet water stream [16].

The amounts of water, as well as their temperatures, total water hardness, conductivity and pH values, were measured using digital meters, WFH36 DVN Qvedis GmbH (D), at the inlet pipes. Power consumption was measured using an EMU Check electricity metre, EMU Elektronik AG (CH).

Determination of primary laundering effects – soil removal efficiency

Non-laundered and laundered stain strips were measured with the spectrophotometer Datacolor SF600 (CH) (d/8 measurement geometry, with measurement wavelength range from 400 nm to 700 nm and measurement area of 20 mm). Reflection measurements were calculated with the help of Datacolor Datamaster (CH) Software resulting in CIE tristimulus values *XYZ*, *L*C*h* CIELAB 1976 and colour differences *dE** according to [17].

The washing performance *q* was calculated in accordance with [13]. The reference laundering procedure was performed in a Wascator FOM 71CLS Electrolux (S) under the following conditions: 5 kg cotton ballast load, stain strips, "Cotton Normal" washing programme (main washing, four rinsing phases), laundering temperature 40 °C, bath ratio 1:5.

The Cleaning performance index CPI_{dE}* was calculated based on [18].

Determination of secondary laundering effects

The ballast load and SC fabric were laundered 25 times in a household washing machine according to the selected laundering procedure. Dimensional change, stiffness, decrease in breaking strength, incineration residue and colour characteristics were determined later.

The conditioned unwashed and 25 times washed standard fabrics were subjected to dimensional change and stiffness measurements, which were evaluated according to [19–20] methods. The breaking strength and incineration residue of unwashed and washed samples of standard fabric were determined by the [21–22] methods, respectively. The colour characteristics were determined by measuring reflection values and calculations of CIELAB values and CIE whiteness indexes WI_{CIE}.

The methodology for determining the secondary laundering effects has been described briefly in earlier studies [23–24].

RESULTS AND DISCUSSION

Five different household laundering procedures, the classical and with ozone combined procedure, were carried out regarding primary and secondary laundering effects. The characteristics of the used stain test strips and the structure of tested procedures are shown in tables 1 and 2. The measured parameters of the performed one- and two-bath laundering procedures are presented in table 3, whilst the results of the primary and secondary laundering effects are shown in figures 1 and 2.

It is evident from table 3 that the washing performance indices are equal for procedures CO_{RI} and CL (*q* = 1.097), while somewhat higher washing performance differences occur for the procedure CO_{MR} (diff. 0.0042 units) compared to the classical laundering procedure CL. The lower washing performance index of procedure CO_{MR} can be explained by the reaction between the ozone in the inlet water and detergent ingredients starting in the dosing vessel of the household laundering machine. It is known that ozone is an unstable molecule that decomposes spontaneously by a complex mechanism, thus generating hydroxyl free radicals which react with organic and inorganic compounds [16]. Dissolution of detergent in water raises the pH of the laundering bath, and, consequently, accelerates the generation of free radicals and, thus, decomposition and lower ozone concentration in the water. [25] found that the simultaneous use of ozone and some surfactants can even cause a decrease in detergency compared to the one achieved with the surfactant alone. This observation was attributed to the degradation of this surfactant in the presence of ozone.

Table 3

Parameter		Unit	Laundering procedure				
			CL	CO_{MR}	CO_{RI}	PO_{30}	PO_{40}
WPI q		—	1.097	1.093	1.097	1.022	1.100
Cycle duration		min	111	117	119	105	119
Water	PW	L	—	—	—	13.69	13.74
	MW	L	22.18	21.73	22.06	7.32	7.26
	RI1	L	19.97	20.14	20.54	16.17	15.39
	RI2	L	20.32	21.30	20.90	—	—
	SUM	L	62.47	63.17	63.50	37.18	36.40
BR	PW	—	—	—	—	1:3	1:3
	MW	1:5	1:5	1:5	1:5	1:5	1:5
RWC		%	63.66	64.40	66.33	63.25	66.59
Energy		kWh/kg	1.054	1.050	1.026	0.406	0.867

Note: WPI – Washing Performance Index, PW – Pre-Washing, MW – Main-Washing, RI1, RI2 – Rinsing, BR – Bath Ration, RWC – Remaining Water Content

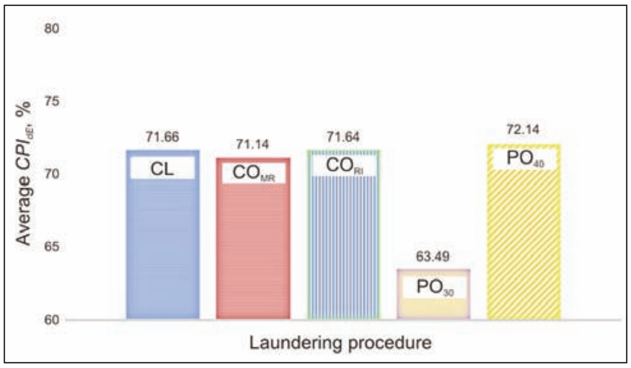


Fig. 1. Average Cleaning Performance Indices CPI_{dE^*} of laundering procedures

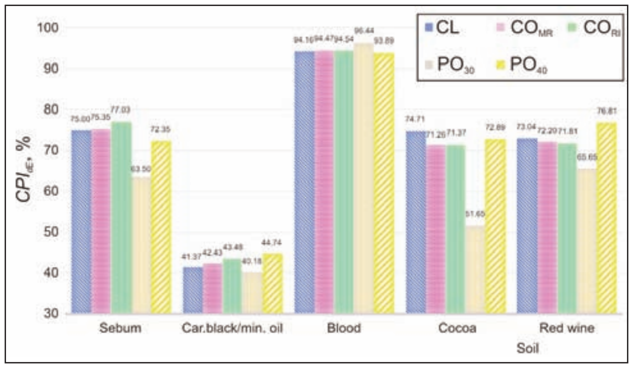


Fig. 2. Soil removal efficiency as CPI_{dE^*} of laundering treatments

From the results shown in table 3, it can be noticed that the CO_{MR} and CO_{RI} laundering cycles last longer (6 and 8 min); concurrently the increased water consumption, whereas the electricity consumption declined compared to the classical procedure CL. Increased total water consumption in ozone laundering procedures is accordant with [26]. It has been reported that the increase in water absorbency of the ozonised samples is assumed to occur as a result of the oxidation of the hydrophobic impurities by ozonation [27]. Another hypothesis is that this phenomenon happens due to oxidation, which weakens the amorphous regions of the fibres, hence the liquid can find its way to be easily transported through [15].

In terms of efficiency as well as environmental impact, the two-bath ozone laundering PO_{30} and PO_{40} procedures (table 3) are in the foreground. With regard to the CL process, the washing performance of the low temperature procedure PO_{30} is noticeably lower (6.83%), while for procedure P_{40} it is surprisingly even higher in absolute values. Realization of the PO_{30} procedure demands 40.49% less water and 61.50 less energy compared to the classical laundering procedure, whilst the one of procedure PO_{40} demands 41.74% less water and 17.75% less electric energy. The cause for the lower energy efficiency of procedure PO_{40} is the laundering bath heating in the main-washing phase, which influences lower electricity saving and longer duration (119 min) of the procedure PO_{40}.

From the results of soil removal efficiency shown in figure 1, one can summarise that the two-bath ozone laundering procedure PO_{40} removes, on average, the highest amount of stains (72.14%), followed by procedures CL (71.66%), CO_{RI} (71.64%), CO_{MR} (71.14%), and, at the end, the procedure PO_{30} with the lowest average CPI_{dE^*} (63.49%). It was found that the most efficient removal (figure 2) for all ozone procedures, on average, was noted for pig's blood (94.83%), followed by moderate soil removal of synthetic sebum (72.06%), red wine (71.62%) and cocoa (66.79%), while for carbon black and paraffin oil soil the removal efficiency was noticeably lower (42.71%). The low soil removal efficiency of the mentioned procedure could be attributed to the low temperature during the main-washing phase (30 °C) and the after-effect of inactivation of the system of bleaching agent SPB and bleach activator TAED [28].

Analyses of the primary laundering show that the household ozone laundering procedure PO_{40} provides the best results: highest washing performance and, at the same time, the lowest water and energy

Table 4

Parameter		Unwashed standard fabric	Laundering procedure	
			Classical (CL)	Ozone (PO_{40})
Dimensional change (%)		—	–13.35	–10.25
Stiffness (cN·cm²)		6.14	4.86	5.08
Breaking strength	F_{25} (N)	999.41	909.57	932.91
	Z_{25} (%)	—	8.99	6.65
Incineration residue (%)		0.0219	0.1158	0.1044
Colour characteristics (D65/10)	R_{460}	76.57	88.22	90.57
	Y	78.74	82.95	83.57
	L^*	91.11	92.99	93.26
	C^*	2.90	2.37	3.05
	h	104.66	278.55	266.64
	WI_{CIE}	65.51	93.55	97.55

consumption. These were the deciding factors in the ozone PO_{40} procedure being selected and carried out in investigation of secondary laundering effects. Table 4 shows the characteristics of standard cotton fabric washed 25 times in the classical or ozone procedures.

The results show that the dimensional change of fabric laundered in the classical procedure was noticeably higher (13.35% shrinking) compared to ozone laundering PO_{40} (10.25% shrinking). Classical laundering caused a higher change in fabric stiffness values (by 20.84%) than laundering with ozone (by 17.28%), compared to the un-washed fabric. Moreover, the breaking strength F_{25} of a fabric laundered classically 25-times was lower (diff. 89.84 N) than ozone laundering (diff. 66.5 N) compared to the breaking strength of the un-washed fabric. This also reflected in a decrease in breaking strength Z_{25} and, thus, mechanical damage. In the case of ozone treatment, the value Z_{25} was considerably lower (6.65%) than in the classical procedure (8.99%). These results can be explained by the fact that, after a certain amount of time, the ozone treatment deteriorates yarn tensile properties drastically, while the wickability increases simultaneously. The phenomena could be attributed to the weak links introduced in the fibre`s amorphous region and their damage [15].

The results indicate a small difference in incineration residue between classically and ozone treated standard cotton fabric. However, the ash content of classical laundering was 5.2 times higher, and of ozone laundering 4.7 times higher, compared to the ash content of un-washed fabric. It is known that incrustation is caused by precipitation of calcium salts from hard water, together with the detergent ingredients, textile structure, washing and rinsing conditions (temperature, duration, bath ratio). During the laundering process accumulated incrustations in the textiles lead to soil retention, greying, fabric handle (higher stiffness values), mechanical damages, reduced absorbency, etc. [23, 29]. From the results of incineration residue we can conclude that repetition of ozone treatments obstructs the mineralization process of textiles during the laundering process.

Ozone oxidation potential and reduction of accumulated incrustations probably contribute to the colour characteristics and higher whiteness WI_{CIE} of the PO_{40} process compared to the classical treatment CL.

CONCLUSIONS

Evaluation of the primary and secondary effects of classical and different household ozone laundering procedures was the main subject of the presented research. Procedures were performed with the help of a household laundering machine and commercial ozone-generator, while the laundering effect was evaluated with measuring equipment and methods which meet suitable Standards.

Results show that household ozone laundering provides higher soil removal efficiency and appreciable consumption of water and electricity, compared to the classical washing process.

The common characteristics of 25 time laundered standard cotton fabrics with ozone proved to be surprisingly good. We can conclude that laundering with ozone in a household drum washing machine causes lower damages to cotton fabric than the classical procedure.

However, the scope of further investigations will be the development of new ozone laundering processes, introduction of powerful ozone-generator and disinfection efficiency, but the first and foremost priority will be the improvement of additional security systems to prevent ozone escaping from the household machine into the surroundings.

ACKNOWLEDGMENTS

We are grateful to the Gorenje d.d. and OTRI ZT d.o.o. for the financial support of the project. We want to acknowledge Shelagh Margaret Hedges for the useful suggestions which she gave us during the origin of the presented article, and also for the final proof-reading.

BIBLIOGRAPHY

[1] Scheid, F., Lambert, E., Maitra, W., Niestrath, M., Fäh, D., Portmann, C., Gorny, S., Stamminger, R. *Textile quality depletion due to household machine wash – Ways to measure and impacts of wash duration and temperature on textiles*. In: Tenside Surfactants Detergents, 2016, 53, pp. 438–444

[2] Fijan, S., Fijan, R., Šostar-Turk, S. *Implementing sustainable laundering procedures for textiles in a commercial laundry and thus decreasing wastewater burden.* In: Journal of Cleaner Production, 2008, 16, pp. 1258–1263

[3] Neral, B., Fijan, S., Šostar-Turk, S. *Implementing sustainable laundering procedures for textiles in a commercial laundry and thus decreasing wastewater burden.* In: Industria Textila, 2012, 63, 5, pp. 246–251

[4] Fonseca P, Almeida, A., Feilberg, N., Markogiannakis, G., Kofod, C. *Characterization of the household electricity consumption in the EU, potential energy savings and specific policy recommendations.* In: ECEEE Summer study, 2009, pp. 781–793

[5] Almeida, A, Fonseca, P., Schlomann, B., Feilberg, N. *Characterization of the household electricity consumption in the EU, potential energy savings and specific policy recommendations.* In: Energy and Buildings, 2011, 43, pp. 1884–1894

[6] Corina Moga, I., Pricop, F., Iordănescu, M., Scarlat, R., Dorogan, A. *Quality monitoring for wastewater generated by the textile finishing.* In: Industria Textila, 2013, 6, 4, pp. 222–228

[7] European Environment Agency. *Energy efficiency and energy consumption in the household sector*. Available form: http://www.eea. europa.eu

[8] Cardis, D., Tapp, C., DeBrum, M., Rice, G.R. *Ozone in the Laundry Industry – Practical experiences in the United Kingdom*. In: Ozone: Science in Engineering, 2006, 29, 2, pp. 85–99

[9] Global Energy Partners LLC. *Operations evaluation report – Presurized Ozonation System-Final Report*. In: Lafayette CA, 2006, pp. 11–13

[10] Rice, R.G., DeBrum, M. *The ozone laundry handbook*. In: Lulu, 2011, pp. 14–20

[11] Tapp, C. *Ozone laundry, a detailed review of the method and science involved in a properly designed cold water wash ozone system*. In: 46th IDC Conference, WFK – Cleaning Technology Institute, 9 – 11 April 2013, Düsseldorf

[12] ISO 2267, 1986. *Surface active agents – Evaluation of certain effects of laundering- methods of preparation and use of unsoiled cotton control cloth*

[13] SIST EN 60456, 2010. *Clothes washing machines for household use- Methods for measuring the performance*

[14] Atav, R. *Eco-friendly textile dyeing and finishing*. 2014. Available from: http://www.intechopen.com/books/eco-friendly-textile-dyeingand-Finishing.pdf, 2014, pp. 10–15

[15] Maqsood, H.S., Wiener, J., Baheti, V., Eldeeb, M., Militky, J. In: *Ozonation: a green source for oxidized cotton*. In: Fibres & Textiles in Eastern Europe, 2016, 24, 1(115), pp. 19–21

[16] Langlais, B., Reckhow, D.A., Brink, D.R. *Ozone in drinking water treatment: Application and engineering*. In: AWWARF and Lewis, Boca Raton FL, 1991, pp. 100–132

[17] CIE 15.3, 2004. *Colorimetry – Colour of objects. Colour vision. Perception of colour*

[18] Sutanto, S., Roosmalen, M.J.E., Witkamp, G.J. *Redeposition in CO_2 textile dry cleaning*. In: Journal of Supercritical Fluids, 2013, 81, pp. 183–192

[19] SIST EN 25077, 2007. *Textiles – Determination of dimensional change in washing and drying*

[20] DIN 53362, 2003-10. *Testing of plastics films and textile fabrics (excluding nonwovens), coated or not coated fabrics – Determination of stiffness in bending – Method according to Cantilever*

[21] DIN EN ISO 13934-1, 2013-08. *Textiles – Tensile properties of fabrics – Part 1: Determination of maximum force and elongation at maximum force using the strip method* (ISO 13934-1:2013)

[22] ISO 4312, 1989. Surface active agents – *Evaluation of certain effects of laundering – Methods of analysis and test for unsoiled cotton control cloth*

[23] Fijan, S., Šostar Turk, S., Neral, B., Pušić, T. *The influence of industrial laundering of hospital textiles on the properties of cotton fabrics*. In: Textile Research Journal, 2007, 77, 4, pp. 247–255

[24] Lipuš, L.C., Ačko, B., Neral, B. *Influence of magnetic water treatment on fabrics' characteristics*. In: Journal of Cleaner Production, 2013, 52, pp. 374–379

[25] Jurado-Alameda, E., Miguel García Román, M.G., Vaz, D.A., Pérez J.L.J. *Fatty soil cleaning with ozone and lipases – A way to develop more environmentally friendly washing processes*. In: Household and Personal Care Today, 2012, 7, 4, pp. 49–52

[26] Eren, H.A., Ozturk, D. *The evaluation of ozonation as an environmentally friendly alternative for cotton preparation*. In: Textile Research Journal, 2011, 81, 4, pp. 512–519

[27] Prabaharan, M., Nayar, R.C., Kumar, N.S., Rao, J.V. *A study on the advanced oxidation of a cotton fabric by ozone*. In: Coloration Technology, 2006, 116, 3, pp. 83–86

[28] Dannacher, J.J. *Catalytic bleach: most valuable applications for smart oxidation chemistry*. In: Journal of Molecular Catalysis A: Chemical, 2006, 251, 1–2, pp. 159–176

[29] Anonymus. *Laundering process control regarding gentle treatment. Evaluation of detergents and washing processes.* In: Empa AG, 2003, pp. 10–14

Authors:

BRANKO NERAL

University of Maribor, Faculty of Mechanical Engineering,
Institute for Engineering Materials and Design, Maribor, Slovenia

Corresponding author:

Branko Neral
e-mail: branko.neral@um.si

Aspects regarding vital functions monitoring through an adaptive textile system

DOI: 10.35530/IT.069.04.1505

ANGELA DOROGAN
IOANA CARPUS
DIMITRIE NANU
MIRCEA IGNAT

REZUMAT – ABSTRACT

Aspecte privind monitorizarea funcțiilor vitale printr-un sistem textil adaptiv

În prezent, există aproximativ 80 de milioane de persoane cu diverse tipuri de dizabilități în Uniunea Europeană, dar acest număr este de așteptat să crească în următorii ani, în principal ca urmare a proporției crescânde a cetățenilor în vârstă.

La nivelul Uniunii Europene, dizabilitatea este văzută ca o problemă a întregii societăți. Aceasta presupune pregătirea și adaptarea continuă în toate sferele vieții, pentru primirea și menținerea acestor persoane în curentul principal al vieții sociale, pentru asigurarea tuturor facilităților. Sunt stimulente puternice pentru cercetare și inovare în domeniul social (servicii în folosul oamenilor), medical (boli cărora nu li se cunoaște originea, protocoale medicale personalizate, instrumente neconvenționale de monitorizare, etc.) sau tehnologic (robotică, informatică, textile, etc.), deopotrivă. Un rol important revine îmbrăcămintei adaptive caracterizate prin confort, accesibilitate, siguranță și stil. Lucrarea include aspecte privind realizarea unor modele experimentale de elemente textile cu funcții elctronice destinate sistemelor de monitorizare a unor funcții vitale.

Cuvinte-cheie: dizabilitate, funcții vitale, textile adaptive

Aspects regarding vital functions monitoring through an adaptive textile system

Currently, there are about 80 million people with various types of disability in the European Union, but this number is expected to grow in the coming years, mainly due to the increasing proportion of older citizens.

At European Union level, disability is seen as a problem of the whole society. This requires continuous training and adaptation in all spheres of life, for receiving and maintaining these persons in the mainstream of social life, in order to ensure all the facilities. There are powerful incentives for research and innovation in the social field (services for the benefit of people), medical field (diseases whose origin is unknown, customized medical protocols, non-conventional monitoring instruments etc.), or technology field (robotics, informatics, textiles etc.) in an equal manner. An important role is played by the adaptive clothing characterized by comfort, accessibility, safety and style. The paper includes aspects regarding the making of some experimental models of textile elements with electronic functions intended for vital functions monitoring systems.

Keywords: disability, vital functions, adaptive textiles

"More than one billion people in the world live with some form of disability, of whom nearly 200 million experience considerable difficulties in functioning. In the years ahead, disability will be an even greater concern because its prevalence is on the rise. This is due to ageing populations and the higher risk of disability in older people as well as the global increase in chronic health conditions such as diabetes, cardiovascular disease, cancer and mental health disorders"

Dr. Margaret Chan, General Director, World Health Organization

INTRODUCTION

Professor Stephen W. Hawking mentions: "It is my hope that, beginning with the Convention on the Rights of Persons with Disabilities, and now with the publication of the World report on disability, this century will mark a turning point for inclusion of people with disabilities in the lives of their societies" [1]. In analyzing the needs of the people with disabilities, it is important to see the interaction between the individual and the environmental factors – from impairments, activity limitations and participation restrictions, to the highest level of functioning that a person may attain, probably, at one moment and which defines their capabilities in different areas of activity and participation. Improving living and working conditions for people with special needs and the elderly has convergence points, these are powerful incentives for research and innovation in the social field (services for the benefit of people), medical field (diseases whose origin is unknown), or technology field (robotics, informatics, textiles etc.) in an equal manner. Disability is a social state and not a medical condition. Clarity and precision are needed to define different concepts [2]. According to the decision-makers in the field, disability has different definitions and a sum of characteristics specific to each of them [3–4]. According to **Disabled Peoples' International (DPI)**, disability is defined as the "results from the interaction between persons with impairments and attitudinal and environmental barriers which they confront".

