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Modelling and testing the electromagnetic near field shielding effectiveness achieved by woven fabrics with conductive yarns

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REZUMAT – ABSTRACT

Modelarea și testarea atenuării câmpului electromagnetic cvasistaționar obținută prin materiale țesute cu fire conductive

Dezvoltarea accelarată a dispozitivelor electrice și a telecomunicației, necesită soluții adecvate pentru asigurarea compatibilității electromagnetice (CEM). Una dintre soluțiile principale oferite de CEM este ecranarea radiației electromagnetice (EM). Ecranele convenționale pentru radiație EM sunt construite din plăci metalice, însă utilizarea materialelor textile cu fire conductive inserate prezintă la rândul lor multiple avantaje: masă redusă, flexibilitate, rezistență mecanică și adaptabilitate la forme 3D.
Acest articol abordează ecranarea câmpului electromagnetic cvasistaționar și propune o relație analitică pe baza metodei separării variabilelor, care ține cont de parametrii geometrici și electrici ai materialului textil. S-a realizat un studiu de validare pentru relația analitică, prin determinarea atenuării electromagnetice într-o incintă, acoperită cu o husă din material textil cu fire conductive. Ansamblul experimental include atât dispozitivele electrice de măsurare, cât și un set de cinci materiale textile țesute cu fire conductive din inox și argint. Rezultatele experimentale pentru domeniul de frecvență al câmpului apropiat (1–20 MHz), prezintă valori bune în raport cu relația analitică.
Relația analitică simplificată permite calcularea distanței între firele conductive ale materialului țesut, în raport cu o atenuare EM specificată. Această relație sprijină procesul de proiectare al materialului textil, prin luarea în considerație a factorilor de cost și a atenuării EM specificate.

Cuvinte-cheie: ecranare, validare, distanță între firele conductive, bătătură, inox, argint

Modelling and testing the electromagnetic near field shielding effectiveness achieved by woven fabrics with conductive yarn

The current extensively development of electrical devices and telecommunication requires adequate solutions for ensuring electromagnetic compatibility (EMC). One of the main solutions provided by EMC is the shielding against electromagnetic (EM) radiation. Conventional screens for EM radiation are constructed from metallic plates, however, fabrics with conductive yarns may be used as well, with multiple advantages: lightweight, flexibility, mechanical resistance and 3D shape ability.
The paper addresses the shielding of the electromagnetic near field, by proposing an analytic relation taking into account both geometrical and electrical parameters of the fabric, based on the circuit method. A validation study was performed, by measuring the shielding effectiveness of an enclosure with a cover from woven fabrics with conductive yarns. The experimental setup includes both the electrical measurement devices, as well as a set of five woven fabrics with conductive yarns from stainless steel and silver. The experimental results for the electromagnetic near field frequency range (1–20 MHz) present values in good relationship to the analytic relation.
The simplified analytic relation allows the computing of the distance between the conductive yarns of the woven fabric in relation to the targeted shielding effectiveness. This relation supports the design process of a fabric, with balance between its costs and its target shielding effectiveness.

Keywords: shielding, validation, distance between conductive yarns, weft, stainless steel, silver

INTRODUCTION – the relevance of EM shielding textiles

Fabrics with inserted conductive yarns may find adequate application in the shielding of electromagnetic waves [1–3]. Compared to the classical metallic shields, woven fabrics are flexible, lightweight and yet provide mechanical resistance. The applications of fabrics with conductive yarns range from curtains, tents or tarpaulins for protection of humans towards the outer radiation environment, to covers for limiting the inner radiation produced by enclosed electronic equipment [4–5]. Many applications are already on the market, however the modelling of the shielding effectiveness of woven fabrics is still an up-to-date question [6–7].
Modelling the shielding effectiveness of woven fabrics has numerous purposes and is an issue of current research [8–15]. One important purpose is related to

the possibility of predicting the electrical properties of shielding based on the fabric's geometrical and electric parameters, before physically manufacturing the woven fabric. The modelling achieves valuable data for a cost-effective design. One basic question received from the textile industry's enterprises is related to the distance between the conductive weft yarns of a woven fabric, meant for achieving a certain shielding effectiveness. Moreover, the shielding of the electromagnetic near field is especially problematic to be achieved and requires special attention [4–5].

Thus, main aim of this paper is to propose and validate an analytical relation, comprising both geometrical and electrical parameters of the woven fabric, meant to answer the tasks above.

THE ANALYTIC SHIELDING EFFECTIVENESS FOR THE ELECTROMAGNETIC NEAR FIELD

The analytic shielding effectiveness relation was processed according to the circuit method, provided by Heinrich Kaden [16]. This analytic relation describes the shielding produced by conductive grid structures and thus, it is applicable for woven structures with conductive yarns. It represents a "mechanistic" mathematical model, as opposed to previous research operated with phenomenological mathematical models [17–18]. The analytic relation contains geometric and electric parameters and is valid for the electromagnetic near field. The figure 1 presents the principle of shielding for an enclosure build up with conductive grids (in our case woven fabrics), based on the Eddy currents induced by the incident variable electromagnetic field, which create an opposing field and consequently a shielding effect. The figure 1 includes the geometric parameters of the model.

The upper graph of figure 1 shows the two walls of the shielding enclosure, composed of fabric with conductive yarns in weft direction. It presents a front view of the enclosure. The distance between the walls is denoted with $2x$, the distance between the conductive yarns in the weft structure with a, while the radius of the yarns is denoted with r. The lower graph of figure 1 presents an upper view of the shielding enclosure. According to this model, the yarns from the two walls of the enclosure are electrically connected at a certain specified distance, allowing the Eddy currents to flow withinclosed electrical circuits. The shielding factor Q describes the ratio between the magnetic field strength of the inner field (H_y) and the incident field (H_a). It has according to [16] the following expression (1):

$$Q \equiv \frac{H_y}{H_a} = \frac{\rho_i + j\left(\frac{r}{\delta}\right)^2\left[\lambda_i + \left(\frac{\pi r}{a}\right)^2 W - \ln 2\sinh\frac{\pi r}{a}\right]}{\rho_i + j\left(\frac{r}{\delta}\right)^2\left[2\pi\frac{x}{a} + \lambda_i - \ln 2\sinh\frac{\pi r}{a} - \left(\frac{\pi r}{a}\right)^2 W\right]} \quad (1)$$

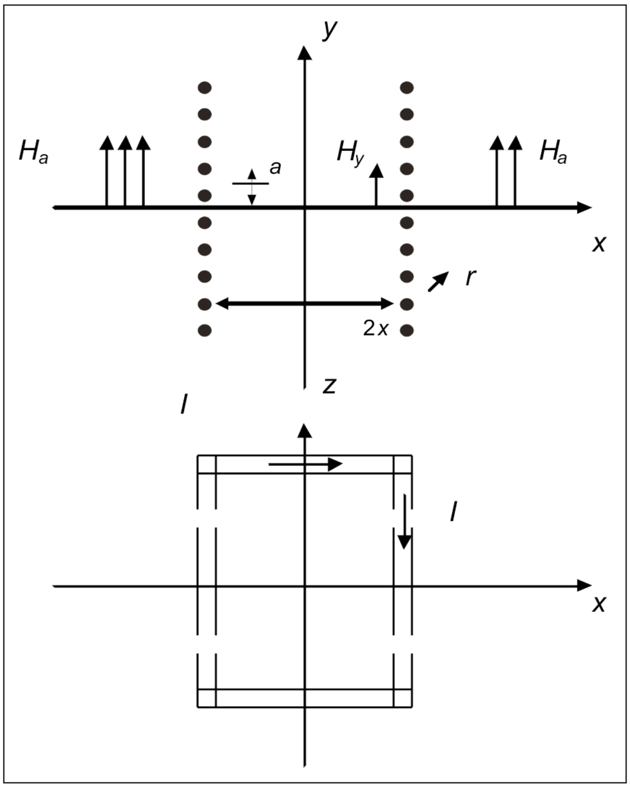

Fig. 1. The enclosure with electrically conductive grid

where the electric and geometric parameters are:

r – yarn diameter;
a – distance between the conductive weft yarns;
$2x$ – distance between the two walls of the enclosure;
δ – the skin depth (related to the frequency);
ρ_i – resistance function;
λ_i – induction function (expressed as ratio between r and δ);
W – reflexion factor.

The shielding effectiveness is expressed related to the shielding factor Q, either in Neper (2) or in Decibel (3), according to the following relations:

$$SENp = \ln\left(\frac{1}{|Q|}\right) \text{ [Np]} \quad (2)$$

$$SEdB = 20\log_{10}\left(\frac{1}{|Q|}\right) \text{ [dB]} \quad (3)$$

THE FABRICS WITH CONDUCTIVE YARNS

In order to achieve the desired shielding properties for the woven fabrics, conductive yarns from ferromagnetic (stainless steel – Fe) and diamagnetic (Ag) raw materials were introduced into the weft system of the fabrics. A number of six electrically conductive yarns were analysed and used for the study. The first two yarns (F1001 and F1002) were twisted from three respectively two filaments, one of which from stainless steel. The third yarn (F2002) was a spun yarn with 80% cotton and 20% stainless steel content. The last three yarns (F1003, F1004, F1005) were from PA6.6 coated with Silver, having different yarn counts. Table 1 presents the physical-mechanical and electrical properties of these yarns.

Table 1

PHYSICAL-MECHANICAL AND ELECTRICAL PROPERTIES OF THE USED YARNS						
Property	**F1001**	**F1002**	**F2002**	**F1003**	**F1004**	**F1005**
Yarn count	470 dtex	220 dtex	200,5 × 2 dtex	301 × 2 dtex	312 × 4 dtex	148 × 2 dtex
Diameter yarn (μm) / conductive yarn (μm)	287 / 60	146 / 40	273 / 54.6	284	444	228
Twist (tors/m)	488 (S)	621.3 (S)	593.6 (S)	408 (Z)	480 (Z)	474.6 (Z)
Torsion (tors/m)	828 (Z)	699.9 (Z)	827.6 (Z)	470 (S)	502 (S)	616.6 (S)
Tenacity at breaking strength (N/tex)	0.3657	0.1603	0.1365	0.4795	0.976	0.4564
Tensile strength (N)	17.19	3.528	5.46	28.77	58.5	13.69
Relative elongation (%)	27.05	5.90	5.8	29.00	37.38	27.36
Linear electrical resistance (Ω/m)	6700	750	2200	76	30	220
Electrical resistivity (Ω * m)	$4.3*10^{-4}$	$1.25*10^{-5}$	$1.29*10^{-4}$	$4.81*10^{-5}$	$4.65*10^{-5}$	$9.01*10^{-5}$
Electrical conductivity (S/m)	$2.31*10^{3}$	$7.97*10^{4}$	$7.77*10^{3}$	$2.08*10^{5}$	$2.15*10^{5}$	$1.11*10^{5}$
Relative magnetic permeability (1)	7.36	9.93	7.36	1	1	1

The diameter was determined with support of the optical microscope. The linear electrical resistance was determined with the multimeter and the electrical resistivity and conductivity was computed according to the formulae (4) and (5), whilethe relative magnetic permeability was computed by means of the formula (6) [19]:

Electrical resistivity

$$\rho = R \frac{A}{l} \quad (4)$$

Electrical conductivity

$$\sigma = \frac{1}{\rho} \quad (5)$$

Relative magnetic permeability

$$\mu_R = M_{de} MM_{de} \mu_{MM} \quad (6)$$

The following notations have been used:

R is the linear electrical resistance for 1 m;

A – the surface of the yarn section;

l – the length of 1 m of yarn;

M_{de} – the equivalent percentage of the material from total volume;

MM_{de} – the equivalent percentage of the magnetic material from total volume;

μ_{MM} – relative magnetic permeability of the magnetic material.

A relative magnetic permeability of stainless steel was set to μ_{MM} = 40, accordingly to [20], while M_{de} and MM_{de} were computed according to the yarn's twist/spun structure.

Based on these types of yarns, five variants of woven fabrics were manufactured. The woven fabrics were designed with the conductive yarns in the weft system at distances of 2 mm and 4 mm. One woven fabric was designed with stainless steel conductive yarns in warp and weft system, with a grid of 4 mm. Cotton yarns were used for the support structure of the fabrics. The following structural and physical-mechanical properties for the fabrics apply (table 2):

Table 2

STRUCTURAL PARAMETERS AND PHYSICAL-MECHANICAL PROPERTIES OF THE WOVEN FABRICS						
	Standard	**RAZ-1**	**RAZ-2**	**RAZ-3**	**RAZ-4**	**RAZ-5**
Conductive yarn	-	F2002	F1002	F1005	F1005	F1003
Pattern Conductive / Cotton yarns	-	Warp: 2:6 Weft: 2:6	Warp: - Weft: 6:2	Warp: - Weft: 6:1	Warp: - Weft: 3:1	Warp: - Weft: 6:1
Weave	-	plain	plain	plain	plain	plain
Specific mass [g/m²]	EN 12127:1999	143	124	113.4	121.2	134
Density [no. yarns/ 10 cm] – Warp	EN 1049:2:2000	180	290	65	66	420
Density [no. yarns/ 10 cm] – Weft		170	330	34	33	270
Material's thickness [mm]	EN ISO 5084/2001	0.55	0.72	0.33	0.33	0.49
Surface resistivity [W]	EN ISO 1149-1/2004	$9.5*10^{2}$	$2.72*10^{3}$	$1.96*10^{14}$	$8.83*10^{14}$	446
Volume resistivity [W*cm]	EN ISO 1149-2/2004	$3.7*10^{4}$	$2.4*10^{4}$	$2.18*10^{15}$	$5.49*10^{15}$	-

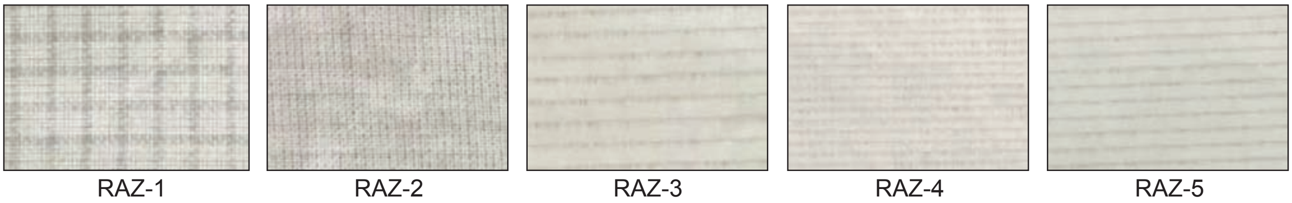

Fig. 2. Pictures of the five woven fabrics performed

The surface resistivity is measured according to the standard EN ISO 1149-1/2004 in Ωs, due to the special geometry of the testing device, with two concentrically rings of specified dimension. The index s indicates this exceptional measurement unit for the electrical resistivity. The investigation of yarns and fabrics was performed in the INCDTP accredited laboratories. Some pictures of the 5 woven fabrics are presented in figure 2.

EXPERIMENTAL RESULTS FOR THE SHIELDING EFFECTIVENESS

In order to validate the analytic shielding effectiveness relation presented at section 2, numerous physical tests on the fabrics were performed, within the EMC Laboratory of the Faculty of Power Engineering in University "Politehnica" Bucharest. An experimental setup was achieved, consisting of a shielding enclosure and the electric measurement system. The enclosure is constructed of a cube from wooden bars, each having a cross section of 2×3 cm and a length of 100 cm. Dry wood was chosen as material, for it has similar magnetic (permeability) and electric (permittivity) properties ofthe air, with no influence on the shielding measurements. The enclosure was completed by five covers out of the obtained textile materials for the cube with a side of 100 cm.

The electric measurement system is composed of the following electronic devices:

- the signal generator;
- the power amplifier;
- the matching circuit for the magnetic emitting antenna;
- the magnetic field emitting antenna;
- the magnetic field receiving antenna (it's an active antenna);
- the spectrum analyser.

Thus, several measurements were performed, by placing the emission antenna inside the enclosure and the receiving antenna outside, both at a 30 cm distance from the wall of the enclosure. Figure 3 presents a block schema of the experimental setup, while figure 4 presents its elements.

The measurements were performed for two situations:

- without shielding enclosure (in order to measure the reference magnetic field H_a);
- with shielding enclosure (in order to measure the inside magnetic field H_y).

The shielding measurements were performed at the frequency ranging between 1 MHz to 20 MHz for the electromagnetic near field. The upper limit of 20 MHz was set accordingly to the standard IEEE 299.1, as the frequency range of [20 MHz, 300 MHz] is considered to initiate resonances within an enclosure

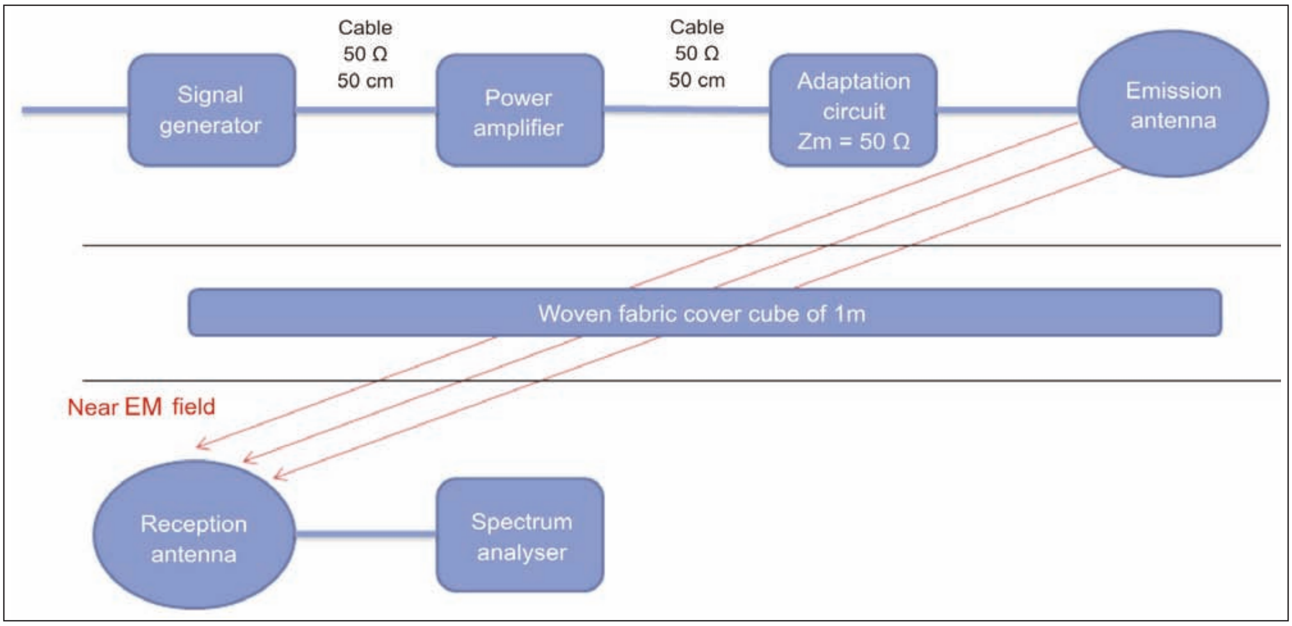

Fig. 3. Block diagram of the experimental setup

Table 3

EXPERIMENTAL RESULTS SHIELDING EFFECTIVENESS WOVEN FABRIC RAZ – 1 (STAINLESS STEEL)				
f [MHz]	**Output of power generator** [dBm]	**Reference measurement without enclosure** [dBm]	**Shielding measurement with enclosure** [dBm]	**Shielding effectiveness (difference)** [dBm]
5	–20	–7.2	–6.4	–0.8
10	–20	–10	–10	0
12	–20	–10.4	–10.8	0.4
14	–20	–10	–10.4	0.4
16	–20	–9.6	–10.4	0.8
18	–20	–10.4	–12	1.6
20	–20	–6.8	–16.8	10

Table 4

EXPERIMENTAL RESULTS SHIELDING EFFECTIVENESS WOVEN FABRIC RAZ – 5 (SILVER)				
f [MHz]	**Output of power generator** [dBm]	**Reference measurement without enclosure** [dBm]	**Shielding measurement with enclosure** [dBm]	**Shielding effectiveness (difference)** [dBm]
5	–20	–4.4	–6	1.6
10	–20	–8	–7.6	–0.4
12	–20	–8.4	–8	–0.4
14	–20	–7.6	–7.2	–0.4
16	–20	–7.2	–6.8	–0.4
18	–20	–9.2	–8	–1.2
20	–20	–8	–6.4	–1.6

having maximal dimension between 0,1 m and 2 m. For frequencies exceeding 300 MHz, the electromagnetic near field condition is no longer satisfied. Repeatability conditions were ensured for all the measurements. Table 3 and table 4 present the shielding effectiveness results for the covers manufactured from the textile materials RAZ-1 (stainless steel yarns) and RAZ-5 (silver yarns).
The power of the electromagnetic signal is expressed in dBm, while the shielding effectiveness is computed as difference between the reference measurement and the measurement with textile shielding enclosure. Table 4 shows that the measurements for the shielding effectiveness of the fabric with silver yarns has negative values, in the noise zone. This fact can be explained due to thediamagnetic behaviour of silver yarns and the better results of the ferromagnetic stainless steel yarns for the electromagnetic near field.

SIMPLE FORM FOR THE ANALYTIC SHIELDING EFFECTIVENESS AND ITS VALIDATION

Several mathematical simplification operations were performed on the analytic relation (1), by studying the premises of variation for the single parameters. The resulting relation (7) expresses the shielding factor depending both on the geometric parameters and the electric parameters of the enclosure. The electric parameters are included in the formula for the skin depth (8):

$$|Q| = \frac{1}{2\pi}\frac{a}{x}\left(\frac{\delta}{r}\right)^2 \qquad (7)$$

$$\delta = \frac{1}{\sqrt{\pi f \sigma \mu}} \qquad (8)$$

with the following electric parameters of the conductive yarn's raw material (table 1):
σ – electric conductivity [S/m];
μ – magnetic permeability [H/m].
Figure 5 presents the shielding effectiveness related to the frequency on logarithmic scale. The following colour codes apply for the figure:

Colour code	Description
(red)	The analytic shielding effectiveness according to the literature (1)
(yellow)	The simplified analytic shielding effectiveness (5)
(blue)	The measured experimental data for the shielding effectiveness for stainless steel

Thus, figure 5 shows in the first place, that the simplified analytic relation (7) models quite well the full analytic relation (1) from the literature, for the specified frequency range [16]. Secondly, the experimental values are smaller than the predicted ones and this fact can be explained by the fact that the analytic relation describes an ideal model and the electric conductivity for the yarns at the edges of the cube is only partially insured. However, the stainless steel yarns have

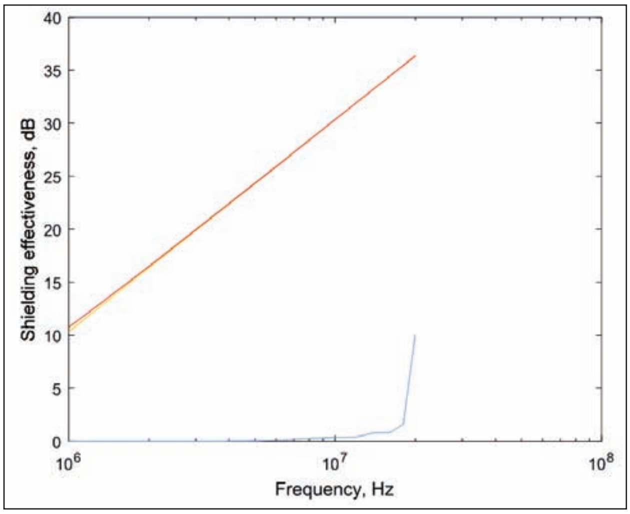

Fig. 5. Shielding effectiveness for analytic, simplified and measured values

a shielding effect on the magnetic near field, mainly due to their ferromagnetic nature.

DISCUSSION

One of the main questions identified at textile producers of woven fabrics with conductive yarns, was the necessary step of the grid – namely the distance between warp/weft yarns and its raw material, in order to achieve a specified shielding effectiveness. Figure 6 shows a parametric study for the shielding effectiveness (simplified relation) with various distances between conductive yarns. The following colour codes apply:

Colour code	*a* – distance between conductive yarns
	4 mm
	2 mm
	1 mm

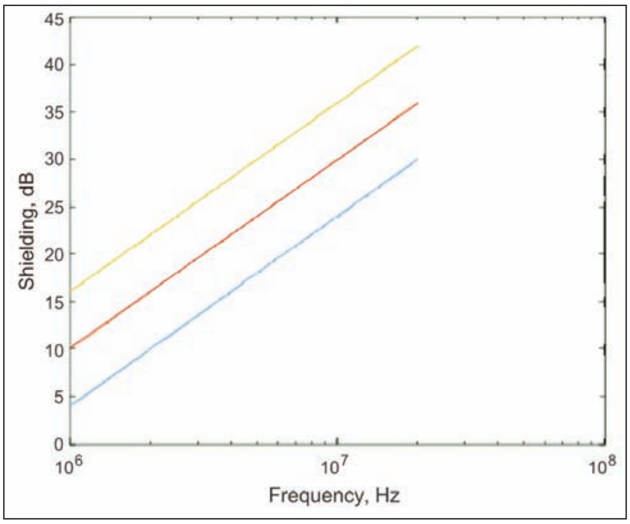

Fig. 6. Parametric study upon the distance between yarns

Figure 6 shows that a closer grid of conductive yarns has a better shielding effectiveness. This can be explained due to the higher electrical properties of the woven fabric. The simplified analytic relation for the shielding factor allows the computing of the distance between yarns *a*, in relation to the electric parameters of the yarn (electric conductivity σ and magnetic permeability μ, which are included in the formula of the skin depth (8)) and the geometric parameters of the enclosure (radius of the yarn *r* and distance between shielding walls 2*x*). Hence, the distance between conductive yarns (parameter *a*) results from the relations (3) and (7):

$$a = 2\pi x \left(\frac{r}{\delta}\right)^2 10^{-\frac{SEdB}{20}} \qquad (9)$$

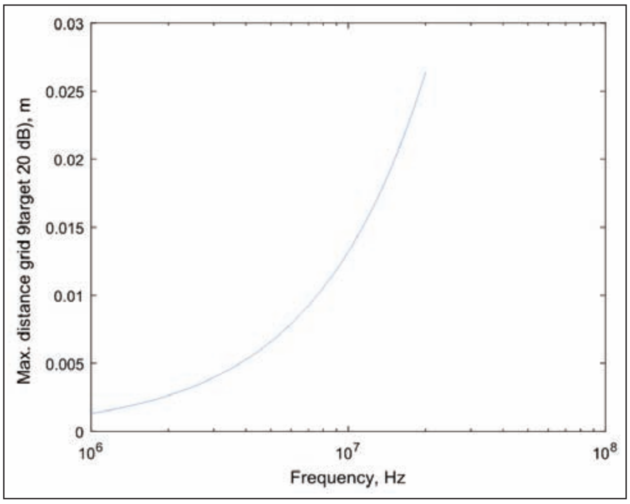

Fig. 7. Distance between conductive yarns for 20 dB shielding effectiveness and given parameters

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Target Shielding effectiveness SEdB = 20 dB
Frequency range: f = [1e6:1e5:2e7] Hz
Electric conductivity: σ = 7700 S/m;
Relative magnetic permeability: μr = 7.36;
Magnetic permeability of vacuum: μ0 = 4π*e-7
H/m;
Magnetic permeability: μ = μr*μ0 =
29.44π*e-7 H/m;
Radius of the conductive yarn: r= 135e-6 m;
Distance between shielding walls of enclo-
sure: x= 100e-2/2 m;
```

Figure 7 shows that the fabric requires a closer grid for smaller frequencies, at the same value for the shielding effectiveness. This is according to physics rules, for as known, the shielding of electromagnetic near field of low frequencies is very difficult to be achieved. On the other hand, the mechanical properties of a fabric with great density of conductive yarns could be a problem, due to their different mechanical tensile strength (5.46 N) and tenacity (0.1365 N/tex) when compared to the cotton yarns of the substrate tensile strength (4.788 N) and tenacity (0.1197) N/tex (table 1). This aspect can lead to difficulties when processing the woven fabrics. The cost of the conductive yarns represents another aspect, which requires optimization.

Thus, the design of a conductive fabric for shielding of the electromagnetic near field has to achieve a balance between the specified shielding effectiveness, the distance between conductive yarns and the mechanical behaviour of the fabric. It is recommended to use stainless steel yarns for their ferromagnetic properties and their improved shielding of the magnetic field.

CONCLUSIONS

The paper proposes to study the shielding effectiveness of an enclosure for the near electromagnetic field. An analytic relation for the shielding effectiveness, taking into account both geometric and electric parameters of the conductive fabric, was simplified by the authors and a validation study was conducted. For the experimental part of validation, five woven fabrics with conductive yarns were manufactured, both ferromagnetic (based on stainless steel yarns) and diamagnetic (based on silver yarns). The proposed frequency range for testing is limited by the near electromagnetic field condition on one hand, and the resonance conditions specified by the standard IEEE 299.1, at 1 MHz – 20 MHz. The experimental results show smaller values for the shielding effectiveness as the analytic values, however these facts have two explanation: the electric continuity at the edges of the cube is only partially insured and the analytic relation represents an ideal model, very difficult to be reproduced with the used equipment. The experimental arrangement and the applied procedure are useful firstly to compare the features of different fabrics.

The simplified analytic relation givesa good approximation for the analytic relation fromthe literature for the specified frequency range and supportsthe computing of the distance between the conductive weft yarns in relation to the targeted shielding effectiveness. Thus, an important question addressed by the enterprises in the textile industry, that is the required distance of the conductive grid for woven fabrics and its raw material, may find an answer. A parametric study for the distance of the conductive weft yarns shows that the denser the conductive yarns, the better the shielding effectiveness of the electromagnetic near field. Calculations based on the proposed simplified relation are possible, in order to achieve an optimization between fabrics process ability, the costs and the targeted shielding effectiveness.

Future work envisages to refine and to extent for other frequencies the simplified analytic relation and also to add measurements, based on other arrangements and other set of antennas.The authors propose to achieve a correction of the analytic shielding effectiveness, meant to explainin a more accurate way the experimental values, as well as to provide additional experimental values for the electric properties of the conductive fabrics, based on other measurement methods.

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Air, moisture and thermal comfort properties of woven fabrics from selected yarns

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REZUMAT – ABSTRACT

Proprietățile de confort la aer, umiditate și termic ale țesăturilor din fire selectate

Sunt studiate proprietățile de transport ale aerului și umidității ale țesăturilor cu legatură pânză, realizate din bumbac 20^sNe_c în urzeală și fire pure de tencel, modal, pro-modal, bambus, polyester și bumbac 20^sNe_c în direcția bătăturii. Caracteristicile majore adăugate acestui studio include permeabilitatea la vaporii de apă, permeabilitatea la aer, timpul de umiditate și viteza de capilaritate. Comparând cele șase eșantioane diferite de materiale cu compoziție diferită în direcția bătăturii, permeabilitatea la aer a firelor de tencel a fost minimă, iar cea a poliesterului a fost maximă, în timp ce rezultate opuse au fost observate pentru ambele eșantioane în cazul permeabilității la vapori de apă. Dintre amestecurile cu bumbac, conductivitatea termică a bambusului și absorbția termică a poliesterului au obținut valori maxime, în timp ce rezistența termică minimă a fost observată pentru firul pro modal în bătătură. Un model similar a fost observant în viteza de împrăștiere și timpul de umezire a poliesterului atunci când este observat din partea superioară sau inferioară. Proprietățile de confort ale firelor de bambus și pro modal, având valori aproape similare, sunt sugerate a fi utilizate în articolele de îmbrăcăminte utilizate pentru golf.

Cuvinte-cheie: proprietăți de management al umidității, permeabilitate la vapori de apă, permeabilitate la aer, proprietăți de confort termic și umiditate

Air, moisture and thermal comfort properties of woven fabrics from selected yarns

Air and moisture transport properties of plain woven fabric made from 20^sNe_c cotton in warp and 20^sNe_c pure yarns of tencel, modal, pro-modal, bamboo, polyester and cotton yarn inweft direction are studied. Major characteristics added for this study include water vapour permeability, air permeability, wettingtime and wicking speed. In comparison of six different samples of variously composed materials in weft direction, the air permeability of tencel was minimum and polyester was maximum, whereas the reverse results were observed for both the samples in case of water vapour permeability. Among the blends with cotton, thermal conductivity of bamboo and thermal absorptivity of polyester was found maximum whereas the minimum thermal resistance was observed for pro modal yarn in weft. Similar pattern was observed in spreading speed and wetting time of the polyester when observed from either side top or bottom. Air and moisture comfort properties of bamboo and pro modal, having nearly similar values are suggested to be used in garments used for golf players.

Keywords: moisture management properties, water vapour permeability, air permeability, wetting and *thermal comfort properties*

INTRODUCTION

In addition to provide a physical cover to human aesthetics, comfort and protection are the essential features of apparels. Woven fabricsare the backbone for production of apparel manufacturing mainly due to both comfort and cost of manufacturing that makes it preferable over others. Similarly, the demand of comfortable fabric is increasing for general and specific purposes like players in the sports field need breathable fabric during their practices. Hence, yarn should be properly selected and strengthened during the production of fabric that should fulfill all the basic considerations. Additionally, it should not restrict the movement and should provide ease for the user of the garments [1]. Natural as well as regenerated fibers have increased importance with aspects of textile industry to meet performance challenges. Apparels have highest rates of strength comfort and drape by using these fibers [2].

In addition to popularity of trend, garment-fitting and fashion, the clothing comfort is also important and can be measured by various aspects related to physiological comforts of garments [2]. Human comfort is the state of mind expressing the level of satisfaction provided by the environment around an individual. The surrounding environment changes with the change in temperature and with the result of this thermal change, human comfort level changes. Therefore, human comfort and thermal comfort are counter parts of each other. The major factors incorporating for apparel comfort are mixing, yarn twists, texturizing, fabric structure and its properties, mechanical treatments, moisture- and vapour-permeability and finish treatments [3, 4]. Moisture management and breathability of fabric are related to ease of fabric provided to individuals [5]. Especially during sports, body presipitates a lot and when the prespiration occurs the body feels comfortable and cool. Therefore, the garments manufactured fulfilling said purposes allow comfortability.

The regenerated fibers have many excellent properties with respect to tenacity, thermal conductivity and water and perspiration absorption. Cotton on the other hand has best absorbency and breathability. All regenerated fibers are having progressive values when compared to synthetic fibers [6, 7]. The fabrics made from 100% bamboo were comfortable and have excellent moisture and temperature management properties [8]. Regenerated fibers are used in different apparels including sports textiles, socks, t-shirts and in ligerie products [9]. Tencel due to good moisture absorption characteristics could be used to enhance the moisture handling and other properties of sportswear fabrics while at the same time improving the aesthetics [10]. Similarly, modal and promodal, containing soft and cozy fibers also show good moisture management properties.

A lot of resaerch has already been established for investegating the comfort properties of woven fabrics [11]. Hereby, the work is done to investigate the influence of regenerated yarns in weft direction and compare the comfort properties of woven fabric with fabric made from 100% cotton fixed at warp direction. In this study, testing of air permiaility, wetting, wickbility and water vapour permeability of plain fabrics is investigated.

MATERIALS

The pure yarns of 100% modal, tencel, pro-modal, bamboo, polyester, cotton yarns were produced in a local spinning mill in Pakistan. The count of all yarns was fixed at $20^{s}Ne_{c}$. The characteristics of various yarns are given in table 1.

WEAVING AND PROCESSING

The fabric was woven on an air jet loom in local weaving mill according to given specifications, where warp count was fixed at $20^{s}Ne_{c}$ for cotton yarn only and all above yarns were used in weft for production of 6 different samples (**A-F**) of fabric. In this work, the plain woven fabrics were chosen to be weaved. The fabric samples were scoured and bleached according to standard recipe, the geometrical properties of fabric are presented in table 2 and the related comfort properties with respect to each fabric are given in table 3.

METHODS

Different experiments were done to evaluate the comfort properties of given fabric samples.

TESTING

All the finished fabric samples before testing were conditioned at standard atmospheric temperature 20ºC ± 2 ºC and relative humidity of 65 ± 2%. The tests that had been conducted for fabric samples (**A-F**) are air permeability, fabric mass, water vapour permeability, and moisture management. The tests were

Table 1

Weft yarns	Modal	Tencel	Pro modal	Bamboo	Polyester	Cotton
Linear irregularity (U%)	7.01	7.55	7.58	7.71	10.34	11.73
Thin place/km (–50%)	0	0	0	0	0	3
Thick place/km (+50%)	2.0	3.5	6.3	8.3	1.3	204
Neps/km (+200%)	2.5	5.8	10.5	17.8	5.3	141
Hairiness	5.23	6.11	6.09	4.44	5.23	7.05
Count strength product	3637	4400	3700	2601	4949	2050
Single yarn strength	956	1013	823	656	930	439
Elongation at break %	11.81	9.78	10.20	12.30	13.20	3.47
Tenacity RKM	32.40	34.30	27.85	22.24	31.50	14.89

Table 2

Sample	Warp yarn	Weft yarn	Ends per inch	Picks per inch	Warp cover factor (K_1)	Weft cover factor (K_2)
A	100% Cotton	100% Modal	60	60	13.6	13.1
B		100% Tencel	60	60	13.6	13.1
C		100 %Pro Modal	60	60	13.6	13.1
D		100% Bamboo	60	60	13.6	13.1
E		100% Polyester	60	60	13.6	13.1
F		100% Cotton	60	60	13.6	13.1

Table 3

Sample	Thickness [mm]	Fabric weight [g/m²]	Air permeability [cm³/cm²/sec]	Water vapour permeability [g/m²/day]	Top wicking	Bottom wicking	Top wetting	Bottom wetting
A	0.61	171	193.2	623.38	4.89143	4.81872	2.9673	2.967
B	0.66	163	166.02	818.83	4.775896	4.58564	2.941	3.04661
C	0.66	168	180.2	603.27	4.045	3.93809	3.1813	3.28856
D	0.62	177	226	703.71	3.83287	3.68287	3.1547	3.18051
E	0.64	155	230.8	536.11	1.702366	4.54823	5.248	3.9885
F	0.60	157	228	724.47	4.47424	4.54823	2.9943	3.0436

conducted in National Textile University, Faisalabad and Pakistan Council for Scientific and Industrial Research (PCSIR) laboratories, Lahore, Pakistan. The standard procedure followed for moisture management test was ASTM D1776, for Water vapour permeability ASTM E96 and air permeability was tested by ISO 9237. All thermal comfort properties tests (thermal-, resistivity, absorptivity and conductivity) were performed in Technical University of Liberec, Czech Republic.

RESULTS AND DISCUSSION

Wetting time

The wetting time is shown in figure 1. When observed from top, the results specify that wetting time is higher in sample ***E*** composed of 100% polyester material. Similar effects were observed for the polyester when observed from bottom [7]. All other material shows similar tendency towards wetting time from both sides, top and bottom. In sum, low ability to have moisture management transfer is due to the fact that wettability of the fabric depends on the material being used. The testing of samples ***A-D*** and ***F*** clearly predicts about their good moisture management property.

Wicking

The top and bottom spreading speed of samples ***A*** and ***B*** is higher due to higher GSM and better moisture management transfer. Here again the the value for top spreading speed is less in case of sample ***E***. The experimental results shows that wicking property of fabric depends upon the characteristics and structure of fibers (figure 2). The wicking behavior of fabric is relevant on the structure of the constituent yarns, their direction in the fabric, the fabric structure, the pretension and the force applied.

Air permeability

The air permeability of different materials observed is given in figure 3. The variation in the results shows that material has high significance on the air permeability of the fabric. As the weft material changes in the fabric, the change in air permeability occurs. The air permeability of sample ***E*** is the best as compared to other material samples. Due to round structure and low fiber density and porosity in these materials show in increased value of air permeability, whereas as the moisture absorption was less in ***E*** due to fewer number of fibrils in its cross section as compared to samples ***B***, ***C*** and ***D***. Therefore, good air permability was observed in sample ***E***. Similarly, the sample ***F*** shows

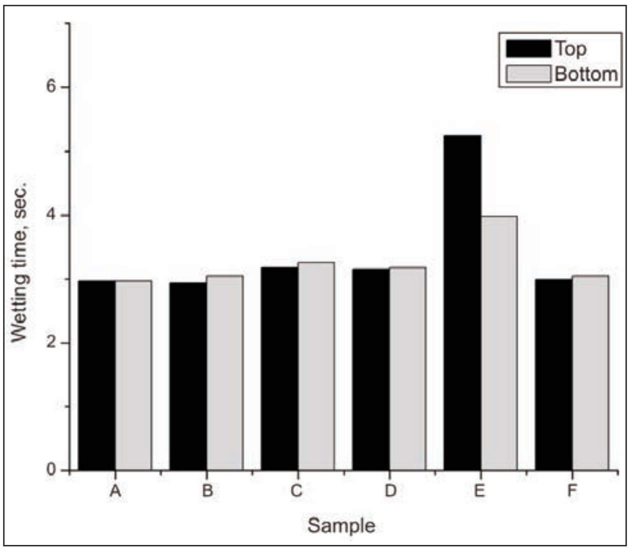

Fig. 1. Wetting time in seconds for different weft material from top and bottom

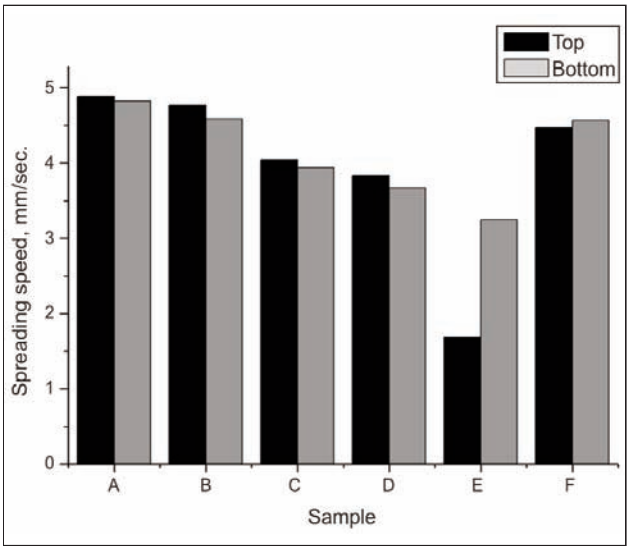

Fig. 2. The spreading speed from top and bottom of different materials

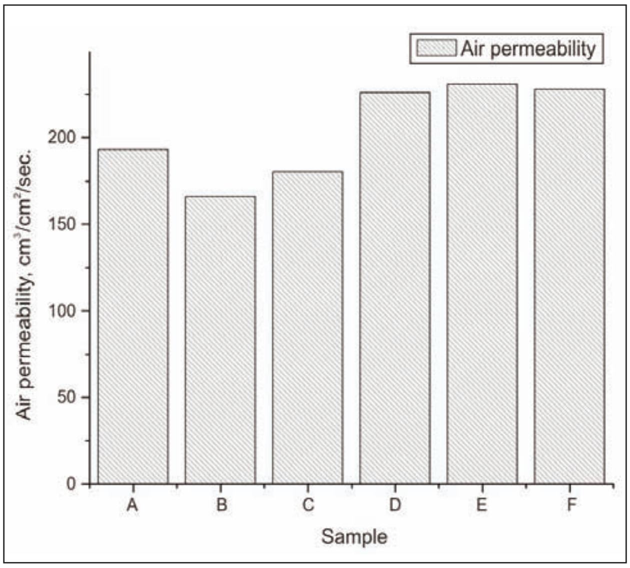

Fig. 3. The air permeability of variously structured weft materials

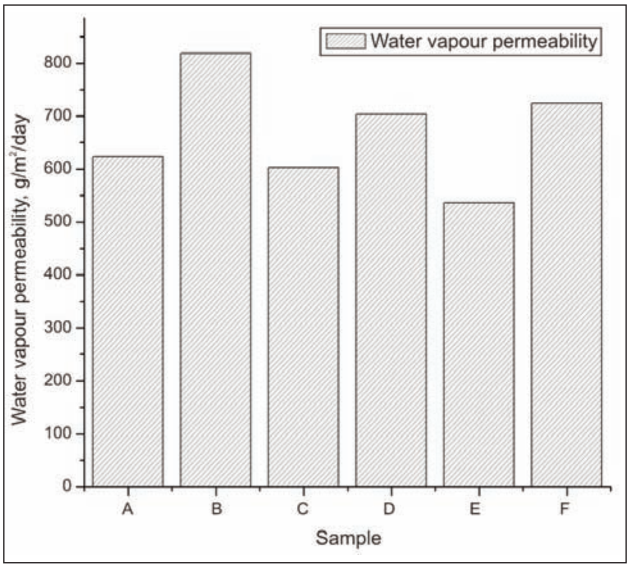

Fig. 4. Water vapour permeability of 100% pure weft yarns based fabrics

greater value as compared to sample ***D***. The same reason lies in this case where less crystallanity and bigger amorphous region of sample ***F*** gives more air permeability than sample ***D***. Similarly, sample **A** shows better air permeability value as compared to sample ***B***. Cotton is caracterized by ribbon like twist structure. These fibers like convolutions form hairiness in cotton yarn due to which air resistance of cotton yarns increases. When tencel is used with cotton the effect of air permeability shows its lowest values as tencel fiber itself has air conditioning property. Air permiabilty also decreases as the fiber fineness increases. This effect is also well elaborated as sample A shows good airpermeability value with respect to sample ***C***. It means sample a has more coarser fibers while using 100% modal in weft direction. Sample ***C*** gives higher number of fibers per yarn cross-section in weft direction due to which the fabric is less open and have low value of permeable structures so less air permeability occurs.

Water vapour permeability

Ability of fabric to transport its water in form of vapours through it is called water permeability. Figure 4 illustrates that water vapour permeability of sample ***B*** is much higher than other fabrics. As the microdenier, synthetic and natural fibers give good moisture absorption so sweat can easily be vaporized from these types of fabrics. Similarly, sample ***F*** also shows good behavior in water vapour permeability and hence thermo-comfortability. On the third number is sample ***D*** that shows more permeability than ***A*** and ***C***, whereas sample ***E*** stands at last position for this test. Lesser the value of water vapour permeability less will be the value of prespiration, due to which more vapours will accumulate and discomfort will be more. Sample ***D*** shows more higher value than ***A*** and ***C*** as bamboo has higher moisture regain value. The water vapour permeability also depends on macroporous structure of the constituent fibers. Therefore, the higher values of vapour permeability was observed for sample ***B*** as compared to other samples. The tencel has nanostructures due to which their moisture transportation is excellent, whereas the modal is compact from outside, its inner side is porous and the inner fiber skin is semi permeable. Therefore moisture absorption of modal will be lower than tencel.

Thermal parameters testing

Thermal parameters such as thermal conductivity, thermal absorptivity and thermal resistance play an important part in thermal comfort of human body when interaction of fabric with human body [11]. Thermal parameters have their values that any kind of irregularity in thermal equilibrium in human body can cause discomfort in body (figure 5). Thermal properties are very sensitive to measure. Sensora™ company in Czech Republic has developed an instrument called *Alambeta* which measures thermal properties accurately. The samples which have been used in this study were measured under controlled environment of 20–22 °C and relative humidity of 24–25%.

Thermal conductivity of fabric is total impact of chemistry of fiber and composition of fabric. Fabric is composed of polymer, air and moisture. Thermal

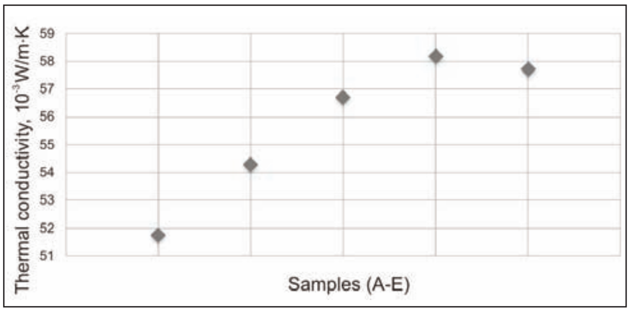

Fig. 5. Thermal conductivity of the samples

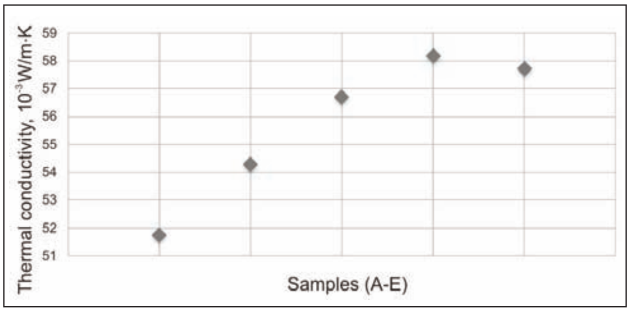

Fig. 6. Thermal absorptivity of blended fabrics

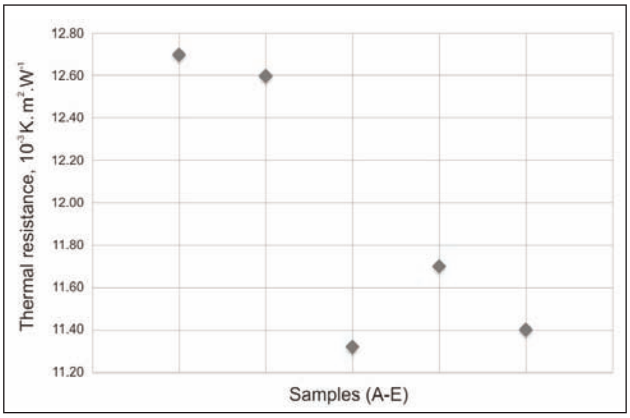

Fig. 7. Thermal Resistance of samples

conductivity of polymer is quite different from the thermal conductivity of fabric made of same polymer. For example, thermal conductivity of polyester fiber is different from thermal conductivity of fabric made using 100% polyester, mainly due to the presence of other factors like, air, moisture, textile auxiliaries, dyes molecules etc. Keeping this point in view, it was more likely that thermal conductivity of differently woven fabrics ***(A-E)*** will be different due to a lot of variation in increase in area of contact that can increase the thermal conductivity. It is mainly due to fewer spaces for air to be trapped as the surface of fabric and it becomes flat and more contact points are available to touch the skin. It facilitates the heat flow and more heat flow is a sign of higher thermal conductivity.

Thermal absorptivity is a vital characteristic of fabrics and it is the subject of numerous studies as well. It relies on the thermal conductivity of fibers, density and specific heat of the material. Thermal absorptivity demonstrates the capacity of a material to give warm-cool feeling when a material is touched for a short time approximately for two seconds. Thermal conductivity is anisotropic in nature and relies on the structure and chemistry of the material. Density of fabric depicts the mass per unit volume of a fabric [Kgm^{-3}]. It indicates the ratio of solid and void area in the fabric (figure 6). Fabric consists of polymers (filaments), air trapped inside fabric and dampness in voids in case of humid environment. Thermal absorptivity [$Wm^{-2}s^{-1/2}K^{-1}$] is linked with the thermal conductivity [$10^{-3}W\,m^{-1}K^{-1}$] and thermal capacity of fabric [$Jm^{-3}K^{-1}$]. Thermal capacity is a product of density [Kgm^{-3}] and specific heat [$JKg^{-1}K^{-1}$].

Thermal resistance is directly proportional to thickness of the slab and indirectly proportional to thermal conductivity of the material. It has been observed from figure above that different fiber types correlate differently between contact points and hence show different thermal conductivity. As thermal conductivity increases, there is a definite decrease in thermal resistance (figure 7). It shows that fabric having smooth surface provides less heat resistance and gives a cool effect, whereas, fabric with low number of contact points is better to keep body temperature intact and provides a thermo-physiological comfort to wearer. The above results show that as the fabric ratio and blends are changing and are imparting different impact on the thermal properties of fabric. For example, when the blend comes with different weft- and warp-wise directions these above results shows that blending do play a role in the thermal properties of fabrics.

CONCLUSION

Knitted fabrics are less air permeable than weaved fabrics so the moisture management parameters of woven fabric made from Tencel, modal, pro modal, bamboo, polyester and cotton were analyzed. The properties like air permeability, wetting, and wicking and water vapour permeability had been studied. The fabrics in which bamboo and pro modal were used in weft showed average values of the all above properties. Since this work is established on 100% pure weft yarns and single construction of the fabric so in future the fabric construction will be varied from 20*20/61*59 with respect to 100% cotton, however the same study can be done on pure yarn other than cotton on warp with other blended fabrics as well with different constructions. Herein, the bamboo and pro-modal due to their nearly similar moisture management properties and the most economic prices, in comparison with tencel and modal, make it preferable choice in many practical applications including sports garments.

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Novel portable device to analyze the moisture permeability of car seat

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REZUMAT – ABSTRACT

Nou dispozitiv portabil pentru analiza permeabilității la umiditate a scaunului auto

Performanța de confort a scaunelor auto este un factor important în producerea acestora, fiecare strat al scaunului auto fiind testat separat pe aparatele de testare convenționale, care nu au același nivel de performanțe atunci când toate straturile sunt intercalate. Complexitatea designului scaunelor auto și metoda de testare creează o cerere ridicată de dispozitive portabile, care pot măsura performanța de confort a scaunului auto in mod real. În cadrul acestei cercetări este proiectat un dispozitiv portabil nou care funcționează cu senzor de flux de căldură special, fiind conectat la calculator prin USB, valorile fluxului de temperatură al apei și temperatura suprafeței fiind furnizate de software. Senzorii fluxului de căldură măsoară transferul de căldură printr-o suprafață, exprimată în kw/m^2. Software-ul controlează ajustarea plăcii de încălzire utilizând controlerul PID. Dispozitivul este testat cu scaun auto real și prezintă rezultate repetabile și reproductibile.

Cuvinte-cheie: scaun auto, dispozitiv portabil, flux de căldură

Novel portable device to analyze themoisture permeability of car seat

The comfort performance of car seat is important factor while producing car seats, each layer of the car seat is tested separately on classical testing machines, which lacks the real car seat performance when all layers are sandwiched. The complication of car seat design and the testing method bring a great demand of portable device which can measure the comfort performance of the real car seat. In this research a novel portable device is designed which work with special heat flux sensor and the device is connected to computer by USB port and values of heat flux temperature of the water and temperature of the surface is provided by the software. Heat flux sensors measure the heat transfer through a surface, and are expressed in kw/m^2. The software controls the heating plate adjustment using PID controller. The device is tested with real car seat and shows repeatable and reproducible results.

Keywords: car seat, comfort, portable device, heat flux

INTRODUCTION

Today, comfort has become a major quality criterion of cars. Comfort in a car is a complex phenomenon and comprises such different aspects as, for example, noise, driving behavior, or ease of handling. One of the most important factors influencing passenger convenience is thermal comfort. Therefore, car manufacturers are paying a lot of attention to this aspect, as can be seen by an increased application of air conditioning in the car [1].

A particularly important aspect of vehicle comfort is the seats. Seats do not only have to have an attractive design or meet specific design criteria for safety reasons, they must also have optimum comfort properties. But seat comfort is much more than just passenger convenience. Scientific findings show that the performance of a driver over long distances significantly decreases if the car seats do not support posture and heat balance as required. This leads to exhaustion and loss of concentration, which, in extreme cases, could result in serious accidents [2, 3].

In addition to ergonomic considerations of comfort, the climatic or thermophysiological comfort of the seat is of particular importance. This indicates whether the seat is able to support the thermoregulation of the body via heat and moisture transport.

PARAMETERS OF SEATING COMFORT

From the physiological point of view, seat comfort comprises the following four parameters [4]:

i. The initial heat flow following the first contact with the seat. In other words; the sensation of warmth or cold in the first few minutes or even seconds after entering the car.
ii. The dry heat flow on long journeys, i.e. the amount of body heat transferred by the seat.
iii. The ability known as “breathability” to transfer any sweating away from the body. In so-called “normal sitting situations” there is no perceptible perspiration, but, nevertheless, the human body constantly releases moisture (so-called ‘insensible perspiration’), which has to be taken away from the body
iv. In the event of heavy perspiration (a car in the summer heat, stressful traffic situations) the ability to absorb perspiration without the seat feeling damp.

Warmth sensation

25% of human body is in contact with car seat and the car seat acts as an extra layer of the clothing thus the effecting parameter of the clothing comfort is the same for car seat thermal comfort as well.

The passenger is already sensing his first thermal impression of a car seat while entering the vehicle. This initial perception of warmth after sitting depends on the thermal absorptivity of the car seat. It is effected by is its heat capacity of the car seat material. Heat capacity is amount of heat required to raise its temperature one degree. Heat capacity varies with the mass of the cushion and the type of material. Thermal conductivity is also another parameter of the thermal absorbency and the thermal absorptivity should be as low as possible; otherwise a car seat feels cold in the winter time or hot during summer [1, 5].

Although this initial feeling may last only a few minutes, it is nevertheless very important for the user's acceptance, as it is being repeated frequently. If a car is used every day during the winter time and each morning the driver is dissatisfied when entering the car, acceptance can be significantly decreased.

During long journeys it is favorable if the seat offers a high steady state heat flow, to minimize the tendency to sweat , whereas for the initial perception a low heat flux is required [3]. Hence a conflict arises between these two scenarios.

This conflict can be overcome, because the cover, which determines the initial perception, is only of minor influence on the steady state heat flux, which is mainly determined by the thermal insulation of the seat. Owing to its greater thickness and, hence, higher thermal insulation in comparison to the cover, the cushion becomes the dominant part.

On the other hand, the heat flux is also dependent on the ventilation in the seat. Ventilation itself is determined by the design of the seat (side supports, surface grooves), the elasticity and air permeability of the cushion and, if present, a fan to enforce ventilation [6].

For the car seats with heating, the dominant seat components are the cover. Other than thermal properties of the car seat cover, heating power and its position are of great importance [7, 8].

As a common material used in car seats, foams are poor conductors of heat and have a low heat capacity. A thin layer of foam (plus cover) warms up to skin temperature when driver sits on it, but does not draw much heat from the body's tissues. In warm environments, or during physical exercise, the body attempts to lose heat but is prevented from doing so in the buttocks area and back rest due to the insulating foam of the cushion. This region may therefore begin to heat, resulting in uncomfortable dampness.