The World Health Organization proposes the following definition of disability: “restriction or lack (resulting from an impairment) of ability to perform an activity in the manner or within the range considered normal for a human being”. **The United Nations Organization (UNO),** based on the Convention on the Rights of Persons with Disabilities, uses the following definition: “Persons with disabilities include those who have long-term physical, mental, intellectual or sensory impairments which in interaction with various barriers may hinder their full and effective participation in society on an equal basis with others”. Disability for CIF/CIF-CY (The International Classification of Functioning, Disability and Health CIF and CIF for Children and Youth: an umbrella term for the deficiencies in the functions and structures of the body, activity limitations and participation restrictions. Disability is perceived and approached through two models: medical and social [5–8]. *The medical model* defines people with disabilities from the perspective of their disease or medical condition. In this model, disability is perceived as the individual’s problem, the latter being dependent on the others and requiring appropriate treatment for their problem.

The social model is promoted by the European Union and focuses on the social environment that is not adapted to the needs of the people with disabilities, hence the difficulties they face. Thus, the social model no longer perceives disability as an individual problem, but as a social fact, generated by politics, practice, attitudes and the environment. Disability is not an attribute of an individual, but a complex of conditions created by the social environment. Considering the main characteristics that define the social model vs. the medical model (table 1), it can be emphasized that the purpose of the social model was to eliminate the obstacles, so that the people with disabilities benefit of equal opportunities, in order to have an independent existence being treated by virtue of their qualities and not defects.

Table 1

Medical model	Social model
Disability is a personal problem	Disability is a social problem
The person with disabilities must adapt	People with disabilities must be provided with facilities
“Disability” has an individual identity	People with disabilities have a collective identity
People with disabilities need help	People with disabilities need rights
Individual adaptations	Social changes

Source: [http://www.eupd.ro/wp-content/uploads/2011/09/Curriculum.pdf]

A third *model* is the *biopsychosocial* one adopted by the World Health Organization (WHO) and constitutes an integral framework of the medical and social model in what regards incapacity. In the biopsychosocial model, incapacity is approached as an interaction between biological, psychological and social factors [9], the functioning of an individual in a certain field is a complex interaction or relation between their health condition and contextual factors (for example, environmental factors and personal factors). The human being is a complex biopsychosocial entity; therefore, regardless of the nature and the action of an external factor, whether harmful, aggressive or beneficial, the human individual, their body reacts as a whole on all its manifestations: physical, physiological, neuroendocrine, psycho-emotional, behavioral and social. An important role in the implementation of the biopsychosocial models is given to the adaptive/ interactive clothing. The trend in the textile sector to include consumer requirements in the technical aspects of the product is the key to the sustainable development of the sector. Theoretically, meeting customer requirements and the technical aspects (functionality, ergonomic aspects, comfort etc.) are just as important in ensuring the success of the product [10]. Companies have quickly learned that clothing should be functional, versatile and durable. There are two product-making philosophies: a so-called “product-out” one in which the manufacturer’s decision takes into account the product technological and design specifications and another one, “market-in”, that embraces the consumer’s requirements in the product making process [11]. In this manner, textile products that goes beyond the normative body type is created, which approaches the spectrum of the body types and ensures comfort, accessibility and style in the conditions of a certain functionality.

EXPERIMENTAL PART

The making of an interactive textile system is dealt with in several phases, in which the contribution of different transdisciplinary departments is, in turn, of utmost importance. Of these phases, we mention:

a) detection of a need and its transposition into technical requirements;
b) establishing the specifications of each component of the interactive textile system;
c) researching and designing the new system;
d) designing, making and validating the system.

Given the variety of the problems imposed by the interactive textiles systems and the multiple solutions for solving them, it is difficult to establish a generally valid template according to which we can conduct the design activity. For these reasons it can be argued that there can be no method to be applied based on a logical scheme, starting from an initial point, going through a number of procedures and arriving at the end point with a determined number of return loops and ramifications. If this were possible, with the existing computer technologies, programs could be developed to solve the task of the design engineer.

Generically, the design process consists of a structured set of planned, ordered and controlled activities aimed at making products that meet market demands. The search for solutions can be done heuristically or based on logical methods [12]. Modern design, focused on meeting market demands, implies the application of some global concepts such as: *simultaneous or convergent engineering, total design, ecological engineering, product life cycle engineering* etc. The balance between functionality, durability, economicity, ergonomicity and beauty for the textile systems that change the quality of life and add value is the result of implementing the textile design of interaction. The textile design of interaction proposes a new space for the designing (spatial and temporal) of the dynamic elements that combines the fields of textile design and interaction design. There are also taken into account the user's actions (micro-interactions) that can trigger another action on the part of the device, and each of these interactions rely on a man centered design concept based on a new qualitative level of the science, technology and art correlation. The algorithm for designing the exprimental models of interactive/adaptive textile products has been finalized following a corrective-type modeling activity that included the logical interpretation/analysis of:

– the processing capacity of selected yarns;
– the relations of interdependence between the physical & mechanical characteristics and the functional characteristics of the textile structures;
– the "architecture" of the textile system with customized areas, with specific functionalities and differentiated advantages;
– the factors that influence the "anatomical form" of the product;
– the physical and mechanical potential of the textile structures produced on textile machines with systems which design the structure in "anatomic cuts" for comfort at movement and action;
– the potential field of use requirements.

To make a textile element with embedded electronic functions (fig. 1), there are used:

• at the textile product level:
  – an adjustment band according to the perimeter of the signal pickup area, by means of a velcro demountable joint;
  – a modular undershirt incorporating the band-type module, mentioned above; the other modules of the undershirt may include other components for monitoring some physiological parameters in the context of providing a predefined well-being state.
• at the textile support level:
  – a woven fabric with structures that expose a large surface of contact in order to take over the physiological signal; examples of structures are highlighted in the images in figure 1. The functionality embedded in the textile structure, in relation to the yarns systems that define it, lies in the direction of the weft yarns. The unidirectional, continuous or discontinuous arrangement ensures the generation of an electrical circuit, in which the interferences that might occur are avoided, only by intersecting the yarns from the two yarns systems of the woven fabric.
• at the yarn level;
  – a multi-component yarn that provides a "mantle" effect for the yarn with the electrical conductivity functionality.

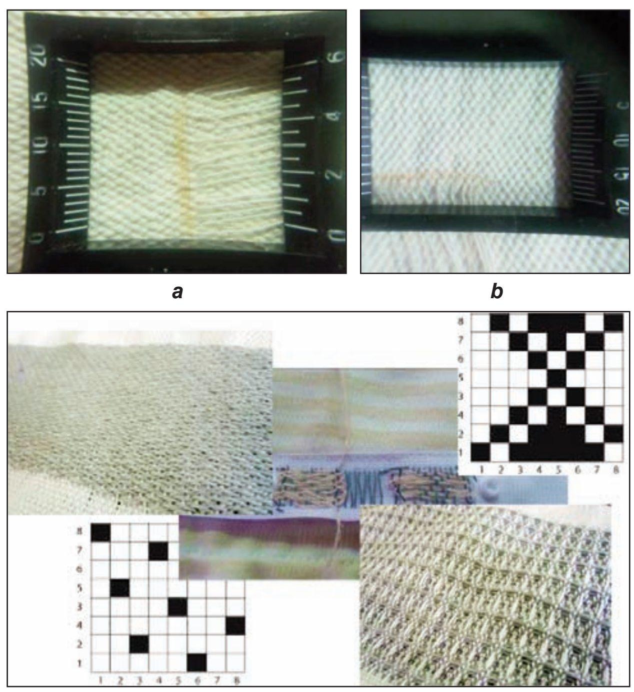
The yarns used are recognized in the specialized media existing research.

The novelty in this research at national level refers to the incorporation of conductive yarns with the role of monitoring some physiological signals, in order to maintain a preset/ predefined well-being state, and at an international level, respectively, it refers to two aspects:

a) the confirmation by preliminary experimentation of the referential, taken from an experience declared in the specialized media,

b) the development of the research, by defining some optimized surfaces for arranging the functionalised yarns, respectively, by selecting certain woven fabrics specific structures that ensure a more faithful take-over, as a specific law, amplitude, frequency, corresponding to a selected **physiological signal.**

The interactive thread used is of double type, between a spun cotton yarn and a monofilament based on copper (lithium). The joining of the two yarns has technical reasoning, workability and comfort in wearing, after being part of a fabric/fabric. The selection of the textile support, the fabric, compared to a knit or nonwoven, has technical reasoning of dimensional stability, minimizing elongations under the traction load, by itself known as the elasticity of a fabric (under certain conditions of thread and bond) is minimal. The interactive thread can be embedded in the



a *b* *c*

Fig. 1. Variants of embedding the functionalized yarn for monitoring physiological signals a) and b) detail about the embedding of functionalized yarns – the beige-orange yarns, to highlight the frequency of their deposition, compared to the sewing – embroidery deposition, where the yarn density is inferior; c) variants of structures for surfaces woven with embedded functionalized yarns

weaving structure, in a normal weaving process, preferably on machines with unconventional insertion. This aspect has both positive parts (providing a non-stressed fabric, considering that there is a conventional or multifilamentary textured or non-textural thread and the interactive thread that contains a lithic component (ie stretching and flexibility much inferior to conventional wires).

Taking into account that an important role in maintaining health is played by *the heart rate and respiratory rate*, the static testing of the electronic functions for the textile element dealt with the identification of the independent conductors in the textile structure.

The importance of the vital functions mentioned [13–15] is supported by the following aspects:

Cardiac rhythm: The primary function of the heart is to ensure the transport of blood and nutrients in the body. Regular heart beats, or contractions, ensure the transport of blood in the body. Each beat of the heart is controlled by a nervous impulse that circulates through the heart at regular intervals. There are several heart rate diseases (for example: a malfunctioning of the sinus node or interruption of the electrical stimuli system; arrhythmia makes your heart beat either too quickly or too slowly or determine its irregular rate; tachycardia occurs when the heart rate exceeds 100 beats per minute, if the number of the beats of the heart per minute reaches 150 or above, the person in question suffers from supraventricular tachycardia; bradycardia is a condition in which the heart rate is too low, below 60 beats per minute, that may be the result of problems with the sinoatrial nodule or heart damage following a heart attack or cardiovascular disease). The cause of these rate disorders is usually a coronary artery disease that nourish the patient's heart, a myocardial infarction or heart failure. Patient monitoring is very important given that the symptoms are very varied: most often, the patient feels nothing, but there can appear palpitations, vertigo and loss of consciousness and, also, irregular rate.

Respiratory rate is another parameter used in patients monitoring. Respiratory failure is not a disease, but a functional disorder caused by various pathological causes. Respiration is a vital function of the human body, which is continuous and cyclical and has the role of ensuring the bi-directional exchange of gases between the body and the air in the atmosphere. Respiratory failure is the body's inability to maintain the normal gases exchange at the cellular level and, consequently, to maintain the aerobic metabolism. Sleep apnea is the respiration interruption during sleep. Sleep apnea may be associated with: arterial hypertension, myocardial infarction, heart failure, irregular beats of the heart (arrhythmias); strokes; drowsiness throughout the day; increased risk of road accidents. The hyperventilation syndrome refers to the respiration acceleration, causing an increase in the amount of air that ventilates the lungs. Hyperventilation can cause dizziness and weakness, feeling of lack of air, loss of balance, muscle spasms in the hands and legs, tingling around the mouth or in the fingers. The causes are multiple: fear, asthma; chronic obstructive pulmonary diseases; congestive heart failure; costochondritis or the Tietze syndrome; deep vein thrombosis and pulmonary embolism; myocardial infarction; hyperthyroidism; pregnancy; central nervous system disorders (stroke, encephalitis, meningitis), drug overdose, fever, infections (pneumonia or septicemia), lactic acidosis, metabolic acidosis, the chronic altitude disease, stress, pulmonary edema, pleural effusion, severe shock, severe anemia etc. [18].

Considering the above mentioned, the experimentation of the experimental model – a textile element with electronic functions as part of the system for monitoring some vital functions – was made by means of capacity measurements (table 2 and figure 2), in static state, using the RLC ESCORT ELC-132A bridge rectifier (the measurements were made at the Electrical Engineering Institute ICPE-CA).

On the analyzed textile structure independent conductors were identified and the capacity measurements were made in static state. Considering the flexibility of the textile element, the distance between the yarns giving electronic properties can be modified in correlation with the phases of the respiration process (at rest, the diaphragm is curved upwards and tends to flatten when contracting, thus increasing the vertical diameter of the thoracic cavity). If the distance increases, the capacity decreases and vice versa.

The results obtained following the static state measurements demonstrate:

– the potential of the textile element to monitor respiration or heart rate as a result of the capacitive microsensors introduced into the textile structure;

Table 2

Connections	Capacity [pF]
1-1[a]	2,5
2-2[a]	2,4
3-4	2,2
3-5	2,1
4-5	2,6

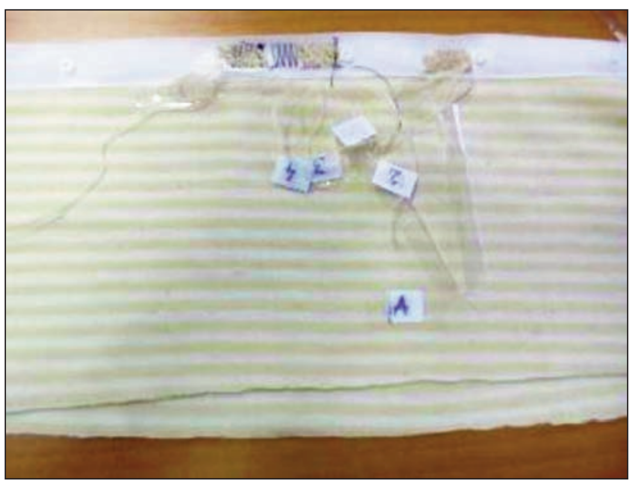


Fig. 2. Textile element with electronic properties

– the networks or the independent conductors can be used as microsensors that may have applications regarding both the appearance of the biological fluids and the evolution of humidity and the capacity permittivity (depending on the characteristic of the liquid) changes with the appearance of the fluid.
– considering the flexibility of the textile element, the distance between the yarns giving electronic properties can be modified in correlation with the phases of the respiration process (at rest, the diaphragm is curved upwards and tends to flatten when contracting, thus increasing the vertical diameter of the thoracic cavity).

CONCLUSIONS

- The social policies promoted at the national level are those of inclusion, which opens new perspectives for the multidisciplinary research.
- The human being is a complex biopsychosocial entity; therefore, regardless of the nature and the action of an external factor, whether harmful, aggressive or beneficial to the human body, this reacts as a whole on all its manifestations: physical, physiological, neuroendocrine, psycho-emotional, behavioral and social.
- The human body controls a multitude of complex interactions to maintain its balance or to make the systems function at a normal rate. An important role in maintaining health is played by the heart rate and respiratory rate.
- The performances imposed on the interactive/adaptive textile systems can be ensured by applying the "triple propeller" model, a neo-evolutionary model of the innovation process that describes the multiple reciprocal relations at different points in the knowledge accumulation process.
- The results obtained following the static state measurements demonstrate the potential of the textile element to monitor respiration or heart rate due to the capacitive microsensors introduced into the textile structure.

BIBLIOGRAPHY

[1] http://apps.who.int/iris/bitstream/10665/44575/20/9789730135978_rum.pdf?ua=1
[2] http://www.combat.info.ro; Ordinul 1306 /1883/2015;
[3] http://motivatie.md/ edia/Publicatii/Carti_brosuri_rapoarte_analiza/Educatie_incluziva_w2.pdf
[4] http://www.eupd.ro/wp-content/uploads/2011/09/Curriculum.pdf
[5] https://www.prostemcell.ro/articole/dizabilitate.html
[6] http://parteneriat-transnational.ro/wp-content/uploads/2014/08/Modelul-bio-psiho-social-pentru-persoane-cu-dizabilitati.pdf
[7] http://www.assoc.ro/wp-content/uploads/2015/10/POSDRU-54702-Ocuparea-persoanelor-cu-dizabilitati_Psihologia-angajatorului-cu-privire-la-angajarea-acestora.pdf
[8] Manea L. *Dizabilitatea ca factor de risc privind accesul la serviciile de educație*.In: Calitatea vieții, 2006, nr. 1–2, pp. 1–10, 41–50
[9] *Clasificarea internationala a functionarii, dizabilitatii si sanatatii*, In: Organizatia Mondiala a Sanatatii Geneva, 2001, P.25; ISBN 924 154542 9.
[10] http://parteneriat-transnational.ro/wp-content/uploads/2014/08/Modelul-bio-psiho-social-pentru-persoane-cu-dizabilitati.pdf
[11] Norman, Donald A. *Emotional design,* Published by Basic Books, 2004, ISBN 0-465-05135-9.
[12] https://www.researchgate.net/publication/233349460_*Concepts_methods_and_tools_in_Kansei_Engineering*
[13] http://documents.tips/documents/proiectarea-unui-produs.html]
[14] Loscalzo, Joseph, *Harrison, Medicină cardiovasculară,* Editura ALL, București, 2013, ISBN: 9786065871281
[15] Carp, Costin, *Tratat de cardiologie*, Editura Medicala Nationala, 2003, ISBN: 9736590100
[16] http://www.romedic.ro/respiratie-dificila-0R1317
[17] Loscalzo, Joseph, *Harrison, Pneumologie si terapie intensiva*, Editura ALL, București, 2017, ISBN 978-606-587-350-6
[18] www.romedic.ro/sindromul-de-hiperventilatie

Authors:

ANGELA DOROGAN[1]
DIMITRIE NANU[2]
IOANA CARPUS[2]
MIRCEA IGNAT[3]

[1]The National Research and Development Institute for Textiles and Leather
[2]Univ. of Medicine and Pharmacy "Carol Davila"
[3]National Institute for Research and Development for Electrical Engineering – ICPE-CA

Corresponding author:

ANGELA DOROGAN
e-mail: angela.dorogan@certex.ro

Comfort properties of nano-filament polyester fabrics: thermo-physiological evaluation

MUSADDAQ AZEEM
LUBOS HES
JAKUB WIENER

DOI: 10.35530/IT.069.04.1529

MUHAMMAD TAYYAB NOMAN
AZAM ALI
TARIQ MANSOOR

REZUMAT – ABSTRACT

Proprietățile de confort ale țesăturilor din polyester nanofilament

Confortul, împreună cu proprietățile estetice ale îmbrăcămintei textile pentru sport sunt extrem de valoroase pentru nevoile consumatorilor. Diferite tipuri de fibre și fire sunt utilizate pentru a îmbunătăți gestionarea umidității și confortul țesăturii în contact cu pielea. În prezent, multifilamentele sau nanofilamentele din poliester cu diametre cuprinse la nivelul de câțiva nanometri și lungimi de până la kilometri sunt utilizate în diferite game de aplicații tehnologice importante, cum ar fi țesături funcționale, biomedicină, compozite etc. Firele de poliester multifilament sunt realizate prin agregarea mai multor filamente continue, caracterizate prin tenacitatea lor ridicată și suprafața mare pe unitatea de masă. Firele nanofilament au, de asemenea, efecte semnificative asupra proprietăților de confort termic, deoarece țesătura din nanofilament are o conductivitate termică mai redusă decât țesătura de bumbac, dar este egală cu țesătura din poliester multifilament, în timp ce țesăturile din nanofilament oferă o senzație mai mare de rece cu o absorbție termică mai ridicată. În plus, țesătura coolmax a prezentat o valoare mai mare a rezistenței termice în comparație cu țesăturile din nanofilament. Țesăturile din nanofilament au prezentat o valoare mai mare a permeabilității la vapori de apă decât țesăturile din bumbac.

Cuvinte-cheie: confort termofiziologic, țesătură din polyester nanofilament, permeabilitate la vapori de apă

Comfort properties of nano-filament polyester fabrics: thermo-physiological evaluation

Comfort along with the aesthetic properties of textile clothing in activewear and sportswear are *utmost worthwhile for costumer demand as latest trends. Different types of fibers and yarns are being used to improve the moisture management and comfort of the fabric for next to skin. Nowadays, multifilaments or nano-filaments of polyester with diameters in the range of a few nanometers and lengths up to kilometers are used in different range of important technological applications such as functional fabrics, biomedicine, composite, etc. Multifilament polyester yarns are made by aggregating many continuous filaments together characterized by their high tenacity and large surface area per unit mass. The nano-filament yarn has also significant effects on thermal comfort properties as a nano-filament fabric has less thermal conductivity than cotton fabric, but equal to multichannel polyester fabric while nano-filament fabrics gave the cool feelings with higher thermal absorptivity. Moreover,coolmax fabric showed the higher value of thermal resistance as compared to nano-filament fabrics. Nano-filament fabrics exhibited higher value of watervaporpermeability than cotton fabric.*

Keywords: thermo-physiological comfort, nano-filament polyester fabric, water vapour permeability

INTRODUCTION

Clothing comfort is mainly split into three divisions like sensorial comfort, thermal comfort and psychological comfort. Sensorial or tactile comfort deals with the mechanical properties of the fabric along with its surface hand feel [1]. Psychological comfort properties relate to the new fashion trend, influenced by culture, status, occasion, gender, age, profession and social attitude. Physiological comfort demonstrates the absence of human body discomfort to fabric, measurement of sweat rate, absorbency and transportation of this sweat from the body by clothing [2]. Physiological comfort and psychological comfort are closely related to know about the perception of the comfort level [3]. Thermo-physiological comfort can be defined in terms of heat and mass transfer through clothing [4]. The mutual relationship of heat and mass transfer properties produces a microclimate all around the human body, which provides a comfort zone [5]. Clothing provides protection against unnecessary effects of environmental conditions while executing physical movements. This layer of clothing should be friendly to the skin [6].