A car sit with impermeable foam can increase the skin temperature 10 °C in 2 hours and increase of the temperature of the skin will cause sweating [5].

Moisture sensation

The moisture sensation of the passenger is very important for perceived overall seat comfort. In order to achieve a dry microclimate, the ability, known as 'breathability', of the seat to transport any perspiration formed away from the body is crucial. Not only under warm summer conditions is good water vapour transport necessary, but even when there is no perceptible perspiration. The human body constantly releases moisture, the so-called 'insensible perspiration'. As the skin is not totally water vapour tight, our body loses on average 30 grams of moisture per hour. Because a car seat covers large areas of the body, the seat has to manage a large part of the perspiration formed, and, hence, a considerable amount of moisture [1].

Moisture accumulation results in discomfort and, in some cases, an increased risk of soft tissue damage. Many factors determine the causes and prevention of moisture accumulation.

Generation of excessive quantities of heat can cause the sweating. Sweat is normally generated to assist in the thermoregulation of the body by the evaporation of moisture to cool the surface of the skin. Normally, sweating is suppressed locally by pressure. However, sweating can occur in an uncontrolled manner, independent of thermoregulation as insensible perspiration.

Poor exchange of air is one of the reasons of moisture accumulation if there is poor exchange of air in the supported area and the supported area is thermally insulated by the cushion, the interface temperature can exceed 38°C, where upon sweating increases rapidly with increasing temperature. So that use of impermeable covers for car seat can increase the moisture accumulation. If materials in close contact with the skin do not "breathe" the sweat from body is not being evaporated so that natural environmental cooling cannot occur and resulting in more heat build-up and more sweating.

Methods for preventing moisture build-up include the use of cushion and cover materials that encourage air exchange between the cushion and skin. Any impermeable layer of car seat will be the barrier for moisture transport and will make the complete structure impermeable so that uncomfortable. Cushions with good heat dissipation characteristics help to reduce moisture build-up, if they include absorbent materials like wool or cotton, it helps to reduce moisture build-up.

Some cushions naturally pump air that is trapped in their structure when compressed. This effect can contribute to maintaining comfortable moisture levels at the cushion/skin interface, if the cushion is fitted with an air permeable cover [5].

One solution to reduce the degree of discomfort can be ventilation of the car seat. This can be the solution of both sense of high temperature and the high moisture. To be able to use the car with ventilation systems it is important that the car seat should have the sufficient air permeability and should give the good distribution of the air [9–12]. Suction or blowing of air is also another parameter that may affect the flow of air in car seats.

Insertion of a component blocking the transport of moisture (e.g. polyurethane foam of a thickness greater than 5 mm, leather and artificial leather products, flame and the other adhesive lamination of the layers) inside a car seat disqualifies the whole car seat, irrespective of the quality of the remaining components [9]. This is unwanted situation for both with or without ventilation seats. In this case the water vapour absorbency is the car seat cover layer is the only source to remove the moisture from microclimate in between human body and the car seat.

Liquid and moisture transfer

Liquid and moisture transfer mechanisms in the fibrous textiles include [13–15]:

- Vapour diffusion in the void space
- Absorption, transmission and desorption of the water vapour by the fibres.
- Adsorption and migration of the water vapour along the fibre surface
- Transmission of water vapour by forced convection.

Water vapour moves through textiles as a result of water vapor concentration differences. Fibres absorb water vapor due to their internal chemical compositions and structures. The flow of liquid moisture through the textiles is caused by fibre-liquid molecular attraction at the surface of fibre materials, which is determined mainly by surface tension and effective capillary pore distribution and pathways. Evaporation and/or condensation take place, depending on the temperature and moisture distributions [15].

Moisture vapour transmission parameters are calculated by following different standard methods [16]:

i. Evaporative dish method or control dish method (BS 7209);
ii. Upright cup method or Gore cup method (ASTM E 96-66);
iii. Inverted cup method and desiccant inverted cup method (ASTM F 2298);
iv. The dynamic moisture permeable cell (ASTM F 2298) and
v. The sweating guarded hot plate, skin model (ISO 11092).

METHODOLOGY

PID controller

The device is controlled using the PID controller

- Proportional (P)
- Integral (I)
- Derivative (D)

Here is the classic block diagram of a process under PID Control (figure 1 and figure 2).

The ideal version of PID controller is controlled by this equation.

$$\mu(t) = Kp \cdot e(t) + Ki \int_0^t e(\tau)\,d\tau + Kd \frac{de(t)}{dt} \qquad (1)$$

Where μ is the control signal and e – the control error. The control signal is thus a sum of three terms:

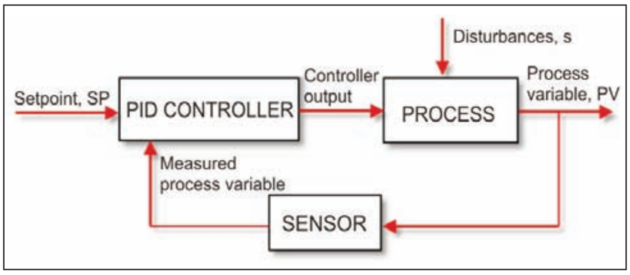

Fig. 1. Block diagram of PID controller

a proportional term that is proportional to the error, an integral term that is proportional to the integral of the error, and a derivative term that is proportional to the derivative of the error. The controller parameters are proportional gain *kp*, integral gain *ki* and derivative gain *kd.* Proportional-Integral-Derivative (PID) control is the most common control algorithm used in industry and has been universally accepted in industrial control. The popularity of PID controllers can be attributed partly to their robust performance in a wide range of operating conditions and partly to their functional simplicity, which allows engineers to operate them in a simple, straightforward manner.

Proportional response

The proportional component depends only on the difference between the set point and the process variable. This difference is referred to as the Error term. The proportional gain (K_c) determines the ratio of output response to the error signal. For instance, if the error term has a magnitude of 10, a proportional gain of 5 would produce a proportional response of 50. In general, increasing the proportional gain will increase the speed of the control system response. However, if the proportional gain is too large, the process variable will begin to oscillate. If K_c is increased further, the oscillations will become larger and the system will become unstable and may even oscillate out of control.

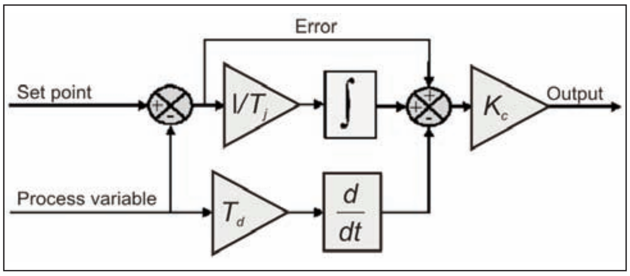

Fig. 2. Block diagram of a basic PID control algorithm

Integral response

The integral component sums the error term over time. The result is that even a small error term will cause the integral component to increase slowly. The integral response will continually increase over time unless the error is zero, so the effect is to drive the Steady-State error to zero. Steady-State error is the final difference between the process variable and set point. A phenomenon called integral windup results when integral action saturates a controller without the controller driving the error signal toward zero.

Derivative response

The derivative component causes the output to decrease if the process variable is increasing rapidly. The derivative response is proportional to the rate of change of the process variable. Increasing the derivative time (T_d) parameter will cause the control system to react more strongly to changes in the error term and will increase the speed of the overall control system response. Most practical control systems use very small derivative time (T_d), because the Derivative Response is highly sensitive to noise in the process variable signal. If the sensor feedback signal is noisy or if the control loop rate is too slow, the derivative response can make the control system unstable.

Schematic diagram

The portable device to analyze the comfort performance of car seat is always a dream for the car seat producer. The complication of design and the testing method makes it hard to have a portable device which can measure the comfort performance of the car seat even in uncontrolled condition. Some factors like the moisture permeability under different condition, heat of absorption of material negatively affect the measurement. In this research a first prototype design of device is made and later in future more advancement can be made to the technology.
For this experiment a special heat flux sensor is embedded in a measuring head which is insulated from outside. The heat transfer can be increasing or decreasing and can be in the form of convective, radiative or conductive heat transfer. Heat flux through a thermal resistance layer will create a temperature gradient. Under a temperature gradient, the two thermopile junction layers will be at different temperatures and will therefore register a voltage. The heat flux is proportional to this differential voltage.
The distilled water is added from the tubes above the measuring head and heated to 35 °C. Special microporous membrane (Cellophane) is used on the measuring head to restrict the water drops and allow only the water vapors to pass by. The device is connected to computer by USB port and values of heat flux temperature of the water and temperature of the surface is provided by the software. Heat flux sensors measure the heat transfer through a surface, and are expressed in kW/m^2. The schematic diagram of the device is shown in figures 3–5.

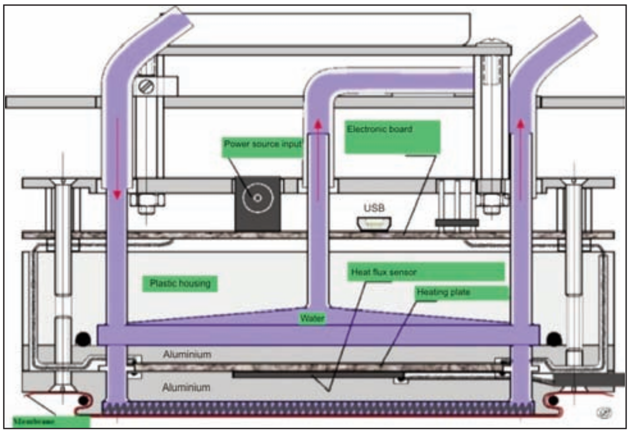

Fig. 3. Schematic diagram of the new device

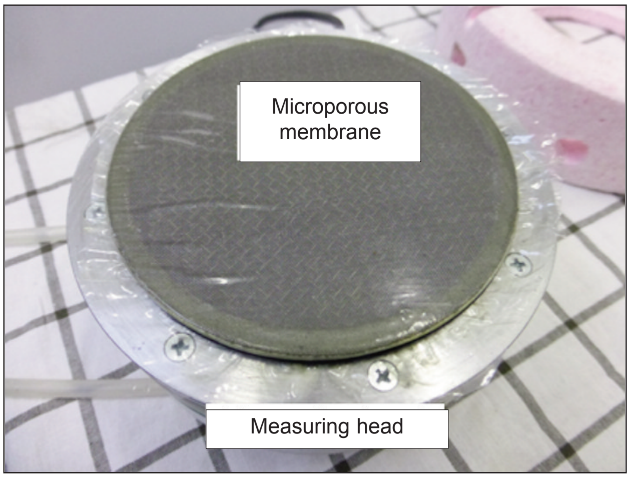

Fig. 4. Measuring head of the new device

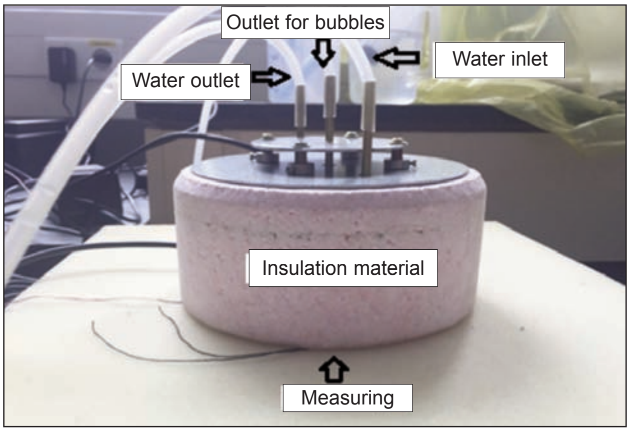

Fig. 5. Part description of the new device

EXPERIMENTAL PART

In this research firstly 4 standard car seats are used to test the performance of breathability. For this purpose the car seat's cover is tested for the water vapour permeability under the standard Sweating guarded hotplate by standard ISO11092. The new device is used directly on the car seat and to obtain the results, new device is used to test four car seats in actual form to see the performance of device for different car seats and to see the repeatability of the results (figures 6, 7, 8, 9).
The device can be used over a real car seat as shown in figure 10.
After testing on real car seat, the new device is tested with 1 top layers with different backing materials to see the performance of device. The sample properties are shown in table 1.

Fig. 6. Tractor seat A

Fig. 7. Truck seat B

Fig. 8. Truck seat C

Fig. 9. Truck seat D

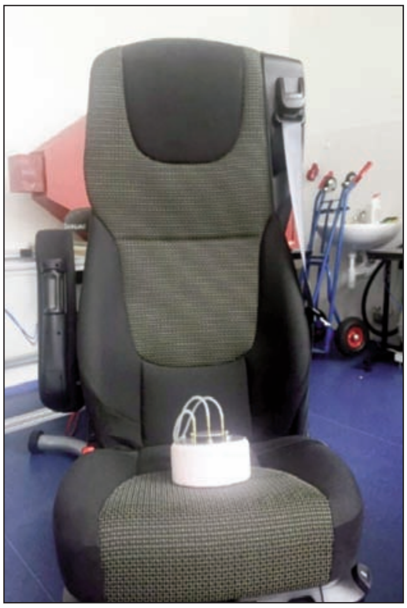

Fig. 10. Portable measuring device on a real car seat

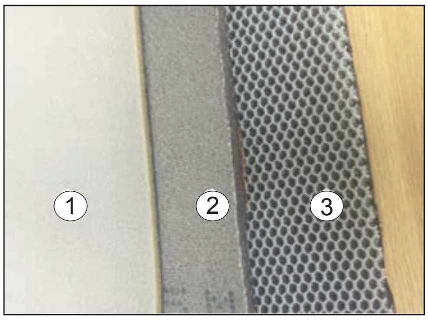

Fig. 11. Top layer with different interlinings

Table 1

Top layer backing material	Thickness [mm]
Plain woven top layer + Classic PU-foam	5
Plain woven top layer + Retroculated foam	5
Plain woven top layer + 3D spacer fabric	5

The real pictures of the samples are shown in figure 11.

RESULTS AND DISCUSSION

The experiment was performed for 30 min to avoid the initial heat flux change due to the first touch with the sample. Following results are obtained (table 2). The top layer of the four car seats is tested by SGHP and the real car seat by the new device, results shows similar trend lines.

The table 2 gives us a good idea that the trend of measurement by ATLAS SGHP (Ret) value and the measurement by the new device are comparable and knowing more information about the temperature and humidity on other side of the sample the Ret value can be also calculated.

The device was also tested for classical and perforated PU cushion as backing. 1 = classic PU foam, 2 = Retroculated foam, 3 = 3D spacer fabric.

Table 2

Sample	Ret [m^2.Pa/w] (stnd.dev) by standard SKIN model	New device [watt/m^2] (stnd.dev)
Seat A	20 (± 1.67)	149 (± 5.46)
Seat B	39 (± 2.34)	240 (± 7.94)
Seat C	45 (± 3.72)	263 (± 8.21)
Seat D	29 (± 1.55)	164 (± 3.76)

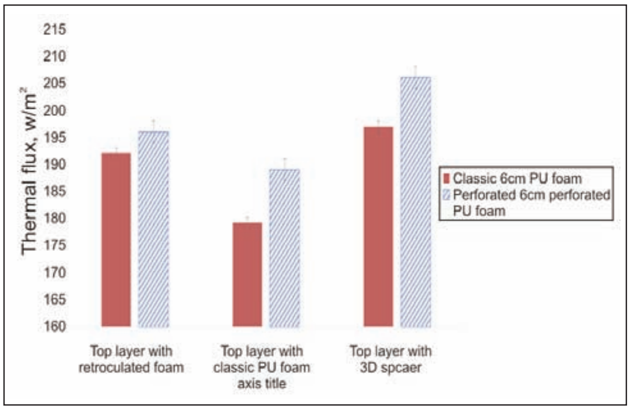

Fig. 12. Effect of perforated and classical PU foam on heat flux

The sandwich material is placed above classical PU cushion foam and perforated PU-foam, following results are achieved as shown in figure 12.

The results are repeatable and the 3D spacer with the perforated cushion shows highest heat flux.

The device is initial prototype and with further improvement can be a very reliable device to measure the performance of the car seat comfort from a real car seat, without any need to remove the material test separately in testing equipment. The idea is very unique and results are repeatable and the device can be further modified in future.

CONCLUSION

The newly fabricated device is portable and can be used to obtain the thermal and comfort related properties of the car seat. The device can be used on real car seat and the results are comparable, repeatable and reproducible. It can be seen from the results that the standard testing method of sweating guarded hot plate and this new device shows comparable results. Also the new device takes much less time and is portable and can be used in any part of the samples. The device needs further testing to compare results under different ambient conditions. The device is initial prototype and with further improvement can be a very reliable device to measure the performance of the car seat comfort from a real car seat, without any need to remove the material test separately in testing equipment. The idea is very unique and results are repeatable and the device can be further modified in future.

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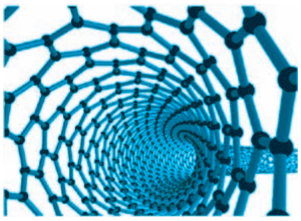

3D print additive technology as a form of textile material substitute in clothing design – interdisciplinary approach in designing corsets and fashion accessories

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JASMINKA KONČIĆ JOSIPA ŠČAPEC

REZUMAT – ABSTRACT

Tehnologia aditivă de imprimare 3D ca formă de substitut al materialului textil în proiectarea îmbrăcămintei – abordare interdisciplinară în proiectarea corsetelor și a accesoriilor de modă

Acest studiu de cercetare investighează aplicarea tehnologiei aditive de imprimare 3D în designul vestimentar. Studiul are ca scop găsirea opțiunilor de proiectare pentru articolele de îmbrăcăminte prin înlocuirea materialului textil cu soluții tehnologice noi. Lucrarea se concentrează pe cercetarea interdisciplinară a modelelor inovatoare de corsete și accesorii de modă, realizate prin utilizarea tehnologiilor aditive de imprimare 3D. Principalul obiectiv al lucrării este procesul interdisciplinar de creare a articolelor de îmbrăcăminte, variind de la schițe preliminare la prototipuri în trei domenii diferite: arta contemporană, design vestimentar și tehnologia aditivă.

Cuvinte-cheie: corset, tehnologia aditivă, imprimare 3D, sculptura mobile

3D print additive technology as a form of textile material substitute in clothing design – interdisciplinary approach in designing corsets and fashion accessories

This research paper enquires into the application of 3D print additive technology in fashion design. The research aims to find the design options for garments by substituting the textile material with new technological solutions. The focus of the paper is the interdisciplinary research of innovative corset and fashion accessories designs made using 3D print additive technologies. The main focus of the work is the interdisciplinary process of creating clothes ranging from preliminary sketches to prototypes within three different areas: contemporary art, fashion design and additive technology.

Keywords: corset, additive technology, 3D print, mobile sculpture

INTRODUCTION

Historically, clothes manufacturing and design are linked to the use of textile materials which are still commonly used in the production of clothing today. Any attempt to resort to another type of material fundamentally was governed by meeting specific functions dictated by the purpose of clothing, not dictated by the official fashion. While alternative materials in the history of clothing were intended for making specific purpose clothes (e.g. metal, wood and leather in making of military clothing), the contemporary fashion sees in them the primary functional character, but also recognizes the aesthetic and conceptual potential and uses them confidently in the creation of fashion collections (Iris van Herpen *Lucid* 2016, Alexander McQueen *Coiled Corset* 1999, Hussein Chalayan *Bodice* 1995, Issey Miyake *Rattan Suit* 1982...) [1–3]. It is interesting that in most of the above examples it is about the shaping of corsets or garments inspired by corsets. The reason for this can be found in the manner of treating the textile material used for making traditional corsets in which the textile materials are further reinforced with metal or wire structures thus eliminating the textile softness and transforming it into a new material with altered properties. The modern era offers new technological possibilities to completely replace the textile material in the making of clothes. The growing interest of fashion designers for the production of fashion collections using the 3D additive technology is not surprising. This technology is now widely used and its application in fashion is rapidly growing [4]. Although the manufacturing using additive technology production is most commonly found in the aerospace and automotive industries and medicine, innovations in the application of new polymer and metal materials can be encountered in other areas. Because of the specificity, fashion design and accompanying fashion industry should be singled out because the additive technology is used for the production of fashion accessories and complete garments. The postmodern time opens up the possibility of a new interdisciplinary aesthetics whose task is to connect technology, art and design. The transformation of the body into a living machine – body cyborgization – takes place simultaneously with the transformation of technology into a new body/outfit. Cognitive body cybernetics therefore leads to connecting life, body, technology, art and design. As one of the most illustrative examples of the use of a 3D print additive techniques in fashion design the designer is Iris van Herpen [5] who stands out with her highly sculptural clothing products. As a fashion designer she offers an important clothing design example; due to the skeletal structure it is a conceptual and aesthetic connection to the *Relief* collection by the fashion designer Josipa Ščapec. A corset, created in the *Relief* collection and its fundamental hallmark, is based on the idea of the thin waist affirmation by Victorian corsets of the 19th century which resulted in an extremely rigid garment. This 3D print additive technology has been recognized as a good opportunity for the negation of the fundamental values of immobility and rigidness in Victorian corsets. With the inversion of the values, it was attempted to translate rigidness into mobility without losing the ultimate aim – to emphasize the narrow waist. The aim was to achieve a corset that moves with the body, quite the opposite to the rigid historical template.

EXPERIMENTAL PART

First phase of research: corset – rigidness vs. pliability

In the first phase of work on the *Relief* collection a research was done on the historical context of the corset development. For a more detailed research, it was necessary to look at a historical overview of the corset development and design from an etymological, structural and aesthetic perspective. A corset (German Korsett, French corset ≈ cor(p)s; body) already in its definition emphasizes the body in three situations: aesthetic, medical and protective [6]. In the aesthetic context it is perceived as a part of women's underwear that shapes the waist; in the medical context it represents the armour of skin or plaster to be placed around the torso usually due to deformations or fractures of the spine and a bulletproof vest in the protective context. From the three interpretations of a corset its basic characteristic clearly forms: a corset defined as a rigid copy of the waist. In the formative sense it is achieved by a direct framing of its pattern shapes in order to reduce the clothing silhouette. In this context it seemed interesting for this research to attempt to redefine the meaning: the idea of inversing the meaning as a guideline of which there are examples and recognition in the history of clothing. It is interesting that the first interpretation of the corset was defined by pleating, rather than tailoring the waist (*Snake goddess* statue from 1650 BC and Renaissance corsets of the 16th century). Until the Victorian corset in the 19th century, corsets did not emphasize the curves as later models did, but shaped the body in a fashionable cylindrical shape [7]. They had straps and ended at the waist smoothing and lifting the breast area. In the beginning they were made of steel, but later were softened using fish bone and cloth, such as twill, satin and silk. In the design of modern corsets there are examples created through the processes of deconstruction, replacing its meaning (a corset becomes the sweater Comme des Garcons) and introducing alternative materials which are favoured by Japanese designers Rei Kawakubo, Issey Miyake and Junko Koshino. These works are a good example of an art and fashion interrelation emphasizing the interdisciplinary approach to the design. In further research the characteristics of a corset will be associated with the work aesthetics and philosophy of a Croatian artist Miroslav Šutej. With his mobile graphics and sculptures he is an excellent interdisciplinary link in creating models of a corset and bracelets, also he himself gave considerable thought to fashion and clothing.

Second phase of research: Miroslav Šutej – aesthetics and design of mobile sculpture

After exploring the historical context of the corset development comes the second phase of research, which carefully considers the aesthetic and structural value of the garment. The principles on which the appearance of a corset and the fashion accessories bracelets tend to be created are present in the renowned works of art by a Croatian artist Miroslav Šutej (1936–2005). He is one of the most important representative of the art movement Nove tendencije. Works by Miroslav Šutej are characterized by the purity of concept, the imagination of composition and the high technical quality of performance. Forming his artistic expression within the optical art, in his works there is a strong tendency for converting optical into tactile and that is apparent across the entire Šutej's work starting from drawings to sculptures and site-specific works. The work *Bum-Bum I-68* (1968) is taken as a template for further research. It is a mobile sculpture – an object of expressive colours based on the complementary contrast of red and green, which is used to clearly evoke the effect of movement and explosion based on the fundamental stylistic features of optical art [8].

The work consists of disconnected wooden skeleton on whose limbs small balls are placed. The impression of explosive radial movement is compositionally organized from the centre of the sculpture itself. It is of great importance for the research that the sculpture is made of beads which are actually bearings to accommodate the resilient limbs and to upgrade a whole range of smaller bead elements. A similar approach will be used in the construction of a corset and bracelets. The sculpture and the observer are in a dynamic interactive relationship where the observer also participates in shaping the appearance of the sculpture. As the corset and bracelet from the *Relief* collection follow the individual characteristics of the body that wears them.

Third stage of research: ad technology – originality vs. Ready-made

In order to possibly start with the creation of the models for the *Relief* collection it was important to investigate what modern technologies and media were available for designing the collection. Due to the complexity of the concept, the mobile mesh structure of a corset and the related accessories, plus excluding the use of textile materials, the decision was to use the additive technologies and the processes of 3D printing for the prototype as the perfect medium for individual production. One of the reasons for selecting the 3D print additive technology is that the meeting point of the additive technology and the fashion design is not one of a producer and a fashion designer but more of a consumer and the consumer's needs to personalize the appearance. It is the additive manufacturing that offers the ability to create a personalized unique item of clothing, which in the fashion world is of crucial importance when creating a consumer's personal/fashion identity. The new 3D print additive technology will be used for the purpose of changing the historical fundamental characteristics in a Victorian corset, which is changing an extremely rigid and static garment into a garment which is pliable and mobile and which provides the body with comfort.

The modern 3D print additive processes have been developing and used more frequently since the middle 1980s. They have gone through several stages of development during their use: RP (Rapid Prototyping), RT (Rapid Tooling) and RM (Rapid Manufacturing) [9]. Their main characteristic of a unique and small-scale production has been recognized as a great advantage and as a possibility of leaving the trend of mass production. The uniqueness of a product derived by the 3D print additive technology is guaranteed by the manner of production. The method of making a desired product is carried out by adding materials layer by layer until the final product is made. The technique is named printing because of its similarity to ink jet printing. The difference is that in the 3D printing instead of the ink either adhesive or glue is used.

Fourth stage of research: production and work on prototype

The work on the production of prototypes for the *Relief* collection is divided into several stages. These include creative research, technical preparation and the production of the prototype. The creative research includes brainstorming and making of the initial sketches on a specified concept as a direct association to the study of the historical context of the corset development. The study of the historical concept of a corset adds to it additional concept of liberation and emancipation of women's bodies, which becomes obvious when focusing on breathing. The concept of mobility is introduced, which brings us to the aesthetic qualities of a mobile sculpture by Miroslav Šutej and ultimately to the deconstruction of a corset in the physical and sociological sense. By the inversion of the organic (body, torso) and technical elements (corset construction) a complete freedom of movement and breathing is achieved, which makes it extremely functional.

CONSTRUCTION PROCESS OF MECHANICAL MOVING JOINT IN COMPUTER PROGRAMMES PTC CREO PARAMETRIC

Elaboration of the *Relief* collection model started by hand-sketched drawing (figure 1). The sketches roughly determined the silhouette of a model corset, the bracelet and necklace position in relation to the body as well as the desired aesthetic properties. Moving away from the static and the desire for the mobility of corset and fashion accessories as well as the abandonment of textile materials have resulted in the introduction of moving joints and their mutual interaction. The model corset in the collection is deprived of the classic construction as one of the main distinguishing characteristics in the corset design and it is replaced with the mechanism of moving joints which

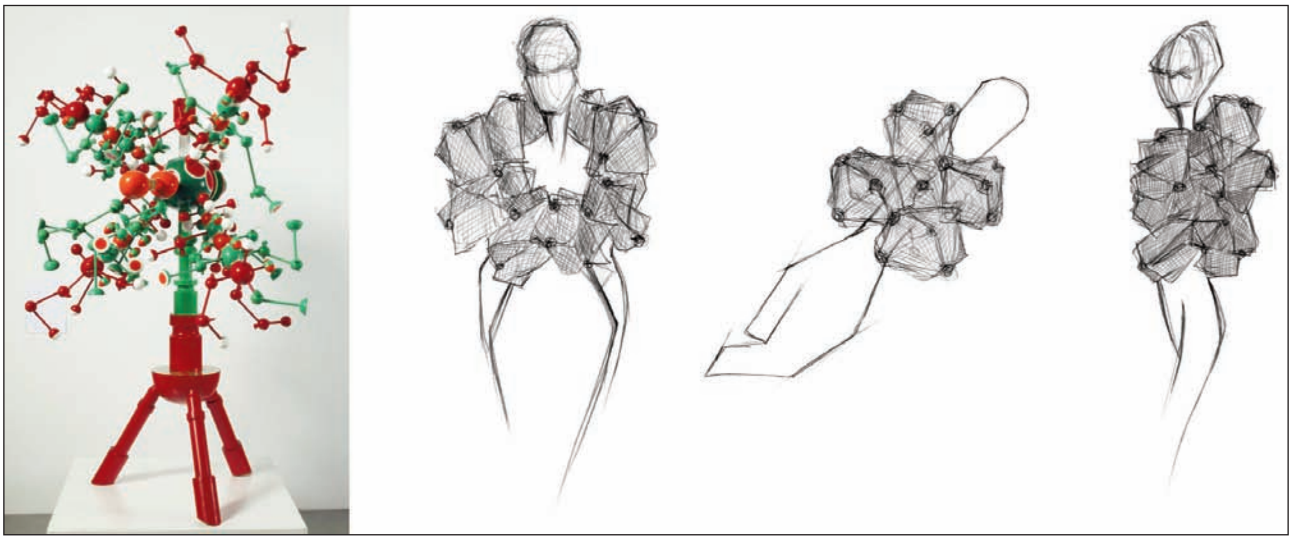

Fig. 1. Miroslav Šutej, *Bum-bum I-68*, 1968, mobile sculpture (left); Josipa Ščapec, drawings for the *Relief* collection following the aesthetics of the work by Miroslav Šutej, *Bum-bum I-68* (1968) (right)

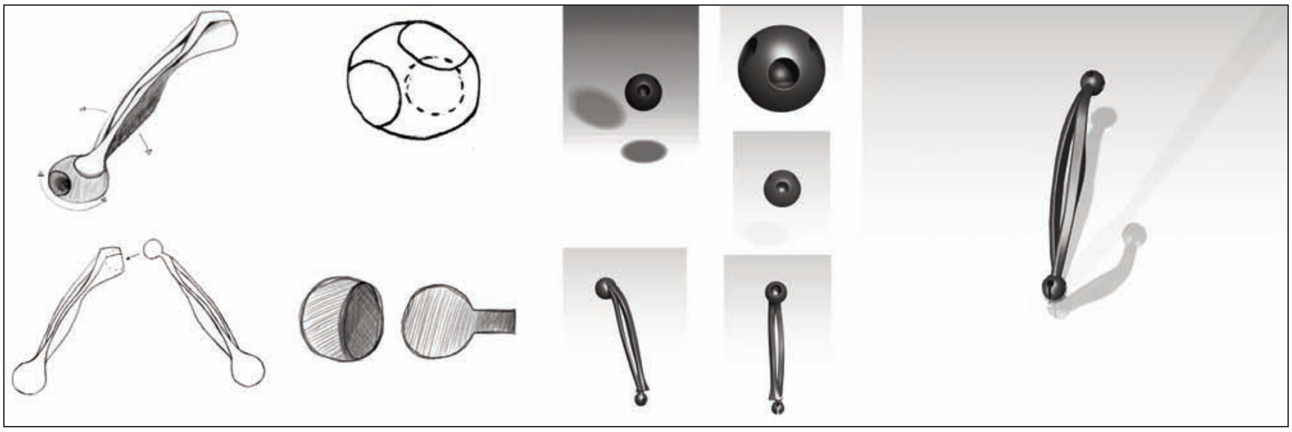

Fig. 2. Elaboration of moving joints and bearings from preliminary sketches to computer construction

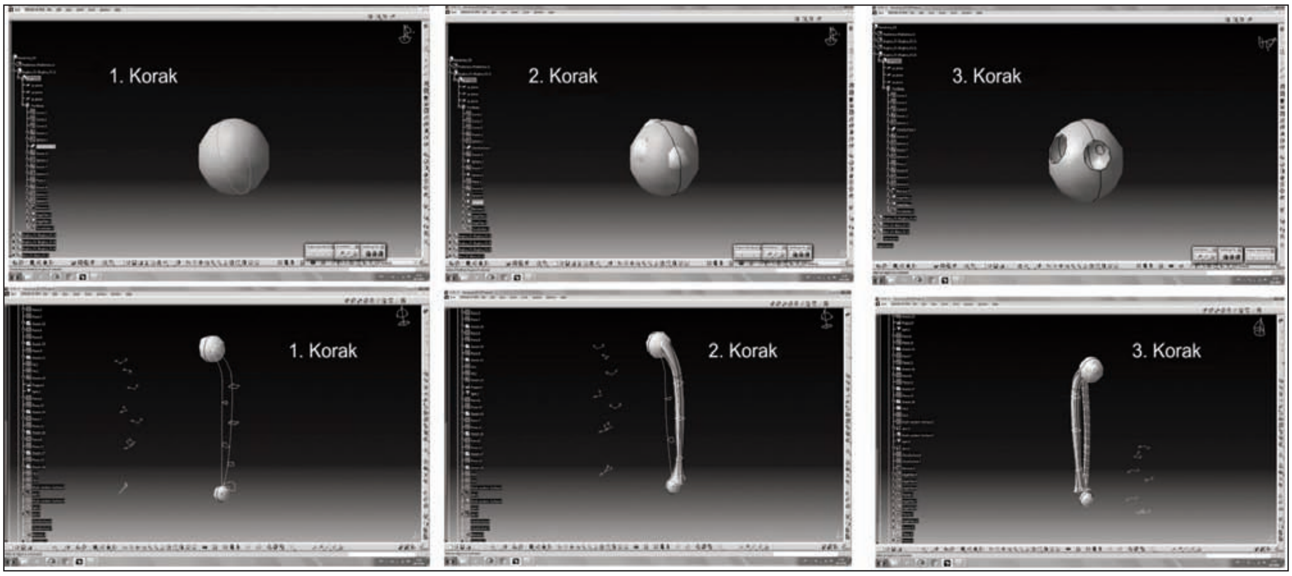

Fig. 3. Steps in moving joints construction (above) and mobile limbs (below)

is the foundation for the entire structure in the *Relief* collection. The moving joint and limbs were inspired by the bones and joints of the human body which suffered under a Victorian corset (figure 2). The bones of the torso that were trapped underneath a corset now appear as a metaphor in the form of mechanical clothes and accessories worn on the body. The body forms the shape of a model and not vice versa as it was the case when wearing a Victorian corset in the 19th century.

The construction process of the moving joints mechanism was carried out in three steps: defining the sphere and cuboid as the foundation for the design, determining their size and designing the shapes most similar to the initial sketches. Figure 3 shows the steps of construction of the moving bearing. The bearing is holed out in three or four places depending on the position of the body part on which it rests. By determining the biggest prominence and indentation on the human body, the positions of bearings were established. These were six key points, three on the front (shoulder, upper chest, waistline) and three on the back (blades, the seventh cervical vertebra and waistline). Because of the proportion of a female torso, the positions such as breast demanded four holes on a bearing, while in the area of the waistline, which is convex, three holes were necessary. In the area of the shoulder blades and sleeves two holes were sufficient. The holes are spaces for the placement of the limbs and shaped to follow their forms and dimensions. The design of the limbs begins by defining the dimensions of sphere and cuboid surfaces that in their final stylized form resemble human bones. The shape of the limbs changes depending on their placement on the body: chest and hips take on slightly curved arc to the body while in the waist they take a bow-like shape facing the opposite direction i.e. the space.

CONSTRUCTION PROCESS OF CORSET AND FASHION ACCESSORIES (NECKLACE AND BRACELET) IN COMPUTER PROGRAMME PTC CREO PARAMETRIC

The construction of the model corset and fashion accessories is based on individually connecting mechanical moving parts using the ‘‘click’’ method.

Table 1

	CORSET	BRACELET	NECKLACE
Number of bearings	168	32	26
Number of limbs	198	40	24
Length of front limbs	5 cm (chest) 6 cm (waistline) 7 cm (shoulders)	5 cm	6 cm (shoulders, area below neck)
Length of back limbs	6 cm (waistline, shoulder blades) 8 cm (shoulders, seventh cervical vertebra)	5 cm	10 cm (seventh cervical vertebra, shoulders)
Bearing diameter on body	1.4 cm	1.4 cm	1.4 cm
Bearing diameter in space	0.7 cm	0.7 cm	0.7 cm
Hole profile on bearings	0.4 cm	0.4 cm	0.4 cm

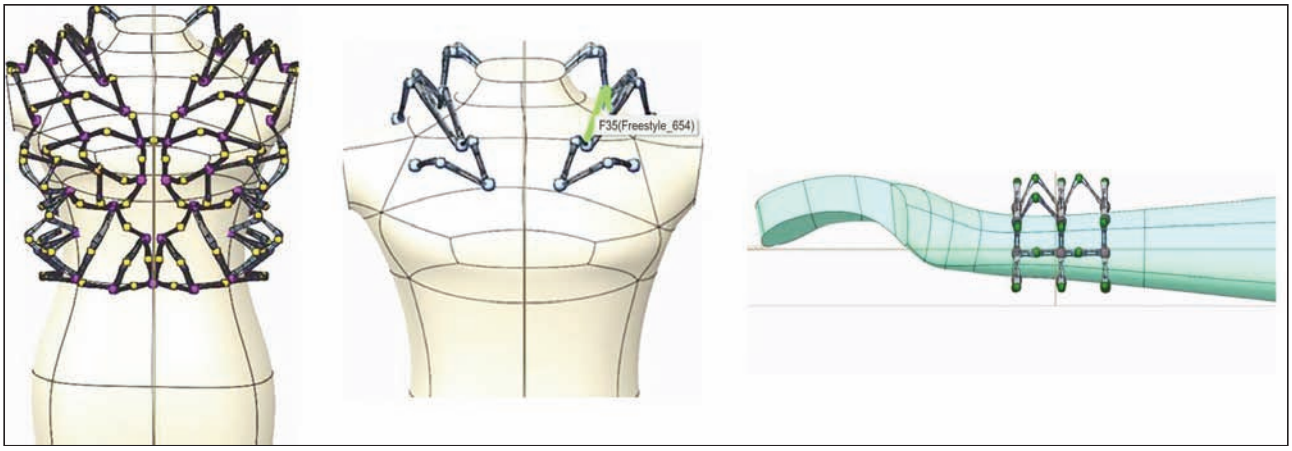

Fig. 4. Construction of corset and fashion accessories in the program PTC Creo Parametric 23

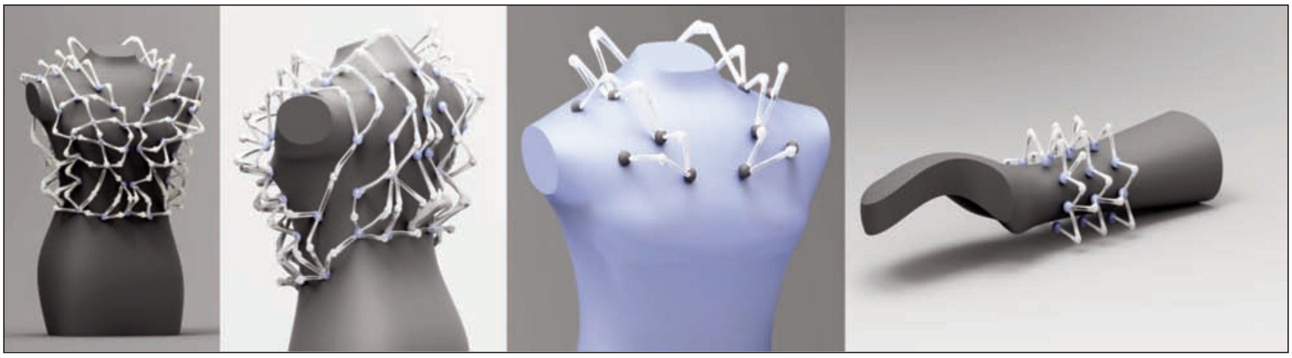

Fig. 5. Rendering of 3D models

This is made possible by a small longitudinal incision of 0.1 cm on limbs balls. To avoid material tear there is a cavity in bearings of the same size as the additional part on the limbs that fits the cavity which is 0.4 cm in size. The models are constructed in a computer program PTC Creo Parametric 23 (figures 4 and 5). Due to different proportions of the human body parts, the mechanical moving parts are designed in sizes from 5 to 10 centimeters (table 1) where the limbs cannot be less than 5 cm. The universal clothing sizes ranging from XXS to XXXL are ensured by this. For this reason the corset and fashion accessories completely follow the silhouette of the body and adhere to the torso.

RESULTS AND DISCUSSIONS

The prototype bracelet from Relief collection is printed on the Stratasys machine Connex 350 in STL format 24. To create the prototype PolyJet photopolymers were used that simulate the appearance and functionality of polypropylene material Rigur (RGD450). Rigur (RGD450) is an advanced simulated polypropylene material that provides durability and gives a nice look to the final layer of the surface.

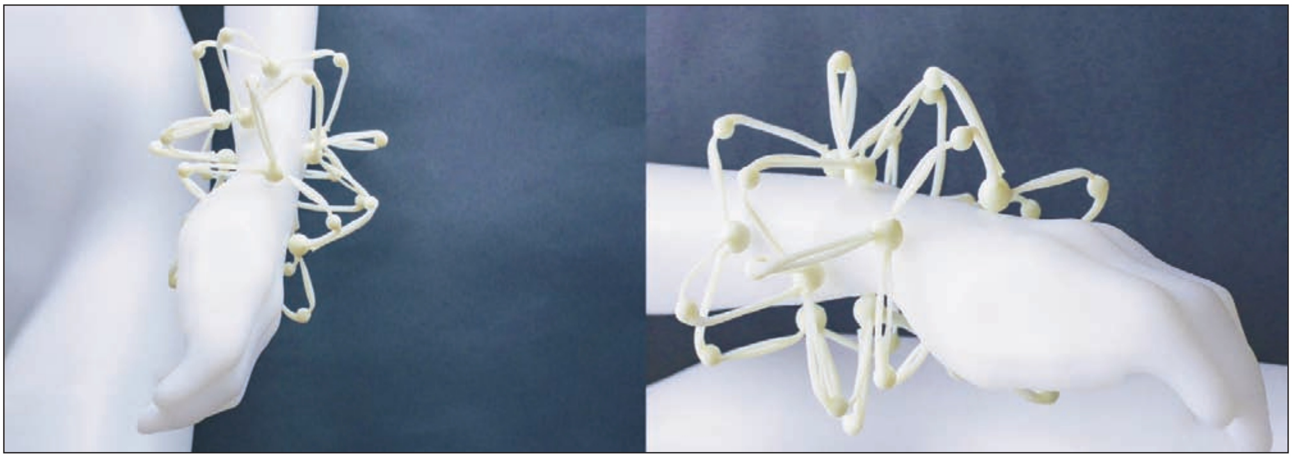

Fig. 6. The final *Relief* collection prototype bracelet

It is used for a quick printing of complex prototypes and demanding applications. It comes in white which ensures fine resolution and ultimately smooth curves of a printed product. It is flexible and resistant to shock, which is of crucial importance for ensuring the idea of mobility and flexibility in making corsets and accessories for the *Relief* collection (figure 6).
The design and manufacture of mechanical moving joints are fully achieved and successfully implemented in the clothing surface area and the surface area of fashion accessories. This resulted in maximum mobility and complete flexibility of the collection model to the human body. The *Relief* collection consists of three models: the corset, the necklace and the bracelet. On the model bracelet the fundamental design principle was achieved and can be used for other two models. The prototype was created in white, but the range of colour can be changed according to the consumer with each new printing since the additive technology enables personalization and unique production of products. Every consumer can choose the color, the size of the elements, their shape and their placement in the model and thus the consumer becomes a participant in creating individualized models.

CONCLUSION

In this research the understanding of art, of design and of modern technologies have been unified. The Relief collection was created by studying the historical Victorian corset, mobile sculptures by Miroslav Šutej and additive technology. Through the collection's interdisciplinary approach to fashion design and clothing design, the moving, mechanical system/joint was created which in return was used to create a corset and fashion accessories such as necklaces and bracelets.
The tendency to emancipate the torso through changing the historically given idea of 'to corset' resulted in transformation of a rigid form into a mobile garment which does not inhibit the body.
An additional challenge to create a mobile garment is the fact that almost all approaches using 3D print additive techniques in contemporary fashion are static and sculptural or require further intervention. The intervention is often finishing work done by hand or connecting certain elements of 3D printing with textile materials which this collection aimed to avoid.

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Effect of yarn structure on cover factor in woven fabrics

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REZUMAT – ABSTRACT

Efectul structurii firului asupra factorului de acoperire al țesăturilor

Acest studiu experimental investighează, prin metoda de transmisie a luminii, efectul structurii firelor asupra factorului de acoperire al țesăturilor la diferite dispuneri ale firului de bătătură. Pentru a analiza acestă influență, au fost pregătite două tipuri diferite de seturi de țesături prin utilizarea firelor filate cu jet de aer și a firelor filate cu rotor cu aceleași densități liniare în direcția firelor de bătătură și cu menținerea firelor de urzeală neschimbate. Pentru fiecare țesătură, dispunerea firelor de bătătură a fost schimbată treptat. Diametrul secțiunii transversale al firelor și densitatea lor de compactare au fost analizate pentru găsirea diferențelor dintre cele două structuri de fire. Diametrul efectiv al firelor și densitatea de compactare sunt aproape identice pentru ambele fire, în timp ce pilozitatea este mai mare la firele filate cu jet de aer, comparativ cu firele filate cu rotor. Secțiunea transversală a firelor din tesatură a fost, de asemenea, analizată pentru a se examina deformarea firelor, care a fost relativ mai mare la firele filate cu jet de aer. La aceeași desime a firelor de bătătură, factorul de acoperire (CF) al țesăturii cu fire filate cu jet de aer este considerat a fi mai mare decât în cazul țesăturii cu fire filate cu rotor, iar această diferență scade pe măsură ce desimea firelor de bătătură din țesătură crește. Rezultatele analizei de corelație arată relația dintre factorul de acoperire și desimea firelor de bătătură. Analiza rezultatelor varianței evidențiază efectul semnificativ din punct de vedere statistic al sistemului de filare (fir filat cu jet de aer și fir filat cu rotor) și desimea firului de bătătură asupra factorului de acoperire al țesăturii.

Cuvinte-cheie: fir filat cu jet de aer, fir filat cu rotor, desimea firului de bătătură, factor de acoperire, țesătură

Effect of yarn structure on cover factor in woven fabrics

This experimental work investigates the effect of yarn structure on cover factor of fabrics at different weft settings by the light transmission method. To analyze the effect, two different types of fabric set have been prepared by using airjet and rotor yarns of the same linear densities in the weft direction and keeping the warp yarn unchanged. For each fabric, weft setting has been changed gradually. Cross-sectional diameter of yarn and its packing density has been analyzed to find out the differences between both yarn structures. The effective yarn diameter and packing density have been found to be almost same for both yarns while the hairiness is found to be higher in airjet yarn as compared to rotor yarn. Yarn cross-section in the fabric has also been analyzed to examine the deformation (flatness) in yarn, which was relatively higher in airjet yarns. At the same weft setting the cover factor (CF) of fabric woven by air jet yarn is found to be higher than fabric woven by rotor jet yarn, and this difference decreases as the weft setting increases in fabric. Correlation analysis results show the relation between the cover factor and weft setting. While analysis of variance results show statistically significant effect of spinning system (airjet and rotor yarn) and weft setting on the cover factor of woven fabric.

Keywords: airjet yarn, rotor yarn, weft setting, cover factor, woven fabric

INTRODUCTION

The end-use and performance requirements of woven fabrics are strongly related to their cover factors (CF) or in opposite terms, to their porosity and permeability [1–3]. Different features that are closely related to CF are weaving efficiency, fabric quality, thermo-physiological comfort of garments, air permeability and protection against ultraviolet radiation [4–6]. It is a basic feature of multiple base fabrics used in the elaboration of protective garments and textiles designed to protect the working environment or the natural environment.

Tapias et al. estimated the warp and weft CF and their mean yarn diameters automatically from microscope digital images of woven fabric samples [1]. While Szmyt and Mikolajczyk used light transmission technique to determine the CF on the basis of experimental and theoretical analysis for jacquard knitted fabrics [7]. Similarly Cardamone et al. employed digital image analysis technique to analyze fabric structural parameters [8] and Militky et al. reported that image analysis could be used for determination of air permeability of various weave structures and fiber types [9]. Whereas Nazir et al. developed a statistical model for predicting the air permeability and light transmission properties of woven cotton fabrics and determined the level of correlation between the two parameters [10].

Literature shows that there is a need to understand the effect of yarn structure (produced by different spinning systems)upon cover factor of woven fabrics. As they deform differently based on their structures in the woven fabrics, sothe purpose of this study is to get a better understanding about the effect of yarn structure in the woven fabrics at different weft settings during the CF measurements.

MATERIAL AND METHOD

Yarn and fabric production

16 tex yarns were produced by Rieterairjet and rotor spinning units using 100% viscose fibers. Satin fabric was made by using these spun yarns in weft. Satin weave was selected because of its easiness to make samples with high weft settings. Rapier loom with eight frames and weft insertion speed of 330 picks/min was used to weave two sets of fabrics having different weft setting. The warp tension was kept the same for all fabric samples. 6×2 tex twisted compact cotton ring spun yarn was used as warp, keeping the same density (setting) for both sets of fabrics, i.e. 58 ends/cm. To study the CF of air jet and rotor yarn woven fabrics, the weft setting for both sets were kept 10, 20, 30, 40 and 50 picks/cm. Yarns were preconditioned for 24 hours at standard temperature (20 ± 2 °C) and relative humidity (65%) before yarn testing and fabric production.

Yarn testing

Uster 4 was used in order to measure yarn irregularity, imperfections, hairiness and shape factor. For each yarn sample the testing speed was kept 200 m/min for one minute and ten readings were recorded.

Cross-section of yarn

Image analysis method was used to measure the cross-sectional diameter of airjet and rotor yarn. Ten yarn samples were selected randomly from airjet and rotor yarn cones. These samples were immersed in a media and after hardening the block in which the textile sample was found, slices (sections) were produced by applying special technique. The micrometric slices (sections) were separated and examined under projection microscope equipped with a digital camera, which was later processed by LUCIA and Prize software to calculate the effective diameter and effective packing density of yarn. One section was obtained from each block [11].

In order to measure the geometry of the yarn cross-section in woven fabric, ten fabric samples were selected randomly from each fabric sample. After that, the same procedure (as described earlier for yarn) of impregnation in media, hardening of blocks and slicing was used. Later images were taken and processed by LUCIA software [11].

Shape of yarn

The shape of yarn cross-section in the fabric is shown in figure 1. The major diameter (*a*) of yarn in the plane approximately parallel to the fabric surface and minor diameter (*b*) of yarn in the plane approximately perpendicular to the fabric surface of the elliptical yarn can be measured. To check the flatness of yarn major diameter was measured for all fabric samples.

Cover factor of fabric

Cover factor (CF) is defined as the area of yarn in the solid unit cell rectangle [12]. The coefficient of CF is the characterization of the degree of area covered by the threads in the fabric. It can be written as:

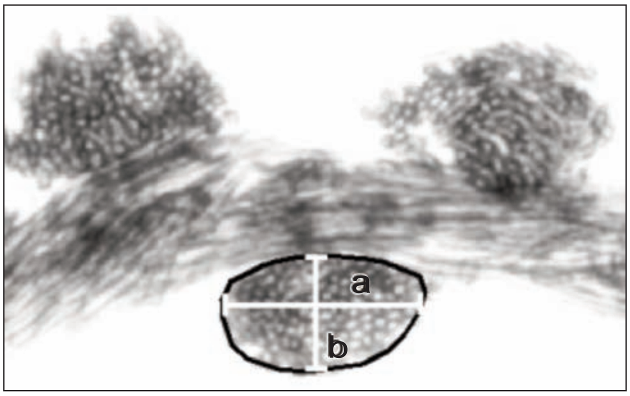

Fig. 1. Measuring method of yarn cross section

$$\text{cover factor (CF)} = \frac{\text{area covered by yarn}}{\text{whole accessible area}} \quad (1)$$

From pure geometrical point of view surface porosity can be evaluated from the cover factor of fabric [9].

$$\text{surface porosity (Ps)} = 1 - \text{cover factor} \quad (2)$$

The CF of a woven samples was determined by the principle of light transmission through the sample. A light microscope and system of the image analysis LUCIA was used for this measurement. The sample size was kept according to the dimensions of the width of bedding glass. It was passedin-between two bedding glasses and then put under the microscope. For each sample, 100 pictures were taken to measure CF of fabric at different weft settings for airjet and rotor yarn woven fabrics. Later, these images were transformed from the color image to a binary image so that the separation of areas covered by threads from areas without covering by threads was possible. The special threshold procedure was adopted for estimation ofthe relative pore area. The area was measured using LUCIA system for each fabric sample separately [13].

To check the significance of yarn type and weft setting on the cover factor of yarn in fabric, analysis of variance (ANOVA) was carried out using SAS PROC GLM (alpha level of 0.05).

RESULTS AND DISCUSSIONS

Realization of single yarn

The yarn properties for both airjet and rotor yarn can be seen in table 1. It can be analyzed that irregularity of rotor yarn is slightly higher than airjet yarn due to presence of irregular wrappings. Differences in thin and thick places are insignificant for both yarns, howeverneps in rotor yarns are found to be very high. The reason for this is the difference in structure as the airjet yarn has more parallel fibers in core and continuous wrapping around it, while in rotor yarn the fibers are not parallel in core and sheath, causing a bit irregular shape. Similarly the shape factor of rotor yarn is also slightly higher than its corresponding airjet yarn, which shows that airjet yarn is slightly more flat in shape than rotor yarn. The hairiness of rotor yarn is less as compared to airjet yarn, which may be

Table 1

AIRJET AND ROTOR YARN PROPERTIES								
Sample	**Count (Tex)**	**CV_m (%)**	**Thin (–50%/km)88**	**Thick (+50%/km)**	**Neps (+140%/km)**	**IPI / km**	**Hairiness (H)**	**Shape**
Airjet	16	14.12	35.6	29.2	166	230.8	3.96	0.80
Rotor	16	14.72	18.4	29.6	792.4	840.4	3.54	0.82

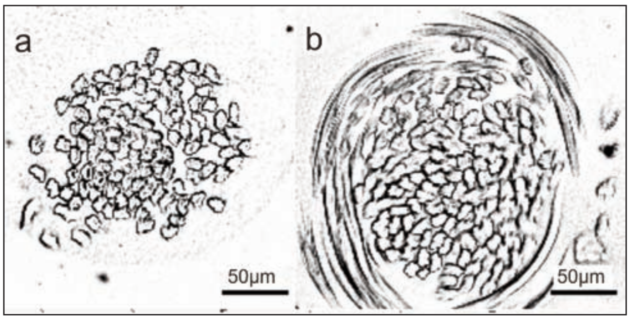

Fig. 2. Cross-sectional view of yarns (a) airjet (b) rotor

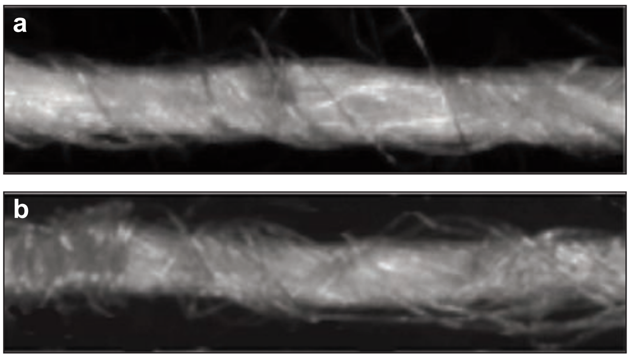

Fig. 3. Longitudinal view of yarns (a) airjet (b) rotor

due to the irregular belt shape wrapping which act as a binding of outer yarn to the core, while this is not the case in airjet yarn.

Figure 2 and 3 show the cross-sectional and longitudinal images of airjet and rotor yarn. It can be observed that in rotor yarn, wrapper fibers are irregularly wrapped around the core fibers with varying angles and some of them can be seen forming an angle of 90° taking the belt shape. While in airjet yarns, wrapping effect is much regular and wrapper fibers are identifiable forming a cap-like shape.

The average values of yarn cross-sectional results for both airjet and rotor yarns are shown in table 2. The effective diameter of airjet and rotor yarn is the same and the difference in effective packing density of both yarn systems is also insignificant. So it can be said that the fiber and yarn parameters for both yarns are almost the same.

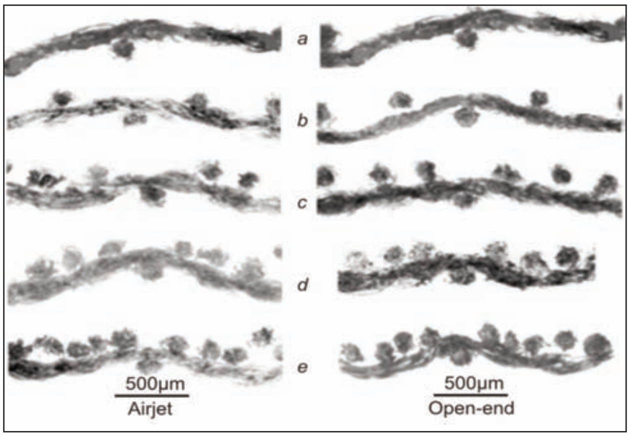

Fig. 4. Cross sectional images of airjet and rotor yarn woven fabrics with different weft settings:
a – 10; *b* – 20; *c* – 30; *d* – 40; *e* – 50

Table 2

CROSS-SECTIONAL RESULTS OF YARN		
System	**Airjet**	**Rotor**
Fiber fineness [Tex]	0.13	0.13
Yarn fineness [Tex]	16	16
No. of fibers in cross-section [-]	118	127
Effective diameter [mm]	0.15	0.15
Effective packing density [-]	0.64	0.63

Realization of yarn into woven fabric

Figure 4 shows the cross-sectional images of airjet and rotor yarn woven fabric samples at different weft settings. It can be understood that with the increase in weft setting (pick density), free spaces in weft yarns reduces and forces on weft yarn in the intersecting region increases, which causes its deformation (flatness) in the fabric.

To study the effect of airjet and rotor yarn structure at different weft settings, the major diameter (flatness) of the elliptical shape of each yarn cross-section was measured and results are shown in figure 5. It can be seen that the flatness (major diameter) of airjet yarn is more than that of rotor yarn in the fabric because unlike rotor spun, the core fibers in airjet are arranged parallel to the yarn axis without twisting and are enclosed periodically by the wrapper fibers as described earlier. So upon same warp tension (force) airjet yarn have a tendency to deform more than rotor spun yarn in woven fabric.

Cover factor of fabric

Cover factor of the fabric was calculated by applying equation 1 as described earlier. The LUCIA system helped in measuring of the binary area fraction, which is the ratio of the binary area and total measured area. Similarly the porosity was calculated by using equation 2.

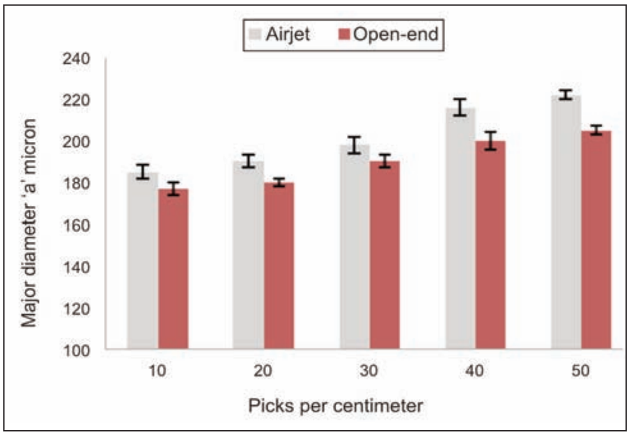

Fig. 5. Effect of weft setting on major diameter of airjet and rotor yarn in fabric

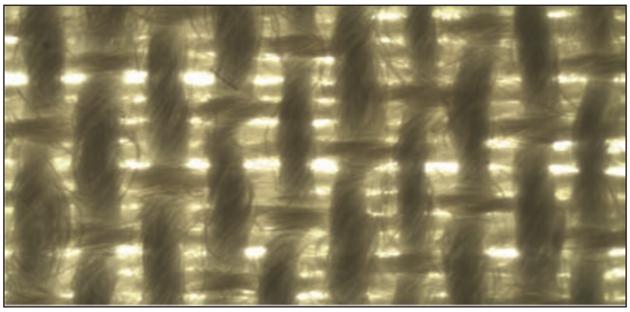

Fig. 6. Orignal image of fabric

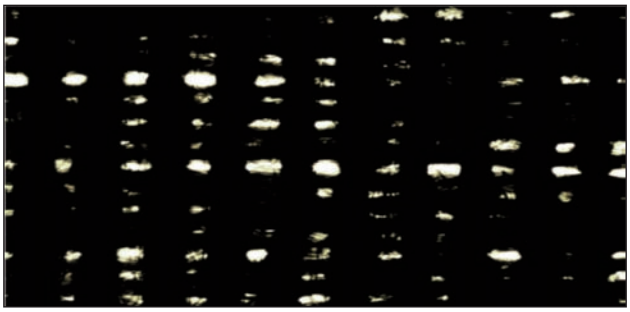

Fig. 7. Inverted image of fabric

In figure 6 and 7 the originaland inverted image of one fabricsample can be seen respectively. The white objects are corresponding to the area transmissible for light and black for the area which is not transmissible.

It can be seen in figure 8 that for both airjet and rotor yarn woven fabrics, the cover factor % is continually increasing as the weft setting increases. While upon

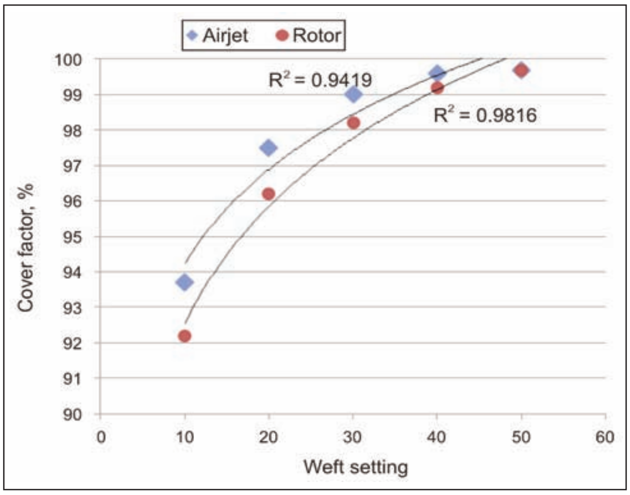

Fig. 8. CF of Airjet and Rotor yarn woven fabics at different weft setting

same weft setting the CF of airjet yarn woven fabric is higher than rotor yarn woven fabric and with the increase in weft density this differece reduces. There are two factors for this behavior, one is the hairiness, which is more in case of airjet yarn as compared to rotor yarn. It limits the transmission of light through a fabric, hence increasing CF of airjet fabrics. Whereas the other factor is the flatness of yarns in a fabric. Flatness of airjet yarn in woven fabrics is slightly more than rotor yarn as explained earlier in figure 5. The more flat yarn in the fabric, the more will be the hinderence for transmission of light through the fabric. Hence it is also a reason for higher CF of airjet fabrics. The logarithmic type model was used for parameter smoothing and a fitted line plot between the CF and weft setting exhibited a significant correlation with R-sq. value of 94.19% and 98.16 % for airjet and rotor yarn woven fabrics respectively, which shows abetter predictability of the model. The reason for non-linear curve in figure 8 is that, upon an increase in number of yarns (i.e; 10 picks/cm to 20 picks/cm), the yarn diameter also adds to the space and hence it limits the transmission of light through the fabric.

Table 3 also shows the values of CF and porosity of airjet and rotor yarn woven fabrics at different weft settings and it can be seen as the cover factor increases in woven fabric (with increase in weft settin, the porosity of fabric is decreasing in the same way.

It can be seen from the results in table 4 that the independent variables (yarn type and weft setting) and their interaction (Yarn type * weft setting) have a statistically significant effect on the dependent

Table 3

COVER FACTOR AND POROSITY OF AIRJET AND ROTOR YARN WOVEN FABRICS AT DIFFERENT WEFT SETTING

	AJ 10	AJ 20	AJ 30	AJ 40	AJ 50	R 10	R 20	R 30	R 40	R 50
Cover factor	93.7	97.5	99	99.6	99.7	92.2	96.2	98.2	99.2	99.7
Porosity	6.3	2.5	1	0.4	0.3	7.8	3.8	1.8	0.8	0.3
St.Dev	1.0	0.7	0.4	0.2	0.2	0.9	0.7	0.6	0.3	0.2

Table 4

ANNOVA RESULTS OF COVER FACTOR					
Source	**Type III Sum of Squares**	**df**	**Mean Square**	**F**	**P**
Yarn_type	169.168	1	169.168	226.512	.000
Weft_setting	6174.222	4	1543.555	2066.784	.000
Yarn_type * Weft_setting	80.589	4	20.147	26.977	.000

variable which is cover factor as p-value obtained from all factors is less than the alpha value (0.05).

CONCLUSION

The results presented here show thelight transmission properties of airjet and rotor yarn wovenfabricswhichdecreases with increase in weft settings in fabric or in contrary, it can be said that the cover factor of fabric increases as the weft setting in fabric increases but in a non-linear way. Whereas the fabrics woven by using airjet yarns have more cover factor than the competing rotor yarn woven fabrics at the same weft setting and it is due to the two facts, the hairiness of airjet yarn and flatness of airjet yarn in the fabric. The hairiness and flatness of airjet yarn have been found slightly more than rotor yarns because of the structural difference of both yarns. A strong correlation was found between thecover factor and weft setting of the airjet and rotor yarn woven fabrics. Similarly the input parameters (yarn type and weft setting) were observed to produce a strong effect on cover factor. Two way ANOVA results show the statistical significance of yarn type and weft setting on CF of fabric.

Acknowledgement

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Investigation of the effect of fabric properties on the fabric use efficiency

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REZUMAT – ABSTRACT

Investigarea efectului proprietăților țesăturii asupra eficienței în utilizare

Există mai mulți factori care afectează eficiența utilizării țesăturilor, unul dintre aceștia fiind proprietățile țesăturilor. Utilizarea diferitelor țesături pentru confecționarea aceluiași produs crește sau scade cantitatea de țesătură necesară, ceea ce afectează costul produsului. În acest studiu, a fost investigat efectul proprietăților țesăturii asupra eficienței utilizării țesăturilor. Pentru procesele de aplicare au fost utilizate 3 proprietăți diferite ale țesăturilor și 3 articole de îmbrăcăminte diferite și au fost elaborate în total 9 marker planuri. Analizând marker planurile pregătite, au fost obținute rapoartele de utilizare a țesăturii și a fost investigat efectul proprietăților țesăturii asupra eficienței utilizării acestora.

Cuvinte-cheie: proprietățile țesăturii, eficiența utilizării țesăturii, marker plan

Investigation of the effect of fabric properties on the fabric use efficiency

There are several factors affecting fabric usage efficiency, one of them is fabric properties. The usage of different fabrics for production of the same product increases or decreases the amount of fabric needed, which affects the cost of the product. In this study, effect of fabric properties on the fabric usage efficiency was investigated. For the application processes, 3 different fabrics properties and 3 different garments were used and totally 9 marker plans were prepared. By analyzing the prepared marker plans fabric usage ratios were obtained and effect of fabric properties on the fabric usage efficiency was investigated.

Key-words: fabric properties, fabric usage efficiency, marker plan

INTRODUCTION

Cost is the most important element in making product decisions. Cost is the main subject in companies. Because the savings in production without compromising on quality will positively influence costs, using all kinds of material, system, and manufacturing time should be the main purpose. When cost structure of apparel products is analyzed, it is seen that fabric and accessories subscribe 50–60% of product costs [1].

Increasing the efficiency of the fabric usage which is one of the most important inputs of the ready-made garment production decreases the product cost. Prediction, planning and control of the waste are very important for the ready-made garment companies, as they want to obtain maximal profit with minimal input. Therefore, the production cost of the companies decreases and their competitiveness increases [2].

The greater part of the readymade garment cost as being fabric, reveals the importance of the fabric waste [1]. A minor increase or decrease of the fabric waste highly affects the product cost. Therefore, the effective usage of the fabrics and minimized fabric waste positively affects the product cost.

Recent researches regarding the parameters that matter for fabric operation productivity indicate that it is affected by the CAD system usage [3–7], the imperfection of fabric width [4, 8–11], marker plan length, garment size and assortment size distribution [1, 11–12].

When the studies were investigated, it was seen that only fabric width was analyzed under the heading of fabric properties. In this study, different from the previous studies, effects of structural properties of the fabrics were investigated on fabric usage efficiency.

The structural properties of the fabric used in garment production highly affect the fabric waste and therefore the product cost, which is the basis that determines how to place the pattern parts of the garment on the marker plan. For example, the manufacture of the same garment from the pile or figured fabric affects the fabric waste, therefore the garment cost.

In this study, three different featured fabrics and three different products were chosen and nine different marker plans were prepared with the same assortment and fabric width. Fabric properties' effects on fabric usage efficiency were observed via marker plans. The aim of the study is to reveal to what extent fabric properties effect on fabric usage efficiency and to provide an insight into production units.

MATERIAL AND METHOD

There are three products chosen for this study; t-shirt, shirt and trousers as seen in figure 1.

Three different marker plans were prepared for each of the products. In total nine marker plans were used to determine the fabric properties effects on marker plan productivity.

Three different fabric properties were considered on marker plans. There are:

1. Fabric: The fabric was considered without any pile or figure. Thus, pattern parts of the products were placed in the desired direction of the fabric.
2. Fabric: The fabric was considered to have pile and pattern parts that compose the products were placed just in one direction.
3. Fabric: The fabric was considered to have both horizontal- and vertical-striped. Pattern parts of the products were placed as lines guzzle to each other, just in one direction.

The fabric width was considered as 170 cm for all marker plans. The assortment distribution was as follows in table 1.

Table 1

ASSORTMENT PLAN				
Sizes	34	36	38	40
Assortment	1	2	2	1

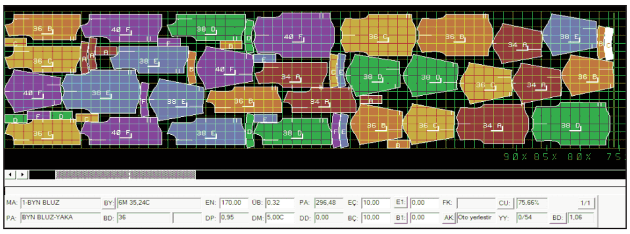
The marker plans were prepared by Gerber operator with using Gerber Accumark V8 program. Marker efficiency values were taken from the Gerber system. Figures 1–3 show three different marker plans of the shirt, the t-shirt and the trousers respectively.

According to Glock and Kunz; marker efficiency is determined from fabric utilization, the percentage of total fabric that is actually used in garment parts [13]. For the calculation of the fabric usage efficiency from the marker plans, the ratio of the total pattern area to marker area is based on:

Fabric Usage Efficiency (FUE %) = Total Pattern Area / Marker Area [5].

a – Marker plan prepared according to the 1st fabric

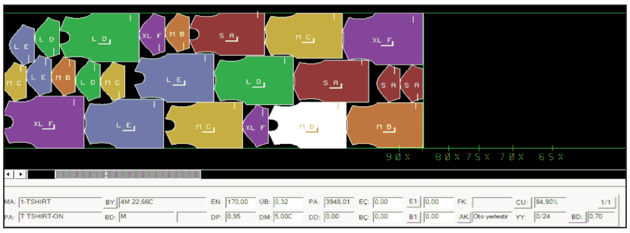
b – Marker plan prepared according to the 2nd fabric



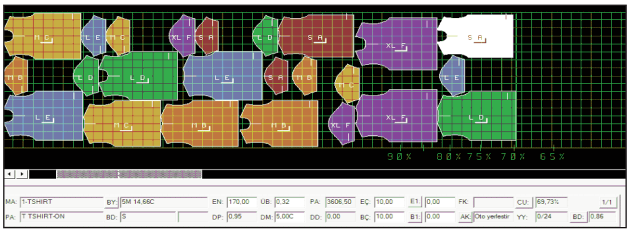
c – Marker plan prepared according to the 3rd fabric

Fig. 1. Three different marker plans of the shirt

a – Marker plan prepared according to the 1st fabric

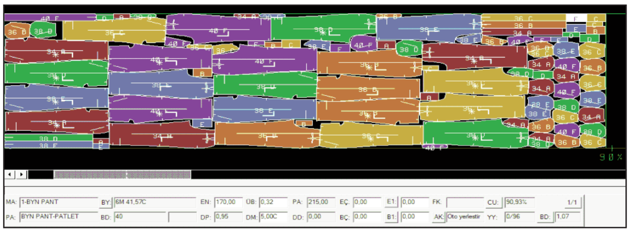


b – Marker plan prepared according to the 2nd fabric

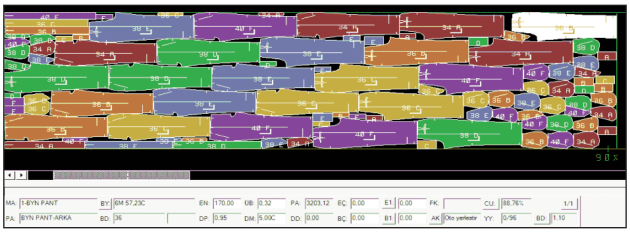


c – Marker plan prepared according to the 3rd fabric

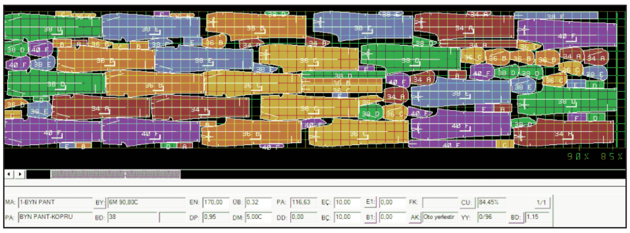
Fig. 2. Three different marker plans of the t-shirt



a – Marker plan prepared according to the 1st fabric



b – Marker plan prepared according to the 2nd fabric



c – Marker plan prepared according to the 3rd fabric

Fig. 3. Three different marker plans of the trousers

RESULTS

After the preparation of the marker plans, the results for fabric usage efficiency and fabric consumption are given in figure 4 and figure 5.

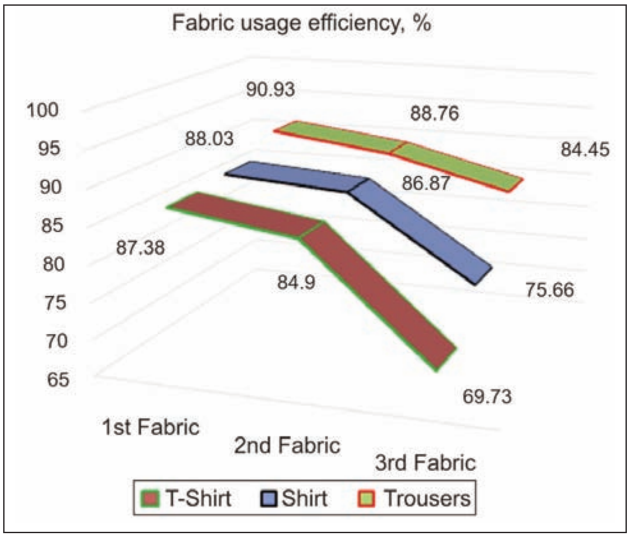


Fig. 4. Fabric Usage Efficiency (%)

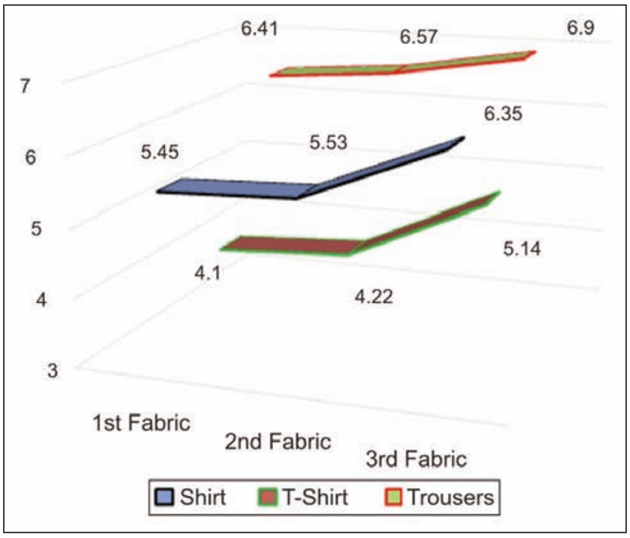


Fig. 5. Fabric Consumption (m)

Fabric usage efficiency of trousers was found 90.93%, 88.76% and 84.45% for first, second and third fabric in marker plans, respectively. On the other hand, fabric usage efficiency of shirts was found 88.03%, 86.87% and 75.66% for first, second and third fabric in marker plans, respectively. Whereas, fabric usage efficiency of t-shirts was found 88.03%, 86.87% and 75.66% for first, second and third fabric in marker plans, respectively, as seen in figure 4. In the light of these results, it was observed that fabric features affect the operational productivity of the fabric.