Literature has been reported on the water vapor permeability (WVP) of textile fabrics [7–9], but the term "warm/cool feeling" is not completely known to the researchers. Increase in WVP can be demonstrated by planar conduction of condensed vapors from the border of the calculating area to the directionof fabric fringe [10].

Change in the internal and external condition of the system influences the thermal balance of the body. Thermal properties of textile materials like thermal conductivity and thermal absorptivity are important to consider the thermal comfort study [11–12].Thermal conductivity expresses the material's abilityto permit the heat passage due to temperature difference. Material structure is significantly related to this property due to anisotropy in nature. Fabrics made of polymer get less moisture and air in the voidsof fabric structure [13–14]. Moisture causes the higher thermal conductivity within fabric composition [12]. Textile clothing comfort technologycomprises a thermal characteristic associates "warm/cool behavior", called thermal absorptivity denoted by "b" $\left(\frac{Ws^{1/2}K}{m^2K}\right)$, firstly introduced in the textile field by L. Hes [15]. The first feeling of human skin when it gets into touch with any object called warm/cool behavior [16]. Fabrics, knitted or woven made of polyester fibresare widely used in textile industry, known by their hydrophobic nature (low moisture regain). In this modern era, surface modification can be used to obtain best moisture transportation, especially, by utilizing multifilament and fine filament yarns [17].

Making endless fabric forced the researcher to invent multifilament polyester. Multifilament polyester yarns became the part of observation when clothing comfort properties were concerned. These multifilaments were produced by assembling continual filaments jointly. Continuous strands of this yarn are depicted by its better mechanical and chemical properties, along with good sensorial properties [18]. Furthermore, the space and voids between all filaments creates capillarity which provides liquidtransport. Garment industry is taking great advantages of this invention. Absorption and capillary channels facilitate the fluid dynamics and mass transfer [19]. In modern technological era, multi-filament (micro or nano-filament) polyester with endless strands (upto kilometers) are being utilized in functional and composite textiles. These nano-filaments are characterized by a high range of capillarity which provides the steady internal nano-scale inertia of the fluid for transportation [20]. Nano-filaments yield a quick passage of moisture away from the body to the environment because of its desired interaction amongst the filament spacing and permeability of fabric [21].

The moisture content of a fabric is directly proportional to the relative water vapor permeability (RWVP) and inversely related to the temperature [22]. This phenomenon is due to the evaporation of the water from the fabric surface. RWVP is the relative heat flow accountable for cooling of the body. Permetester was used to determine the relative water vapor permeability (%) and the evaporation resistance (m^2Pa/W) of fabrics within 3 to 5 minutes [23, 24]. The water vapor resistance (WVR) of textiles under variable conditions is closely concerned with relative humidity (RH). Fundamentally, water vapor resistance comprises of varying the position of the sample in the air gap linking the dry and wet surface while assuming the all other specifications constant [22].

Application of nano-filament fibres affects the cotton industry as well due to hygroscopic nature. Heavy physical tasks in daily life suffers the wearer from perspiration generate discomfort. Multi-filament polyester is much convenient substitution to get rid of discomfort by fast drying. Expeditious evaporation is also preferred in tropical weather and deserts for the comfort point of view. Under garment industry acquired more advantage of multi-filament polyester fiber because of its better water transport properties. The novelty of this work is to define the structural form of yarn used in this fabric. This special fabric is highly hydrophilic as compared to other polyesters. The results of physiological and sensorial comfort properties make it more recommendable for the comfort point of view.

MATERIALS AND METHODS

Continuous yarn composed of thousands nanofibresis most likely attractive due to its versatile ability to provide a huge range of microscopic capillarity. Lubos Hes from the Technical University of Liberec (Czech Republic) introduces the following six aspects of psychological comfort [7]:

1. Climatic: routine clothing concerns the climatic requirements.
2. Economical: it belongs to the resources, political system, food technology and objects manufacture.
3. Historical: tendency to manufacture organic materials, pure natural smell and modern lifestyle.
4. Culture: this aspect is for the religious and cultural clothing especially for women
5. Social: this feature reflects the social status like age and qualification
6. Individual and group aspects: it shows the brand and style craze, personal preferences.

Materials

Samples of nano-filament polyester fabric were collected from Japanese textile industry to evaluate the thermo-physiological properties.

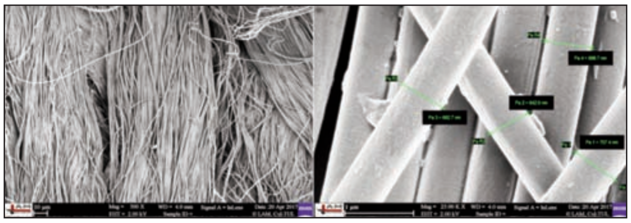


Fig. 1. SEM images of polyester warp knitted fabric (S1) made from nano-filament fibre of 600~710 μm diameter

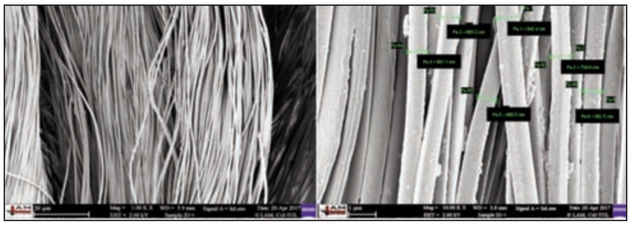


Fig. 2. SEM images of Polyester warp knitted fabric (S2) made from nano-filament fibre of 650~850 μm diameter

Two samples of nano-filament fabric were used for this study in the comparison with cotton and coolmax fabric.

Table 1

Sample #	GSM (g/m^2)	Thickness (mm)	Yarn fineness (Dtex)	Yarn DIA (mm)
S1 Nano-filament	200±2	0.44	152±3	0.08
S2 Nano-filament	250±2	0.55	152±3	0.08
S3 Coolmax (100%)	210±2	0.68	295±3	0.12
S4 Cotton (100%)	200±2	0.62	295±3 cmb	0.15

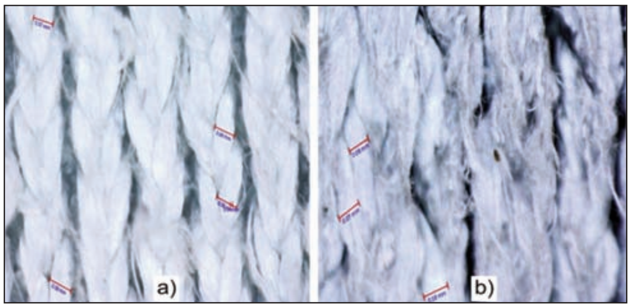


Fig. 3. Microscopic structure of Nano fibre polyester fabric S1 (a) and S2 (b)

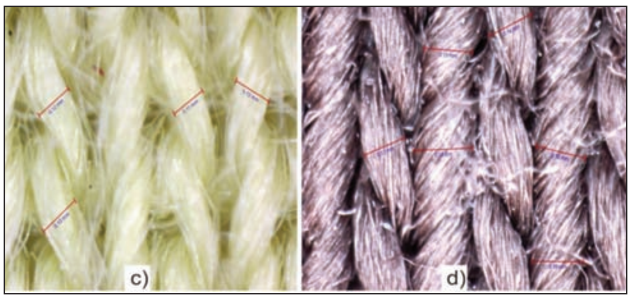


Fig. 4. Microscopic structure of coolmax (c) and cotton (d) fabric

Methods

In this study, thermal contact feeling of skin to fabric Thermal absorptivity, Thermal conductivity and Thermal resistivity were evaluated by the ALAMBETA thermal tester.

ALAMBETA

This instrument developedby L. Hes [16, 25] measures the thermal absorptivity "b" $\left(\frac{Ws^{1/2}K}{m^2K}\right)$, thermal conductivity "λ" $\left(\frac{W}{mK}\right)$, thermal resistance "r" $\left(\frac{m^2K}{W}\right)$ and thickness of the fabric samples (mm). The Contact pressure of this instrument is 200 kPa. 12 cm x 12 cm samples are used to place in the instrument for measurement.

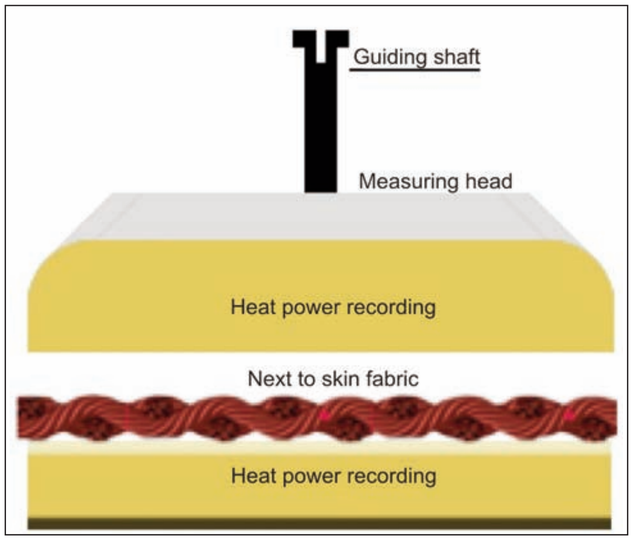


Fig. 5. Measuring head of the computer controlled ALAMBETA instrument

PERMETEST

Permetest is used to measure the water vapor resistance "Ret" $\left(\frac{m^2Pa}{W}\right)$ and Relative water vapor permeability (RWVP) by following the standard ISO 11092 [15, 23].

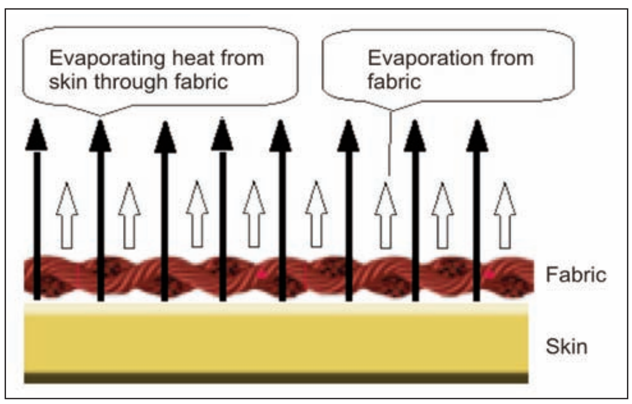


Fig. 6. Schematic diagram of Perme Tester

Table 2

Quantity	Symbol	Multiplier	Unit
Thermal conductivity (coefficient)	λ	10^{-3}	$W \cdot m^{-1} \cdot K^{-1}$
Thermal absorptivity, Thermal activity coefficient	b	1	$W \cdot m^{-2} \cdot s^{1/2} \cdot K^{-1}$
Thermal resistivity	r	10^{-3}	$K \cdot m^2 \cdot W^{-1}$

Atmospheric conditions

The wetness of the atmosphere can be calculated in terms of humidity.

$$RH\ (\%) = \frac{\text{absolute humidity of the air}}{\text{absolute humidity of the air saturated with water}} \times 100$$

RH (%) = 65% ± 2%;
Temperature = 20°C ± 2°C.

ANOVA test

ANOVA is the way to discover the significance of experimental results by the software SPSS statistics 17.0. Degree of freedom (df) of an estimate is the number of independent pieces of information that used in calculating the estimate. Mean squares are estimates of variance across groups and used in analysis of variance and calculated as a sum of squares divided by its appropriate degrees of freedom. The F-value is simply a ratio of two variances.

$$F\ \text{value} = \frac{\text{variance of the group means (Mean Square Between)}}{\text{mean of the within group variances (Mean Squared Error)}}$$

The F-value in the ANOVA test leads to P-value. P-value helps you determine the significance of your results

- p > .10 = not significant
- p ≤ .10 = marginally significant
- p ≤ .05 = significant
- p ≤ .01 = highly significant

RESULTS AND DISCUSSIONS

The present study is the sequel of clothing comfort of nano-filament polyester fabric. In a first part sensory evaluation has been reported which was experimented witha Kawabata evaluation system (KES). Sensorial evaluation of nano filament polyester fabrics were reported with the comparison in PC and PV blended suiting fabrics [26]. Total hand value (THV) resulted in lower stiffness (Koshi), and higher smoothness (Numeri) and fullness (Fukurami). THV of Polyester/Viscose blended fabric andnano-filament polyester fabric were almost same.The tensile, shearing, bending, compression and surface characteristics of nano-filament polyester fabric was notices best as compared to Polyester/Cotton and Polyester/Viscose blended fabric.

Thermal conductivity

The coefficientof thermal conductivity "λ" is used to narrate the heat quantity, passed through 1 m^2 of the material from 1 meter distance in 1 second to make 1 Kelvin temperature difference. The thermal conductivity range for the textile clothing is 0.033 – 0.01 $\left(\frac{W}{mK}\right)$.

Thermal conductivity of water is 0.61 $\left(\frac{W}{mK}\right)$ which is 25 times lesser than air 0.025 $\left(\frac{W}{mK}\right)$ [12]. Thermal conductivity (λ) is a fundamental parameter to determine the heat transfer through fabrics. Thermal conductivity is expressed by the equation,

$$\lambda = \frac{Q}{A \cdot \frac{\Delta t}{h}} \qquad (1)$$

λ is thermal conductivity;
Q – heat transmitted;
A – area;
Δ*t* – temperature gradient;
h – sample thickness.

According to figure 7, samples made of nano-filament yarns have higher thermal conductivity than other samples.

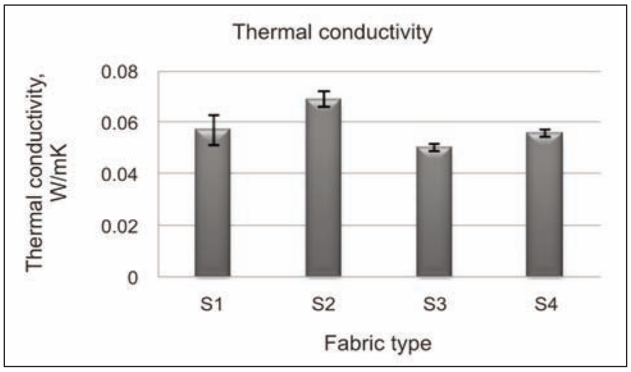


Fig. 7. Thermal conductivity of the tested fabric samples

It can be explained by the amount of entrapped air in the fabric. With the increase in weight (fiber per unit area), the amount of air layer decreases. As known for textile materials, still air in the fabric structure is the most important factor for conductivity value, as still air has the lowest thermal conductivity value when compared to all fibers $\left(\left(\lambda_{air} = 0.025 \left(\frac{W}{mK}\right)\right)\right)$.

Thus, heavier fabric (S2) with with more GSM (250 GSM) has the highest thermal conductivity values. However, Coolmax fabric (S3) has the loose structure and the lowest thermal conductivity value. Structures of each fabric samples are clearly demosrated in figure 3, *a, b* and 4, *c, d* by microscope. In table 3, the findings from the statistical results showed that the thermal conductivity hasa high significance effect on fabric type.

Thermal absorptivity

The uncommon parameterthermal absorptivity "b" serves to evaluate the thermal sensation when fabrics get into touch with human skin. Thermal absorptivity (b) is the warm-cool feeling of fabrics and determines the contact temperature of two materials. However, thermal absorptivity "b" is generally the superficial characteristic which can be modified by surface treatment (coating, raising, brushing). It is expressed as:

$$b = (\lambda \rho c)^{1/2}, \left(\frac{Ws^{1/2}}{m^2K}\right) \qquad (2)$$

Where λ is the thermal conductivity $\left(\frac{W}{mK}\right)$, ρ is the fabric density $\left(\frac{kg}{m^3}\right)$ and c is the specific heat of fabric $\left(\frac{J}{kgK}\right)$. If the thermal absorptivity is high, it gives a cooler feeling at first contact with the skin. The surface character of the fabric greatly influenced this sensation [15].

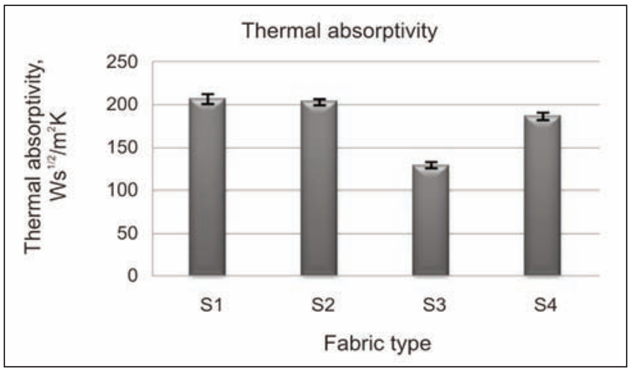


Fig. 8. Thermal absorptivity of the tested fabric samplesss

The results showed that samples made of nano-filaments yarns have higher thermal absorptivity, while coolmax fabric had a lower value. Fabrics with a lower value of thermal absorptivity provided ‘warm’ feeling, since it provided better thermal insulation and warmer feeling at initial touch. However, fabric having a higher value gave a ‘cool’ feeling. Thus, sample 3 (coolmax) exhibited a ‘warm’ feeling rather than other samples. The samples 1 and 2 revealed a higher value, which implies ‘cooler’ feeling at first contact.It can be explained by the construction of the fabric surface. In fact, the nano-filaments of polyester are characterized by their large surface area per unit mass as shown in figure 8 [20]. In fact, the surface area between the fabric and skin was bigger for smooth fabric surfaces like nano-filament fabrics and these structures caused a cooler feeling, as mentioned by Pac [27]. ANOVA results in table 3 determined that the thermal absorptivity have a high significance effect on the dependent variable (Fabric Type).

Thermal resistance

Thermal resistance expresses the thermal insulation of fabrics and is inversely proportional to thermal conductivity. In a dry fabric or containing very small amounts of water, it depends essentially on fabric thickness and, to a lesser extent, on fabric construction and fiber conductivity [28]. Thermal resistance (R) depends on fabric thickness “h” (mm) and thermal conductivity “λ”.

$$R = \frac{h}{\lambda}, \quad \left(\frac{m^2K}{W}\right) \tag{3}$$

or

$$R_{ct} = \frac{a-b}{a} \times 100 \tag{4}$$

R_{ct} is thermal resistance [%];

a = heat flow (no sample) [W];
b = heat flow (all samples) [W].

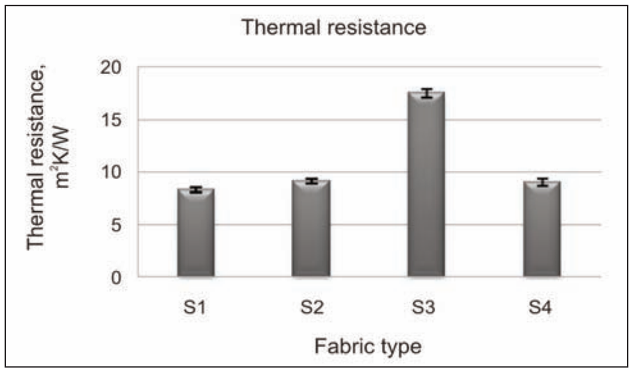


Fig. 9. Thermal resistance of the tested fabric samples

According to figure 9, coolmax fabric (S3) showed the higher value of thermal resistance. Samples made of nano-filaments yarns showed lower values. As the fabric thickness increases the thermal resistance increases. As expected, there is an inverse relationship between thermal conductivity and thermal resistance. ANOVA table given below showed that the independent variable (thermal resistance) has a statistically significant effect on the dependent variable (Fabric Type) as p-value obtained from all factors is less than the alpha value (0.01).

Table 3

Source	Type III sum of squares	df	Mean square	F	P
Thermal conductivity	.001	3	.000	22.619	.000
Thermal absorptivity	19190.000	3	6396.667	281.172	.000
Thermal resistance	285.738	3	95.246	712.118	.000
RWVP	1102.638	3	367.546	1374.003	.000

Relative Water Vapor Permeability (RWVP)

Pore size, air gap and structure of the textile material defines the RWVP. In this study, relative the water vapor permeability (%) and evaporation resistance “Ret” $\left(\frac{m^2Pa}{W}\right)$ of the studied fabrics was quantified by Permetest instrument within 3–5 minutes. Permetester

Table 4

RWVP AND R_{et} VALUES		
	RWVP (%)	**R_{et}** $\left(\frac{m^2Pa}{W}\right)$
S1	69.7	3.6
S2	66.3	4.1
S3	67.1	3.8
S4	50.8	4.8

also allows to simulate the thermal perception of wearer in wet conditions [22–23].

Relative water vapor permeability is the rate of water vapor transmission through a material. RWVP (%) of the textile clothing samples in the isothermal steady state is measured by the given equation:

$$\text{RWVP (\%)} = \frac{\text{Heat loss measured with sample}}{\text{Heat loss measured without sample}} \times 100$$

According to results, it is apparent that Sample 1 has a higher watervaporpermeability, while cotton sample exhibits lower value. Nano-filament fabrics have almost the same watervaporpermeability as coolmax fabric.