Fabric waste of trousers was found 6.41 m, 6.57 m and 6.90 m for first, second and third fabric in marker plans, respectively. On the other hand, fabric waste of shirts was found 5.45 m, 5.53 m and 6.35 m for first, second and third fabric in marker plans, respectively. Whereas, fabric waste of t-shirts was found 4.10 m, 4.22 m and 5.14 m for first, second and third fabric in marker plans, respectively, as seen in figure 5. In the light of these results, it was observed that fabric waste affects the operational productivity of the fabric.

When marker plan lengths were considered as seen in figure 5, product based fabric consumption amount was shown in table 2.

Fabric consumption for each garment is calculated using the formula shown below.

Fabric consumption = Marker plan length / Total size on marker plan.

Table 2

FABRIC CONSUMPTION FOR EACH PRODUCT			
Products	1st Fabric [m]	2nd Fabric [m]	3rd Fabric [m]
Trousers	1.068	1.095	1.150
Shirt	0.908	0.922	1.058
T-shirt	0.683	0.703	0.857

Fabric consumption by amount was observed as 1.068 m, 1.095 m and 1.150 m from the first fabric to third for pant, 0.908 m, 0.922 m and 1.058 m from the first fabric to third for shirt, 0.683 m, 0.703 m and 0.857 m from the first fabric to third for t-shirt respectively, shown in table 2. Relatively, it was observed that fabric waste affects the operational productivity of the fabric.

Results from figures 4–5 and values from table 2, the change of operational productivity of the fabric according to its feature and fabric consumption amount was analyzed as seen in table 3.

As seen in table 3, the change of operational productivity of the fabric between first and second fabrics were 1.32–2.83 %, between second and third fabrics were 4.85–17.86 % and between first and third fabrics were 7.12–20.2 % for all three products.

The change of fabric consumption amount between first and second fabrics were 1.46–2.93 %, between

Table 3

EXCHANGE RATIO OF FABRIC USAGE EFFICIENCY AND FABRIC CONSUMPTION						
	Fabric Usage Efficiency (%)			Fabric Consumption (m)		
Products	Between 1st Fabric and 2nd Fabric	Between 2nd Fabric and 3rd Fabric	Between 1st Fabric and 3rd Fabric	Between 1st Fabric and 2nd Fabric	Between 2nd Fabric and 3rd Fabric	Between 1st Fabric and 3rd Fabric
Trousers	2.38	4.85	7.12	2.49	5.02	7.64
Shirt	1.32	12.90	14.05	1.46	14.82	16.51
T-shirt	2.83	17.86	20.2	2.93	21.80	25.36

second and third fabrics were 5.02–21.80 % and between first and third fabrics were 7.64–25.36 % for all three products.
To conclude up, the change ratio of both operational productivity and the consumption amount of fabric showed an increase from the first fabric to third.

CONCLUSION

The aim of the study is to examine the effects of fabric properties on marker plan productivity, in parallel with the effects on product cost. For this purpose, three different fabrics which have different properties were chosen for three different garments and nine different marker plans were prepared. Results were evaluated for fabric usage efficiency and waste amount of the fabric.
At the end of this study, first fabric with no grain no figure was determined to have the highest operational productivity, whereas both cross- and the vertical-striped third fabric was determined to have the lowest operational productivity for all three products.
Supportively, the lowest consumption was observed in first fabric, whereas the highest in third fabric.
These results revealed that the consumption amount of the fabric was highest in striped or figured fabrics compared to others. The reason is that when lines were needed to guzzle to each other, pattern parts of the products cannot be placed as desired.
The highest fabric consumption amount after the striped or figured fabrics was observed in grain fabrics. The reason is again the limitation to place pattern parts of the products to the marker plans. At this point, all of the pattern parts must be placed in the same direction.
Otherwise, grains on the fabric surface cause different color reflections occurrence.
Fabric features affect the consumption amount, operational productivity and also cost. If the same fabrics were used for the same products (fabric prices are ignored), product costs will vary. Therefore, fabric features must be taken into consideration while calculating the product cost.
By this study, effects of fabric features on operational productivities and consumption amounts of the fabrics were studied to point out especially for garment manufacturers.

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The methodology for evaluation and predicting of clothing comfort for functional apparel

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REZUMAT – ABSTRACT

Metodologia de evaluare și predicție a confortului îmbrăcămintei funcționale

Scopul acestui studiu a fost testarea primului strat de îmbrăcăminte. Poate fi utilizat separat sau împreună cu alte straturi de textile în structura de tip sandwich a îmbrăcămintei. Deoarece acest strat intră în contact direct cu pielea, evaluarea nu se axează doar pe proprietățile sale termofiziologice, ci și pe percepția senzorială a țesăturii. Scopul principal al acestui strat este de a transporta căldură și umiditate de la piele către suprafață sau către celelalte straturi. O modalitate de a evalua confortul fiziologic al îmbrăcămintei este testarea articolelor de îmbrăcăminte în condiții și standarde de laborator. Pentru testare au fost alese tricouri din fibre naturale 100%, fibre chimice și fibre mixte pentru comparație. Lucrările experimentale s-au desfășurat în următoarele două etape de testare în laborator: măsurarea proprietăților pentru confort fiziologic și gradul de măsurare a valorii totale a tușeului în sistemul de evaluare Kawabata. Pentru predicția confortului îmbrăcămintei și evaluarea rapidă a performanței îmbrăcămintei, a fost creată, de asemenea, o ecuație simplă pentru compararea setului selectat de tricouri.

Cuvinte-cheie: confortul îmbrăcămintei, evaluare obiectivă, îmbrăcăminte funcțională

The methodology for evaluation and predicting of clothing comfort for functional apparel

The aim of this study was testing the first layer of clothing. It can be used separately, or together with other layers of textiles in the sandwich structure of clothing. As this layer is in direct contact with the skin, the evaluation does not focus only on its thermo physiological properties, but also on sensory perception of the fabric. The main purpose of this layer is to transport heat and moisture from the skin to surface, or to the other layers. One way of assessing the physiological comfort of the garment is testing garments under defined conditions and standards in a laboratory. For testing, T-shirts made from 100 percent natural fibres, chemical fibres, and also mixed fibres for the comparison were chosen. Experimental work was carried out in the following two steps of laboratory testing: measurement of selected utility properties in the Laboratory of Physiological Comfort, and the measurement degree of Total Hand Value in the Kawabata Evaluation System. For the prediction of clothing comfort and the garment performance quick assessment, a simple equation for the comparison of the selected set of T-shirts was also created.

Keywords: clothing comfort, objective evaluation, functional apparel

INTRODUCTION

Sensorial comfort of clothing is a result of the interaction between the fabric and human skin sensory system and the atmospheric conditions [1]. Several studies have focused on sweating and heat loss of the wearer, since the amount of sweat and produce of heat reflects their physiological state [2–4]. The observation of the moisture distribution in clothing, its amount and location is also important for understanding the thermal stress and the thermal protection [5]. Moisture closed inside the structures of clothes can decrease the thermal protection of clothing and comfort of a wearer. It also influences other parts of clothing and it has a direct impact on subjective feelings and performance of wearers. The microclimate formed by human skin and the clothing reflects the interaction of a human, the environment and clothing. Our previous studies have been concentrated on the subjective evaluation of comfort perception by the human subject and the evaluation of the microclimate between the skin and the first layer of clothes according to the heat index WBGT standards [6]. The index WBGT (Wet Bulb Globe Temperature) is a good indicator of the physiological safety of human subject under permanent load stress in the course of exercise [7]. This study deals with the first layer of clothing because it is the basic clothing layer which is in constant interaction with a wearer´s skin. The prerequisite for achieving good clothing comfort is that this layer must not cause unpleasant sensory feeling when it is worn by the user. Our research has been primarily focused on selected objective methods, but we must consider the shape of clothing construction as well; therefore deal with a required fit and sequence of a clothing layer on human body surface [8–9]. The phenomenon of heat transfer under the sewing process has also influence on manufacturing clothes [10–11]. Clothing helps thermoregulation when the body itself is not capable of auto-regulation. “Comfort” can therefore be defined as the state of an organism when its physical functions are optimized and its environs, including clothing, do not produce any unpleasant sensations [12]. Heat transport depends on ambient temperature and a person’s physical load. The most important material parameters, the thermal resistance R_{ct}, and the resistance to water vapour R_{et} of the tested T-shirts were also evaluated in accordance with the EN ISO standard under standard conditions for testing textiles at 20 °C and 65 % of relative humidity on the skin model – SGHP 8.2 (Sweating Guarded Hot Plate) [13].

MATERIALS AND METHODS

The characteristics of the selected transport layer – 1st layer of clothing

The set of T-shirts for testing clothing comfort was selected based on the requirements for optimal physiological comfort both during normal activity and a medium weight job, especially in long term moderate loading of an organism during fitness training. The selected set of T-shirts covers a wide range of work apparel (for firefighters, maintenance, police, army, stewards, etc.) and is also suitable for sports activities. It is designed primarily for an environment without the possibility of easy replacement one piece of clothing by another, as it is common in professional sports activities. The first layer may serve as the outer layer of garment, or, as in our case, as the top layer of the garment. The table 1 shows the labelling of samples of clothing that have been selected for testing and their basic and selected material parameters measured relative to the investigated parameters.

Transformation of determining characteristics

The basic problem of the theory of utility properties is the transformation of variables of different physical significances and sizes to the commensurate variables of psychometric importance, as perceived by the user of the garment.

The user perceives the value of utility properties of fabrics only in a certain range (limits) and if the value falls below the limits of moral and physical endurance, the property is globally graded as unsatisfactory; if the value rises above the limits of the optimal perception, i.e. the user is not able to assess whether “it is better or worse”, it will be generally evaluated as fully satisfactory [14].

The graph in figure 1 shows an example of evaluation when using the normalized index. This type of transformation is valid for determining the properties reaching mutually restricted optimum for determining

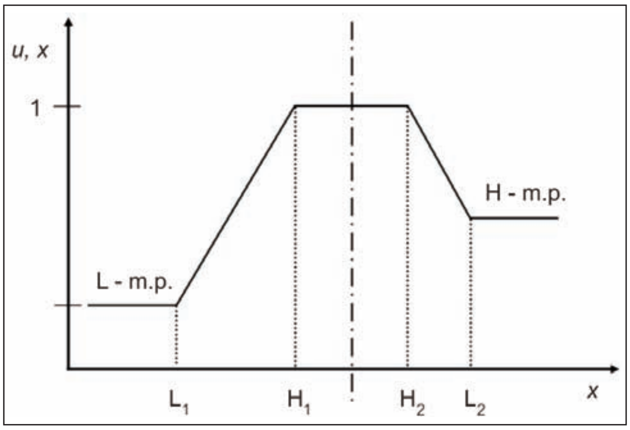

Fig. 1. Illustration of one or two-sided bonded transformation. L_1, L_2 – the lower limits, H_1, H_2 – the highest limits, *L-m.p.*, *H-m.p.* – the high/low limit of usability of the product in terms of the properties of *x* [14]

Table 1

THE BASIC PROPERTIES OF THE SELECTED SET OF T-SHIRTS					
Mark.	**Material**	**Origin**	**Structure**	**Thickness [mm]**	**Weight [g/m^2]**
Ts1	100% CO	Czech Republic	weft single plain	0.69	170
Ts2	100% WO (Merino)	Norway	weft double	0.94	217
Ts3	100% PL	USA	weft interlock	0.92	179
Ts4	100% CO	Bangladesh	weft single plain	0.69	160
Ts5	100% WO (Merino)	Norway	weft single plain	0.68	150
Ts6	100% CV	Czech Republic	weft interlock	0.68	210
Ts7	96% WO (Merino)/ 4% PADh	Czech Republic	weft single plain	0.71	170
Ts8	100% PP	Czech Republic	weft double	0.90	115
Ts9	48% WO/ 25% PorexilThermocool/ 25% Tencel/ 2% PADh	Czech Republic	weft double	1.15	240
Ts10	100% Porexil Warm-light	Czech Republic	weft single plain	0.88	178
Ts11	50% PorexilThermocool/ 50% Tencel	Czech Republic	weft single plain	0.79	167
Ts12	35% PorexilThermocool/ 35% Tencel/ 28% PL VR micro/ 2% PADh	Czech Republic	weft double	0.93	182
Ts13	91% PL/ 9% Antistatic fibre	Czech Republic	weft single plain	1.52	210
Ts14	100% PP	Czech Republic	weft interlock	1.51	189
Ts15	50% CO/ 50% PL	Macedonia	weft single plain	0.67	157
Ts16	100% PL	USA	weft single plain	0.57	124

the property. Determining the limits of determining features is a necessary step for the transformation into a commensurate quantity usable for the expression of the user´s extent of perception by means of standardized utility properties. Resulting standardized utility property (normalized index of property) is a dimensionless value and may move in the interval <0; 1>. The above shown “stair function” represents a typical course of the dependence of standardized determining property on the value of utility property.

EXPERIMENTAL WORK

Evaluation of total hand value in the Kawabata Evaluation System

When examining a product by touch, hand value affects comfortable feelings of users. It is possible to assess user comfort with subjective or objective methods of measurement. All tested garments (T-shirts) of laboratory research have been the subject of an objective hand evaluation according to the Kawabata Evaluation System. The result is THV (Total Hand Value). THV is the World Standard of the Hand Evaluation guaranteed by The Hand Evaluation and Standardization Committee, The Textile Machinery Society of Japan. KES FB allows testing basic mechanical properties of fabrics [15].

This system uses four devices:

- KES FB1 for determination of tensile and shear characteristics of fabrics,
- KES FB2 for determination of bending characteristics of fabrics,
- KES FB3 for determination of compression characteristics of fabrics,
- KES FB4 for determination of surface characteristics.

Conditions of measurements on these machines were set with respect to specificity of measured fabrics. Deformations of tensile of knitted T-shirts were measured on the KES FB1 under mode with reduced standard tensile force. Surface characteristics of knitted T-shirts were measured on KES FB4 in mode of the adjustments of samples for reducing the elongation at clamping in the machine. The modified method can be considered comparative in the context of measurement and evaluation set of high strain knits. The evaluation was performed in Category KN-203-LDY, KN-302-W. In this category, the primary properties are stiffness (Koshi), smoothness (Numeri), fullness and softness (Fukurami). The Total Hand Value (THV) is the zone of ratings from 1 to 5, where the zone 1 is poor hand value and the zone 5 means excellent hand value. The results are presented in table 2.

Evaluation of selected utility properties

For material evaluation of T-shirts, the following parameters were chosen: thermal resistance R_{ct} and resistance to water vapour R_{et}. Both of them have significant influence on the subject’s physiological comfort feelings. These material parameters also reflect the ability of textile fabrics to keep the optimal clothing comfort. From the measured parameters, the index of water-vapour permeability (1) was accordingly calculated [13]:

$$I_{mt}\,[-] = (R_{ct} / R_{et}) \cdot S \qquad (1)$$

where:

R_{et} is resistance against water-vapours [m^2.Pa.W^{-1}], R_{ct} – thermal resistance [m^2.K.W^{-1}], S equals 60 [Pa/K].

Table 2

THE MEASURED PARAMETERS AND CALCULATED RESULTS OF THE TESTED T-SHIRTS

Mark.	R_{ct} [m^2·K·W^{-1}]	R_{et} [m^2·Pa·W^{-1}]	I_{mt}[–]	THV [Degree]	I_{THV} [–]
Ts1	0.019	2.560	0.450	4.20	0.82
Ts2	0.037	2.590	0.860	4.31	0.84
Ts3	0.030	3.140	0.570	4.75	0.94
Ts4	0.025	2.786	0.550	5.04	1.00
Ts5	0.037	3.657	0.610	5.21	1.00
Ts6	0.026	3.125	0.500	3.60	0.69
Ts7	0.055	3.606	0.920	5.20	1.00
Ts8	0.028	2.550	0.650	3.30	0.62
Ts9	0.038	5.420	0.420	5.86	1.00
Ts10	0.034	3.840	0.530	4.10	0.80
Ts11	0.023	2.860	0.480	3.61	0.69
Ts12	0.024	3.610	0.390	4.52	0.89
Ts13	0.031	3.877	0.480	4.59	0.91
Ts14	0.046	5.120	0.540	4.58	0.91
Ts15	0.020	2.820	0.430	5.02	1.00
Ts16	0.026	3.125	0.500	3.41	0.64

Table 3

SPECIFICATION OF THE UTILITY QUALITIES AND COEFFICIENT OF SIGNIFICANCE FOR USE AS THE FIRST LAYER OF CLOTHING						
PARAMETERS of utility properties for textile clothing **Way of Use:** First layer of clothing – Overall direct contact with the human organism				**Interval of recommended values**		**Coefficient of relevance**
	Determination of the utility qualities	**Dimension**	**Measuring method**	**min**	**max**	**k**
1	Area weight	g/m^2	ČSN EN ISO12127	80	120	0.981
2	Wet strength	N	ČSN EN ISO13934-1	100	300	0.932
3	Dry elongation	%	ČSN EN ISO13934-1	15	35	1.185
4	Abrasion-Accelerator-300s	%	ČSN 800833	5	8	0.852
5	Pilling	Etalon	ČSN EN ISO12945-2	3	5	1.006
6	Change of dimensions-5.washing	%	ČSN EN ISO 3077	1	3	1.466
7	Colour fastness	Etalon	ČSN EN ISO 105.....	3	5	1.275
8	Resistancetowater vapour-R_{et}	$Pa{\cdot}m^2/W$	ČSN EN 31092	2	6	0.828
9	Heat-resistance-R_{ct}	$m^2{\cdot}K/W$	ČSN EN 31092	0.02	0.04	0.826
10	Air Permeability	mm/s	ČSN EN ISO 9237	100	400	0.792
11	Absorbency and capillary action	mm	ČSN 800828	30	80	1.438
12	Moisture transport MMT Unidirectional transport of moisture Overall management of moisture Moistening the ratio obverse/reverse	Degree	AATCC 195	3.5 3.5 1	5 5 >1	1.438
13	Objectivehand evaluation(THV) KAWABATASYSTEM	Degree	IS KOD 01-2004 (Internal Standard)	3	5	0.980

The resulting index value of water-vapour permeability, where $I_{mt} = 0$ is the lowest limit, represents infinite resistance, while the resulting value 1 has a thermal resistance to water vapour, i.e. the same as an air layer of the same thickness [13].

Specifications of the utility qualities and determination of the coefficients of significance

For the first layer of the garment, very important qualities are to be able to convey a perception of wearing comfort to the user. These are determining utility qualities in the order of 8, 9, 10, 11, 12, and 13 (table 3). Utility properties 2, 3, 4 are carriers of durability characteristics of clothes. Properties 5, 6, 7 bring the wearers a feeling of good or bad product look. For the specification of parameters of utility properties in selected categories of use, the applicable standards DIN, EN and research work in the field of utility properties of fabrics [14, 16] were the basis.

Evaluation of the experiment – suggesting an objective method for garment comfort evaluation

For the purpose of garment performance quick, objective and comparative assessment, and the physiological comfort which provides clothing tested for a long-term physical activity of users, comfort index I_{com} was designed. The evaluation is based on three objectively measured parameters of textiles, which affect the user´s overall feeling of comfort.

Clothing comfort index is calculated by the following equation (2):

$$I_{com}\ [–] = k_1 \cdot I_{mt} + k_2 \cdot I_{THV} \qquad (2)$$

where:

k_1, k_2 – constant of significance [–], I_{mt} – water-vapour permeability index [–], I_{THV} – index of sensorial feeling from a textile [–].

Selected parts of the comfort index are an important component for the evaluation of thermo-physiological comfort and sensorial feeling from a textile and allow us to evaluate qualitatively a garment made therefrom. For determining a scale of coefficient of significance k_1 and k_2, it is possible and recommended to take the values listed in the table 3. In this case $k_1 = 0.83$, $k_2 = 0.98$.

RESULTS AND DISCUSSION

The first layer of clothing can be used separately, or together with other layers of textiles in the sandwich structure of clothing. The functional basis of this garment structure is the first layer which removes perspiration and vapour from the skin surface into next layers and therefore this function is primarily focused on this layer of garment. In the final table, table 4, there are individual T-shirts put in order based on the highest index achieved by multi-criteria assessment according to I_{com}. The higher number, the better chances of achieving optimum physiological properties during long-term load.

Table 4

THE OVERALL INDEX OF COMFORT CALCULATED FOR THE EXAMINED SET OF TEXTILE																
Order	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.	13.	14.	15.	16.
Mark.	Ts7	Ts2	Ts5	Ts4	Ts3	Ts14	Ts15	Ts9	Ts13	Ts10	Ts12	Ts1	Ts8	Ts6	Ts11	Ts16
I_{com} [–]	1.74	1.54	1.49	1.44	1.39	1.34	1.34	1.33	1.29	1.22	1.20	1.18	1.15	1.09	1.07	1.04

The obtained results from the research are included in table 2 and table 4. From the results of THV from the Kawabata system we can conclude that all of the tested T-shirts obtained good and very good rating, with the best result being obtained by the T-shirts No. 9, 5, 4, 15. From the resulting index of water-vapour permeability, the best rating obtained T-shirts No. 7, 2 made from merino wool. According the multi-criteria index of comfort clothing I_{com}, it can be concluded that T-shirt No. 7 (96.33 %), T-shirt No. 2 (84.92 %), T-shirt No. 5 (82.12 %), which are made from merino wool, obtained optimal results.

CONCLUSIONS

This article is primarily focused on the possibility of objective evaluationand comparison of the sensorial feelings of knit fabrics in the Kawabata Evaluation System.The first layer of clothing is in direct contact/interaction with human skin and its basic function is to transfer moisture and heat to reach and maintain the wearer´s physiological, thermo-physiological and sensorial feeling of comfort. Reaching these comfort zones is crucial for the overall comfort of the wearer. The experiment was focused on objective methodology for evaluating and predicting clothing comfort for functional apparel using the index of clothing comfort. The multi-criteria index proposal which includes all the aspects mentioned above was developed to evaluate physiological comfort and it allows a quick comparison of a set of T-shirts. The methodology is based on objectively measured data and the basic formula may be easily extended by additional parts such as the index WBGT (Wet Bulb Globe Temperature), MMT test, air permeability, etc. The basic equation consists of thermo-physiological properties and sensorial characteristic of knit fabrics, represented by the THV index and the index of water-vapour permeability. The clothing comfort index proposal can be used for quick assessment of garment performance mainly designed for recreational sportsmen, with no other special requirements for clothing and with the possibility of a piece of clothing to be easily replaced by another. On the contrary, if there are special requirements for the garment, it is appropriate to extend the equation by further evaluation criteria. T-shirts made from merino wool obtained the best result, but certain sensitive people could feel discomfort when wearing T-shirts made from natural merino wool. From the above mentioned results it is clear that the choice of a suitable first layer of clothing is complicated and it will be a compromise (mix) between different properties and preferences of wearers. Therefore, it is always necessary to choose a T-shirt according to its intended use. Moreover, other conditions must be taken into account as well, such as the expected length of wearing, physical activity, weather conditions etc.

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The behavior in finishing of textile materials made of man-made fibers containing ZnO in blends with cotton

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REZUMAT – ABSTRACT

Comportamentul la finisare al materialelor textile realizate din fibre artificiale cu conținut de ZnO în amestecuri cu bumbac

Obiectivul acestui studiu a fost de a investiga comportamentul la finisare al materialelor textile realizate din fibre artificiale cu conținut de ZnO în amestec cu bumbac. Au fost studiate posibilitățile de reducere a concentrației agenților chimici considerați a fi agresivi pentru fibrele textile funcționale, temperatura și durata proceselor, precum și numărul operațiilor tehnologice efectuate, astfel încât calitatea vopsirii să nu aibă de suferit, iar probele vopsite să fie acceptabile din punctul de vedere al uniformității și al rezistenței vopsirii. Pentru a evidenția influența auxiliarilor chimici utilizați în operațiile de finisare, temperatura procesului, pH-ul și durata tratamentului asupra caracteristicilor fizico-chimice și fizico-mecanice ale fibrelor funcționale, s-au aplicat diferite metode de tratare preliminară și vopsire în diferite variante experimentale. Pentru evaluarea performanțelor tratamentelor preliminare din punctul de vedere al gradului de alb și al hidrofiliei, țesăturile au fost testate înainte și după efectuarea tratamentelor preliminare. În scopul determinării eficienţei tratamentelor realizate, ţesăturile finite (tratate preliminar și vopsite) au fost testate din punctul de vedere al diferenței de culoare și al rezistenței vopsirii. Țesăturile finite au fost, de asemenea, caracterizate din punctul de vedere al principalelor caracteristici fizico-chimice și fizico-mecanice: masa, rezistența la tracțiune, rezistența la rupere, permeabilitatea la vaporii de apă, permeabilitatea la aer. Analiza SEM a fost utilizată pentru a investiga morfologia de suprafață a țesăturilor tratate. Activitatea antibacteriană a probelor tratate a fost testată împotriva tulpinii test Staphylococcus aureus.

Cuvinte-cheie: fibre funcționale, tratament de finisare preliminară, proprietăți fizico-mecanice-chimice, activitate antibacteriană

The behavior in finishing of textile materials made of man-made fibers containing ZnO in blends with cotton

The objective of this study was to investigate the behavior in finishing of textile materials made of man-made fibers containing ZnO in blends with cotton. It has been studied the possibilities of reducing the concentration of the chemical agents considered to be aggressive for the functional textile fibers, the temperature and the duration of the processes, as well as the number of technological operations performed, so that the dyeing quality will not suffer and the dyed samples to be acceptable from the uniformity and fastness point of view. To highlight the influence of the chemical auxiliaries used in finishing operations, the process temperature, pH and the treatment duration on the physical-chemical and physical-mechanical characteristics of the functional fibers, various methods of preliminary treatment and dyeing were applied in different experimental variants. In order to assess the preliminary treatments performance from whiteness degree and hydrophilicity point of view, the fabrics were tested before and after preliminary treatments. Finished fabrics (preliminary treated and dyed) were tested for the efficiency of the performed treatments in terms of color difference attributes and color fastness. The finished fabrics were also characterized in terms of the main physical-chemical and physical-mechanical characteristics: mass, tensile strength, tearing strength, water vapor permeability, air permeability. SEM analysis was used to investigate the surface morphology of treated fabrics. Antibacterial activity of treated samples was tested against the Staphylococcus aureus test strain.

Keywords: functional fibres, preliminary finishing treatment, physical-mechanical-chemical properties, antibacterial activity

INTRODUCTION

Textile industry continuously searches for new technologies in order to accomplish the consumers' demands. Especially in recent years, new developments allowed the production of functional and smart textiles which are capable of sensing changes in environmental conditions or body functions and responding to these changes. As a consequence, the number of bio functional textiles with an antimicrobial activity has increased considerably over the last few years [1–3]. Several major classes of synthetic (quaternary ammonium compounds, silver, polyhexamethylene biguanides (PHMB), triclosan) or natural antimicrobial agents (chitosan, plant extracts, essentials oils) are used in the textile industry in order to control the bacterial growth efficiently and to keep its durability [4–9].

Antimicrobial agents can be applied to textile by different methods such as pad-dry-cure, coating, spraying and foam techniques. It can also be applied directly by adding the antimicrobial agent into the spinning fiber solutions. Development of antimicrobial fibers is based on the process of incorporating active antimicrobial agents into the fiber in its manufacturing stage and this technology is rather increasing today, mainly being supported by fiber manufacturers [10]. Some commercial bioactive fibres with antimicrobial agents and finishing products are: SeaCellR Active, a cellulose-base fibre; MicroFresh®, SoleFresh® and Guard-Yarn®, polyester or nylon yarns with Alpha San®, a zirconium phosphate-based ceramic ion-exchange resin containing silver; Trevira Bioactive®: polyester fiber with silver incorporated prior to the extrusion process; SmartSilver®, wool fibers with silver added by typical exhausting dyeing methods and other finishing silver-based products like Smart Silver™, SilpureR, Sanitized®, AlphaSan® and Ultra-Fresh. Cotton fibers are also being commercialized under a pre-treatment with ReputexR (PHMB attached to cotton) and more recently, polyamide with PHMB is sold as Purista®. Moreover, polyamide and polyester fibers treated with Tinosan AM 100®, cellulose acetate yarns named Silfresh®, Microban® textile and Irgaguard® and Irgacare® products, all contain triclosan as antimicrobial agent [11].

Smartcel™ Sensitive fibers developed by Smartpolymer (Germany) are Lyocell fibers that have integrated ZnO into their matrix for skin protection and skin care, produced without aggressive chemical agents for the skin [12]. Textiles materials containing these novel zinc fibers allow natural, soft and pure skin care with an additional antibacterial and odor-reducing effect. The antibacterial effect of zinc is based on the “oligo dynamic effect” which describes a disruption in the antibacterial metabolism.

For the finishing of textile materials made of functional fibers have to pay special importance on every technological process involved in the technological flow of finishing, so that the additives contained in the fiber structure, giving them functionality, are not eliminated by the finishing, dyeing or final finishing procedures applied. In this respect, the specific objective of this study was to investigate the behavior in finishing of textile materials made of man-made fibers containing ZnO in blends with cotton. It has been studied the possibility of reducing the concentration of the chemical agents considered to be aggressive for the functional textile fibers, the temperature and the duration of the processes, as well as the number of technological operations performed, so that the dyeing quality will not suffer and the dyed samples to be acceptable from the uniformity and fastness point of view.

EXPERIMENTAL WORK

Materials

For laboratory experiments 80% cotton/20% Smartcel™ Sensitive (with ZnO content) plain weave fabric with 290 yarns/10cm in warp and 230 yarns/10cm in weft, 246 g/m^2 weight was used. For preliminary finished operations Kemapon PC/LF (Kem Color S.p.a, Italy) or Imerol JFS (Clariant) was used as wetting and detergent agents. Kemaxil Liq (Kem Color S.p.a., Italy) was used as stabilizer agent for H_2O_2 and Sequion 48/98 (Giovanni Bozzeto S.p.a, Italy) was used as a dispersant and sequestrant for calcium, magnesium and iron ions. Sirrix SB (Clariant), a multi-action anionic product, has been used as a dispersant for fatty impurities, oxygen active generator, activator and stabilizer for H_2O_2. For pre-treatment operations performed at low temperatures, Imerol LTB (Archroma) was used, a chemical product especially designed for the low temperature bleaching process, having superior wetting and removal properties of fatty impurities, oils, accidental pigments and high emulsifying properties of impurities, and as H_2O_2 stabilizing agent was used the product formulated for low temperature process, Stabilizer LTB (Archroma).

Preliminary treatments

To highlight the influence of the chemical auxiliaries used in finishing operations, the process temperature, pH and the duration treatment applied, on the physical-chemical and physical-mechanical characteristics of the functional fibers, various methods of preliminary treatment and dyeing were applied, in different experimental variants. Laboratory experiments were performed on the jigger (Roaches-England) laboratory apparatus at 1:10liquor ratio (material: liquor ratio), as follows:

- **Strong alkaline pre-treatment-bleaching in successive phases (classical process)** (**Code V_1**): Alkaline treatment – Bath 1 ® 2 g/L Kemapon PC/LF, 2 g/L Sequion 48/98, 6 ml/L NaOH 38°Be, 3 g/L trisodium phosphate, 90 minutes, 98°C; Bath 2 ® Bleaching: 1g/L Kemapon PC/LF, 2 ml/L Kemaxil Liq, 4 ml/L NaOH 38ºBe, 20 ml/L H_2O_2 30%; 60 minutes, 98°C;
- **Mild alkaline pre-treatment-bleaching in successive phases (mild process)** (**Code V_2**): Alkaline treatment – Bath 1 ® 2 g/L Kemapon PC/LF, 2 g/L Sequion 48/98, 2 g/L Na_2CO_3; 45 minutes, 98°C; Bath 2 ® Bleaching 1g/L Kemapon PC/LF, 2 mL/L Kemaxil Liq, 2.3 mL/L (pH = 12) NaOH 38ºBe, 20 mL/L H_2O_2 30%; 45 minutes, 95ºC;
- **Pre-treatment in single phase with a multiple action chemical auxiliary (mild process) (Code V_3):** 0.5 g/L Imerol JSF, 0.8 g/L Sirrix SB, 2.6 g/L NaOH 38ºBe, 6.5 g/L H_2O_2 30%; 30 minutes, 95ºC;
- **Preliminary treatment – dyeing in single phase with a multiple action chemical auxiliary** (preliminary treatment followed by dyeing without intermediate rinsing) (**Code V_4**): Bath 1 ® 0.5 g/L Sirrix SB, 0.8 g/L, 2.6 g/L NaOH 38° Be, 6.5 g/L H_2O_2 30%; 30 minutes, 95ºC ® Bath evacuation, without intermediate rinsings ® Bath 2 ® 0.2 mL Sirrix NE, 0.35 g/L Bactosol ARL liq. (catalase) ® adding of appropriate chemicals and dyes for dyeing operation;
- **Pre-treatment in a single-phase with low concentration of chemical auxiliary special formulated for low temperature processes** (**Code V_5**) at: 0.5 g/L Imerol LTB, 1g/L Stabilizer LTB, 3 g/L NaOH 38ºBe, 4 g/L H_2O_2 30%; 40 minutes, 80°C;

• **Pre-treatment in a single-phase with higher concentration of chemical auxiliary special formulated for low temperature processes** (**Code V_6**): 1 g/L Imerol LTB, 1 g/L Stabilizer LTB, 6 g/L NaOH 38 °Be, 4 g/L H_2O_2 30%; 40 minutes, 80 °C.
After the preliminary treatment operations the samples were successively rinsed with water at 90 °C, 70 °C, 40 °C and cold rinsing, except for V_4V.

Dyeing operation

After the preliminary treatments, the dyeing operation has been performed by using the following dyeing recipe: 1.5% Drimaren Gelb CL-2R, 70 g/L NaCl (added in two portions), 20g/L Na_2CO_3 (added in two portions). After dyeing operation the samples were rinsed as follows: warm rinsing at 60 °C, soaping with 1 g/L Kemapol SR (Kemcolor) at 90 °C, 20 minutes, rinsing at 80 °C, 40 °C, 30 °C and cold, 10 minutes each rinsing, followed by drying at room temperature.

Methods

Physical-chemical and physical-mecanical characteristics

In order to asses the preliminary treatments performance, the 80% cotton/20% Smartcel™ Sensitive fabrics were tested before and after preliminary treatments in terms of whiteness degree (SR EN ISO 105-J01:2003) and from hydrophilicity point of view by determining the wettability (drop test method according with SR 12751/1989 standard) and the water absorbency (capillarity test according with SR 6146/1989 standard). Finished fabrics (preliminary treated and dyed) were tested for the efficiency of the performed treatments in terms of color difference attributes (SR ISO 105 J03: 2001) and color fastness to washing (SR EN ISO 105-C10:2010), acid and alkaline perspiration (SR EN ISO 105-E 04: 2013) and light (SR EN ISO 105-B02: 2003).
The finished fabrics were also characterized in terms of the main physical-chemical and physical-mechanical characteristics, respectively: mass (SR EN 12127-2003), density (SR EN 1049-2: 2000-Method A, B), tensile strength (SR EN ISO 13934-1/2013), tearing strength (SR EN ISO 13937-3: 2002), water vapor permeability (STAS 9005: 1979), air permeability (SR EN ISO 9237: 1999).

Antibacterial testing

The antibacterial activity of the dyed samples and pre-treated in different variants was qualitatively determined according with the ISO 20645: 2004 (E) standard method, by using of cultures in liquid medium replicated at 24 hours of ATCC 6538 *Staphylococcus aureus* strains (Gram-positive). For determination, the samples were cut in circular shape with a diameter of 2 cm and subsequently disposed in the middle of Petri plates. The culture medium was poured into two layers in Petri plates, lower layer consists of culture medium free from bacteria and the upper layer being inoculated with the test bacteria, then incubated at 37 °C and analyzed after 48 hours.

Scanning Electron Microscopy (SEM)

The surface morphology of treated samples in different variants was investigated by a FEI Quanta 200 Scanning Electron Microscope with a GSED detector, at 2000 x magnification and accelerating voltage of 12.5 kV – 20 kV.

Energy Dispersive X-ray analysis (EDX)

EDX was used to identify the presence of Zn in textile materials. The analysis was made with a FEI Quanta 200 Scanning Electron Microscope coupled with EDX detector. The detector has the ability to convert the X-ray energy emitted by the samples into voltage signals that are specific to different chemical elements.

RESULTS AND DISCUSSIONS

Whiteness degree

The values obtained for the whiteness degree of 80% cotton/20% Smartcel™ Sensitive fabrics preliminary treated in different variants, are shown in table 1.
From the series of experimental variants is highlighted the alkaline pre-treatment – bleaching in successive phases (classical and mild process) (V_1 and V_2) for which higher values of the whiteness degree were found. Lower values of the whiteness degree are obtained for the preliminary treatments in single phase using the multiple action chemical auxiliary (Sirrix SB) (V_3) and also for the low temperature processes (Imerol LTB) (V_5).
Tha values obtained for the hydrophilicity of 80% cotton/20% Smartcel™ Sensitive fabrics after the applied preliminary treatments are shown in table 2.
From the table 2 it can be seen that the hydrophilicity is good for all applied preliminary treatment (below

Table 1

WHITENESS DEGREE

Code	Whiteness degree (Berger)	Whiteness degree (CIE)
V_1	75.58	76.16
V_2	73.25	74.40
V_3	55.55	56.41
V_5	45.99	45.82
V_6	60.36	60.05

Table 2

HYDROPHILICITY FOR 80% COTTON / 20% SMARTCEL™ SENSITIVE FABRICS PRELIMINARY TREATED IN DIFFERENT VARIANTS

Hydrophilicity	Code					
	Raw	V_1	V_2	V_3	V_5	V_6
Wettability, drop test [s]	> 600	< 1	< 1	2	< 1	< 1
Water absorbency [%]	-	58.52	52.44	44.09	45.75	51.65

1 second according to drop test and water absorbency between 44% and 58% respectively). Slightly lower values of hydrophilicity is obtained for the fabric treated in single phase with the multiple action chemical auxiliary (mild process) (V_3), for which a wettability of 2 seconds and 44% water absorbency have been obtained.

Color measurements

Colour differences attributes obtained for 80% cotton/ 20% Smartcell™ Sensitive fabrics preliminary treated in different variants and dyed with Drimaren Gelb CL-2R are presented in table 3. As reference, the sample treated by strong alkaline treatment – bleaching in successive phases (classical process) (Code V_1) was used. The values obtained reveal significant color differences between the analyzed samples. This behavior is due to the fact that the applied treatments provide a differentially removal of the natural impurities of cotton (pectin, waxes, pigments) depending on: the chemical auxiliaries used in the process, the main process parameters (pH, temperature, treatment duration), the number of operations and rinsings performed with water at high temperature, with implicit influences on whiteness degree and hydrophilicity. In conclusion, the dye uptake varies from one variant to another, being influenced by all these factors. Compared to the reference samples treated by strong alkaline pre-treatment – bleaching in successive phases (classic process) (V_1), the total color difference (DE*) of pre-treated samples in different variants ranging between 2.14 and 5.30, which corresponds to a total color difference of ½ up to 2½ tons compared to the reference. Analyzing the obtained data, it is possible to appreciate that the classical treatment in successive phases, considered the reference standard, is the most effective in terms of removing the impurities of cotton and implicitly in terms of dye adsorption.

Table 3

COLOR DIFFERENCES ATTIBUTES FOR FABRICS PRELIMINARY TREATED IN DIFFERENT VARIANTS AND DYED

Code	Color differences				
	DL*	DC*	DH*	DE*	Mark
V_1	Refference				
V_2	–0.25	2.10	–0.33	2.14	4–5
V_3	–2.13	4.62	–1.49	5.30	3–4
V_4	–2.73	3.41	–1.66	4.67	3

Color fastness

Regardless of the pre-treatment method, applied prior to dyeing operation, color fastness to washing, acid and alkaline perspiration, dry and wet rubbing are very good, with marks obtained for change of shade and staining of the multi-fiber standard between 4–5/5 (table 4).

The main physical-mechanical characteristics are present in the table 5. Analyzing the obtained results,

Table 4

COLOR FASTNESS

Code	Washing				Acid perspiration				Alkaline perspiration				Rubbing	
	Color change	Color staining			Color change	Color staining			Color change	Color staining			Dry	Wet
		CO	PA	W		CO	PA	W		CO	PA	W		
V_1	4-5	4-5	4-5	4-5	4-5	4-5	4-5	5	4-5	4-5	4-5	5	4-5	4-5
V_2	4-5	4-5	4-5	4-5	4-5	5	4-5	5	4-5	4-5	4-5	5	4-5	4-5
V_3	4-5	4-5	4-5	4-5	4-5	5	4-5	5	4-5	4-5	4-5	5	5	4-5
V_4	4-5	4-5	4-5	4-5	4-5	4-5	5	5	4-5	4-5	5	5	5	4-5
V_5	4-5	4-5	4-5	4-5	4-5	4-5	5	5	4-5	4-5	5	5	5	4-5
V_6	4-5	4-5	4-5	4-5	4-5	4-5	5	5	4-5	4-5	5	5	5	4-5

Table 5

PHYSICAL-MECHANICAL CHARACTERISTICS

Code	Mass [g/cm²]	Density [No counts/10cm]		Tensile strength [N]		Elongation at break [%]		Tearing strength [N]	
		Weft	Warp	Weft	Warp	Weft	Warp	Weft	Warp
Raw fabric	246	290	230	1788	717	21.8	11.30	71.3	38.9
V_1	260	310	236	1716	787	26.8	18.26	33.1	15.67
V_2	260	324	238	1823	786	26.5	19.51	31.9	15.50
V_3	261	314	232	1778	780	28.0	18.92	54.4	35.4
V_4	265	306	240	1892	818	38.0	15.0	61.2	39.5
V_5	265	310	237	1879	627	32.1	25.9	44.9	34.5
V_6	263	312	234	1757	671	30.4	18.05	38.3	19.36

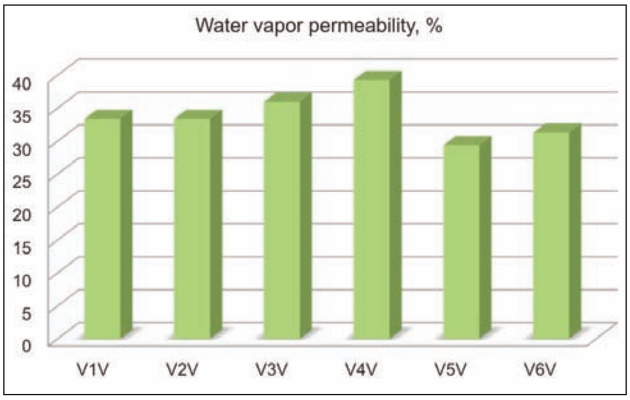

Fig. 1. Water vapor permeability of fabrics treated in different variants

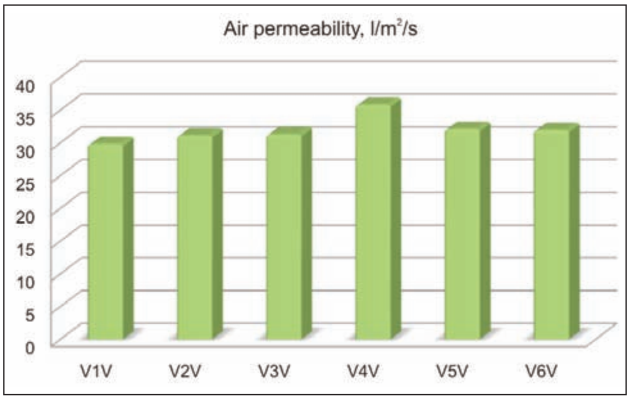

Fig. 2. Air permeability of fabrics treated in different variants

it can be observed that, during the finishing process, the fabric contraction took place, leading to the increasing of the mass (g/m^2) and density in the warp and weft direction, compared to the raw fabric, without significant differences between variants. This behavior is normal for the finishing processes of cotton fabrics carried out in aqueous medium and high temperatures. Tensile strength does not show significant changes after finishing treatments, just only small variations (decreases or increases) ranging from 0.5 to 5.8 % as compared to the raw fabric, but these variations can be considered negligible.

Tearing strength shows decreases values in the case of classic treatment variant – hot alkaline treatment in the presence of NaOH (V_1) and also for the mild alkaline treatment in the presence of Na_2CO_3 (V_2), with more than 50% decreases of values in warp and weft direction. From the applied treatments, the preliminary treatment with the multiple action chemical auxiliary followed by dyeing without intermediate rinsings (V_4) affects the least the tearing strength of the treated samples.

The air and the water vapor permeability recorded for the 80% cotton/20% Smartcell™ Sensitive fabrics have certain variations between the experimented finishing variants, in close relation with the fabrics density. Higher values of this caracteristics is obtained for the fabric pre-treated with the multiple action chemical auxiliary followed by dyeing without intermediate rinsings (V_4) (figures 1–2), for which the lowest value of the density in weft direction is obtained.

SEM-EDX

Electronic images recorded at a magnification of 2000 x for textile materials treated in different variants are shown in figure 3. Analyzing the obtained images can be observed that applied preliminary treatments do not change differentially the surface of functional man-made cellulosic fibers.

Quantification of the Zn content existing in the matrix of Smartcell™ Sensitive fibers is shown in table 6.

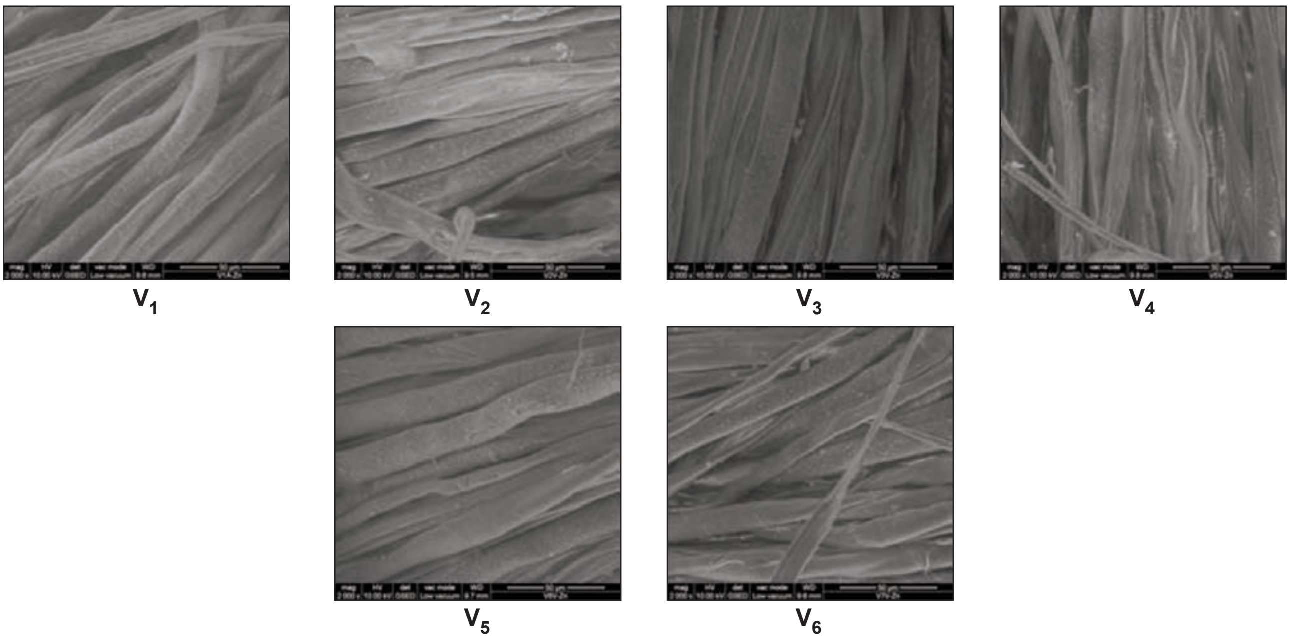

Fig. 3. SEM images of textile materials treated in different variants

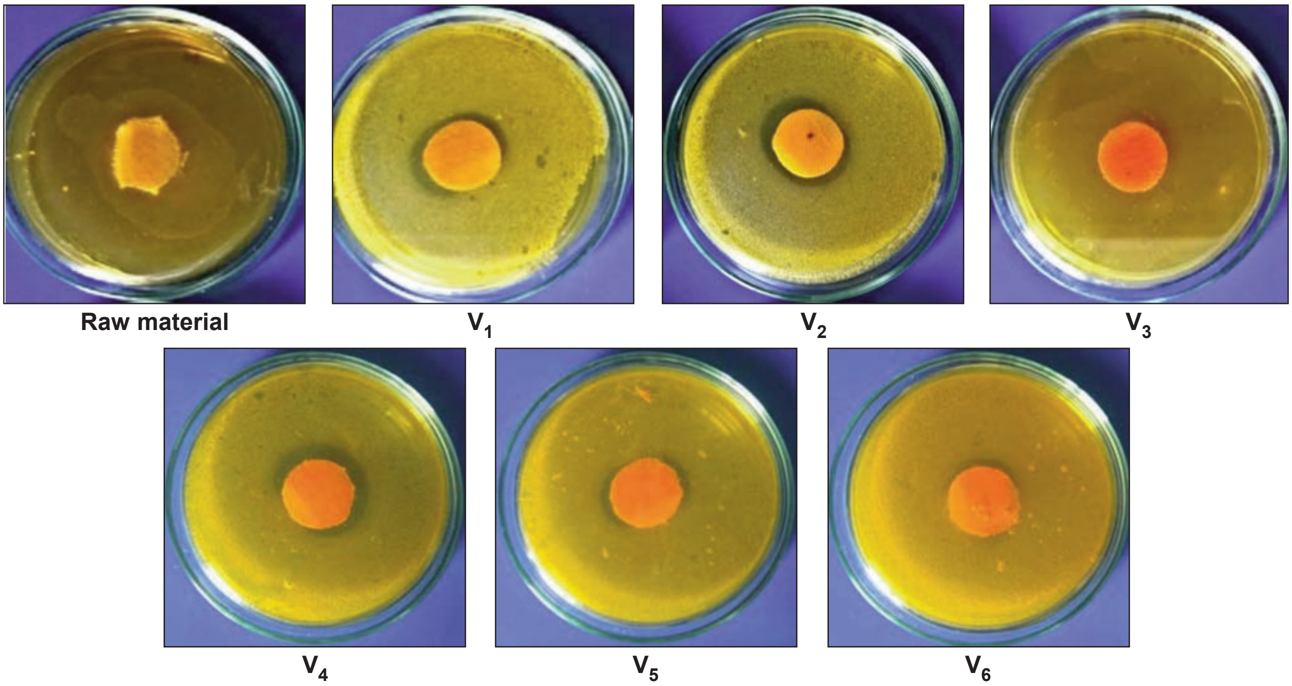

Fig. 4. Images of Petri plates after 48 h incubation

Table 6

Zn CONTENT							
Zn content		Code					
	Raw	V_1	V_2	V_3	V_4	V_5	V_6
Wt %	11.39	1.32	9.92	9.63	7.62	2.34	5.59
At %	2.59	0.30	2.28	2.21	1.71	0.51	2.10

Analyzing the obtained data, it can be appreciated that regardless of the finishing applied variant, the Zn presence was identified in the percentage of mass between 1.32% and 9.63%. It should be noted, however, that the appreciation of the Zn content is qualitative and by this method it was not possible to make a definite differentiation between the experimented variants.

Antibacterial activity

Images of Petri plates after 48 h incubation are shown in figure 4.

The results obtained from the evaluation of antimicrobial activity for the treated samples in different experimental variants are shown in table 7.

From the evaluation of the results obtained for all the variants. an antibacterial effect against the *Staphylococcus aureus* test strain is observed. In the case of the raw fabrics (unfinished) and the samples treated according to the pre-treatment in single phase with a multiple action chemical auxiliary Sirrix SB (code V_3), the inhibition zone or the *Staphylococcus aureus* test strain in the whole medium of the culture was not observed, thus completely inhibiting the growth and inhibition of the test microorganism.

Table 7

ANTIMICROBIAL ACTIVITY		
Sample	Inhibition zone [mm]	Evaluation
Raw material	-	Satisfactory effect
V_1	2.5	Satisfactory effect
V_2	4	Satisfactory effect
V_3	-	Satisfactory effect
V_4	5	Satisfactory effect
V_5	2	Satisfactory effect
V_6	4	Satisfactory effect

CONCLUSIONS

Laboratory experiments have highlighted that the hydrophilicity obtained after pre-treatment is very good for the all experimental variants, slightly lower values of hydrophilicity is obtained for the fabric pre-treated in single phase with the multiple action chemical auxiliary by a mild process (V_3). The strong alkaline treatment – bleaching in successive phases (V_1 – classical process), being considered the reference standard process, is the most effective in terms of removing the impurities of cotton and implicitly in terms of hydrophilicity, whiteness degree and dyes adsorption. However, tearing strength shows significant decreases values in the case of classical treatment variants – hot alkaline treatment in the presence of NaOH (V_1) or mild alkaline treatment in the presence of Na_2CO_3 (V_2), with over 50% decreases of values in warp and weft direction. The preliminary treatment affecting the least tearing strength of the treated sample is the one who uses the multiple action chemical auxiliary in the first process step being followed by the dyeing, without intermediate rinsings between technological operations (V_4). In terms of tensile strength, there are no significant differences between experimented finishing treatments, yet existing small variations (decreases or increases) compared with the raw fabric, being considered negligible. Color fastness to washing, acid and alkaline perspiration, dry and wet rubbing fastness are very good, with marks obtained for all the samples between 4–5/5. An antibacterial effect against the *Staphylococcus aureus* test strain is observed for all finished samples, with or without in inhibition zone.

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Export competitiveness analysis of Pakistan garments industry based on GEM Model

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REZUMAT – ABSTRACT

Analiza competitivității exportului din industria de îmbrăcăminte din Pakistan pe baza modelului GEM

Obiectivul principal al acestui studiu de cercetare este de a investiga competitivitatea exportului din industria de îmbrăcăminte din Pakistan pe piețele globale prin aplicarea modelului GEM. Modelul GEM este aplicat pe scară largă în multe industrii pentru a analiza competitivitatea exportului unui anumit cluster. Metoda sondajului se aplică colecției de date primare printr-un chestionar structurat. Competitivitatea exportului din industria de îmbrăcăminte din Pakistan bazată pe modelul GEM este analizată utilizând tehnica procesului de ierarhie analitică (AHP). După o analiză detaliată, scorul GEM total calculat este 382 pentru industria de îmbrăcăminte din Pakistan. Scorul GEM 382 înseamnă că industria de îmbrăcăminte din Pakistan depășește nivelul mediu național și posedă avantaje competitive la nivel național. Obiectivul viitor al cercetării este că pot fi studiate asociațiile dintre unul sau mai mulți alți factori pentru a verifica nivelul de competitivitate al industriei de îmbrăcăminte din Pakistan. Această activitate de cercetare are implicații practice foarte importante pentru toate părțile interesate de a evalua nivelul de competitivitate a exportului din industria de îmbrăcăminte. Prin aplicarea modelului GEM, organizația poate evalua punctele forte și punctele slabe ale acesteia, astfel încât să poată face față concurenței internaționale și lua decizii pentru afacerile lor.

Cuvinte-cheie: industria de îmbrăcăminte din Pakistan, exporturi, competitivitate, model GEM, piețe globale

Export competitiveness analysis of Pakistani garments industry based on GEM Model

The main purpose of this research study is to investigate export competitiveness of Pakistani garment industry in the global markets by applying the GEM Model. GEM model is vastly applied in many industries to analyse the export competitiveness of the particular cluster. Survey technique applies to primary data collection through a structured questionnaire. Pakistani garments industry export competitiveness based on GEM Model is analysed by using the analytic hierarchy process (AHP) technique. After thorough analysis, overall calculated GEM score is 382 for Pakistani garment industry. GEM score 382 means that Pakistani garment industry is above the national average level and possess country wide competitive advantages. The future research scope is that there can be studied the associations between one or many other factors to check the competitiveness level of Pakistani garment industry. This research work has very important practical implications for all stakeholders to evaluate the export competitiveness level of the garment industry. By applying the GEM model, the organization can evaluate its strengths and weaknesses, so that organizations can cope with the international competition accordingly which is supportive to make decisions for their businesses.

Keywords: Pakistani garment industry, exports, competitiveness, GEM Model, global markets

INTRODUCTION

The textile industry is playing a key role in the growth of Pakistan's economy. Pakistan is the 8th major significant textiles merchandise exporter in Asia. Pakistani textiles pay almost 9.5% of Gross Domestic Product (GDP) of Pakistan. This industry employed approximately 15 million people of the country. Pakistan has huge cotton resources which are utilized by the textile industry for value addition in different textile products like clothing, garments, and apparel that are helpful to grow economically. At present, there are 1,221 cotton ginning companies, 442 yarn spinning firms, 124 big yarn spinning firms, 425 medium and small size enterprises are operating which are producing different textile products [1]. The textile industry has inherited with cheap labor and raw material, but still, the industry is lacking in some areas. There is strong need to speak and cure them and need to improve the sector performance [11]. The textile process is lengthy from the production of cotton to final ready-made garment production but despite having all the many other advantages, even Pakistan's international share in the world market is less than 1% which needs work out and to improve the international trade. The Pakistani ready-made garment industry has the capability to produce and offer large volumes in different international markets. The Pakistani textile industry is well competent to produce different sorts of ready-made garments for men, women, girls, and boys, etc. The garments export of Pakistan has been improved from 21.434 million dozen in various sorts of ready-made garment exports of the amount with US$ 1426.826 million July to March 2013–14. These figures have been improved to 22.843 million dozens of the amount with $1548.282 million July to March 2014–15; consequently, this was presenting 8.51 percent upsurge and also increased the value of ready-made garment industry [6]. Pakistan has been pursuing an open gate economic policy over a couple of past decades. Pakistan was the first in South Asia region that adopted a generous economic policy by liberalizing and shrinking the government control, encouraging the private sector, and privatizing country's assets and liabilities [9]. Growing anxiety about competitiveness can be acknowledged the response to economic issues which are confronting the nation. Across the globe, economies can be characterized according to their industrialisation level and the competitiveness level that they have achieved. Developed countries are considered to be more competitive than developing countries. With the passage of time developing countries have applied numerous approaches to get better industrialization and competitiveness level [21]. Across the world, governments are frequently appealing to define the competitiveness a very important objective in their nationwide economic planning policy [15]. Competitiveness is associated with economic consequences in diverse means like precise objectives or advancement i.e. job formation or foreign direct investment. All the advancement of opinions on competitiveness has proposed the main three thoughts like product cost, international market share, and productivity outcomes [5].

Pakistan has a competitive advantage of being a 4th largest cotton producer in the world and also has the capability to increase the output of cotton crop through utilizing different production techniques. There are many factors for the decline in cotton crop production like the effect of insect pests, cultivation area, the situation of the disease, and the role of the government. In the year 2016, cotton was sowed 20 percent less area in Punjab due to consistent lower price trend, lessening rate of return compared to other crops production and situation of the weather forecast [17]. Global textiles products businesses are playing vital Pakistan's economic growth.

Competitiveness has been widely studied all over the world but in textile sector of Pakistan comprehensive research study still lacking concerning competing at an industry cluster level [12]. The Export trend of Pakistan Textiles showed that despite rich resources in cotton still, Pakistan is in the lowest position with having less than 1% market share in global markets. Even Bangladesh, UAE, Sweden and many other countries have good export volume in international markets. At present, Pakistan is facing tough competition from major giants in the region. In current situation, some Asian countries like India, Bangladesh, China, South Korea, Malaysia, and Thailand are achieving a good export share in the global markets [9]. Generally, textiles are a labour intensive industry. It is suggested that huge volume textiles producing countries, for example, China, India, Pakistan and Bangladesh have attached worldwide economies since the year 1980s [14].

Pakistan is the main supplier of textile products including grey clothing, finished clothing, apparel, ready-made garments and other textile products in the international markets. In one way, Pakistan's internal domestic markets are also growing for textiles products and garments demand and ultimately this would be helpful for growing the income source of Pakistan. A readymade garment export data of different countries for the year of 2012–13 and the year of 2013–14 is in table 1.

Table 1

Country	Value (USD $Millions)	
	2013–2014	2012–2013
United State of America	498,203	515,595
United Kingdom	261,329	234,368
Spain	227,517	201,238
Germany	190,963	240,486
Belgium	129,099	114,092
Netherlands	118,414	67,205
France	85,138	17,651
Italy	75,890	62,485
UAE	46,349	38,999
Sweden	38,980	32,669
Canada	34,198	35,761
Bangladesh	24,492	21,515
Poland	22,802	16,326
Norway	17,623	12,036
Japan	10,542	5,969
China	10,315	7,432
Mexico	8,051	5,349
Singapore	7,829	3,462
Hong Kong	6,106	4,367
Malaysia	5,462	4,209
Finland	4,655	3,781
Portugal	4,592	2,333
Greece	3,854	2,879
Pakistan	1,909	1,800
Total	1,834,312	1,652,007

Source: Trade Development Authority of Pakistan (Adapted from Readymade garment industry, Dr. Noor (2015), *Pakistan Textile Journal*)

This research study has worked on the competitive advantages and improved competitiveness of garments industry through GEM model introduced by Tim Padmore and Hervey Gibson. The Porter diamond model guides and improves the thoughtful for organization's international export competitiveness level in diverse product ranges [20]. This is first competitiveness theory that persuasively connected with industries, firms, and nations [18].

GEM formula is the main application to calculate the final score to know that where the garment industry stands up in present situations. If all six factor score is on point 5, it means every factor of the cluster touched at average level; in this case, GEM score would be 250 points which specifies industry cluster competitiveness grasped at average in its country. Likewise, if all six factors score is on point 7, it means that the GEM score would be around 490 points that specifies the competitiveness level of the industrial cluster is very much strong in the nation. If all six factors score is close to 10 points, it means GEM score would be near to 1000 that specifies industrial cluster's competitiveness level is categorized like a first or second class in the whole world [3].

RESEARCH PROBLEM STATEMENT

This research study works on ready-made garment industry of Pakistan, which has potential to enhance the garment exports in global markets. Pakistan's competitiveness position was very depressing as compared to new emerging economies, so, Pakistani garment industry experts had poor performance in the global markets [31]. After 2007 no study has been reported on the competitiveness of Pakistani ready-made garments. So the purpose of this study to assess the current competitiveness of Pakistani garment industry through GEM Model.