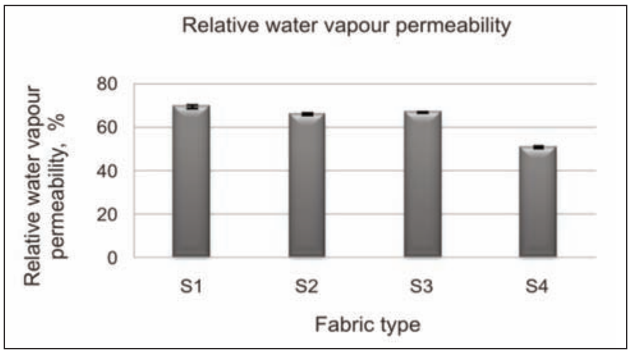


Fig. 10. Relative watervaporpermeability of the tested fabric samples

According to figure 10, nano-filament fabrics provided better water vapor permeability values because it has a larger surface area and nano-fiber structure which improve the transport system that pulls moisture away from the skin to the outer layer of the fabric. These fabrics are characterized by the small gaps between the fibers inside in the yarn. That's why the WPR of these fabrics is quite big as presented in table 4.

Thus, the type of yarn and fiber morphology affects the relative water vapor permeability significantly. Water vapor permeability "WVP" has significant importance in wet state as in dry state. When fabric is introduced to water, a fluid film is created that partially restrict the liquid permeability. Therefore the clothing comfort is also important to the wearer. Measurement of WVP with permetest sensora skin model exhibits certain advantage of giving repeatable values in not only in dry state, but also in wet state [23]. Statistical analysis in table 3 presented that the independent variable (RWVP) have a significant effect on the dependent variable (Fabric Type) as p-value is less than 0.01.

Water vapor resistance

Water vapor resistance presents the water vapor pressure difference between the two sides of the sample divided by the resultant evaporative heat flux per unit area in the direction of the gradient. It depends on the fabric density and structure. According to results, samples made of cotton sample showed a maximum value, while nano-filament sample displays a minimum value. The lower value of water vapor resistance indicates a better moisture transport and a higher value indicates that the fabric is less breathable to vapor transmission. Water vapor resistance is derived from the equation [22]

$$M = \frac{C_1 - C_2}{R} \tag{5}$$

M is the rate of diffusion of the mass of water vapor per unit area over the specimen $\left(\frac{\text{kg}}{\text{m}^2\text{s}}\right)$;

C_1, C_2 – concentrations of water vapor in the air on either side of the sample (kg/m^3);

R – resistance of the sample (s/m).

For fabrics with low water vapor resistance values, it is easier for water vapor to pass through the fabric and into the environment, resulting in drier skin thereby improving comfort [29]. Maximum value of R_{et} for layer of air in clothing is 5 mm.

CONCLUSIONS

Nano-filament fabric sample 2 (with GSM 250) showed the highest thermal conductivity because of lower air permeability as compared to S3 and S4. Similarly nano-filament polyester fabric demonstrated 'cool' feeling with higher thermal absorptivity, while multi channel coolmax fabric provided 'warm' feeling with low thermal absorptivity, since it gave better thermal insulation at initial touch. Coolmax fabric revealed the higher value of thermal resistance, in contrast with nano-filaments fabric because there is an inverse relationship between thermal conductivity and thermal resistance. In fact, nano-filament fabrics exhibited the better water vapor permeability by the reason of a larger surface area and nano-fibre structure implies to improve the transport system that pulls moisture away from the skin to the atmosphere. A fall in water vapor resistance raised the moving speed of water droplets through the nano-filament polyester fabric. ANOVA results showed the statistical significance of independent variables (Thermal properties and RWVP), on the dependent variable (Fabric Type) as p-value is less than 0.01.

Acknowledgments

The authors express their thanks to Mr. Satoshi Tonomura, Technical Assistantat Teijin Frontier Co., Ltd., providing the fabric samples.

Funding

This work was supported byTechnical University of Liberec (TUL), Student Grant (SGS 21200) 2017.

BIBLIOGRAPHY

[1] Pamuk, O. *Clothing comfort properties in textile industry*. In: Natural and Applied Sciences, 2008, vol. 3, issue 1, pp. 69–74.

[2] Hes, L., Araujo, M., Storova, R. *Thermal comfort of socks containing pp filaments*. In: Textile Asia, 1993, vol. 27, issue 12, pp. 57–59.
[3] Li, Y. *The science of clothing comfort*. In: Textile Progrogress, 2001, vol. 31, pp. 1–135.
[4] Behmann, F.W., Meissner, H.D. *Importance of the physiological behavior to humidity of textile fibers in garments*. In: Melliand Textilber, 1959, vol. 40, pp. 1209–1214.
[5] Mehrtens, D.G., Mcalister, K.C. *Fiber properties responsible for garment comfort*. In: Textile Research Journal, 1962, vol. 32, issue 8, pp. 658–665.
[6] Chakraborty, S., Kothari, V.K. *Effect of moisture and water on thermal protective performance of multilayered fabric assemblies for fire fighters*. In: Indian Journal of Fibre & Textile Research, 2017, vol. 42, issue 1, pp. 94–99.
[7] Hes, L., Sluka, P. *Introduction into clothing comfort*. Textbook of Technical University of Liberec, 2005.
[8] Gibson, P.W. *Factors influencing steady-state heat and water-vapour transfer measure for clothing materials*. In: Textile Research Journal, 1993, vol. 63, issue 12, pp. 749–764.
[9] Utkun, E. *Comfort-related properties of woven fabrics produced from Dri-release® yarns*. In: Industria Textila, 2014, vol. 65, issue 5, pp. 241–246.
[10] Hes, L. *The effect of planar conduction of moisture on measured water vapour permeability of thin woven fabrics*. Fall Fiber Society Conference, Lake Tahoe, 2002.
[11] Schneider, A.M., Hoschke, B.N., Goldsmid, H.J. *Heat transfer through moist fabrics*. In: Textile Research Journal, 1992, vol. 62, issue 2, pp. 61–66.
[12] Hes, L., Loghin, C. *Heat, moisture and air transfer properties of selected woven fabrics in wet state*. In: Journal of Fiber Bioengineering and Informatics, 2009, vol. 2, issue 3, pp. 141–149.
[13] Chen, Q., Zhao, T. *The thermal decomposition and heat release properties of the nylon/cotton, polyester/cotton and nomex/cotton blend fabrics*. In: Textile Research Journal, 2015, vol. 86, issue 17, pp. 1859–1868.
[14] Ahmad, S., Ahmad, F., Afzal, A., Rasheed, A., Mohsin, M., Ahmad, N. *Effect of weave structure on thermo-physiological properties of cotton fabrics*. In: AUTEX Research Journal, 2015, vol. 15, issue 1, pp. 30–34.
[15] Hes, L. *Thermal properties of nonwovens*. Proceedings of Congress Index 1987; 87: Geneva.
[16] Hes, L., Dolezal, I., Hanzl, J., Miklas, Z. *New method and apparatus for the objective evaluation of thermal contact properties of textile fabrics*. In: Melliand Textilber, 1990, vol. 71, p. 679.
[17] Sampath, M.B., Mani, S., Nalankilli, G. *Effect of filament fineness on comfort characteristics of moisture management finished polyester knitted fabrics*. In: Journal of Industrial Textile, 2011, vol. 41, issue 2, pp. 160–173.
[18] Park, S.W., Hwang, Y.G. *Comparison of total hand of single knitted fabrics made from linclite® and conventional wool yarns*. In: Textile Research Journal, 2002, vol. 72, issue 10, pp. 924–930.
[19] Yip, J., Ng, S.P. *Study of three-dimensional spacer fabrics: physical and mechanical properties*. In: Journal of Materials Processing Technology, 2008, vol. 206, issue 1, pp. 359–364.
[20] Chronakis, I.S. *Micro-/nano-fibers by electro spinning technology: processing, properties and applications*. In: Micro manufacturing Engineering & Technology, Boston, Elsevier, 2010, pp. 264–286.
[21] Wakeham, H., Spicer, N. *Pore-size distribution in textiles-a study of windproof and water-resistant cotton fabrics*. In: Textile Research Journal, 1949, vol. 19, issue 11, pp. 705–710.
[22] Farnworth, B., Lotens, W.A., Wittgen, P.P. *Variation of water vapour resistance of microporous and hydrophilic films with relative humidity*. In: Textile Research Journal, 1990, vol. 60, issue 1, pp. 50–53.
[23] Hes, L., Dolezal, I. *A new portable computer controlled skin model for fast determination of water vapour and thermal resistance of fabrics*. Asian Textile Conference, 2003, ATC 7, New Delhi.
[24] Hes, L., Bogusławska-Baczek, M., Geraldes, M.J. *Thermal comfort of bed sheets under real conditions of use*. In: Journal of Natural Fibers, 2014, vol. 11, issue 4, pp. 312–321.
[25] Hes, L., Araujo, L. *Simulation of the effect of air gaps between the skin and a wet fabrics on resulting cooling flow*. In: Textile Research Journal, 2010, vol. 80, issue 14, pp. 1488–1497.
[26] Azeem, M., Boughattas, A., Siddique, H.F., Havelka, A., Hussain, S. *Comfort properties of nano-filament polyester fabrics: Sensory evaluation*. In: Industria Textila, 2018, vol. 2.
[27] Pac, M.J., Bueno, M.A., Renner, M., Kasmi, S.E. *Warm-cool feeling relative to tribological properties of fabrics*. In: Textile Research Journal, 2001, vol. 71, issue 19, pp. 806–812.
[28] Haghi, A.K. *Moisture permeation of clothing*. In: Journal of Thermal Analysis and Calorimetry 2004, vol. 76, issue 3, pp.1035–1055.
[29] Fan, J., Tsang, H.W.K. *Effect of clothing thermal properties on the thermal comfort sensation during active sports*. In: Textile Research Journal, 2008, vol. 78, issue 2, pp.111–118.

Authors:

MUSADDAQ AZEEM *MSc.*
Prof. eng. LUBOS HES *DrSc.*
Prof. eng. JAKUB WIENER *Ph.D.*
MUHAMMAD TAYYAB NOMAN *MSc.*
Eng. AZAM ALI *MSc.*
TARIQ MANSOOR *MSc.*

Technical University of Liberec, Faculty of Textile Engineering
Studentska 1402/2, 461 17, Liberec 1, Czech Republic

Corresponding author:

MUSADDAQ AZEEM
e-mail: musaddaqazeem@yahoo.com

Air permability of worsted fabrics

DOI: 10.35530/IT.069.04.1448

HAKAN ÖZDEMİR

REZUMAT – ABSTRACT

Permeabilitatea la aer a țesăturilor din fire pieptănate

Confortul reprezintă unul dintre cele mai importante aspecte ale îmbrăcămintei. Permeabilitatea la aer, una dintre caracteristicile de confort ale țesăturilor, depinde în principal de structura țesăturii, care poate fi descrisă prin legătură și densitatea firului. În acest studiu, au fost produse 16 mostre de țesături din fire pieptănate pentru îmbrăcăminte de iarnă, utilizând opt tipuri de legături implementate frecvent, împreună cu o desime de urzeală (28 fire de urzeală/cm) și două desimi de bătătură (25 și 28 fire de bătătură/cm). Suplimentar, un finisaj semi-mat a fost aplicat pe țesăturile brute. Rezultatele au arătat efectul legăturii, al desimii firelor de bătătură și al finisajului asupra permeabilității la aer a țesăturilor. Țesătura cu legătură diagonal 2/2, a cărei porozitate este cea mai mică, are cele mai scăzute proprietăți de permeabilitate la aer, de aceea este mai potrivită pentru a fi utilizată pentru confecționarea îmbrăcămintei de iarnă. Se observă că, în toate tipurile de legătură, o creștere a desimii firelor de bătătură a determinat scăderea permeabilității la aer și a valorilor de porozitate. Procedeul de finisare duce, de asemenea, la scăderea porozității, reducând astfel proprietatea de permeabilitate la aer.

Cuvinte-cheie: permeabilitatea la aer, țesături din fire pieptănate, țesături, legătură, densitatea firului, porozitate

Air permability of worsted fabrics

Comfort is one of the most important aspects of clothing. Air permeability, one of the comfort charectaristics of fabrics, depends mainly on the fabric structure, which can be described by weave and yarn density. In this study, 16 worsted woven fabric samples were produced for winter clothing using eight frequently implemented weave types together with one warp density (28 ends/cm) and two weft densities (25 and 28 picks/cm). Additonally, semi-dull finish was applied on raw fabrics. Results revealed the effect of weave, weft yarn density and finishing process on air permeability of woven fabrics. 2/2 twill woven fabric, whose porosity is the lowest, have the lowest air permeability properties, therefore it is more convenient for winter clothing. It is observed that in all weave types, an increase at weft setting caused to decrease in air permeability and porosity values. Finishing process also leads to decreasesin porosity thereby to decrease air permeability property.

Keywords: air permeability, worsted fabrics, woven fabrics, weave, yarn density, porosity

INTRODUCTION

Air permeability, which is an important factor in clothing comfort, is an essential characteristic of apparel fabrics. In summer, the transfer of heat and sweat from human body to the atmosphere depends mainly on the permeability of the clothing material; therefore, a highly permeable material is preferable. However, the winter clothing should be less permeable to protect the human body from the cold weather. The effects of various fabric and test parameters on the air permeability of fabrics have been studied by many researchers.

Behera, Ishtiaque, and Chand measured air permeability of plain and twill fabrics [1]. They observed that plain fabric is more permeable to air than twill fabric. Almetwally and Mourad investigated the effect weave structures on the air permeability properties of cotton/spandex woven fabrics [2]. They observed that the order of fabric air permeability is as follows: plain > satin > twill. Zupin, Hladnik and Dimitrovski investigated the air permeability of 36 samples in nine different weave types and four different densities [3]. From this analysis it was found that samples woven in plain weave had nearly 25% higher air permeability than the samples woven in twill weave at the same density of the woven fabrics and also warp and weft densities strongly influenced the air permeability of woven fabrics. Vimal produced a series of woven fabrics differing only in weave structures and having the common count and fabric sett from three types of doubled yarns, namely compact/compact, conventional/conventional and compact/conventional [4]. Among the parameters, thickness exerted a strong influence on the air resistance. Buyukbayraktar investigated the effects of bagging deformation of the fabric to the air permeability performance [5]. She observed that weave type determined the air permeabilityresults of deformed fabrics when all other structuralparameters were same.

Umair et al. produced six different woven samples on air jet loom with two different weave designs (i.e. 3/1 twill and plain), three different picking sequences (i.e. single pick insertion (SPI), double pick insertion (DPI) and three pick insertion (3PI)) [6]. They found that fabrics woven in plain weave design and with simultaneous 3PI gave significantly better air permeability as compared to twill woven fabrics and those with double or SPI. Turan and Okur examined the effect of different weft settings on air permeability and porosity [7]. They observed that in all weave types (plain, 2/2 twill, 3/1 twill) an increase at weft setting caused decrease in air permeability and porosity values. Çay and Tarakçıoğlu dried thirty woven fabrics with different porosities by vacuum extraction method [8]. Due to the increase of the warp and weft yarn density, the air permeability of the fabrics decreased. Basal, Mecit, Duran and Ilgaz produced woven fabrics at three weft densities [9]. They observed that at high weft densities airpermeability was low. Oğulata and Mezarcioz carried out on seven woven samples (one panama weave, six plain woven) in different warp and weft densities [10]. They observed that if a fabric has very high porosity, it can be assumed that it is permeable.

Lolaki, Shanbeh and Borhani investigated the effect of fabric structural parameters of double-face woven fabrics [11]. Results revealedthe effect of kind of porous yarn, hole size of hollow yarn, and weft density on air permeability and moisturetransfer of woven fabrics. Angelova et al. prepared 14 systems of fabrics, used for the production of outerwear clothing for protection from cold, on the basis of 16 single textile macrostructures: 14 woven and two non-wovens [12]. They observed that the air permeability of the single layer decreased with the increment of its thickness and mass perunit area, while the higher porosity had a positive effect on the transfer of air. Urbas, Kostanjšek and Dimitrovski wove six different structures of woven cotton fabrics – one-layer fabric, double-weft fabrics and double fabrics [13]. They found that air permeability is only the function of porosity of samples and their pore structure.Mahbub et al. investigated the air permeabilities of plain woven Kevlar/wool and Kevlar ballistic fabrics [14]. They observed that the Kevlar/wool fabric has higher airpermeability and optical porosity than Kevlar fabric.

Önder, Kalaoğlu and Özipek examined ten samples varying in raw materials, yam production methods, and fabric construction [15]. They observed that polyester and yarn type significantly affected fabric air permeability.

The studies in literature focused on fabrics woven with basic weaves such as plain, twill, satin. However matt (basket), herringbone and diced weaves and worsted woven fabrics have not been investigated. The aim of this study was to investigate the effects of fabric structural parameters and finishing process on the air permeability of the commonly used clothing worsted fabrics. In this regard, an experimental study has been carried out and then, the effects of the parameters were detected firstly by graphics formed by obtained data and secondly by analysis of variance.

THEORETICAL

Since textiles are discontinuous materials, being produced from macroscopic sub-elements such as fibres and filaments, they have void spaces or pores and therefore finite porosities [16]. Hseih defines porosity as [17]

$$\varepsilon = 1 - \frac{\rho_a}{\rho_b} \quad (1)$$

where ρ_a is the fabric density (g/cm^3), ρ_b – the fibre density (g/cm^3) and ε – the porosity. Fabric density is calculated by dividing the fabric weight per unit area, by fabric thickness.

The pores of a fabric can be classified as pores between the yarns and the pores within the yarns between the fibres (micro voids). The dimensions of the pores between the yarns are directly affected by the yarn density and yarn thickness. By the increasing of the yarn density, the dimensions of the pores become smaller, thus the permeability decreases [18–19]. The dimensions of pores within the yarns between the fibres (micro voids) are generally affected by fibre fineness, yarn count, yarn twist and crimp, and also the deformation and flattening of the yarns. During the air flow, air tends to pass through the largest pore. For loose fabrics, air mainly passes through the pores between the yarns due to the large pore dimensions; however, a dominant air flow through the yarns between the fibres can occur in the case of dense fabrics that have very small pores between the yarns [20]. The resistance of the fabric to air is very high in dense fabrics, so air passes through all the voids. According to the fabric structure, a great variation on the amount of the air flow and the air flow paths can be possible.

MATERIALS AND METHOD

Materials

In this research sixteen types of worsted fabric samples were woven by DORNIER modified loom with rapier picking mechanism. Nm 80/2 staple fiber of 45/55% WO/PES blend worsted yarn in blackcolor was used. Weave patterns are shown in figure 1. While warp setting on the loom of was 28 cm^{-1}, weft settings on the reed were 25 and 28 cm^{-1}. Semi-dull finish was applied on fabric samples in singeing, rinsing, mini stenter, foulard and decofast machines, respectively. Face of fabrics was singed with the passing speed of 110 m/min. The temperature of blanket was 80 °C. Internal pressure was 14 mbar. And then, fabrics were rinsed at 50 °C with the speed of 20 m/min in rinsing machine. They were fixed thermally at 190 °C with the speed of 2 m/min in mini stenter. And later, they were treated with the silicone solution, whose concentration was 40 g/l, in foulard. Lastly, they were applied decatizing treatment at cylinder pressure of 3 bar and felt pressure of 0.2 bar with the speed of 18 m/min in decofast.