GARMENTS INDUSTRY CLUSTER COMPETITIVENESS BASED ON GEM MODEL AND EVALUATION PROCESS

The GEM model consists of six classifications which influence the firm's competitiveness as well as the industry. It comprises of "resources", "infrastructure", "supplier & related industries", "enterprise structure, strategy and rivalry", "local market", "external market" [27].

The six classifications are collected in three main pairs.

Groundings is comprised of resources, and infrastructure which named as a factor pair I.

Enterprises comprise of supplier and related industries and enterprise structure, strategy and rivalry, which named as factor pair II.

Markets comprises of local market & external market, which named as factor pair III.

Groundings factor pair I

Groundings contain resources, and infrastructures, that is contained to deliver main raw material input elements supply to business firms to their supply chain process. The details are as under:

Resources

Resources originated usual, instinctive or established in the nation. Normal resources are comprised of the land, forest, labour supply, patent, expertise, stock exchanges, capital markets and planned environmental position of the state.

Infrastructure

Infrastructure includes corporal structures, the official arrangements which are helpful to accelerate easy methods to resource mobilizations, support and to run efficiently. Corporal infrastructure comprises of mostly roads, air ports, sea ports and infrastructure of communication. The incorporeal infrastructure comprises of like research laboratories, training institutes, business associations, business markets, regulatory systems and tax systems, financial markets, research & development institutions, and perfection of associated laws & rules.

Enterprises factor pair II

Enterprises, comprised of suppliers and related industries, the firm's structure, strategy and rivalry which means that physical and nonphysical elements of organizations internally and externally which decide cluster's production efficiency.

Supplier and related industries

Supplier & related industries comprised of products & facilities usages of other organizations in the country. Triumph dynamics contained buyers and supplier quality relationships, the products and service's cost and product quality performance that supports organizations, businesses and to support and develop the associated businesses.

Firm structure, strategy, and rivalry

Firm structure, strategy, and rivalry mean firm's hierarchal levels, firms' strategies in various areas, arrangement manners of products & services, manufacturing amongst firms, the management mode of enterprises and firms proprietary right structure and the scales of enterprises and number in the cluster of the government. The firm's structures influence the competition tactics and strategy path in the whole firm's cluster.

The firm's size and effective management of production can make an effective value-chain in cluster nimble. Therefore complete management working style and the proprietary right structure of the organizations in a given cluster have a significant impact whichever firms have flourished by cost benefits, distinction etc. These good benefits are too supportive to describe the organization's planning and strategies to function efficiently in domestic and global markets.

Markets factor pair III

Market refers that the products and services demand situations in domestic and global markets of organizations in the given cluster.

Local markets

Local markets also refer the national marketplaces. Local could be defined as region marketplaces, the district or nationwide marketplaces. Local market differs in provinces and cities in nationwide. The dissimilarity among internal and worldwide markets is the worldwide marketplaces are widespread whereas local marketplaces are narrow to particular a state. Market size, market prospects, market share and market growth is very important in the local market while considering the degree of national sourcing buyers, product quality standards and uniqueness of national demand with the native cluster of an industry.

External markets

External markets vary than local markets. The pressures on the significance of discerning internal markets, the clusters which are generally exported oriented [20]. For further clusters, the external market approach is very thoughtful from the outer buyers [24]. Different regions confront pretty much regular arrangement of outside business sectors excluding native markets. With different regions distinguishes, there is also a different approach to target the external markets. It comprised some issues like markets intimacy, market size, market growth rate level, entry barriers to other markets, the worldwide market share of the region for a particular cluster and other trade barriers for other businesses and firms. GEM Model is shown in figure 1.

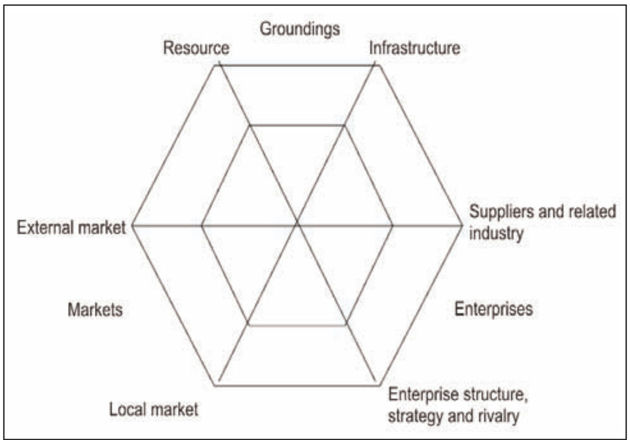

Fig. 1. The GEM Model [16]

RESEARCH METHODOLOGY

In order to conclude this research paper, a quantitative research approach has been applied. Primary data collected through a structured questionnaire from renowned Pakistan's garments industry marketing professionals with having a master degree along with 5 years' experience or more. Primary data also collected from research scholars and industry experts for better assessment of the Pakistani garments industry export competitiveness level. This research study examined the ready-made garment industry by using the analytic hierarchy process (AHP) technique and analysing the export competitiveness by applying the GEM model to Pakistan's garment industry. GEM model is developed by two Canadian scholars Tim Padmore and Hervey Gibson with the improvement of "Diamond Model" by Michael Porter's, the competitiveness evaluation of industry cluster Groundings, Enterprises, and Markets. GEM model comprises of main three factors of six determinants [30]. The GEM model had been already applied in the different countries like in Canada and United Kingdom primarily in consulting viewpoint [16]. GEM model supports the garment industry to evaluate the competitiveness through applying the AHP technique and analysis results guides to make good decisions for the garment industry competitiveness level in domestic and global markets.

This research work applied the random and particularly purpose sampling technique for primary data collection from real respondents of Pakistan's renowned ready-made garments production units. For primary data collection, this research work applied the survey technique. The first part of a structured questionnaire developed on a 10 Likert scale scoring basis to collect data from garments industry marketing experienced professionals with having five years' experience and master degree qualification, preferably M.B.A Marketing and second part of a structured questionnaire developed on a 7 Likert scale to know the importance of sub-factors organized to fill from industry experts and researchers around the country. Respondents are given the scores and weighted to structured questionnaire according to the real situation of the problems in the industry. Scoring means the procedure which is involved in subjective assessment from real respondents by way of supposition means respondents have full knowledge grasped and understanding on the subject of competitiveness with the purpose of rationality.

In the first part of questionnaire 1, about 150 experienced professionals approached of 25 different garment units which are operating in Pakistan with different production scales from small to large scale levels for ready-made garment production. After through putting efforts finally collected 115 filled structured questionnaires from valid and real respondents. The first part of questionnaire 1, average response rate was almost 76.67% with 59 respondents of large garment production firms having more than 2,000 Million Pak Rupees annual turnover, sales volume, 39 respondents of medium garment production firms having annual turnover, sales volume among 500 to 1,000 Million Pak Rupees, 17 respondents of small garment production firms annual turnover sales volume lesser than 500 Million Pak Rupees.

In the second part of questionnaire 2, about 25 industry experts, researchers, and consultant approached overall in Pakistan for primary data collection. After putting hard efforts, finally collected 21 filled structured questionnaires from the valid and real respondents with an average response rate almost 84%. Wang et al., (2005) circulated about 173 *Structured Questionnaires 1* and received 107 filled questionnaires with valid response rate about 61.8% and *Structured Questionnaire 2* total circulated 25 to different researchers, consultants and experts, he collected 19 filled questionnaires with valid response rate about 76% for data analysis.

ANALYTIC HIERARCHY PROCESS (AHP)

Analytic Hierarchy Process rationally comprises of three normal steps [29]:

(i) The hierarchy structure.
(ii) Comparative assessments, or defining & accomplishment of collecting data collection to develop

the valuation data in the form of pairs in hierarchical structure form.

(iii) Creating priorities or building priorities with complete ranking.

AHP scoring matrix applied as the main tool to examine the primary data collected from the garment industry and research scholars and industry experts of Pakistan. Saaty [23], first suggested about the Analytic Hierarchy Process technique, meanwhile its advancement in AHP, this is the best tool for the researchers and decision makers and AHP is one of the utmost mostly used tool for decision making purpose and based on the multiple measures for decision makers [23, 26]. Analytic Hierarchy Process refers to the theory of measurements comprising pair's assessments and it too depends upon the expert's thoughts to choice priority gauges [7].

Analytic Hierarchy Process provisions various characteristics of ranking in hierarchal form, thus AHP permit governments and business consultants to focus on the utmost significant matters [4]. All assessments are prepared by applying complete judgments a scale that explains how a single factor leads to another one as compare to its main factors [23]. AHP is not just backings the experts to settle on the great decisions, be that as it may, this likewise coordinated a reasonable clarification settled for the decision makers [2].

RESEARCH RESULTS

According to the problem statement, this quantitative research process continued with the following three stages.

The first stage involved the subjective scores of sub-factors that are influencing specific cluster's competitiveness level. As per GEM model, all factors are scored on a Likert scale within the scoring range from 1 to 10 which are itemized as per following:

10 = Extremely Excellent refers being top first or second in competitiveness at international level.

9 = Excellent refers being in among top five with good competitiveness at international level.

8 = Very good refers that having exclusive competitive advantages across the country.

7 = Good refers having competitive advantages in the country.

6 = Not bad refers no competitive advantages, but excelling in the nation at anaverage level.

5 = Mean level refers having an average strength at the national level.

4 = Limited level refers having slightly below average strength at the national level.

3 = Very limited level refers having certain gaps in comparison to the national average strength and these gaps influenced the competitiveness of garment industry.

2 = Poor refers having significant gaps, those gaps influence the competitiveness of garment industry.

1 = Extremely poor refers vast gap in comparison to the national average strength and this gap hindered rigorously garments industry developments.

By using the AHP technique and through a quantification process, a thorough analysis will perform based on GEM Model. In the meantime, it is necessary to decide all sub-factors weight's importance to their conforming factors. Second part every factor is categorized in the series from 1 to 7 that is displaying sub-factors importance to its key factors.

The second stage quantification process is started to compute the results and convert to the factor pairs. Pertinent formulas are quantified here as per following:

$$D_{ij} = \sum (\text{Final Score})_{ik} = \sum (\text{Score})_{ik} \times (\text{Weight})_{ik} \quad (1)$$

Here (***i*** = 1~3, ***j*** = 1~2, ***k*** = 1~***n*** and ***n*** is measured like number of the sub-sets)

$(\text{PAIR SCORE})_i = (D_{2i-1} + D_{2i}) / 2$

$(\text{PAIR SCORE})_i$ = Refers that every factor pair score

$(D_{2i-1} + D_{2i})$ = Which presenting the factor's scores

Here factor pair is displaying the demonstration as $(D_{2i-1} + D_{2i})$ that is comprised of two main factors and these factors can be altered by every other. As per GEM model concept, two factors could be replaced by everyone. Such as, complete infrastructures may cover the scarcity of resources in particular industry clusters and vice versa.

Third stage required to compute the (LCS) Linear Cluster Scores of totally factors pairs to calculate final score of competitiveness for Pakistan's ready-made garment industry. Following formulas would be used to know the final results:

LINEAR CLUSTER SCORE = $\Pi_{i=1,3} (\text{PAIRSCORE})_i$

GEM = $2.5 (\Pi_{i=1,3} (D_{2i-1} + D_{2i})^{2/3}$

Linear Cluster Score (LCS) transmutes into numerous factors such as included all the three factors pairs. This refers that those factors influenced each one effectively. For instance, if the score of one, or two factors pair is low, it means that it might move to the lower most level of competitiveness in given cluster. If the score of one or two factors pair is high, it means that it might move to most-highest level of competitiveness in a cluster. In actual sense, if a factor pair likes infrastructure and resources have the lowest score whereas other factors pair's supplier & associated industry, firm structures, strategy & rivalry, local markets, and external markets have maximum level scores of whole factors pairs. In this case, garment business cluster would be unable to find the competitive edge in all markets (due to lowest score in resources and infrastructure) as compare to competitors in that particular industry. There would be balanced competitive edges in all these factor pairs to optimum utilization of the garments industry potential (table 2).

Collected primary data's statistical calculations

According to data received as per above in table 2, the scores of all these six determinants (D_{ij}) received from the garments industry as per following formulas:

$$D_{ij} = \sum (\text{Score})_{ik} \times (\text{Weight})_{ik} \quad (2)$$

Table 2

Factor	No.	Sub factor	Avg. score (1-10)	Weights	Importance score (1-7)	(Average score) * (weight) = final score
Resources (D1)	D1-1	Labour force resources availability	7.1043	0.3447	6.2381	2.4487
	D1-2	Talent Resources Availability	6.0261	0.3286	5.9524	1.9804
	D1-3	Geographic Location	7.2435	0.3267	5.9048	2.3664
Infrastructure (D2)	D2-1	Transportation infrastructure	7.1043	0.1204	6.2381	0.8555
	D2-2	Communication infrastructure	7.3391	0.1242	6.4286	0.9117
	D2-3	Markets infrastructure	6.3304	0.0994	5.1429	0.6290
	D2-4	Trade Association	5.4000	0.0915	4.7619	0.4939
	D2-5	Business Environment	6.3913	0.1119	5.8095	0.7153
	D2-6	Perfection of associated laws/rules	7.2000	0.1204	6.2381	0.8671
	D2-7	Local Financial Market	6.1826	0.1045	5.4286	0.6464
	D2-8	R&D Institution	5.2783	0.1177	6.0952	0.6214
	D2-9	Vocational Training	4.4870	0.1099	5.7143	0.4932
Supplier & Related Industries (D3)	D3-1	Raw material availability	7.6522	0.3555	6.5238	2.7203
	D3-2	Services of suppliers	6.3913	0.3367	6.1905	2.1522
	D3-3	Development of related industries	5.5304	0.3078	5.6667	1.7021
Firm Structure, Strategy & Rivalry (D4)	D4-1	Managerial skills	5.8435	0.1629	5.9048	0.9521
	D4-2	The clarity of property right	4.6435	0.1400	5.0952	0.6499
	D4-3	The level of value added	6.1652	0.1737	6.2857	1.0710
	D4-4	The worth of brand name	7.1652	0.1610	5.8571	1.1538
	D4-5	Production Equipment	7.0174	0.1751	6.3333	1.2287
	D4-6	Product Quality	8.0957	0.1873	6.7619	1.5160
Local Markets (D5)	D5-1	Local market distinctiveness	4.1826	0.3388	5.2857	1.4172
	D5-2	Local market share	4.2696	0.3151	4.9524	1.3452
	D5-3	Local market potential	5.3217	0.3461	5.4286	1.8418
External Markets (D6)	D6-1	Features of foreign end user	6.3739	0.2444	5.6667	1.5575
	D6-2	Export & trade barriers	5.6435	0.2526	5.8571	1.4257
	D6-3	International market share	6.1826	0.2422	5.6190	1.4976
	D6-4	Foreign market relationship	7.3826	0.2608	6.0476	1.9254

Source: Developed by the author

Here (***i***= 1~3, ***j***= 1~2, ***k***= 1~***n*** and ***n*** is measured as number of the sub-sets)
Resources (D_1) = 6.7955
Infrastructure (D_2) = 6.2334
Supplier & Related Industries (D_3) = 6.5746
Firm Structure, Strategy & Rivalry (D_4) = 6.5715
Local Markets (D_5) = 4.6043
External Markets (D_6) = 6.4061
Average Determinants Score (D_{ij}) = 6.1976
After calculations of all other determinants stated as above, then factor pair score can be calculated by using following formula:

$$(\text{PAIR SCORE})_i = (D_{2i-1} + D_{2i}) / 2 \quad (3)$$

$(\text{PAIR SCORE})_i$ = Refers that each factor pair score
$(D_{2i-1} + D_{2i})$ = Which showing the scores of factors
$(\text{PAIR SCORE})_1$ = (6.7955 + 6.2334) / 2 = 6.5145
$(\text{PAIR SCORE})_2$ = (6.5746 + 6.5715) / 2 = 6.5731
$(\text{PAIR SCORE})_3$ = (4.6043 + 6.4061) / 2 = 5.5052

Finally, Linear Cluster Score (LCS) is calculated to know the competitiveness level of the readymade garments industry by applying formulas:

LINEAR CLUSTER SCORE = $\Pi_{i=1,3}\,(\text{PAIRSCORE})_i$
LINEAR CLUSTER SCORE= 6.1976 (Average Score)
GEM = $2.5\,(\Pi_{i=1,3}\,(D_{2i-1} + D_{2i})^{2/3}$
After performing all other calculations, then here calculates the GEM Score of ready-made garment industry of Pakistan, which is **382** by applying the standard formula:

$$\text{GEM} = 2.5 \times \{\Pi i=1,2,3(D2i\text{-}1+D2i)\}\ 2/3 \quad (4)$$

GEM = 2.5 × {(6.7955 + 6.2334) × (6.5746 + 6.5715) × × (4.6043 + 6.4061)} 2/3
GEM = 2.5 × {(13.0289) × (13.1461) × (11.0104)} 2/3
GEM = 2.5 × {(1885.8527)} 2/3
GEM = 2.5 × 152.6412 **GEM SCORE = 382**

The results and discussion

The competitiveness of the firm level mostly dependent upon the competence of the firm to allocate its resources to yield or supply the superior products to those offered by the competitors and fulfilling all the posed challenges for survival in the global markets [8]. The whole GEM Score is 382 only for the Pakistani read-ymade garments industry which is based on primary data collection based on garments units from small scale to large scale level. This research study can be generalized in the textile industry of Pakistan because garments manufacturing units are enjoying the same facilities and benefits and also facing the same problems in the whole country as given by the Government of Pakistan. Based on the GEM Score 382, if the score is between 250 and 640, it means Pakistan readymade garments industry is above the national average level and owns competitive advantages nationwide. If all the six factors score is on point 5, it means every factor of the cluster touched at average level; in this case, GEM score would be 250 points which specifies industry cluster competitiveness grasped at average in its country. Likewise, if all six factors score is on point 7, it means that the GEM score would be around 490 points that specifies competitiveness level of the industrial cluster is very much strong in the nation. If all six factors score is close to 10 points, it means GEM score would be near to 1000 that specifies industrial cluster's competitiveness level is categorized like a first or second class in the whole world [3]. There is a convinced correlation among all factors and the industry cluster situation can be fully shown through all these GEM model six factors [28]. The GEM determinants real factors scores can be shown in following GEM Model (figure 2):

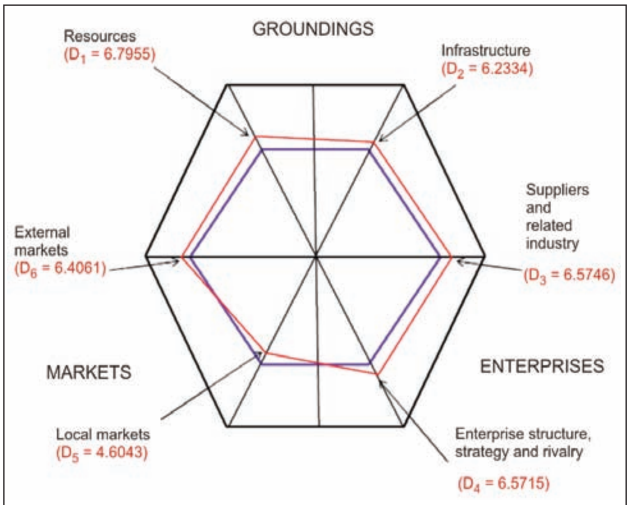

Fig. 2. The average score of all determinants in actual GEM Model

As per above quoted GEM Model in real Pakistani garment industry scenario, outward lines (red) are shown the Pakistani garment industry real average scores, whereas inward lines (blue) are shown standard 5 scores, in which outward lines are more than 5 scores while inward lines showed less than 5 scores.

According to primary data collected from the ready-made garments industry, Resources and Infrastructure average score is 6.7955 and 6.2334 respectively which is not bad and touching towards good. It means the ready-made garment industry is shifting to the good side with having lots of competitive advantages across the nation. The Pakistani ready-made garment industry has good labour pool availability and there is also good and abundant talent availability to manage the business enterprises effectively and on a long term basis. Pakistan has ample resources of best characteristics cotton which is helpful to produce good quality garments and competitive. Pakistan is located on good geographic area on world map, it means Pakistan has a good and easy approach to worldwide markets and Pakistan has also the good advantages of deep sea ports, so this research study is very much helpful to guide the industrialists in a better way to increase the garment exports in the global markets. But on the other hand, the garment industry should be focused to develop the employee training to arrange the skilled employees for the given industry. Pakistan's garments industry has good roads infrastructure and transportation system; there is also a good communication infrastructure which facilitates to increase the garment exports. N and innovated technology facilitate contacting the foreign customers rapidly and with low cost like Skype, mobile phone, vibor and whatsapp etc. In Pakistan, many textile associations are working and backing of the Pakistani ready-made garment industry.

Suppliers & related industries and Enterprise structure, strategy, and rivalry average score are 6.5746 and 6.5715 respectively, which is not bad and touching towards good. It means garments industry is shifting to better with having above average national strength across the nation-state. There are many spinning mills operating in Pakistan, which are providing best and premium quality yarns and best services along with reasonable prices. Beyond the spinning industry, many other industries like accessories, packaging, etc., also providing good support the garment industry of Pakistan. In Pakistan, the textile is a major sector of the economy so the garments industry structure is strong and there are many small, medium and large scale organizations are operating in the country. There are many associations which are protecting the garments industry. Both autocratic and bureaucratic approaches are applied at management level. Due to tough competition, manufacturers are producing good quality garments with competitive prices which attract the foreign customers to work with Pakistani suppliers on along term basis.

Local Markets average score is 4.6043, which is at a very limited level means Pakistani garment industry owing to some extent below the national average strength and shifting to mean level, it refers moving to national average length across the nationwide. Pakistani garments industry, mostly exports oriented and they don't pay attention to local markets and don't have good exposures in the local markets. Just because of that reason local markets have allow score because garments industry has no focused on local markets. The garments industry should pay attention to new product developments, new and innovated garments would attract to the domestic buyers and they will demand more such type of garments and this would be helpful to develop long term business relationships with customers. With more than 190 million populations, Pakistan has a big domestic market which can be entertained with best quality garments and competitive prices.

The external markets average score is 6.4061, which is not bad and moving towards good. It means Pakistani garment industry exports are shifting to better with having a competitive edge across the country. GSP plus also facilitates the garment industry to grow the exports internationally. But very important, the government should assist the garment industry to develop and explore new markets across the world.

As per following table 3, product quality achieved the highest score, 8.0957 amongst all the sub-factors because the quality is very important at all levels for all the customers either nationally or internationally. Due to good cotton dye ability, Pakistani garments have the best quality around the world and even customers don't hesitate to pay more prices. If the quality of the garment is not good, customers will not bother to buy the garments even at cheap prices. On the opposite side, the local markets distinctiveness has very low score 4.1826 amongst all the sub-factors which means the Pakistani garment industry is mostly export oriented and they don't pay attention to local markets and don't have good exposures in the local markets. Standard Deviation describes that how much all the sub-factors deviate from an average score of the factors. The Pakistani garments unit should focus on the local markets with product differentiation.

The average score factors of all determinants of garments industry are 6.1976. All the three factors i.e. Groundings, Enterprises, and Markets have almost

Table 3

No.	Sub-factor	Avg. score (1-10)	Standard deviation	Avg. importance score (1-7)	Standard deviation
D4-6	Product Quality	8.0957	1.2065	6.7619	0.5390
D3-1	Raw material availability	7.6522	1.2499	6.5238	0.6796
D6-4	Foreign market relationship	7.3826	1.2536	6.0476	0.9735
D2-2	Communication infrastructure	7.3391	1.5269	6.4286	0.5976
D1-3	Geographic Location	7.2435	1.1207	5.9048	0.7003
D2-6	Perfection of associated laws / rules	7.2000	1.6233	6.2381	0.8309
D4-4	The worth of brand name	7.1652	1.3040	5.8571	1.2364
D1-1	Labour force resources availability	7.1043	1.3467	6.2381	0.8309
D2-1	Transportation infrastructure	7.1043	1.0952	6.2381	0.6249
D4-5	Production Equipment	7.0174	1.3827	6.3333	0.5774
D2-5	Business Environment	6.3913	1.4061	5.8095	0.9808
D3-2	Services of suppliers	6.3913	1.5142	6.1905	0.8729
D6-1	Features of foreign end user	6.3739	1.3538	5.6667	1.1547
D2-3	Markets infrastructure	6.3304	1.3619	5.1429	0.6547
D2-7	Local Financial Market	6.1826	1.1890	5.4286	0.9783
D6-3	International market share	6.1826	1.5309	5.6190	1.0713
D4-3	The level of value added	6.1652	1.5835	6.2857	0.7171
D1-2	Talent Resources Availability	6.0261	1.6515	5.9524	0.8646
D4-1	Managerial skills	5.8435	1.7701	5.9048	1.0911
D6-2	Export & trade barriers	5.6435	1.7780	5.8571	0.9103
D3-3	Development of related industries	5.5304	1.9025	5.6667	0.8563
D2-4	Trade Association	5.4000	1.5435	4.7619	1.1792
D5-3	Local market potential	5.3217	1.6730	5.4286	1.2479
D2-8	R&D Institution	5.2783	1.9082	6.0952	1.0911
D4-2	The clarity of property right	4.6435	1.7681	5.0952	0.9437
D2-9	Vocational Training	4.4870	2.1739	5.7143	1.1464
D5-2	Local market share	4.2696	1.8840	4.9524	1.1170
D5-1	Local market distinctiveness	4.1826	1.8945	5.2857	0.8452

comparable score except local markets because Pakistan garment industry is export orient industry. But keeping in view the research results Pakistani garments industry should be focused on the local markets to increase the local market share as well. In this situation, competitive advantages would be supportive to become feasible in local and international markets. There should also be more stressed on the groundings and enterprises to optimum utilization of existing resources.

In sum, Pakistani garments industry has good strengths in raw material availability, product quality, communication infrastructure, foreign customer relationships and geographic location etc., whereas poor in local market share, local market distinctiveness, the clarity of property rights, vocational training and R&D associations etc. To gain the good market share, Pakistani garments industry should be more focused on the weak areas to improve the garments competitiveness in the local markets as well as in the global markets.

CONCLUSION

The garment industry is varied and much diversified. Everyone is using the garments for his/her own use. Pakistani garments industry has the capability to offer an extensive range of garments with massive volume for exports to different world markets. In the recent era, the term competitiveness has become a very hot issue in the world. Like Japan is much competition in the electronics products, and at the present Japan's economy is leading in the world Due to increasingly tough competition of garment industry in the international markets, all Pakistani companies should have to find out the dynamics of competitive advantages and utilize them effectively to get the best business volumes in the global markets.