Fabric samples were coded according to finishing, their weave pattern and weft densitiesas in table 1. While the letter in each fabric code represents finishing, numbers represent weave patterns and weft yarn densities. Plain, 2/1 twill, 2/2 twill, 5 end sateen, 2/2 matt and 2/1 herringbone weaves are square

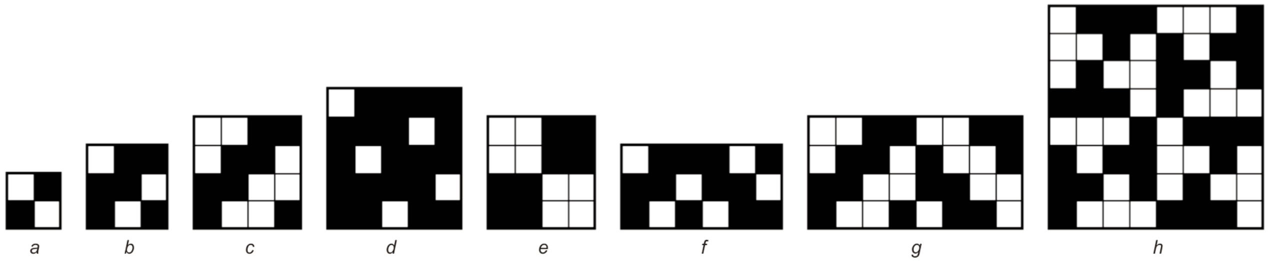


Fig. 1. Weave patterns used in experimental

Table 1

Fabri code	Finishing	Weave	Warp setting on the loom (cm^{-1})	Weft setting on the reed (cm^{-1})	The weave interlacing coefficient	Thickness (mm)	Mass per unit area (g/m^2)	Porosity (ε)
A1	Raw fabric	Plain	28	25	1	0.34	158.5	0.32
A2	Raw fabric	Plain		28		0.36	167.4	0.28
A3	Raw fabric	2/1 Twill	28	25	0.67	0.45	163.9	0.24
A4	Raw fabric	2/1 Twill		28		0.47	172.8	0.20
A5	Raw fabric	2/2 Twill	28	25	0.5	0.40	161.3	0.22
A6	Raw fabric	2/2 Twill		28		0.42	169.5	0.19
A7	Raw fabric	5 End sateen	28	25	0.4	0.38	160.2	0.18
A8	Raw fabric	5 End sateen		28		0.41	170.1	0.14
A9	Raw fabric	2/2 Matt	28	25	0.5	0,36	159.1	0.20
A10	Raw fabric	2/2 Matt		28		0.38	168.3	0.17
A11	Raw fabric	2/1 Herringbone	28	25	1.5	0.44	163.5	0.26
A12	Raw fabric	2/1 Herringbone		28		0.46	172.2	0.23
A13	Raw fabric	2/2 Herringbone	28	25	0.625	0.41	161.8	0.30
A14	Raw fabric	2/2 Herringbone		28		0.43	169.7	0.26
A15	Raw fabric	Diced weave	28	25	0.625	0.42	162.4	0,28
A16	Raw fabric	Diced weave		28		0.44	172.1	0.25
B1	Finished fabric	Plain	28	25	1	0.36	153.7	0.29
B2	Finished fabric	Plain		28		0.38	162.6	0.25
B3	Finished fabric	2/1 Twill	28	25	0.67	0.47	158.7	0.20
B4	Finished fabric	2/1 Twill		28		0.49	149.6	0.17
B5	Finished fabric	2/2 Twill	28	25	0.5	0.42	156.5	0.19
B6	Finished fabric	2/2 Twill		28		0.44	148.6	0.16
B7	Finished fabric	5 End sateen	28	25	0.4	0.40	155.3	0.15
B8	Finished fabric	5 End sateen		28		0.43	145.6	0.10
B9	Finished fabric	2/2 Matt	28	25	0.5	0,38	154.2	0.17
B10	Finished fabric	2/2 Matt		28		0.40	145.7	0.14
B11	Finished fabric	2/1 Herringbone	28	25	1.5	0.46	158.4	0.23
B12	Finished fabric	2/1 Herringbone		28		0.48	150.3	0.20
B13	Finished fabric	2/2 Herringbone	28	25	0.625	0.43	156.7	0.26
B14	Finished fabric	2/2 Herringbone		28		0.45	148.9	0.23
B15	Finished fabric	Diced weave	28	25	0.625	0.44	157.6	0.25
B16	Finished fabric	Diced weave		28		0.46	147.5	0.22

weaves, so the number of each warp and weft yarn interlacing is equal to each other, namely the average yarn interlacing is equal to number of yarn interlacing. The weave interlacing coefficient, defined by Galcerán was calculated by equation 2 [21]

$$KL = \frac{i}{w_1 \times w_2} \qquad (2)$$

where i is the number of interlacing points in weave repeat, w_1 – the number of ends in weave repeat, w_2 – the number of picks in weave repeat.

Table 2

Weave pattern	The warp yarn interlacing coefficient	The weft yarn interlacing coefficient
Herringbone	0.5	0.75-0.5
Diced	0.5-0.75	0.5-0.75

On the other hand, 2/2 Herringbone and diced weaves are not square unit weaves. Moreover, in 2/2 Herringbone, single numbered weft yarns interlace in different way from even numbered weft yarns, namely it has two different weft yarn interlacing coefficients as given in table 2. Besides, in diced weave, the single numbered warp and weft yarn interlacing coefficients are different from even numbered warp and weft yarn interlacing coefficients, calculated by equation 3;

$$yic_{1/2} = \frac{i_{1/2}}{w_{1/2}} \tag{3}$$

where $i_{1/2}$ is the number of warp or weft interlacing points in weave repeat, $w_{2/1}$ – the number of picks or ends in weave repeat.

Methods

Measurements and air permeability tests were conducted on the fabrics in Physical Testing Laboratory of in-house. The fabric samples were conditioned at standard atmosphere conditions (20 ± 2°C, %65 ± 2 relative humidity) for 24 hours in Physical Testing Laboratories.

Determination of fabric properties

Fabric thickness is measured by R&B Cloth Thickness Tester in compliance with EN ISO 5084 [22]. Mass per unit area of samples was determined according to EN 12127 [23]. The specifications of fabric samples are given in table 1.

Air permeability test

Air permeability was measured in accordance with EN ISO 9237:1995 (24), by the Tex-Test air permeability tester (FX3300, Switzerland), where the air permeability is expressed as the quantity of air in cubic centimeters, passing through a square centimeter of fabric per second ($cm^3/sec \cdot cm^2$). The air permeability tests were made for a test pressure drop of 100 Pa (20 cm^2 test area). The average of five measurements was used for comparison. The air permeability tester is shown in figure 2.

Fig. 2. Air permeability tester

Statistical evaluation

Air permeability test results were evaluated statistically by ANOVA according the General Linear Model with SPSS 15.0 software package. In order to analyse the effect of weave and weft yarn density, multivariate analysis was made for the two groups of fabrics: one including fabrics which were not applied any finishing process, the other including fabrics applied finishing process. Significance degrees (p), which were obtained from ANOVA, were compared with significance level (α) of 0.05. The effect, whose significance degree was lower than 0.05, was interpreted as statistically important.

Besides, the effect of finishing on air permeability of fabrics was evaluated by t-tests for raw-finished fabrics. t-tests were done by MATLAB 6.5 with significance level (α) of 0.05 also. Hypothesis of h_0 was defined that averages were equal. If h, the calculated value, was equal to 1, h_0 would be ignored, namely; the difference between the air permeability test results is statistically important.

Results and discussions

Air permeability of WO/PES worsted fabrics before and after finishing is shown in figure 3. From the figures, it was observed that the air permeability of fabric samples change according to finishing, weave pattern and weft density. Air permeability of fabrics that were not applied any finishing process are higher than those of fabrics that were applied finishing process. This is due to the fact that when the finishing process is applied on fabric, yarns swell with liquor and shrink, the density of fabrics increase. Therefore the prosity of raw fabrics are higher than finished fabrics.

The samples A1, A2 whose weaves are plain weave have the highest air permeability property. This is because of the fact that plain weave have the highest weave interlacing coefficient, namely the number of interlacing is the most frequent one in that each yarn goes once over and next under the intersecting yarn and this prevent intersecting yarns stand besides, so porosity of the plain is the highest. The samples A9, A10, A7 and A8 whose weaves are 2/2 matt and 5 end sateen weaves have higher air permeability properties than other samples. Although the calculated porosity of 2/2 matt is low, the matt weave has the less interlacing coefficient than 2/1 twill, 2/1 herringbone, 2/2 herringbone and diced weaves.The floating pairs of matt weaves get close to each other, this increase the porosity of the matt weave. And also, 5 end sateen weave there are warp yarn floats passing

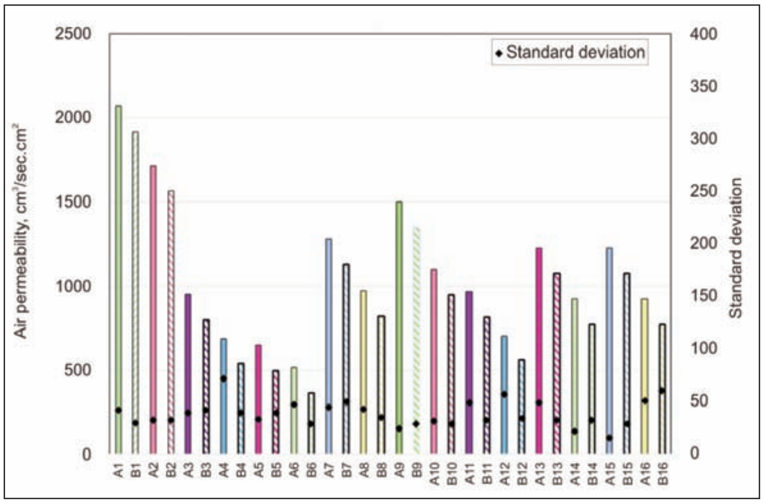


Fig. 3. Air permeability of raw and finished fabrics

The variance analysis showed that both the effects of weave and weft density on air permeability of the raw and finished fabrics are statistically significant, getting the p-values of (0.002) and (0.042) respectively. The results of t-test confirmed that the air permeability changed with the finishing process, having the h-values of (1) for the raw-finished fabrics.

over four weft yarns, these longer yarn floats move away from each other easily by air pressure applied during air permeability test, namely porosity of 5 end sateen fabric increased during the test, the calculated porosity of 5 end sateen is low though. The air permeability of samples A13 and A14 whose weaves are 2/2 herringbone weave are approximately equal to those of samples A15 and A16 whose weaves are diced weave. Because the weave interlacing coefficients and warp and weft yarn interlacing coefficients of these weaves are equal to each other. Additionally, the air permeability of samples A11 and A12 whose weaves are 2/1 herringbone weave are approximately equal to those of samples A3 and A4 whose weaves are 2/1 twill weave. This is due to the fact that the weave interlacing of 2/1 herringbone weave is equal to that of 2/1 twill weave.

When compared binary groups of (A1, A2), (A3, A4), (A5, A6), (A7, A8), (A9, A10), (A11, A12), (A13, A14), (A15, A16) within them, the air permeability of the fabrics decreases, as shown in figure 3, due to the increase of the weft yarn density. Because the dimensions of the pores through which the air would pass are getting smaller, when moving from loose fabrics towards dense fabrics. For dense fabrics, the resistance to air flow is higher than for loose fabrics.

When compared binary groups of (A1, B1), (A2, B2), (A3, B3), (A4, B4), (A5, B5), (A6, B6), (A7, B7), (A8, B8), namely when the finishing process was applied on fabric, wihtin them, air permeability of fabrics decreases. This due to the facts that yarns swell with liquor and shrink, density of fabrics increased, and thereby porosity and air permeability of fabrics decrease.

CONCLUSIONS

This paper presents a comprehensive experimental study, conducted on a series of raw and finished worsted woven fabric samples, which are used for production of outerwear clothing for protection from cold, with commonly used weaves. With the least air permeability, 2/2 twill woven fabric can be preferred for the winter clothing to protect the human body from the cold weather.

Results indicate that the permeability and pore size are strongly related to each other. If a fabric has very high porosity, it can be assumed that it is permeable. So the factors that change the porosity such as weave pattern, weft yarn density and finishing also affect the permeability properties of fabrics. Oğulata and Mezarcioz (10), Lolaki, Shanbeh and Borhani (11), Angelova et al. (12) and Urbas, Kostanjšek and Dimitrovski (13) reached similar results.

The structural properties of weaves such as the weave interlacing coefficient, namely the density of interlacing points as for plain weave, arrangement of yarns side by side as in 2/2 matt weave are factors that increase the porosity of fabrics, so increase their air permeability's. Long length of warp yarn floats in 5 end sateen cause to increase air permeability. Due to the least weave interlacing coefficient, 2/2 twill fabric has the least air permeability values. Behera, Ishtiaque, and Chand (1), Almetwally and Mourad (2), Zupin, Hladnik and Dimitrovski (3) and Umair et al. (6) obtained similar results for plain, sateen and twill weaves.

When the number of yarns per unit area increased, the pores between the yarns become smaller, and then air permeability of tight fabrics decreased. Buyukbayraktar [5], Turan and Okur (7) and Çay and Tarakçıoğlu (8) reached the same result.

It is observed that porosity and air permeability of finished fabrics decreased, because the density of finished fabrics increased as a result of yarn swelling with liquer and yarn shrinkage.

BIBLIOGRAPHY

[1] Behera, B.K., Ishtiaque S.M., Chand S. *Comfort properties of fabrics woven from ring-, rotor-, and friction-spun yarns*, In: The Journal of the Textile Institute, 1997, vol. 88, issue 3, p. 255.

[2] Almetwally, A.A., Mourad M.M. *Effects of spandex drawing ratio and weave structure on the physical properties of cotton/spandex woven fabrics*, In: The Journal of the Textile Institute, 2014, vol. 105, issue 3, p. 235.

[3] Zupin, Z., Hladnik, A., Dimitrovski, K. *Prediction of one-layer woven fabrics air permeability using porosity parameters*, In: Textile Research Journal, 2011, vol. 82, issue 2, p. 117.

[4] Vimal, T. *Regression model for predicting the air resistance of fabric made from doubled yarns and with different weave structures*, In: The Journal of the Textile Institute, 2016, vol. 107, issue 10, p. 1268.

[5] Buyukbayraktar, R.B. *The relationship between the bagging deformation and air permeability performance of woven fabrics*, In: Industria Textila, 2014, vol. 65, issue 1, p. 10.

[6] Umair, M., Hussain, T., Shaker, K., Nawab, Y., Maqsood, M., Jabbar, M. *Effect of woven fabric structure on the air permeability and moisture management properties*, In: The Journal of the Textile Institute, 2016, vol. 107, issue 5, p. 596.

[7] Turan, R.B., Okur, A. *Investigation of pore parameters of woven fabrics by theoretical and image analysis methods*, In: The Journal of the Textile Institute, 2012, vol. 103, issue 8, p. 875.

[8] Çay, A.,Tarakçıoğlu, Işık. *Relation between fabric porosity and vacuum extraction efficiency: Energy issues*, In: The Journal of the Textile Institute, 2008, vol. 99, issue 6, p. 499.

[9] Basal, G., Mecit, D., Duran, D., Ilgaz S., *Comfort properties of double layered knitted and woven fabrics*, In: Industria Textila, 2009, vol. 60, issue 6, p. 299.

[10] Ogulata, R.T., Mezarcioz, S.M. *Total porosity, theoretical analysis, and prediction of the air permeability of woven fabrics*, In: The Journal of the Textile Institute, 2012, vol. 103, issue 6, p. 654.

[11] Lolaki, A., Shanbeh, M., Borhani, S. *Effect of structural parameters of porous yarns and fabric on air permeability and moisture transfer of double-face woven fabrics*, In: The Journal of the Textile Institute, 2016, DOI: 10.1080/00405000.2016.1207270, p. 1.

[12] Angelova, R.A., Reiners, P., Georgieva, E., Konova, H.P., Pruss, B., Kyosev, Y. *Heat and mass transfer through outerwear clothing for protection from cold: influence of geometrical, structural and mass characteristics of the textile layers*, In: Textile Research Journal, 2016, DOI: 10.1177/0040517516648507, p. 1.

[13] Urbas, R., Kostanjšek, K., Dimitrovski K. *Impact of structure and yarn colour on uv properties and air permeability of multilayer cotton woven fabrics*, In: Textile Research Journal, 2011, vol. 81, issue, 18, p. 1916.

[14] Mahbub, R.F., Wang, L., Arnold, L., Kaneslingam, S., Padhye, R. *Thermal comfort properties of kevlar and kevlar/wool fabrics*, In: Textile Research Journal, 2014, vol. 84, issue 19, p. 2094.

[15] Önder, E., Kalaoğlu, F., Özipek, B. *Influence of varying structural parameters on the properties of 50/50 wool/polyester blended fabrics*, In: Textile Research Journal, 2013, vol. 73, issue 10, p. 854.

[16] Rebenfeld, L., Miller, B. *Using liquid flow to quantify the pore structure of fibrous materials*, In: Journal of the Textile Institute, 1995, vol. 86 issue, 2, p. 241.

[17] Hseih, Y.L., *Liquid transport in fabric structures*, In: Textile Research Journal, 1995, vol. 65, issue 5, p. 299.

[18] Brown, J.J., Rusca, R.A. *Effect of fabric structure on fabric properties*, In: Textile Research Journal, 1955, vol. 25, p. 472.

[19] Clayton, F.H., *The measurement of the air permeability of fabrics*, In: Journal of the Textile Institute, 1935, vol. 26, p. 71.

[20] Backer, S. *The relationship between the structural geometry of a textile fabric and its physical properties, Part 4: Interstice geometry and air permeability*, In: Textile Research Journal, 1951, vol. 65, issue 1, p. 703.

[21] Galceran, V. *Tecnologı´adelTejido* (*Weaving Technology*). In: Publication of Technical University of Catalonia Terrassa, Spanish, 1962.

[22] EN ISO 5084. Textiles – Determination of thickness of textiles and textile products, 1996.

[23] EN 12127. Textiles – Fabrics – Determination of mass per unit area using small samples, 1997.

[24] EN ISO 9237. Textiles – Determination of permeability of fabrics to air, 1995.

Authors:

HAKAN ÖZDEMİR

Dokuz Eylül University
Faculty of Engineering, Department of Textile Engineering

Buca-35397, İzmir, Turkey

e-mail: h.ozdemir@deu.edu.tr

Colour properties of cigarette smoke-exposed cotton and silk fabrics and their nicotine release

DOI: 10.35530/IT.069.04.1396

WANTANEEPORN NONGNUCH
POTJANART SUWANRUJI
JANTIP SETTHAYANOND

REZUMAT – ABSTRACT

Proprietățile de culoare ale țesăturilor din bumbac și mătase expuse la fumul de țigară și eliberarea de nicotină

Expunerea la fumul de țigară a determinat modificarea culorii la țesăturile de bumbac și mătase nevopsite, printr-un efect de îngălbenire. Gradul de îngălbenire a fost mai dominant pe țesătura de bumbac. Atunci când țesăturile vopsite au fost supuse la fumul de țigară, s-a observant un efect mai pronunțat asupra țesăturilor vopsite în culori pale. Modificarea culorii a fost invers proporțională cu rezistența culorii țesăturilor vopsite. În plus, un timp de expunere mai lung a determinat, de asemenea, modificarea culorii țesăturilor, în timp ce rezistența culorii țesăturilor vopsite nu a fost afectată. Eliberarea de nicotină din țesăturile expuse la fumul de țigară în stare umedă a fost studiată în medii apoase diferite, precum apa, soluțiile tampon (pH 5,5 și 8,0) și transpirațiile artificiale (acide și alcaline), pentru a reflecta riscul potențial pentru utilizatorii de textile în ceea ce privește substanțele toxice din textilele contaminate cu fum de țigară.

Cuvinte-cheie: fum de țigară, bumbac, mătase, nicotină, vopsire

Colour properties of cigarette smoke-exposed cotton and silk fabrics and their nicotine release

Exposure to cigarette smoke caused colour change to undyed cotton and silk fabrics by a yellowing effect. The degree of yellowing was more dominant on cotton fabric. When the dyed fabrics were subjected to cigarette smoke, a more pronounced effect was observed on the pale shade dyed fabrics. Shade alteration was inversely related to the colour strength of the dyed fabrics. In addition, a longer exposure time also induced colour change in the fabrics while the colour strength of the dyed fabrics was unaffected. Nicotine release from the cigarette smoke-exposed fabrics in the wet state was studied in different aqueous media, viz. water, buffer solutions (pH 5.5 and 8.0) and artificial sweats (acid and alkaline) in order to reflect the potential risk to textile users of the toxicants from textiles contaminated with cigarette smoke.

Keywords: cigarette smoke, cotton, silk, nicotine, dyeing

INTRODUCTION

Cigarette smoke is a harmful source of numerous toxic substances, both volatile and non-volatile. From over 4,000 chemicals found in cigarette smoke, about 250 chemical substances have been identified as harmful and at least 69 of those chemicals are known to be carcinogenic [1]. Nicotine, tar and carbon monoxide are major substances found in cigarette smoke [2]. For textiles, exposure to cigarette smoke causes unpleasant odour and also toxicants deposited on the textiles. The adsorption of cigarette smoke depends on the chemical and physical properties of the textile fibres. Textiles produced from natural fibres exhibit higher cigarette smoke odour adsorption as compared with those from synthetics [3]. In addition, the volatile organic compounds released from natural fibres are higher than that from synthetic fibres. Also, natural fibres of plant origin emit in a different way from animal fibres [4]. Cigarette smoke deposited on cotton textile fabric was studied for its potential danger to human health, by examining permeation of textile-bound nicotine to human skin and evaluating the effect of cigarette smoke extracts from the fabric on fibroblasts, neurocytes and zebrafish embryos. It was found that about 50% of nicotine extracted into artificial sweat (pH 5.5) could permeate through human skin. Moreover, the cigarette smoke extracted into artificial sweat exhibited a concentration-dependent cytotoxicity to fibroblasts and neurocytes. It also caused a delay in development and death to zebrafish embryos. This points out a potential risk of cigarette smoke-contaminated textiles in causing an adverse effect to human health [5].

Nicotine is an alkaloid substance found as a key toxic component in cigarette smoke. It is a cause of addiction to cigarettes. With pK_a values of 3.1 and 8.0, under acidic condition nicotine is mainly in the protonated state, while under alkaline pH, it predominantly exists in the unprotonated free base form. Nicotine in its unprotonated state absorbs much more readily through the airway epithelium and increases with pH [6–8]. Nicotine has been found to cause cardiovascular disease, accelerated atherogenesis and cancers [9–10].

Therefore, the effect of the cigarette smoke retained on cotton and silk fabrics on the colorimetric properties of the undyed and dyed fabrics was investigated in this work. Hot-dyeing reactive dyes were used for cotton, and silk was dyed with acid dyes. Nicotine was chosen as a representative of the cigarette smoke constituents for this study. The release of nicotine deposited on the cigarette smoke-exposed fabrics was monitored in different aqueous media, viz. water, buffer solutions and artificial sweats solutions. This aimed to gain a view of possible nicotine release from cotton and silk textiles in the wet states, especially by human sweats which textiles normally encounter during their usage.

EXPERIMENTAL WORK

Materials

Scoured plain weave cotton and silk fabrics have a weight of approximately 144 g/m^2. Analytical grade nicotine was purchased from Merck. Procion H-E reactive dyes and Supralan acid dyes were kindly supplied by DyStar Co., Thailand. The cigarette used was Marlboro Red. Dypidol 101B anionic wetting agent was from Brenntag Co., Thailand. Sodium sulfate (Na_2SO_4) and sodium carbonate (Na_2CO_3) were purchased from Ajax Finechem.

Methods

1. Exposure of the fabrics to cigarette smoke

The scoured cotton and silk fabrics were cut into 10×50 cm rectangular shapes. The fabrics were oven-dried at 105 °C for 1 h and then kept in a desiccator. For each fabric exposure, fabric pieces were hung vertically in a closed acrylic box with the size of 30×30×30 cm and the distance between the smouldering cigarette and fabric of 15 cm. The exposure times studied were varied at 12, 36 and 60 min, which were equivalent to one, three and five cigarettes smoked at 25 °C. The experiment was conducted with three replicas. The whiteness and yellowness values on the exposed fabrics were then determined in comparison with the unexposed counterparts. An alteration in whiteness and yellowness of the fabrics was expressed as %ΔW and %ΔY, as shown in equations 1 and 2, respectively.

$$\%\Delta W = \left(\frac{W_0 - W_t}{W_0}\right) \times 100 \qquad (1)$$

Where W_0 denotes the fabric whiteness before exposure and W_t denotes the fabric whiteness after cigarette smoke exposure for any designed times.

$$\%\Delta Y = \left(\frac{Y_0 - Y_t}{Y_0}\right) \times 100 \qquad (2)$$

Where Y_0 denotes the fabric yellowness before exposure and Y_t denotes the fabric yellowness after cigarette smoke exposure for any designed times.

2. Dyeing of cotton and silk fabrics

Cotton dyeing was conducted using the hot-dyeing reactive dyes, i.e. Procion Yellow H-E6G, Procion Red H-E7B and Procion Navy H-ER 150%, at 0.5 and 4%owf for pale and heavy shade, respectively, at a liquor ratio of 20:1. Sodium sulfate at 20 g/L was used as an auxiliary to promote the dye exhaustion.The dye and sodium sulphate were added at the beginning and the dyeing was conducted at 80°C for 10 minutes. After that, the alkali, sodium carbonate at 15 g/L was added to accelerate the dye fixation and the fabrics were dyed further for 30 minutes. The dyed fabrics were then washed off in 1 g/L wetting agent at 90 °C for 20 min, rinsed and air dried. Silk fabrics were dyed with 0.5 and 4%owf Supralan Yellow 4GL, Supralan Red GWN and Supralan Blue GLW dyes, at 30:1 liquor ratio. The dyebath was set at pH 5 and sodium sulfate was added at 2 g/L. The dyeing was conducted at 95 °C for 40 minutes.The dyed silk was then rinsed with water and air dried.

3. Colourimetric determination

The colourimetric properties of the dyed fabrics were examined with a Macbeth ColourEye7000 spectrophotometer. The colour yield (K/S values) and the shade alteration (Δa*, Δb* and ΔE_{cmc} values) of the cigarette smoke-exposed dyed fabrics were measured against unexposed counterparts.

4. Nicotine release analysis

The nicotine content released from the fabric exposed to cigarette smoke was investigated in different aqueous media viz. water, buffer solutions and artificial sweat solutions. The scoured and oven-dried cotton and silk fabrics that had passed through the cigarette smoke exposure process were taken to determine their nicotine release ability by impregnating in 50 ml of various aqueous media: water, buffer solutions of pH 5.5 and 8 and artificial sweat solutions both acid and alkaline. The artificial sweat solutions were prepared by following the standard ISO 105/E04 method for testing acid and alkaline perspiration. The fabrics were impregnated with the solutions and incubated at 37 °C for 4 h. After that, the fabric was removed and the nicotine content in the solutions was determined by measuring the absorbance with a Specord UV/Vis spectrophotometer at 260 nm. The nicotine content was calculated from the calibration graph of standard nicotine in various aqueous media. The calibration graph of nicotine was built from the known concentration nicotine solutions and their absorbance values at 260 nm. The nicotine content of the exposed cotton and silk fabrics in various solutions was compared.

RESULTS AND DISCUSSION

1. Effect of cigarette smoke exposure on colourimetric properties of cotton and silk fabrics

As seen in Table 1, undyed cotton had a higher degree of whiteness than the undyed silk fabric, as cotton was an off-white shade, while the colour of silk fabric was pale yellow. When these fabrics were exposed to cigarette smoke, they lost their whiteness and become yellower. The degree of yellowness increased with increased exposure time. The %ΔW and %ΔY indicate the extent of the change in whiteness and yellowness, respectively; larger change accompanying the time of exposure to cigarette smoke. It is expected that the substances comprising cigarette smoke cause yellowing to the fabrics. With more smoke exposure, the more yellowing takes place. Cigarette smoke was previously reported to yellow the hair and nails of the smoker. Yellowing was claimed to be the effect of nicotine contained in the cigarette smoke as nicotine itself is pale yellow [11].

Table 1

WHITENESS AND YELLOWNESS VALUES OF COTTON AND SILK EXPOSED TO CIGARETTE SMOKE

Fabric	Exposure time (min)	Whiteness		Yellowness	
		W_0	ΔW (%)	Y_0	ΔY (%)
Cotton	12	73.60	6.41	1.99	46.51
	36		17.22	2.02	68.97
	60		25.42	1.96	76.69
Silk	12	53.60	5.11	7.89	12.33
	36		14.26	7.75	38.97
	60		21.27	7.90	40.42

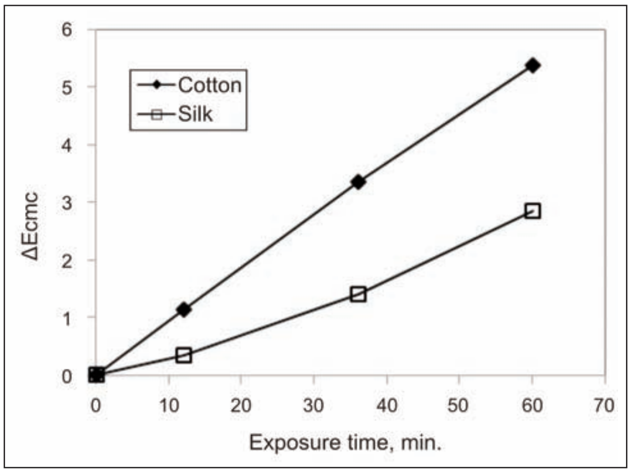


Fig. 1. Colour difference (ΔE_{cmc}) of cotton and silk fabrics exposed to cigarette smoke for various exposure times

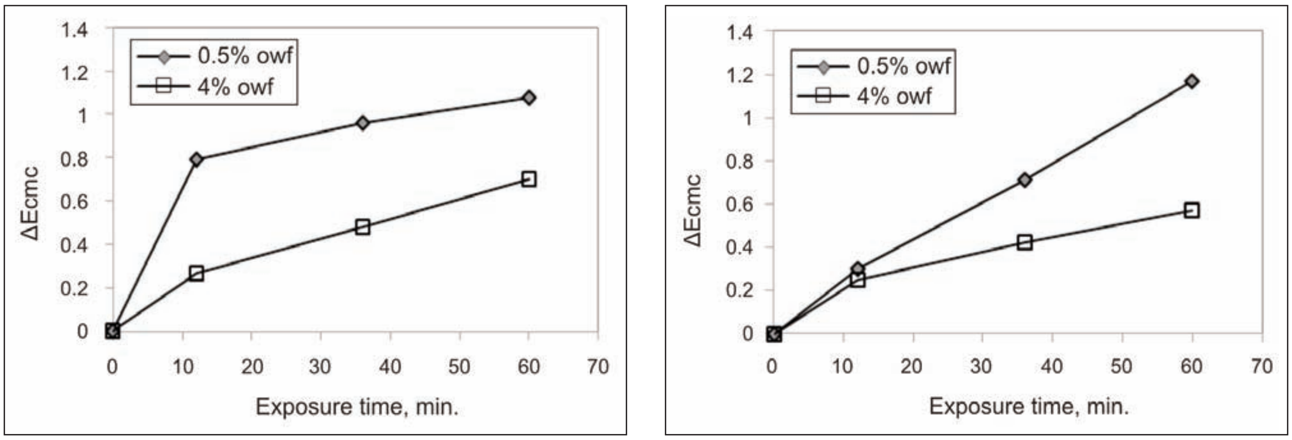
When compared to silk, cotton displayed a more significant change in colour; a higher percentage change in whiteness and yellowness were obtained. A marked colour change was confirmed by the colour difference values (ΔE_{cmc}) as seen in figure 1. A visibly noticeable shade difference (ΔE_{cmc}>1) appeared at an earlier exposure time for cotton than for silk and under the same exposure time, a larger ΔE_{cmc} was shown by the cotton fabric. This may be explained by two possible reasons: the first one is from the base colour of the fabric. Silk is originally pale yellow, so the yellowing caused by deposition of the cigarette smoke substances may not have as much impact on the shade change as in the case of cotton fabric, which is whiter. Another reason is that cotton fibre is likely to absorb the substances contained in cigarette smoke more readily than does silk. The more substances are absorbed, the more yellow the fibre is. This result illustrates that even for short exposure times, cigarette smoke can cause yellowing to cotton and silk fabrics to a considerable extent. Therefore, cigarette smoke not only causes unpleasant odour but also brings about an undesired yellowing of both cotton and silk fabrics even after short-term exposure. The change in the colourimetric properties of cotton and silk was also investigated on the dyed fabric at pale (0.5%owf) and heavy (4%owf) shades. Cotton fabrics dyed with Procion H-E bis-monochlorotriazine reactive dyes were exposed to cigarette smoke and the change in shade of the dyed fabrics was monitored and is illustrated in table 2. At the same applied depth (% owf), Procion Red H-E7B dye gave the highest colour strength (K/S) on cotton, followed by Procion Navy H-ER and Procion Yellow H-E6G. The fabrics dyed with Procion Yellow H-E6G showed the greatest colour differences (ΔE_{cmc}), especially the one dyed at 0.5% owf. It seems that the paler-dyed fabrics would show a greater colour change as compared with the heavier shade-dyed fabrics. Among these three reactive dyes, the Procion yellow with the least colour strength (K/S about 1 for pale depth) exhibited the largest ΔE_{cmc}. This indicates that cigarette smoke exposure can cause shade changes to the dyed cotton fabrics and the effect is more pronounced on the pale shade-dyed fabrics. Regardless of the reactive dye types used in this research, the shade change as a result of cigarette smoke exposure is inversely related to the colour strength of the dyed fabrics. The cigarette smoke showed no effect on the colour strength (K/S) of the dyed cotton fabrics, no signified change in K/S values being observed; implying no severe effect of cigarette smoke on the dye molecules during the time studied. The same trend is also observed in the case of silk fabric (table 3).

Table 2

Dye	(%owf)	K/S		λ_{max} (nm)	Δa^*	Δb^*	ΔE_{cmc}
		before	after				
Procion Yellow H-E6G	0.5	1.00	1.02	420	1.22	–0.11	1.08*
	4.0	4.75	4.75	420	1.66	0.04	0.70
Procion Red H-E7B	0.5	3.48	3.42	550	–1.07	0.02	0.78
	4.0	14.35	13.81	550	–1.18	–0.91	0.41
Procion Navy H-ER 150%	0.5	2.93	2.94	620	–0.20	0.64	0.65
	4.0	12.32	12.14	610	–0.13	0.19	0.59

Table 3

Dye	(%owf)	K/S		λ_{max} (nm)	Δa^*	Δb^*	ΔE_{cmc}
		before	after				
Supralan Yellow 4GL	0.5	2.07	2.06	410	0.33	-0.24	0.35
	4.0	13.47	13.14	410	0.08	-0.24	0.14
Supralan Red GWN	0.5	2.87	2.84	520	-0.55	0.62	0.33
	4.0	14.64	14.74	520	0.03	-0.2	0.12
Supralan Blue GLW	0.5	1.37	1.37	650	-0.43	1.54	1.17*
	4.0	10.60	10.62	650	-0.6	0.92	0.57



a *b*

Fig. 2. Colour difference (ΔE_{cmc}) of the dyed cotton and silk fabrics at different cigarette smoke exposure times: *a* – Cotton, Procion Yellow H-E6G; *b* – Silk, Supralan Blue GLW

Supralan Blue GLW, which provided the weakest colour strength on silk, showed the highest colour differences,while the colour strength of the dyed silk fabric was unaffected by cigarette smoke.

The ΔE_{cmc} values of cotton dyed with Procion Yellow H-E6G and silk dyed with Supralan Blue GLW were examined over various cigarette smoke exposure times and the results are depicted in figure 2, *a* and *b*, respectively. Longer exposure times caused higher colour differences (ΔE_{cmc}); in particular the 0.5%owf-dyed fabrics. This study confirms that exposure of cotton and silk textile fabrics to cigarette smoke, even for a short period of time, can cause shade alteration to both undyed and dyed fabrics, especially those with pale shade, irrespective of the types of dyes used in this study. Furthermore, a stronger colour change effect tends to occur with cotton fabric.

2. Nicotine released from cigarette smoke-exposed cotton and silk fabrics

Nicotine is the main substance contained in cigarette smoke; therefore, it was chosen as a representative of cigarette smoke substances and its content was monitored in the different media viz. water, buffer solutions (pH 5.5 and 8) and artificial sweat solutions (acid and alkaline conditions). The amount of nicotine released into water from cotton and silk fabrics increased along with the longer exposure times as seen in figure 3. Cotton fabric released more nicotine into water compared to silk fabric. This supports the colour change results discussed in the previous section. Larger colour change on cotton is presumably due to higher cigarette smoke substances (including nicotine) absorbed onto cotton fabric; therefore, more yellowing is noticed and the nicotine content released is also higher as compared to silk. However, another factor influencing the release of nicotine is its affinity towards cotton and silk. If nicotine is strongly bound onto the fibres, it will not be released easily. Affinity of the substances contained in cigarette smoke to cotton and silk is believed to depend on the different

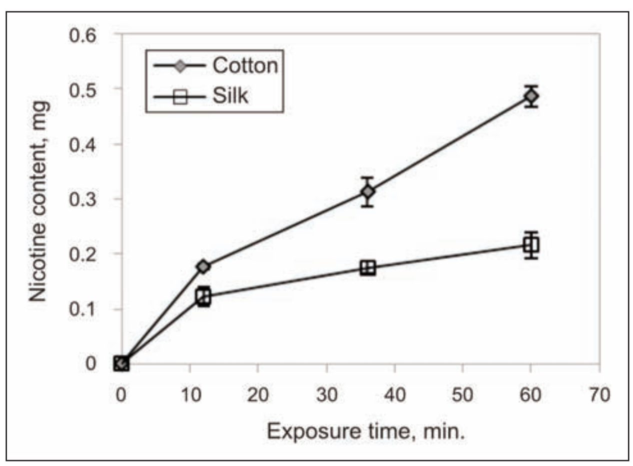


Fig. 3. Nicotine content released into water from the fabrics at different cigarette smoke exposure times

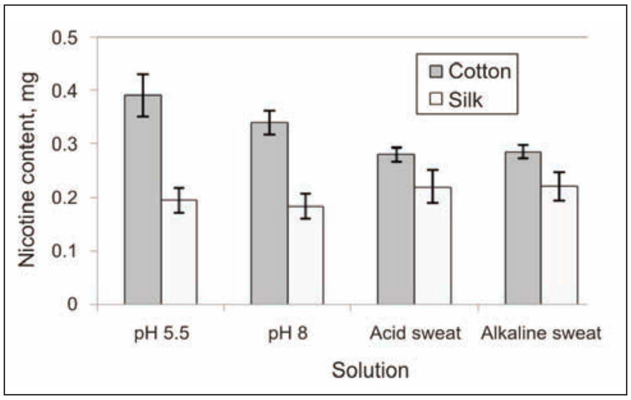


Fig. 4. Nicotine content released into buffers and artificial sweats from the fabrics at 36 min exposure time

natures of these fibres. Nevertheless, the results obtained in this study show corresponding results of colour change and nicotine content.

Nicotine released into buffer solutions at pH 5.5 and 8.0 was determined in comparison to the artificial sweats, in both acid (pH 5.5) and alkaline (pH 8.0) conditions. Figure 4 shows that cotton fabric released more nicotine than did silk into both buffer solutions and the artificial sweats. Cotton and silk released more nicotine into the acidic buffer (pH 5.5) than into the alkaline buffer solution. pH has been reported to influence the ionisation of nicotine [7]. With a pKa of 8.0, nicotine is in its ionised form under acidic pH, while it appears in unprotonated form under alkaline conditions. In artificial sweats, less nicotine was released from the cotton fabrics into both acid and alkaline sweats as compared with the release into buffer solutions, even though it was conducted at the same pH values. The amount of nicotine released was previously reported to be solvent-dependent. More nicotine detached from cotton textiles into phosphate buffer solution than into artificial sweats [5]. The substances contained in the artificial sweats may interfere with the release of nicotine from the fabrics. NaCl can cause a salting-out effect in aqueous nicotine solution, even at small added quantity, consequently lowering nicotine solubility, which can affect the amount of nicotine detected. In the case of silk, a marginal increase in nicotine content released was observed in the artificial sweats as compared with the pH buffer solutions[12–13]. This differing nicotine release from cotton and silk is relevant to the distinctive properties of the fibres.

This study reveals that substances contained in cigarette smoke, including nicotine, can be released from cotton and silk fabrics into human sweats within relatively short times. This nicotine-containing sweat can pose a potentially harmful effect to human health depending on the conditions of smoke exposure and the releasing ability of the fabrics. Permeation through human skin of nicotine extracted into sweat has previously been reported and its toxicity mentioned [5]. Therefore, cotton and silk textiles exposed to cigarette smoke can be a source of toxicants to textile users.

CONCLUSIONS

Exposure to cigarette smoke caused colour changes to undyed and dyed cotton and silk fabrics, with cotton showing a higher degree of colour differences. The shade of the dyed fabrics changed markedly with longer exposure time to cigarette smoke, while the colour strength of the dyes was unaffected. The nicotine content released by cotton into the aqueous media was found to be higher than that by silk; the results agreed with the colour change results. Also, the nicotine content increased with the exposure times. The release of nicotine into artificial sweats implies that cotton and silk textiles contaminated with toxicants from cigarette smoke may pose a harmful effect on human health.

ACKNOWLEDGEMENT

The authors are indebted to Kasetsart University Research and Development Institute for financial support. Special thanks are given to the Center for Advanced Studies in Nanotechnology for Chemical, Food and Agricultural Industries, Kasetsart University, Thailand.

BIBLIOGRAPHY

[1] Brunnemann, K.D. and Hoffmann, D. *Analytical studies on tobacco-specific N-nitrosamines in tobacco and tobacco smoke*, In: Cr. Rev. Toxicol. 1991, vol. 2, no. 4, pp. 235–240.

[2] Rickert, W.S., Robinson, J.C., Bray, D.F., Rogers B., and Collishaw, N.E. *Characterization of tobacco products: A comparative study of the tar, nicotine, and carbon monoxide yields of cigars, manufactured cigarettes, and cigarettes made from fine-cut tobacco,* In: Prev. Med. 1985, vol. 14, no. 2, pp. 226–233.

[3] Noble, R.E. *Environmental tobacco smoke uptake by clothing fabrics*, In: Sci. Total Environ. 2000, vol. 262, pp. 1–3.

[4] Chien, Y.C., Chang, C.P. and Liu, Z.Z. *Volatile organics off-gassed among tobacco-exposed clothing* fabrics, In: J. Hazard Mater. 2011, vol. 193, pp. 139–148.

[5] Hammer, T.R., Fischer, K., Mueller, M. and Hoefer, D. *Effects of cigarette smoke residues from textiles on fibroblasts, neurocytes and zebrafish embryos and nicotine permeation through human skin*, In: Int. J. Hyg. Envir. Hea. 2011, vol. 214, no. 5, pp. 384–391.

[6] Benowitz, N.L., Hukkanen, J. and Jacob, P. *Nicotine Chemistry, Metabolism, Kinetics and Biomarkers*. In: Henningfield J.E., London E.D., Pogun S., editors. Nicotine Psychopharmacology. Berlin, Heidelberg: Springer Berlin Heidelberg; 2009, pp. 29–60.

[7] Barlow, R.B. and Hamilton, J.T. *Effect of pH on the activity of nicotine and nicotine monomethiodide on the rat diaphragm preparation,* In: Brit. J. Pharmacol. 1962, vol. 18, pp. 543–549.

[8] Lawler, T.S., Stanfill, S.B., Zhang, L., Ashley, D.L. and Watson, C.H.*Chemical characterization of domestic oral tobacco products: Total nicotine, pH, unprotonated nicotine and tobacco-specific N-nitrosamines*, In: Food Chem. Toxicol. 2013, vol. 57, pp. 380–386.

[9] Benowitz, N.L. *The Role of Nicotine in Smoking-Related Cardiovascular Disease*, In: Prev. Med. 1997, vol. 26, no. 4, pp. 412–417.

[10] Benowitz, N.L., Porchet, H., Sheiner, L. and Jacob, P. *Nicotine absorption and cardiovascular effects with smokeless tobacco use: Comparison with cigarettes and nicotine gum*, In: Clin. Pharmacol. Ther. 1988, vol. 44, no. 1, pp. 23–28.

[11] Hardin, M.E., Greyling, L.A. and Davis, L.S. *Nicotine staining of the hair and nails*, In: J. Am. Acad. Dermatol. 2015, vol. 73, no.3, pp. e105–e106.

[12] Grozdanic, N.D., Najdanovic-Visak, V., Kijevcanin, M.L., Serbanovic, S.P., d Ponte, M.N. and Visak, Z.P. *Liquid-liquid phase equilibria in nicotine (aqueous) solutions*, In: Fluid Phase Equilibr, 2011, vol. 310, pp. 198–206.

[13] Grozdanic, N.D., Calado, M.S., Kijevcanin, M.L.J., Šerbanoic, S.P. and Visak, Z.P. *Aqueous nicotine solutions: pH-measurements and salting-outeffects – Analysis of the effective Gibbs energies of hydration and ionic strengths of the solutions,* In: J. Serb. Chem. Soc. 2014, vol. 79, no. 7, pp. 829–842.

Authors:

WANTANEEPORN NONGNUCH[1]
POTJANART SUWANRUJI[2]
JANTIP SETTHAYANOND[1]

[1]Textile Technology and Innovation Research Unit, Department of Textile Science, Faculty of Agro-Industry, Kasetsart University Bangkok, Thailand

e-mail: Jantip.s@ku.ac.th

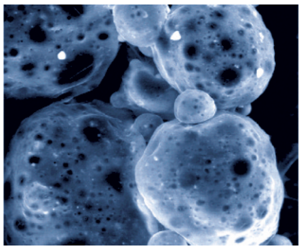
[2]Department of Chemistry, Faculty of Science, Kasetsart University

e-mail: fscipjs@ku.ac.th

Corresponding author:

JANTIP SETTHAYANOND

e-mail: Jantip.s@ku.ac.th



Definition, history of denim fabric and Turkey's denim clothing export in figures

DOI: 10.35530/IT.069.04.1420

LALE MEYANCI

REZUMAT – ABSTRACT

Definiția, istoricul țesăturii denim și exportul îmbrăcămintei din denim din Turcia în cifre

Acest studiu prezintă definiția țesăturii denim, evoluția istorică în Turcia și datele de export global și național ale îmbrăcămintei din denim din ultimii 15 ani din Turcia, care au crescut rapid pe o piață de desfacere foarte importantă în țările din întreaga lume.

Cuvinte-cheie: denim, istoricul țesăturii denim, îmbrăcăminte din denim, exporturile de țesătură denim

Definition, history of denim fabric and Turkey's denim clothing export in figures

This study examines the definition of denim fabric, its historical development in Turkey and in global and product and country based export data of denim clothing of the recent 15 years of export of Turkey which has rapidly risen and become a very important market amongst related countries in the world.

Keywords: denim, history of denim fabric, denim clothing, denim exports

INTRODUCTION

Definition of denim fabric

Fabrics which are named as denim or blue jeans are woven in various textures generally fabricated from yarns such as cotton, polyester, nylon, viscose and lycra, in several unit weights, generally warp yarns dyed with blue indigo dyes, weft yarns in natural white colors. Denim fabrics today are being manufactured in various specifications for different purpose of use. The indigo coloring agent, which is known as "living color", is now being produced synthetically, and the product being dyed with this coloring agent changes its color becomes white in time due to washing. In denim weaving, largely rotor yarn (OE) and rarely ring karde yarn are preferred. Apart from these, there are also denim fabrics where fancy and special yarns are used. There are many kinds of denim that are referred in the market with different names. Some of these are; Natural Denim which is a fabric whose warp and weft yarns are undyed, Antique Denim; which is a denim fabric woven in shuttle looms in 19th century where weft and warp yarns were ring yarns. Nowadays, it is quite difficult to find a fabric with the same effect. Fish Net Denim: is a fabric that warp and weft are from shantung ring yarn. Stretch/Lycra Denim Cotton is woven from warp yarns made of 100% cotton yarn with weft yarns consisting of twisted weaves of elastic lycra yarns.

In the world, denim fabrics are referred as "jeans", "blue-jeans", "jeans wear" and "sportswear". In Turkey, different from the world, the denim clothing is called "jeans" and the pants stitched from denim fabrics are called "jeans pants". In order to eliminate the confusion in definitions related with denim, all of them are described and explained separately.

The term "jeans" was derived from worn blue pants of shipwreckers of Genoa port and other industrial workers as their daily wear. Jeans are fabrics woven by heavier cotton fabrics with warp or weft yarns dominated by D 2/1 Z or D 3/1 Z twill woven, with intact yarns and dyed in different colors.

Blue-jeans; are referred to fabrics and pants made of heavy-duty cotton fabrics where warp yarns are dyed to blue color with indigo coloring agent, weft yarns are not dyed, woven with D 2/1 Z or D 3/1 Z twill weave.

Jeans-wear; are clothing made of jeans type fabrics such as pants, shirts, skirts, vests and jackets. Sports Wear is referred to all kinds of clothing named as sportswear, casual wear or leisure wear [1].

History of denim fabric

The denim fabric used for making jeans is named "Tissu de Nimes" coming from the Rhone valley of southern France, and the name Blue Jeans is derived from the Italian Riviera "Blue de Genes" or "Genoa blue". Blue Jean pants in general; was born with a pair of pockets attached with copper rivets which is the invention of Jacob Davis to the pants manufactured by Lewis Strauss, who had been settled in San Francisco from Germany in 1851, made of blue durable cotton denim fabric taken from France.

The world-wide progress of the Blue Jeans, first prepared by Levi Strauss as for heavy duty workers clothing in the 19th century, started to become popular with Marlon Brando and James Dean in the 1950s movie screen. Since then, it has evolved into a fashion with incredible variations that has been originated by stylists, yarn manufacturers, weavers and handlers. In 1873, Levi Strauss made the first Jean from dark brown "Canvas" for the Californian miners. In 1890, Levi Strauss began producing the first Jeans under the name "501 indigo". In 1950s, the first jeans with zippers started to appear in the market. In 1962,

Burlington produced the heavy Blue Jean (14,75 ounces/yd^2) in Sulzer Ruti shuttle weaving machines, then in 1974, washed Jeans were delivered to the market [2].
If we follow the historical development of Jeans in Turkey, we can summarize it as follows: even though the homeland of Jeans is accepted as America, according to the thesis of Prof. Dr. Halil İnalcık, jeans fabric had been manufactured in Western Anatolia. In 15th and 17th centuries, cotton had been intensively cultivated in Denizli and Akhisar regions,Turkish cotton was not fine grained, therefore rough and cotton clothes had been mostly used by peasants and poor people. Later, these cotton fabrics started to be painted with blue (indigo) dye coming from India. According to İnalcık, the first exports of these rough cotton fabrics brought to İzmir had been realized to Marseille city of France in the 16th century. From here, they were worn by African slaves working in the farms who had been brought to the Colonies in America by the Spanish. The success of America was to convert jeans into an industry [3].
Jeans (Kot) is used in Turkish equivalent of the word Denim in English.
The main reason for the settlement of the jeans (kot) word in Turkish derives from the family name of the person who had first manufactured the jeans in Turkey. When Muhteşem Kot was 3 years old, he moved from Yugoslavia to Turkey and settled in Edremit and became a tailor apprentice after his primary and secondary education and then to improve himself in his profession, he studied in La Deveze Derrox which had been considered as one of the best tailoring schools of that time. When he returned to Turkey, he began to produce this fabric he had seen there. By the end of 1940, Kot who was looking for a cheap but durable product that could be worn by workers and peasants, he met blue jeans during his visit to France, he admired the strength and stitch style and decided to produce the fabric in Turkey. In 1960, 200 pieces had been produced per day. This fabric became popular amongst peasants and workers at that time. In 1960 the name of KOT was branded. The great breakthrough in the textile industry in 1980's was also reflected in the denim production and the production of blue jeans for export, with the contribution of many international brands shifting their production [4]. Particularly since early 1980s, Turkey has been described as a textile country. The grounds of this formation do not only derive from the developments in Turkey but also derives from the orientation of the European Union and USA to East with the purpose of seeking cheaper production opportunities. In countries such as China, Russia, Hong Kong where the costs of production input including the labor force is low, were getting shares from ready-made clothing; Turkey became prominent among them. Turkey, which changed her import policy, has opened its markets to imported brands and has pulled their production into her borders. It has become inevitable for many international ready-made clothing companies to prefer Turkey in search of economic and quality production conditions and which is also a market. Since rapidity in production is so important, industrialists who are capable of adapting themselves to the demand capacity and quality standards could manage to make production for export without facing any difficulties [1].

PLACE OF DENIM CLOTHING IN APPAREL EXPORT OF TURKEY ACCORDING TO YEARS

Turkey is one of the leading countries in global denim clothing trade in terms of both design and branding as well as effective marketing strategies. The intensive and effective marketing strategies that the denim clothing producers have been carrying out for years have started to bear their fruits in the 2000's and in 2003 Turkey's denim clothing exports exceeded 1 billion dollars. In the following years, denim clothing exports continued to rise and in 2007 Turkey's denim clothing exports exceeded 2 billion dollars. In 2000, while the share of denim clothing in Turkey's total garment and apparel exports was 5.6%, this share increased steadily until 2005 up to 14.4%. The aforementioned share declined by 9.4% in 2015 with a fluctuating course [5]. The relevant data are given in table 1.

Table 1

Years	Apparel export (US dollars)	Denim clothing export (US dollars)	Share of denim clothing (%)
2000	7.250.960.266	409.101.332	5,6
2001	7.332.107.194	571.752.041	7,8
2002	8.945.787.240	885.301.679	9,9
2003	11.171.096.393	1.015.716.467	9,1
2004	12.643.689.614	1.510.362.658	11,9
2005	13.422.476.709	1.935.830.021	14,4
2006	13.569.690.083	1.865.061.865	13,7
2007	15.577.956.348	2.174.262.435	14,0
2008	15.251.170.762	1.741.769.414	11,4
2009	12.868.195.771	1.400.969.502	10,9
2010	14.205.917.174	1.502.143.744	10,6
2011	15.648.660.734	1.556.622.886	9,9
2012	15.753.400.255	1.488.677.983	9,4
2013	17.150.270.228	1.609.388.754	9,4
2014	18.484.603.209	8.535.980.789	9,1
2015	16.744.623.554	1.579.325.190	9,4

DENIM CLOTHING EXPORT ON THE BASIS OF PRODUCTS

When we briefly summarize the data in table 2, the denim clothing that are mainly exported from Turkey are women denim pants. In 2015, women's denim pants worth $ 797.6 million were exported and exports decreased by 7.5% compared to 2014. The share of these products in Turkey's total denim clothing

Table 2

Definition	2012 Annual value (US dollars)	2013 Annual value (US dollars)	2012/2013 Change (%)	2014 Annual value (US dollars)	2015 Annual value (US dollars)	2014/2015 Change (%)
Women, girls denim pants	723.533.526	804.708.956	11.3	862.194.671	797.556.579	–7,5
Men, boys denim pants	691.764.472	710.324240	2.7	746.311.751	693.545.003	–7,1
Women, girls, denim jacket, blazer	20.185.528	25.409.349	25.9	26.839.826	19.363.911	–27,9
Women, girls denim skirts	15.503.433	21.703.848	40.0	15.671.885	25.494.561	62,7
Women, girl denim shirts	14.655.340	19.640.524	34.0	11.159.611	8.679.005	–22
Men, boys denim shirts	10.277.083	12.427.131	30.7	14.032.958	9.887.022	–30
Women, girls dress denim	8.027.433	7.777.485	3.1	9.001.282	18.454.620	–105
Women, girls blouse denim	5.131.163	6.399.221	24.7	6.047.127	6.490.699	7.3
Denim clothing export	1.488.677.983	1.609.288.764	8.1	1.678.316.551	1.573.573.513	–6.24

exports is 50.5%. In other words, half of the denim clothing exports made in Turkey are women's denim pants. The second most exported product is men's denim pants. In 2015, exports of $ 693.5 million were performed with a decrease of 7.1%. The share of men's denim pants in total denim clothing exports is 43.9%. Women's denim skirts export with an increase of 62.7% and women denim jackets export with a decrease of 27.9% are the other leading export items. Their share in total denim clothing exports was found to be 1.6% and 1.2%, respectively. The highest rate of exports in 2015 in terms of denim clothes was women's denim dresses. Exports of women's denim dresses increased million from $ 9.1 million in 2015 to $ 18.3 million higher than in 2014. The share of the product group in total exports is 1.2%. Women's denim skirts are another denim clothing group with an high increase rate in exports by 62.6%. In 2015, exports of women's denim skirts increased by 62.7% in dollar terms when compared to 2014, rising to $ 25.5 million from $ 15.7 million.The product group's share in total exports is 1.6% [5]. Relevant data are given in table 2.

LEADING DENIM CLOTHES IMPORTING COUNTRIES FROM TURKEY

The largest markets for Turkey's denim clothing exports are Germany, England, Spain, Netherlands and Denmark. In 2015, denim clothing equal to the value of $ 271.7 million was exported to Germany, and exports decreased by 7.7% in comparison with 2014. The share of exports made to Germany in total denim clothing exports is 17.2%. In other words, about one sixth of total denim clothing exports is directed to Germany. In 2015, the value of $ 236 million of denim clothing was exported to England which is the second largest market and the exports decreased by 6.3%. England's share in total denim clothing exports of Turkey is 14.9%. $ 226.7 million of denim clothing was exported to the third largest market Spain, with an increase of 7.2% and the share of Spain in total denim clothing exports became 14.4%. The highest rate of increase in denim clothing exports was realized in Poland. In 2015, $ 30 million denim clothing was exported from Turkey to Poland and exports increased by 50.9% when compared to 2014. Algeria is the second country that the export of denim clothing has increased significantly. An export increase of 34.1% was recorded for Algeria in 2015.
On the other hand, another EU country, Belgium, has become the country where the highest rate of export decline was observed among the first eighteen exporting countries. Exports to Belgium decreased by 38.1% in 2015 from $ 69 million to $ 42.7 million [5]. Relevant data are given in table 3.

GENERAL EVALUATION AND CONCLUSION

When the producers are observed, USA, which used to be one of the most important producers of the world once, has lost its leadership in production to Asian countries such as China, India, Pakistan, Bangladesh and Turkey in last decade. Today, producers in Turkey are making effort to create new markets by adding new functions to denim clothes. Denim clothing users, even though not accustomed to functional features such as waterproofness, crease resistance, flexibility, stain-proofing, they were not backward from purchasing denim clothing manufactured with innovative features. Since 1980s, in parallel with the development of textile and apparel industry, Turkey has covered important distances in the production of denim fabrics and clothing made of them as one of the oldest fabric varieties of the world. 2015 annual data shows that denim fabrics has a share of 5% of in total textile exports of Turkey and denim clothing has a share of 9.4% in Turkey's total ready-made clothing and apparel exports. This share increases to 27% when only woven apparel products are taken into consideration [5].
Today it can be said that the most distinctive feature of denim clothing is that it is a unique and important clothing and trade category that has always been demanded regardless of market conditions. In Turkey, as people's lifestyles have changed, denim fabrics and clothing produced therefrom have undergone significant changes such as fabric thicknesses, weight, finishing techniques and new applications.

Table 3

Countries	2012 Annual	2013 Annual	2012/2013 Annual change	2014 Annual	2015 Annual	2014/2015 Annual change
Germany	252.115.151	273.425.757	8	294.466.066	271.706.370	–7,7
England	168.672.762	219.648.026	30	251.846.975	235.972.543	14,9
Spain	164.042.891	186.202.746	14	211.499.278	226.672.261	7,2
Netherlands	132.980.764	159.313.564	20	163.173.279	143.568.551	–12,0
Denmark	96.362.339	88.143.104	2	114.127.426	113.060.236	–0,9
Italy	98.384.391	85.792.821	–13	79.381.279	70.719.920	–10,9
Belgium	65.810.683	71.410.828	9	68.999.201	42.712.999	–38,1
Czech Republic	68.749.394	70.788.730	3	56.314.476	40.591.608	–27.9
France	55.040.847	60.175.038	9	70.797.126	56.240.452	–20,6
Russian Federation	52.436.477	57.312.330	9	27.089.641	19.746.624	–27,1
Sweden	30.923.546	37.250.539	20	36.060.652	27.528.333	–23,7 1
Usa	24.416.673	25.139.587	2	26.029.662	33.933.675	30,4
Ukraine	21.89.228	18.840.017	–11	19.402.591	26.022.865	34,1
Algeria	18.888.232	17.197.425	–8	17.150.620	23.480.074	36,9
Bulgaria	12.405.487	14.611.171	18	16.150.098	12.070.294	–25,3
Poland	15.233.770	13.653.017	–10	19.901.058	30.032.042	50,9
Norway	9.628.794	12.401.440	29	14.189.945	12.078.291	–14,9
China	7.950.488	11.811.561	49	10.850.997	12.418.864	14,4
Turkey's total denim clothing export	1.246.429.744	1.423.117.701	14	1.499.682.361	1.401.098.813	6.6

But whatever it is, the denim clothing that are used by all age groups with their durability and comfort have found their places in the wardrobes of almost every consumer. As a result, denim fabrics and clothing produced from them which had been very limited use centuries agohave become a versatile clothing sector over time that has been preferred and worn by all age groups.

BIBLIOGRAPHY

[1] http://denimkumas.net/denim-kumasin-tarihi.htm

[2] http://www.bbc.com/news/magazine-17101768

[3] http://izler ve yansimalar.blogspot.com.tr/2014/04/blucin-ve-muhtesem-kotun-hikayesi.html

[4] http://www.academia.edu/4132169/Blue_Jeans_Tarihi, pp. 1–3

[5] https://www.ihkib.org.tr/fp-icerik/ia/d/2015/06/23/denim-rapor-2013, pp. 5,10

Authors:

Assistant Professor Dr. LALE MEYANCI

Department of Textile Engineering Faculty of Technology – Marmara University
Istanbul 34722, Turkey

Corresponding author:

LALE MEYANCI

e-mail: lmeyanci@gmail.com, lmeyanci@marmara.edu.tr

Economic and IT determinants of innovative projects in the textiles, wearing apparel, leather and related products industry

DOI: 10.35530/IT.069.04.1478

CEZAR-PETRE SIMION
ADRIANA ALEXANDRU
SEBASTIAN ION CEPTUREANU
EDUARD GABRIEL CEPTUREANU

REZUMAT – ABSTRACT

Principalii factori economici şi IT care influenţează proiectele inovative din domeniul textilelor, articolelor de îmbrăcăminte, pielăriei şi produselor înrudite

În această lucrare au fost indentificaţi şi analizaţi principalii factori care influenţează proiectele inovative din domeniul textilelor, articolelor de îmbrăcăminte, pielăriei şi produselor înrudite. Au fost luaţi în considerare unsprezece factori potenţiali ce pot influenţa proiectele inovative, iar în urma analizei de corelaţie au fost identificaţi cei doi factori care au influenţă esenţială asupra proiectelor inovative din domeniu: indicele volumului producţiei din Uniunea Europeană pentru codurile NACE 13-15 şi exporturile din domeniul textilelor, articolelor de îmbrăcăminte, pielăriei şi produselor înrudite. Cercetarea realizată a arătat că amploarea proiectelor inovative din domeniul textilelor, articolelor de îmbrăcăminte, pielăriei şi produselor înrudite depinde de producţia din Uniunea Europeană şi de cererea pe plan mondial.

Cuvinte-cheie: proiecte, inovativ, textile, IT, articole de îmbrăcăminte

Economic and IT determinants of innovative projects in the textiles, wearing apparel, leather and related products industry

In this paper the main factors that influence the innovative projects in the field of textiles, wearing apparel, leather and related products were identified and analyzed. Eleven potential factors influencing innovative projects have been considered and the correlation analysis has identified the two factors that have a major influence on innovative projects in the field: volume index of production in European Union for NACE codes 13-15 and exports value for textiles, wearing apparel, leather and related products. The research has shown that the scale of innovative projects in textiles, clothing, leather and related products depends on European Union production and on global demand.

Keywords: projects, innovative, textiles, IT, wearing apparel

INTRODUCTION

A very long time textiles, wearing apparel, leather and related products industry from Romania has benefited from the competitive advantage of low wages, which has led to the lohn system for the major producers in the field in the European Union. After Romania's accession to the European Union, Romanian companies benefited from the advantages of the single market, but began to lose the competitive advantage of reduced labor as the average salary in Romania started to rise and the skilled workers emigrated to countries within the European Union that offered salaries more attractive and other career prospects and living standards. Popescu (2013) revealed "the lack of qualified personnel in the labor market in Romania's clothing industry, especially among directly productive workers" [9].

In the current period, a number of additional threats to the sustainability of the business sector have emerged at the level of the Romanian textiles, wearing apparel, leather and related products industry: the increase of the national minimum wage, the impossibility to use part-time coupons due to the same contributions as for full-time employment contracts, lack of highly skilled workforce, suppliers' tendency to export raw materials directly due to more attractive prices in other markets. All of these additional threats directly lead to the loss of competitive advantage at the sectoral level and the tendency of big manufacturers to re-orient lohn production to other countries where wage costs are lower.

The Romanian textiles, wearing apparel, leather and related products industry has entered a period of strategic reorientation from looking for competitive advantage based on reduced costs to competitive advantage based on differentiation. In this context, a number of Romanian companies have emerged that have the tendency to innovate permanently and in the same rhythm as the big producers in the field. New entrants have very aggressive marketing policies and create their own brands that they are trying to impose on the local market in front of the European Union brand name competition, with unequivocally uneven resources.

The capacity to innovate of the Romanian textile companies is still low compared to the EU average but the Romanian industry tends to synchronize with the strategic approaches envisaged for the European Union. Thus, in the study "Textiles and Clothing in the EU" of the European Commission, Romania is mentioned in the "low-cost areas" category with a major risk of relocation of production in the 2020 horizon. The main factors of the change mentioned in this study are: global knowledge base (including new applications of textiles such as "smart" textiles in medicine or construction) and environmental costs.

Also, the studies made by other authors start from the hypothesis that "innovation represents the main implication for developed countries to expand the industrial base in textiles and clothing (Şerbănel, 2014) [10].

That is why it is very useful to study the factors that influence the scale of the innovative projects of the Romanian textile industry organizations in order to observe the elements that have direct consequences on the innovation in the field. In this article we study the factors influencing the innovation projects in the field of products as well as in the managerial or marketing fields.

LITERATURE REVIEW

The study of the role and effects of innovation and innovative projects on the textile industry included several approaches. A first approach is to analyze the content of innovative projects and their effect on the textile industry at global, regional or local level. Kaounides, Yu and Harper (2007) analyzed how innovations in nanotechnologies and their applications in the textile industry influence this industry. The authors believe that "emerging nanoenabled performance improvements and new categories in textiles will increasingly drive R&D and commercialization" [6].

Lottersberger (2011) analyzed from a different perspective the relationship between research and the design of new products in the textile industry in order to develop "a strategic model and specific tools for starting a Design Driven Innovation process into a textile company, in order to achieve radical meaning innovations" [7].

Some authors believe that in the textile industry in Romania "technological innovation is at an extremely low level due to the incipient links between universities, research centers and companies but also because research and development expenditures at firm level are very low" (Şerbănel, 2014) [10]. Ceptureanu S.I., Ceptureanu E.G. and Visileanu E. (2017) concluded that "Romanian SMEs from clothing industry prefer cost-based approaches" [2].

Zucchella and Siano (2014) focused on the study of innovation as a resource in the expansion of Italian SMEs in the textile industry on foreign markets. These authors concluded that the success of small Italian firms in foreign markets is the source of internationalization and innovation but not the result of their own R & D activity or taken over from specialized organizations, but rather sources of specialized knowledge from the strong links with pivotal centers of the industry [12].

Gîrneaţă, Giurgiu, Dobrin, Popa, Popescu et al. (2015) following the analysis performance management practices in Romanian textile and clothing companies have determined that in future research "it is necessary to include, among performance indicators, the adaptation to market demands and technological innovation" [3] which shows that performance in the textile industry in Romania can be explained through innovation as well.

A second approach is the work that analyzes the determinants of innovation in the textiles, wearing apparel, leather and related products industry. Macchion et al. (2017) analyzed how environmental protection practices and supply chain collaboration imply better innovation performance and differentiation from competitors in terms of product or process quality [8]. Research conducted on the main Italian companies has shown that there is a positive impact on environmental performance practices in innovation performance. More and more restrictive environmental regulations force companies to innovate and/or adopt innovations in a way that complies with new practices in the field. Organizations that are unable to adapt by innovation to new practices are eliminated from the market due to the impossibility of meeting a number of minimum standards.

Ceptureanu S.I., Ceptureanu E.G., Simion-Melinte C. and Borisov D. (2016) concluded that "a competitive advantage based on innovation in the clothing industry requires the development of organizational strategies based on knowledge organizational capability" [1]. The results obtained by these authors lead to the conclusion that product or process innovation requires actions centered on organizational knowledge. In the same direction, other authors (Florescu and Ivanov, 2016) noted that globalization can act as a factor of influence on the research and development activity of the textile industry in Romania [4]. The presence of foreign firms requires an effort to adapt their products and services to the local market, which may lead to an increase in the potential demand for R & D services.

Another new approach to innovation in the textiles, wearing apparel, leather and related products industry starts from the Fourth Industrial Revolution and the 4.0 Production Concept, very much linked to the Internet of Things and ICT sector. Jayatilake and Withanaarachchi (2016) consider in a study on the IT side of applying the concept of Production 4.0 that Sri Lankan wearing apparel industries have already begun to assimilate a series of characteristics of this type of production and that in terms of information and communication technology sector, the internet and the supporting technologies (such as Internet of Things, embedded systems, big data, etc.) serve as the main pillar to assimilate, human factors, production lines, intelligent machines physical objects and processes across apparel industry to form an agile value chain" [5]. In the textile and clothing industry is used the equivalent term Fashion 4.0 based on digital materials and 3D printing.

Based on the analysis of the literature, it can be noticed that although the majority of authors analyze the link between the innovation activity (or, in general, research and development) and the trends in the textile industry, no analysis has yet been made that determines the factors influencing the more innovative projects in the Romanian textiles, wearing apparel, leather and related products industry.

RESEARCH METHODOLOGY

Since there have been no dedicated studies to analyze the factors influencing innovative textile projects in Romania, the current research has had the following *objectives:*

- Analysis of specialized literature and identification of potential factors of influence on innovative projects in the textile industry in Romania;
- Selection of relevant data for the research performed;
- Analyzing the data and identifying those factors that influence the innovative projects in the textile industry in Romania;
- Reporting the results obtained from other studies in the literature.

The main steps of the research methodology used, as well as their sequence, are shown in the figure 1.

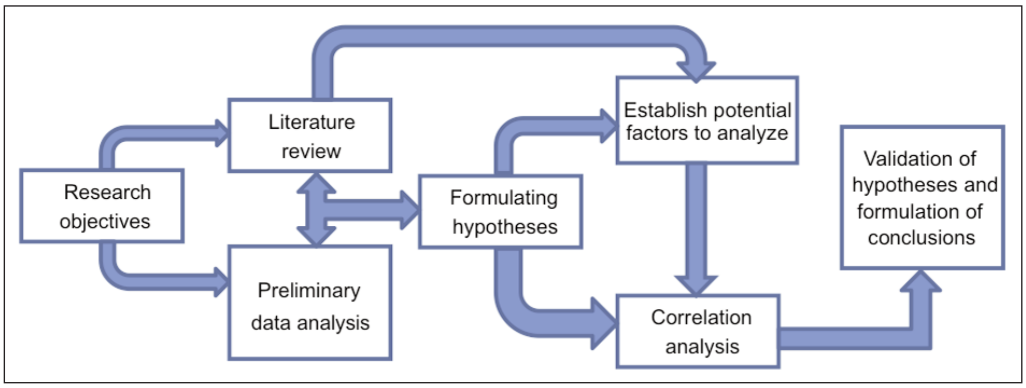


Fig. 1. Research methodology

1. *The establishment of the research objectives* was done taking into account the results obtained in other studies, the actual context of the research and the scientific importance of the analysis of the influence factors on the innovative projects.

2. *Literature review* focused on a technical-economic approach both studies concerning the analysis of the effects of innovative projects on the textile industry and on the main determinants of the scale of this type of projects in the textile industry.

3. *Preliminary data analysis* was conducted to identify the most relevant data sources available. Eurostat databases and national databases were selected:

- "Sold production, exports and imports by PRODCOM list (NACE Rev. 2) – annual data" (DS-066341), for NACE codes 13-15, "manufacture of textiles, wearing apparel, leather and related products".
- "Total production by PRODCOM list (NACE Rev. 2) – annual data" (DS-066342), Volume index of production for NACE codes 13-15, "manufacture of textiles, wearing apparel, leather and related products".
- Trade by commodity and NACE Rev. 2 activity [ext_tec05], – extracted on 8/28/2017, last update 8/22/2017.
- Organisational and marketing innovation in product and process innovative enterprises by NACE Rev. 2 activity and size class: [inn_cis7_mo] [inn_cis8_mo] [inn_cis9_mo].
- Product and process innovation by NACE Rev. 2 activity and size class: [inn_cis7_prod] [inn_cis8_prod] [inn_cis9_prod].
- Total expenditure on R & D activity in the enterprise sector, by category of expenditure and by NACE Rev. 2 activities – current prices (National Institute of Statistics databases).
- Net investment in national economy activities at division and division level, NACE Rev. 2 (National Institute of Statistics databases).

4. *Hypothesis formulation:* eight hypotheses were formulated using preliminary data analysis and literature review.

5. *The identification of the potential factors to be analyzed* was based on the study of literature and previous research. A number of 12 potential factors to be analyzed were identified.

6. *The analysis of the correlations* between the potential factors and the innovative product, management and marketing projects made in the textiles, wearing apparel, leather and related products industry in Romania was made on the basis of the chronological series from the above-mentioned databases. Correlation analysis was performed using the Pearson correlation coefficient (r).

7. *The validation of the hypotheses and the formulation of the conclusions* was based on the previous steps and especially on the results obtained in the analysis of the correlations between the potential influence factors and the innovative product, management and marketing projects in Romania.

RESEARCH HYPOTHESES

Based on literature review and the results obtained in other studies conducted on the same topic, seven hypotheses for the research were formulated. The hypotheses were formulated based on the consideration of 12 potential influence factors: volume index of production in EU for NACE codes 13-15; volume index of production in Romania for NACE codes 13-15; index of turnover (EU) for NACE codes 13-15; index of turnover (Romania) for NACE codes 13-15; employed HRST in EU; employed HRST in Romania; persons with tertiary education (ISCED) and/or employed in science and technology in EU; persons with tertiary education (ISCED) and/or employed in science and technology in Romania; total expenditure on R&D activity of enterprises in the textiles manufacturing sector; net investment in textile manufacturing; enterprises using software solutions.

H.1. *There is a strong positive correlation between the volume index of production in the European Union and the number of innovative projects in the textiles, wearing apparel, leather and related products industry.*

H.1.a. There is a strong positive correlation between the volume index of production in the European Union and the number of innovative product/process projects in the textiles, wearing apparel, leather and related products industry.

H.1.b. There is a strong positive correlation between the volume index of production in the European Union and the number of innovative management projects in the textiles, wearing apparel, leather and related products industry.

H.1.c. There is a strong positive correlation between EU index volumes of production and the number of innovative marketing projects in the textiles, wearing apparel, leather and related products industry.

H.2. *There is a strong positive correlation between the index turnover in the European Union and the number of innovative projects in the textiles, wearing apparel, leather and related products industry.*

H.3. *There is a strong positive correlation between the value of Romanian exports and the number of innovative projects in the textiles, wearing apparel, leather and related products industry.*

H.3.a. There is a strong positive correlation between the volume of Romanian exports and the number of innovative products projects in the textiles, wearing apparel, leather and related products industry.

H.3.b. There is a strong positive correlation between the volume of Romanian exports and the number of innovative management projects in the textiles, wearing apparel, leather and related products industry.

H.3.c. There is a strong positive correlation between the volume of Romanian exports and the number of innovative marketing projects achieved.

H.4. *There is a strong link between Employed HRST (Human Resource in Science and Technology) and innovative projects in the textiles, wearing apparel, leather and related products industry.*

H.4.a. There is a strong link between Employed HRST (Human Resource in Science and Technology) in the European Union and innovative projects in the textiles, wearing apparel, leather and related products industry.

H.4.b. There is a strong link between employed HRST (Human Resource in Science and Technology) in Romania and innovative projects in the textiles, wearing apparel, leather and related products industry.

H.5. *There is a strong positive correlation between people with tertiary education (ISCED) and/or employed in science and technology and innovative process or product projects.*

H.6. *There is a strong link between the total expenditure in the R & D activity of enterprises in the textiles manufacturing sector and the number of innovative projects in the textiles, wearing apparel, leather and related products industry.*

H.7. *There is a strong correlation between the net investment in the textile industry and the number of innovative projects.*

H.8. *There is a strong positive correlation between the number of enterprises using software solutions and the number of innovative projects in the textiles, wearing apparel, leather and related products industry.*

RESEARCH RESULTS

The results of the correlation analysis between 11 factors of influence and the number of innovative product/process projects, innovative marketing and management projects, are presented in the table 1.

The first hypothesis of research, the existence of a positive and strong correlation between the volume index of production in EU for NACE codes 13-15 and the number of innovative projects is confirmed both for innovative product designs (r = 0.979) and for innovative marketing and management (r = 0.999). There is no equally strong link between NACE codes 13-15 and the number of innovative projects in the manufacture of textiles, wearing apparel, leather and related products.

The second hypothesis of research is not confirmed as the correlations between NACE codes 13-15 and the number of innovative products (product, process, marketing and management) is statistically significant, showing a strong link between the variables analyzed but is not positive. The level of turnover either at national or local level does not significantly influence the number of innovative projects in the textiles, wearing apparel, leather and related products industry.

The third hypothesis of research confirming the positive and strong correlation between NACE codes 13-15 and innovative projects is confirmed as the correlation is strong and positive for all types of innovative projects considered (r = 1.00). Romanian exports of textiles, wearing apparel, leather and related products are the most significant determinant of the number of innovative projects in this field.

The fourth hypothesis is only partially confirmed as there is a strong but negative correlation between

Table 1

No.	Influence factors / Innovative projects	Product and process innovative projects	Marketing innovative projects	Management innovative projects
1	Volume index of production in EU for NACE codes 13-15	0.979	0.999	0.999
2	Volume index of production in Romania for NACE codes 13-15	–0.488	–0.644	–0.875
3	Index of turnover (EU) for NACE codes 13-15	–0.674	–0.802	–0.832
4	Index of turnover (Romania) for NACE codes 13-15	–0.733	–0.849	–0.875
5	Exports value for NACE codes 13-15	1.000	1.000	1.000
6	Employed HRST in EU	–0.916	–0.976	–0.986
7	Employed HRST in Romania	0.192	0.374	0.422
8	Persons with tertiary education (ISCED) and/or employed in science and technology in EU	–0.898	–0.965	–0.977
9	Persons with tertiary education (ISCED) and/or employed in science and technology in Romania	–0.782	–0.650	–0.609
10	Total expenditure on R & D activity of enterprises in the textiles manufacturing sector	0.008	0.197	0.248
11	Net investment in textile manufacturing	–0.397	–0.564	–0.606
12	Enterprises using software solutions	0.756	0.501	0.455

HRST (Human Resource in Science and Technology) employed in the European Union and innovative projects but there is not the same strength in the HRST (Human Resource in Science and Technology) at national level and the number of innovative projects in the field. The fifth hypothesis is not confirmed because there is no correlation between persons with tertiary education (ISCED) and/or employed in science and technology in EU or in Romania and the number of innovative projects in the field.

Also, the sixth and seventh hypotheses are not confirmed because there are no significant correlations between the number of innovative projects in the field and total expenditures from the R&D activity of enterprises in the textiles manufacturing sector or net investment in textile manufacturing.

The eighth hypothesis, the link between enterprises using software solutions and the number of innovative projects, is only partially confirmed for innovative product/process projects (r = 0.756) and less for marketing innovative projects and management innovative projects. These two types of projects are dependent on the computerization of activities but not on the same level as product and process innovative projects. Table 2 contains a summary of the hypotheses that have marked the research and their confirmation.

CONCLUSIONS

In the literature there have been several studies on the content of innovative textile projects, the effects of innovative projects, the main determinants of innovative textile projects. The studies were focused either on a particular geographic region or on a particular type of organization (the most common studies conducted on SMEs). There were no other similar studies before the research that analyzed the main factors of influence on the number of innovative projects in the Romanian textiles, wearing apparel, leather and related products industry.

The analysis of the factors influencing the number of innovative projects in the industry was based on the identification of 11 potential factors of influence, preliminary data analysis, selection of significant data series from EUROSTAT databases and national databases and analysis of correlations between the main types of projects (product, process, marketing and management) and the eleven influence factors identified.

Of the seven hypotheses formulated, two (hypotheses 1 and 3) were fully confirmed, showing a strong and positive correlation between the number of innovative projects and:

- volume index of production in EU for NACE codes 13-15;
- exports value for NACE codes 13-15.

The value of Romanian exports and production in the European Union *are the main determinants of innovation and the number of innovative projects* in the field. A partially confirmed hypothesis is the fourth hypothesis, confirmed only for employed HRST

Table 2

No.	Hypotheses	Result
1.	H.1. There is a strong positive correlation between the volume index of production in the European Union and the number of innovative projects in the textiles, wearing apparel, leather and related products industry.	Confirmed
2.	H.2. There is a strong positive correlation between the index turnover in the European Union and the number of innovative projects in the textiles, wearing apparel, leather and related products industry.	Not confirmed
3.	H.3. There is a strong positive correlation between the value of Romanian exports and the number of innovative projects in the textiles, wearing apparel, leather and related products industry.	Confirmed
4.	H.4. There is a strong link between Employed HRST (Human Resource in Science and Technology) and innovative projects in the textiles, wearing apparel, leather and related products industry.	Partially confirmed
5.	H.5. There is a strong positive correlation between people with tertiary education (ISCED) and/or employed in science and technology and innovative process or product projects.	Not confirmed
6.	H.6. There is a strong link between the total expenditure in the R & D activity of enterprises in the textiles manufacturing sector and the number of innovative projects in the textiles, wearing apparel, leather and related products industry.	Not confirmed
7.	H.7. There is a strong correlation between the net investment in the textile industry and the number of innovative projects.	Not confirmed
8.	H.8. There is a strong positive correlation between the number of enterprises using software solutions and the number of innovative projects in the textiles, wearing apparel, leather and related products industry.	Partially confirmed

(Human Resource in Science and Technology) in the European Union. Partially confirmed is the eighth hypothesis, showing a strong link between number of enterprises using software solutions and the number of innovative projects in the textiles, wearing apparel, leather and related products industry.

Of the eleven potential factors of influence, only three have a strong influence on the scale of innovative projects in the field (volume index of production in EU for NACE codes 13-15; exports value for NACE codes 13-15; employed HRST) and only two of them volume index of production in EU for NACE codes 13-15; exports value for NACE codes 13-15) have a positive influence.

The research, although very statistically significant, was focused on the economic factors that condition innovation. For this reason, it should be continued with a questionnaire survey that captures the qualitative factors that influence the innovative projects in the field.

BIBLIOGRAPHY

[1] Ceptureanu, S.I., Ceptureanu, E.G., Simion-Melinte, C., Borisov, D. *Capabilities of SMEs in Romanian clothing industry,* In: Industria textilă, vol. 67, nr. 4, 2016, pp. 265–269

[2] Ceptureanu, S.I., Ceptureanu, E.G., Visileanu, E., *Comparative analysis of small and medium enterprises organizational performance in clothing industry*, In: Industria textilă, vol. 68, Issue 2, 2017, pp. 156–162

[3] Gîrneaţă, A., Giurgiu, A., Dobrin, O.C., Popa, I., Popescu, D., Cuc, S., Voicu, L. *Performance management practices in Romanian textile and clothing companies,* In: Industria textilă, vol. 66, nr. 2, 2015, pp. 108–113

[4] Florescu, M.S., Ivanov, F. *Globalization as a factor of influence on the R&D activity and the case of the textile industry in Romania*, In: Industria Textilă, vol. 67, nr. 5, 2016, pp. 345–350

[5] Jayatilake, H.S.B., Withanaarachchi, A.S. *Industry 4.0 in the apparel-manufacturing sector: Opportunities for Sri Lanka*, *1st Interdisciplinary Conference of Management Researchers, at Sabaragamuwa University of Sri Lanka, 2016*

[6] Kaounides, L., Yu, H., Harper, T. *Nanotechnology innovation and applications in textiles industry: Current markets and future growth trends*, In: Materials Technology Advanced Performance Materials Volume 22, 2007, Issue 4, pp. 209–237

[7] Lottersberger, A., *Design driven innovation for Textile Industry*, In: Advanced Materials Research, vol. 331, 2011, pp. 730–734

[8] Macchion, L., Moretto, A., Caniato, F., Caridi, M., Danese, P., Spina, G., Vinelli A. *Improving innovation performance through environmental practices in the fashion industry: the moderating effect of internationalization and the*

influence of collaboration, In: Production Planning & Control.The Management of Operations, Volume 28, Issue 3, 2017, pp. 190–201

[9] Popescu, D.I. *The correspondence between workforce skills and company needs,* In: Industria Textilă, vol. 64, Isuue 3, 2013, pp. 168–175

[10] Şerbănel, C.I., *Romanian textile industry and its competitive advantage,* In: SEA – Practical Application of Science Volume II, Issue 2 (4) /2014, pp. 395–404

[11] Vogler-Ludwig, K., Valente, A.M. *Skills scenarios for the textiles, wearing apparel and leather products sector*, In: Final Report undertaken for the European Commission, Employment, Social Affairs and Equal Opportunities DG, Unit Working Conditions, Adaptation to Change, 2009

[12] Zucchella, A., Siano, A. *Internationalization and innovation as resources for SME growth in foreign markets*. In: A Focus on Textile and Clothing Firms in the Campania Region, International Studies of Management & Organization, Volume 44, Issue 1, 2014, pp. 21–41

Authors:

CEZAR-PETRE SIMION [1]

ADRIANA ALEXANDRU[2]

SEBASTIAN ION CEPTUREANU[1]

EDUARD GABRIEL CEPTUREANU[1]

[1]Bucharest University of Economic Studies, Faculty of Management, Bucharest, Romania

[2] National Institute for Research and Development in Informatics, Bucharest, Romania

e-mail: cezar.simion@man.ase.ro; adriana_alexandru@yahoo.com; sebastian.ceptureanu@man.ase.ro; eduard.ceptureanu@man.ase.ro

Corresponding author:

CEZAR-PETRE SIMION

e-mail: cezar.simion@man.ase.ro