Many consultants/researchers have worked on competitiveness at all levels, such as at the industry level, at the national level and more precise at the firm level. The GEM model has been extensively applied in national as well as in international cluster analysis and also used to benchmark the particular industry. After thorough analysis, this model has evaluated and defined the strengths and weaknesses of garment industry of Pakistan. This research determined that so far the Pakistani garment industry is performing well in all the concerned areas; however, there are some key problems which can be removed to develop the garment industry at local markets and in global markets. Pakistan has enormous labour force resources availability; on the other hand, there are some unskilled and semi-skilled labours. But still the labour cost is inexpensive than other countries, so these factors can be supportive to become competitive in the foreign markets. There are good communication and transportation infrastructure to facilitate the garment industry of Pakistan. For communication, modern and up-to-date technology is available to contact the customers in different regions of the world and cheap communication reduces the production cost. Garments industry companies are normally privately owned by the domestic businessmen in Pakistan. They are keen to develop and explore the garments business by using various strategies according to the competition situations in domestic and global markets. There is good potential to materialize the local demand in Pakistan because generally local companies are full focusing on garment exports in different world markets and dealing with various brands to manufacture the garments according to their requirements. Now a day the consumer buys products or services not only to have them, but also to define his personality, his image and even his position in society. All these extra-values of a product are given nowadays by the brand [19]. The garment business, companies must work to launch their own brands in domestic and international markets and expand their business accordingly. This would supportive of new innovation in present garments products and the new garments as well as manage the buyer's demand accordingly. Pakistan is a 6th largest populous country in the world with around more than 193 Million populations, this is a huge market for the local garment producers to capture and materialize the business in domestic markets.

The analyses are shown that GEM Score is 382 for the garment industry of Pakistan based on the primary data collection. Based on the GEM Score 382, if the score is between 250 and 640, it means that ready-made garment industry of Pakistan is above the national average level and owns competitive advantages nationwide. The average score factors of all determinants of garment industry are 6.1976. All the three factors, i.e. Groundings, Enterprises, and Markets have an almost comparable score except local markets because the Pakistani garment industry is an export orient industry. But keeping in view, the research results Pakistani garment industry should be focused on the local markets to increase the local market share as well. In this situation, competitive advantages would be supportive to become feasible in local and international markets. There should also be more stressed on the groundings and enterprises to optimum utilization of existing resources.

In order to evaluate the overall scores of all the subfactors, product quality achieved the highest score, 8.0957 amongst all the sub-factors because the quality is very important at all levels for all the customers either nationally or internationally. Due to good cotton dye ability, Pakistani garments have the best quality around the world and even customers don't hesitate to pay even more prices just because of quality level. On the opposite side, the local markets distinctiveness has very low score 4.1826 amongst all the subfactors which means the Pakistani garment industry is mostly export oriented and they don't pay attention to local markets and don't have good exposures in the local markets. The Pakistani garments unit should focus on the local markets with product differentiation as Pakistan has also a big market with more than 193 Million populations.

Future research scope

GEM Model has assessed the competitiveness of Pakistani garments industry in the global markets. This model is worth for further evaluation. This research paper has focused on almost all factors which are affecting the competitiveness of garment industry of Pakistan. So another interesting area of research could be studied like the relationships between one or numerous factors and the competitiveness of garment industry of Pakistan. For instance, the wages cost and the competitiveness, the clusters relationship and the competitiveness. Moreover, existing GEM model of competitiveness can also be applied in other textiles sectors like spinning, weaving etc. to check the possibility of findings other determinants which are impacting the competitiveness of an industry on the cluster level. GEM model has been extensively applied to nationals and international clusters examination to benchmark the industry. After thorough analysis, the GEM model can evaluate and define the strengths and weaknesses of garment industry of Pakistan.

Practical implications

This research study has significant practical implications for several regional governments, garment enterprises, garment associations, R&D institutions for assessing the garments industry competitiveness. Through applying this model, the firm can identify their strengths and weaknesses to confront the competition level and helpful to make best decisions accordingly. This research work also provides guidance to the industry managers, consultants, researchers and experts that where the garment industry stands up at the instant, after detailed analysis, they could take useful decisions to increase the competitiveness level of garments industry.

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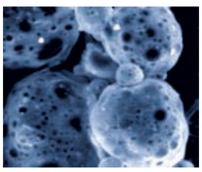

Research on mechanical behavior of needle-punched nonwoven fabric

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WU WEI GAO XIAOPING

REZUMAT – ABSTRACT

Studiu asupra comportamentului mecanic al materialelor textile neţesute interţesute

Au fost studiate proprietățile anizotropice ale comportamentului de rezistență la tracțiune și fluaj al materialelor textile nețesute. Au fost analizate experimental influențele lățimii probei și direcția distribuirii fibrelor asupra comportamentului la tracțiune al materialelor textile nețesute, interțesute. Rezultatul arată că lățimea probei are o influență importantă asupra comportamentului de tracțiune. A fost investigat comportamentul anizotropic de fluaj al materialelor textile nețesute, interțesute, adică influențele tensiunii și unghiului față de directia mașinii (MD) asupra fluajului. Relația dintre alungirea la fluaj și timpul la diferite tensiuni și unghiuri diferite față de direcția mașinii (MD) a materialelor textile nețesute, interțesute se obține prin aplicarea unei fixări liniare și se deduce modelul empiric pentru calculul alungirii la fluaj. Rezultatul are o semnificație importantă pentru predicția comportamentului mecanic, cum ar fi comportamentul de rezistență la tracțiune, fluaj și relaxare a materialelor textile nețesute, interțesute și reducerea cheltuielilor experimentale și a dificultăților.

Cuvinte-cheie: materiale textile interțesut, fluaj, rezistență la tracțiune, anizotropic, lățimea probei

Research on mechanical behavior of needle-punched nonwoven fabric

The anisotropic properties in tensile and creep behavior of needle-punched nonwoven fabric are studied in this paper. The influences of specimen width and direction of fiber distribution on the tensile behavior of needle-punched nonwoven fabric are experimental analyzed. The result shows that the specimen width has important influence on tensile behavior. The anisotropic creep behavior of needle-punched fabric i.e., the influences of stress and the angle with the machine direction (MD) on creep is investigated. The relationship between creep elongation and time at different stress and different angle with the machine direction (MD) of needle-punched fabric are obtained by applying linear fitting and the empirical model for calculating creep elongation are deduced. The result has an important meaning for predicting the mechanical behavior, such as tensile, creep and relaxation behavior of needle-punched nonwoven fabric and reducing experimental expense and difficulty.

Keywords: needle-punched fabric, creep, tensile, anisotropic, specimen width

INTRODUCTION

As a permeable textile structures made of polymeric materials, needle-punched nonwoven fabric is usually used in civil engineering. In contrast to knitted fabric and woven fabric, the random and discontinuous microstructure is the most characteristic features of nonwoven. Due to its discontinuous and non-uniform microstructure, the dimension of specimen plays an important role to its tensile behavior, and different size specimens may demonstrate different type of material behavior [1–2]. Hou, et al. analyzed the influences of the specimen size and shape factor (the ratio of the specimen's length to its width) on mechanical property of thermally bonded nonwoven by means of uniaxial tensile tests [3]. Therefore, it is necessary to study the influence of specimen width on nonwoven tensile behavior.

Mechanical properties in tensile and creep behavior of needle-punched nonwoven fabric are of considerable interest for their satisfactory performance in constructional materials. Due to the complex structure of nonwoven fabrics, some researchers had used considerable efforts to understand the mechanical behavior of nonwoven. For example, Gautier, et al. studied the anisotropic mechanical behavior of needle-punched and thermo-bonded nonwoven fabric by means of uniaxial tensile tests [4]. Debnath, et al. investigated the anisotropy behavior of needle-punched parallel laid jute non-woven [5]. Debnath and Madhusoothanan investigated the compression creep behavior of needle-punched nonwoven with different constituent fibers based on experiment [6, 7]. Since mechanical behavior of nonwoven fabric is influenced by fiber property and its distribution, some Refs. [8–12] investigated the relationship between the mechanical behavior of nonwoven fabric and the constituent fibers. Therefore the mechanical property of nonwoven fabric could be predicted by using the structural parameters of nonwoven fabrics and the behavior of fiber. Kothari and Patel developed a mechanical model to predict the creep behavior of nonwoven fabric using the fiber creep result and structural parameters of the fabric [13].

When constant stress is subjected to nonwoven fabric, there is a creep elongation. The ability of the material to withstand loads without excessive creep is a major factor in material selection and design of geotextile. In order to improve the creep behavior of needle-punched nonwoven fabric, the anisotropy creep behavior i.e., stresses and the angle with the machine direction (MD) on creep is investigated. Das, et al. studied the anisotropy creep behavior of thermo-bonded spun laid nonwoven fabric and observed that the creep of nonwoven depends on the fiber direction, level of load [14]. The same method has been implemented in this article to analyze the anisotropy tensile and creep behavior of needle-punched nonwoven fabric.

In this paper, the anisotropy tensile and creep behavior of needle-punched nonwoven fabric are investigated using wide-width strip tensile and creep test. The influences of specimen width and different angle in the machine direction (MD) of needle-punched fabric are investigated. The influences of different levels of load and different angle in the machine direction on creep behavior of needle-punched nonwoven fabric are analyzed and the empirical equations of calculating creep elongations at different conditions are obtained by applying linear fitting.

MATERIALS PROPERTIES

The needle-punched nonwoven fabric, manufactured using polypropylene fiber (3.10 dtex, 38 mm) by penetrating the fibrous web with needle were used for the study. The nominal thickness, density and needle density of nonwoven fabric are 3.28 mm, 447.11 g/m^2 and 346 penetrations/cm^2, respectively. The SEM images of the needle-punched nonwoven fabric are shown in figure 1.

TENSILE TESTING

The effect of the specimen width

Due to the non-uniform microstructure and material properties of the fabric, different size of specimens may result in different behavior. To investigate the effect of the width, specimens of nonwoven fabric with three different widths were tested using INSTON Universal Testing Machine under standard laboratory condition (20, 65% relative humidity).

The tensile behavior of nonwoven with different width was carried out using 10 nonwoven specimens at a gauge of 100 mm clamp distance and a speed of 50 mm/min. The tensile behavior was studied at different angles in the machine direction (MD) of fabrics, i.e., 0°, 30°, 60° and 90°(CD).

The tensile results of nonwoven fabric with different widths and different angles are shown in table 1.

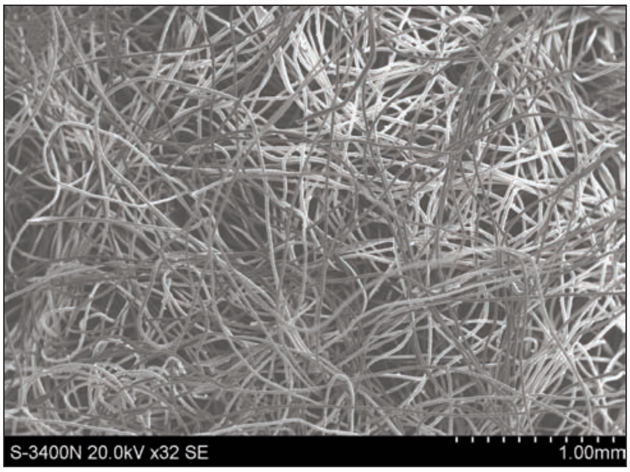
As shown in figure 2, the tensile strength will be varied with increasing of specimen width. When the width of nonwoven is 100 mm, the tensile strength has maximum value. Due to anisotropy of the properties of the nonwoven material, its tensile behavior is highly dependent on fiber distribution.

The effect of angles in the machine direction (MD)

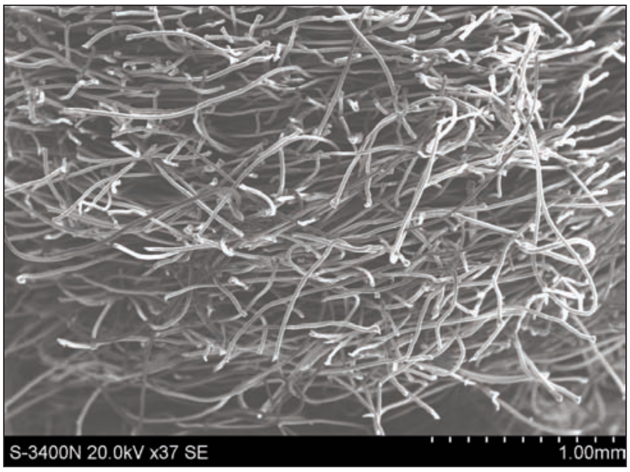
Due to anisotropy properties of the nonwoven material, its tensile behavior is highly sensitive to fiber distribution. It can be obtained that the tensile strength

Table 1

Specimen width	0°(MD)	30°	60°	90°(CD)
	Tensile strength [kN/m]	Tensile strength [kN/m]	Tensile strength [kN/m]	Tensile strength [kN/m]
50 mm	13.49	13.9	18.46	14.23
100 mm	14.02	17.97	19.99	18.13
200 mm	14.13	14.37	19.92	15.11



a



b

Fig. 1. SEM image of the needle-punched nonwoven fabric:
a – fiber distribution in plane; *b* – fiber distribution in thickness

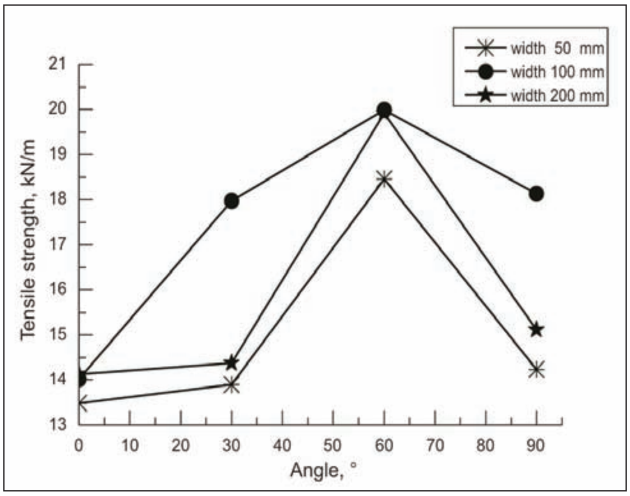


Fig. 2. The tensile behavior of needle-punched nonwoven fabric at different width and angle

is also proportional to the fiber distribution. With respect to figure 2, it can be concluded that the tensile strength at 60° in the machine direction (MD) of fabrics has maximum value no matter the width of specimen. The tensile strength has maximum value in the direction of maximum fibers in the fabric, i.e. 60° direction. Least fibers are aligned in the 30° and 90° directions.

ANISOTROPY CREEP OF NEEDLE-PUNCHED NONWOVEN FABRIC

When the amount of loading is increased the amount of creep will be increased, which has effect on fatigue of needle-punched nonwoven fabric. In order to improve the creep behavior of nonwoven, it is necessary to study the anisotropy creep behavior, i.e., the influences of stress and the angle in machine direction on creep.

Nonwoven creep test were carried out on INSTON Universal Testing Machine using specimens (200 mm × 200 mm) at a gauge of 100 mm clamp distance and a speed of 50 mm/min. The creep behavior of every specimen with different angle and stress was repeated 10 times.

The creep behaviour at varying load at constant angle

The creep behaviors of nonwoven fabric at different levels of loading, i.e., 30%, 45% and 60% of tensile strength in the relevant direction are executed. The elongations subjected to loading are recorded at different time intervals, i.e., 30 sec, 1 min, 2 min, 3 min, 5 min, 10 min, 15 min and 30 min. The experimental results are shown in tables 2, 3 and 4.

The creep elongation will be increased due to the increasing of loading in particular direction, which one can observe from figure 3.

It can be concluded that the creep elongation is proportional to the level of loading and time. The initial extension is instantaneously increases and finally stabilizing at a limiting extension value. With the increasing of loading the creep increases, since the higher load would increase definitely the fiber-to-fiber slippage and also execute higher force on the individual fibers which result in higher creep elongation.

Table 2

Load [MPa]		Time [s]						
		30	60	120	300	600	900	1800
30% (1.38 MPa)	Extension [mm]	18.27	18.28	18.31	18.37	18.41	18.43	18.47
45% (2.07 MPa)		26.32	26.37	26.45	26.56	26.67	26.81	26.92
60% (2.76 MPa)		46.12	46.15	46.19	46.24	46.29	46.37	46.46

Table 3

Load [MPa]		Time [s]						
		30	60	120	300	600	900	1800
30% (1.31 MPa)	Extension [mm]	37.21	37.25	37.29	37.35	37.48	37.57	37.73
45% (1.97 MPa)		44.87	44.91	44.99	45.13	45.27	45.34	45.44
60% (2.63 MPa)		57.51	57.55	57.59	57.70	57.76	57.85	57.93

Table 4

Load [MPa]		Time [s]						
		30	60	120	300	600	900	1800
30% (1.82 MPa)	Extension [mm]	33.54	33.59	33.67	33.74	33.81	33.92	33.99
45% (2.73 MPa)		45.89	45.94	46.11	46.19	46.27	46.34	46.49
60% (3.64 MPa)		54.10	54.23	54.35	54.47	54.63	54.78	54.89

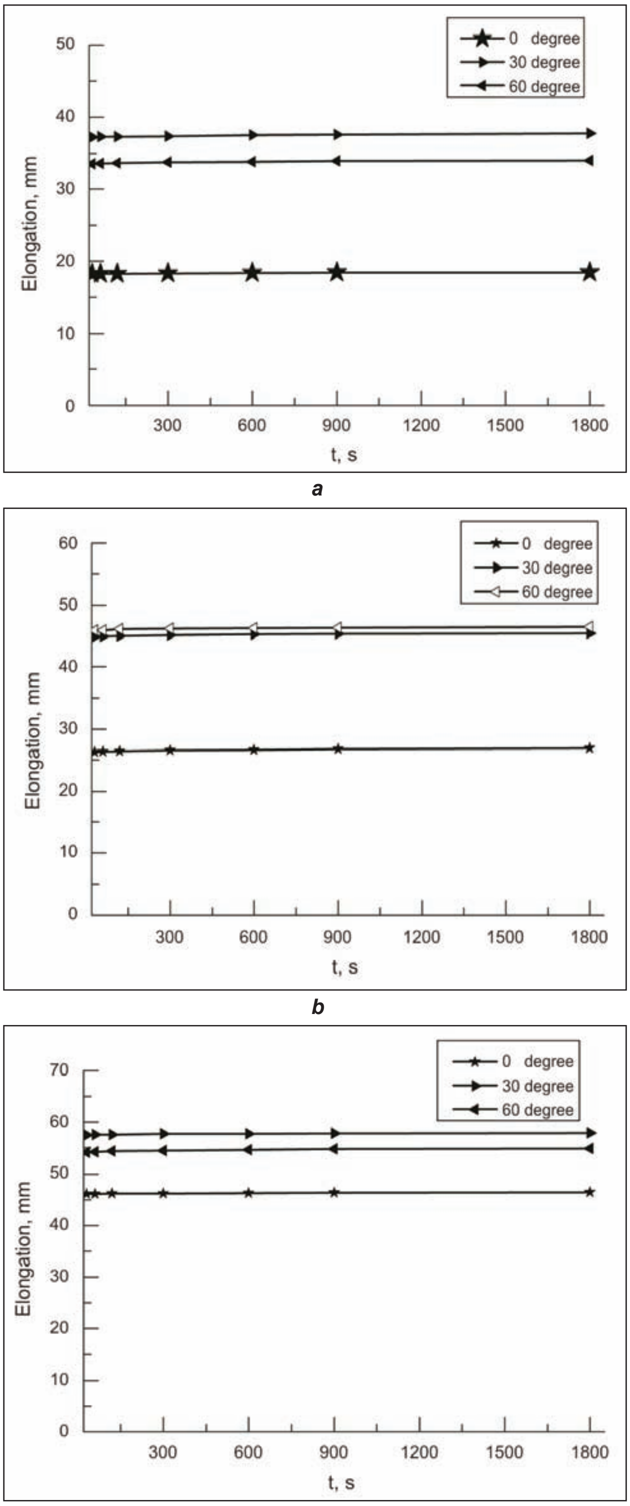


Fig. 3. Anisotropy in creep behavior of needle-punched nonwoven fabric at different level of loading and angle in machine direction: *a* – 30%; *b* – 45%; *c* – 60%

The creep behaviour at varying direction of loading at constant load

The anisotropic creep behavior of needle-punched nonwoven fabric is studied at different angles in the machine direction (MD) of fabrics, i.e., 0°, 30° and 60°, is shown in figure 3. It can be seen that all the curves follow similar trend with a difference in instantaneous extension. The initial elongation at machine direction is lesser than that in 30° and 60° directios, since the fiber distribution at machine direction has more than that in other directions. The maximum extension is observed in a direction with minimum number of fibers and minimum creep extension is occurred for the sample having maximum number of fibers. The creep extension will be decreased continuously with increasing number of fibers in the direction of loading.

The creep extension of nonwoven fabric is found to be affected by the fiber distribution and amount of loading. The relationship between creep elongation and time at different stress and different angles in machine direction of needle-punched fabric is obtained by applying linear fitting and the empirical model for calculating creep elongation is deduced, as shown in table 5. The results show that the creep of needle-punched nonwoven fabrics follow linear relationships with logarithm of time and this is true for all the directions of loading and for all the levels of loading.

Table 5

Direction of loading [degree]	Level of loading [%]	Relationships	R^2
0	30%	$y = 18.08 + 0.12x$	0.979
	45%	$y = 25.77 + 0.34x$	0.957
	60%	$y = 45.82 + 0.18x$	0.925
30	30%	$y = 36.74 + 0.28x$	0.895
	45%	$y = 44.32 + 0.34x$	0.978
	60%	$y = 57.12 + 0.24x$	0.966
60	30%	$y = 33.14 + 0.25x$	0.971
	45%	$y = 45.39 + 0.33x$	0.977
	60%	$y = 53.43 + 0.44x$	0.984

CONCLUSIONS

The effects of specimen width and fiber distribution on tensile properties of needle-punched nonwoven fabric were investigated. The result shows that the tensile behavior is influenced by specimen width and fiber distribution.

The anisotropic creep behavior of needle-punched fabric i.e., the influences of stress and the different angles in machine direction on creep behavior were investigated. The creep test of the nonwoven fabric shows that the creep elongation is dependent on the fiber arrangement and has minimum value in the direction in which the proportion of fiber has maximum value and vice versa. The creep elongation of needle-punched nonwoven has linear relationship with logarithm of time no matter the directions and levels of loading.

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An investigation on the unevenness, hairiness and friction coefficient properties of cotton-bamboo blended ring-spun yarns

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OĞUZ DEMİRYÜREK AYÇA KILIÇ

REZUMAT – ABSTRACT

Studiu asupra proprietăților de uniformitate, pilozitate și coeficient de fricțiune ale firelor filate cu inele din bumbac în amestec cu bambus

Acest studiu își propune să investigheze proprietățile de fricțiune, precum și alte proprietăți importante ale firelor, cum ar fi neuniformitatea și pilozitatea firelor. În acest scop, s-au obținut fire filate cu inele din: 100% bumbac, 50%/50% bumbac/bambus și 100% bambus cu cinci coeficienți diferiți de torsiune (α_e: 3,5; 3,7; 4,0; 4,2, 4,5) și în patru densități liniare (N_e 16/1; 20/1; 24/1; 28/1). Proiectarea generală factorială a fost utilizată pentru analiza datelor. În concluzie, cel mai mare coeficient de frecare și cel mai scăzut nivel de pilozitate au fost obținute pentru amestecurile pure de bambus, iar cele mai ridicate valori ale neuniformității au fost observate în cazul firelor din 100% bumbac.

Cuvinte-cheie: bumbac, bambus, amestec, coeficient de frecare, neuniformitate, pilozitate

An investigation on the unevenness, hairiness and friction coefficient properties of cotton-bamboo blended ring-spun yarns

This study aims to investigate the frictional and other important yarn properties such as unevenness and hairiness of cotton/bamboo blended yarns. For this purpose, %100 cotton, %50/%50 cotton/bamboo and %100 bamboo ring spun yarns were produced in five different twist coefficients (α_e: 3.5; 3.7; 4.0; 4.2; 4.5) and in four different linear densities (Ne 16/1; 20/1; 24/1; 28/1). General factorial design was used for analyzing the data. In conclusion, the highest friction coefficient and the lowest hairiness were obtained for the pure bamboo blends; whereas, the highest unevenness values were observed in pure cotton.

Keywords: cotton, bamboo, blending, friction coefficient, unevenness, hairiness

INTRODUCTION

Regenerated bamboo fibres are preferred for towels, underwear, home textiles and especially in sportswear for its moisture regain, wicking and antibacterial properties. This fibre may be used in pure (%100) form or may be blended with cotton or polyester in the market, in general. There are some studies regarding the fibre, yarn and fabric properties of bamboo and bamboo-cotton blends. Ozgen reviewed and discussed the new biodegradable fibres, yarn properties and their applications in textiles [1]. Prakash et al. investigated the effect of blend ratio on the imperfections, tenacity and hairiness of regenerated bamboo/cotton blended yarns [2]. Sekerden also investigated the unevenness and tenacity properties of regenerated bamboo/cotton blends. In both studies, it was found that increasing bamboo content in the blend affected the quality parameters [3]. Li and Yan studied the tensile properties of regenerated bamboo yarn in different tensile speeds [4]. Majumdar investigated the diameter, tensile, evenness and hairiness properties of cotton-bamboo blended yarns. They found that hairiness increases with increasing bamboo content in the yarn [5]. Erdumlu and Ozipek (2008) investigated the quality parameters bamboo, viscose, carded and combed ring spun yarns in pure form. They found that fibre and yarn characteristics of bamboo fibre are quite similar to viscose fibre [6]. Koc and Demiryurek investigated the breaking strength properties of polyester-viscose blended open-end rotor yarns [7].

The fabric properties of bamboo blended yarns were also studied in some papers. Hussain et al. investigated the comfort and mechanical properties of polyester/bamboo and polyester/cotton blended knitted fabrics [8]. The tribological performance of modified bamboo fibre in brake composites was studied by He et al. [9]. They found that heat treatment of bamboo fibres at 140 °C for 4 hours makes the friction and wear characteristics of brake composite more stable than untreated ones. Kobayashi et al. examined the frictional wear characteristics of the rubber-bamboo fibre composites. Wear characteristics and tensile strength increased in a range that fibre content is lower than 10% [10]. Ma et al. investigated the friction and wear properties of bamboo (*Phyllostachys heterocycla*) fibre reinforced materials. Their results show that carbonized bamboo fibre could reduce the specific wear rate and the noise. In addition it provided stable friction coefficient [11]. Kuhm et al. used capstan equation for examining the fabric friction behavior [12].

Yarn friction is a very important characteristic of yarns in addition to the traditional yarn properties. Fibre type, molecular orientation, fibre surface roughness, yarn linear density, yarn twist, spinning method, yarn unevenness and hairiness may affect the frictional property of the yarns. Balci and Sular reviewed the friction property in yarns in terms of its importance and measurement methods [13]. Altas and Kadoğlu examined the carded and combed cotton yarn frictional behaviour and other yarn properties [14]. Kilic and Sular, studied the frictional properties of cotton-tencel (lyocell) blended yarns produced from different spinning systems [15]. Svetnickiene investigated the friction properties of natural fibressuch as flax, bamboo, bamboo with flax, soy, cotton with sea cell yarns. The highest friction coefficient was found for the flax [16]. Gurarda et al. examined the effects of lubricants on the friction properties of sewing threads [17]. Ozcelik Kayseri investigated the frictional properties of 100% lyocell, modal and viscose yarns. The fibre type and yarn linear density had a significant effect on the frictional and lint shedding properties, however yarn twist was effective only on yarn-to-yarn friction [18].

The structural and physical properties of the blended yarns are important to determine the fabric properties, as expected. In addition to the traditional yarn properties such as unevenness, imperfections and hairiness; frictional property is also important for yarns. Yarns are subjected to the yarn-to-yarn or yarn-to-metal friction during production. In order to avoid rupture during spinning, the friction coefficient of yarns is important in determining the optimum wax application. In literature survey, the traditional yarn characteristics of bamboo-cotton blended yarns were studied and summarized as above. The frictional and wear properties of natural bamboo reinforced composites were also studied. However we could not met a study examining the friction properties of bamboo-cotton blended yarns. For this purpose, %100 cotton, %50/%50 cotton/bamboo and %100 bamboo ring spun yarns were produced having five different twist coefficients (α_e: 3.5, 3.7, 4.0, 4.2, 4.5) in four different linear densities (Ne 16/1, 20/1, 24/1, 28/1). Statistical analysis was carried out and ANOVA tables and regression curves were obtained.

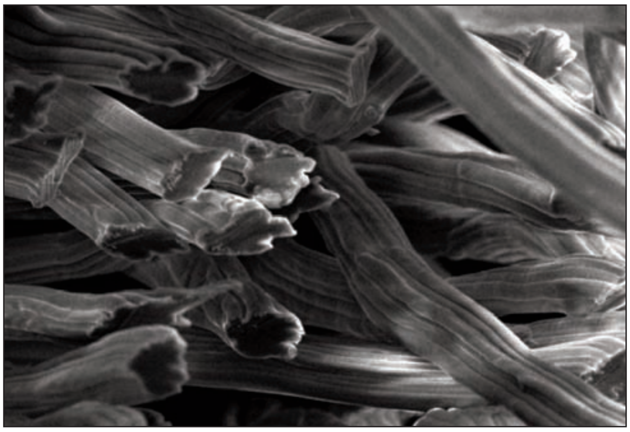


Fig. 1. Microscopic view of bamboo fibre

Table 1

COTTON FIBRE PROPERTIES	
Property	**Value**
Fineness (mic.)	4.57
Length (mm)	29,13
Uniformity index	85.04
Tenacity (cN/tex)	30.04
Extension (%)	6.72

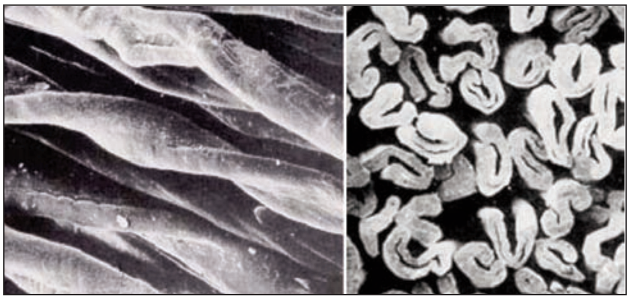


Fig. 2. Microscopic view of cotton fibre

MATERIALS AND METHODS

In this study, cotton/bamboo slivers were prepared in 0/100, 50/50 and 100/0 percentages and yarns were spun in different yarn twist factors (α_e: 3.5, 3.7, 4.0, 4.2, 4.5) and yarn linear densities (Ne 16/1, 20/1 24/1, 28/1). The bamboo fibre was produced in Shangai Xupu from China and supplied from Başyazicioglu Tekstil from Turkey. Bamboo fibre was 1.56 dtex in fineness and 38 mm in length. The microscopic view of bamboo fibre is given in figure 1. The cotton fibre was also supplied from Başyazicioglu Tekstil from Turkey. The fibre type was Urfa St1 and some of the properties of cotton fibre was measured through Premier ART and given in table 1. The microscopic view of cotton fibre is also given in figure 2.

Cotton fibre was processed by Rieter opener B25 and Rieter C51 carding machine whereas Trützchler BOA1600 BM blow room and TC07 carding machine was used for bamboo fibre. The slivers, obtained from both carding machines were blended and drawed two times in Rieter SB-D10 and the third passage is processed in Rieter SB-D15. The drawing parameters were 8 doubling and 8 drawing ratio in 450 m/min speed. Grossenhainer roving frame was used in 1000 rpm spindle speed and rovings were produced in Ne 0.90. Yarns were spun in Shanghai Erfangji Co. sample ring spinning machine having 96 spindles in 14000 rpm spindle speed using 40 mm ring diameter. Cotton/bamboo yarns were obtained in 0/100, 50/50 and 100/0 percentages. In addition five different twist factors were applied as α_e: 3.5, 3.7, 4.0, 4.2. 4.5 and four different yarn linear densities were obtained as Ne 16, 20, 24 and 28. Total number of cops produced can be calculated by taking the number of blends (3), yarn twist factors (5), yarn linear densities (4) and replication (5) as 3×5×4×5=300. Yarn linear densities and twist factors of spun yarns were measured for verification through Zweigle L232 and Zweigle D314, respectively. The traditional yarn properties such as unevenness (CV_m%), imperfections and hairiness

(H) was measured by Premier PT 7000. Here, H is the length of protruding hairs in 1 cm yarn [19]. The frictional property of the spun yarns was measured by Zweigle-G 534 which runs according to the Capstan method which measures the yarn-metal friction coefficient. The coefficient of friction is calculated by:

$$\mu = \frac{\ln \frac{T_2}{T_1}}{\theta} \tag{1}$$

Here, μ is friction coefficient, T_1 – input tension, T_2 – output tension and θ – the contact angle.
Data obtained from the study is analyzed by using general factorial design as a statistical analyzing technique using Design Expert software.

RESULTS AND DISCUSSIONS

In order to select the best model (linear, quadratic or cubic) in this design, F-test and lack of fit test were applied. The model which gives the highest R^2 value, least p-value can be selected as the best model and can be used for analyzing the data. The normality tests were also conducted. Furthermore, the analysis of variance (ANOVA) table was obtained using the selected model. In those tables, 'A' represents the cotton ratio in the blend, 'B' is the yarn linear density in Ne and 'C' is the twist coefficient in α_e. The confidence interval was determined as 95%. The p-values that is lower than 0.05 were considered as significant in these tables. In addition, the percentage contributions of the terms to the model were demonstrated and the regression curves were introduced. The optimum blend ratio, twist factor and yarn linear density on the response variables [unevenness (CV_m%), hairiness (H) and friction coefficient μ] of yarns were discussed below, respectively.

Unevenness (CVm%)

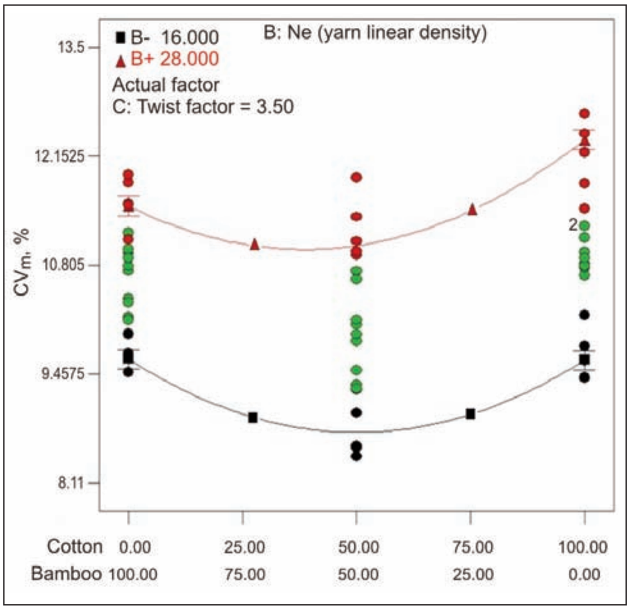
Mass or weight variation per unit length of yarn is defined as unevenness or irregularity. The coefficient of variation of mass (CV_m%) is one of the calculation methods of variation of mass for the yarns [20] and it is expressed as

$$CV_m\% = \frac{s}{\bar{x}} \cdot 100 \tag{2}$$

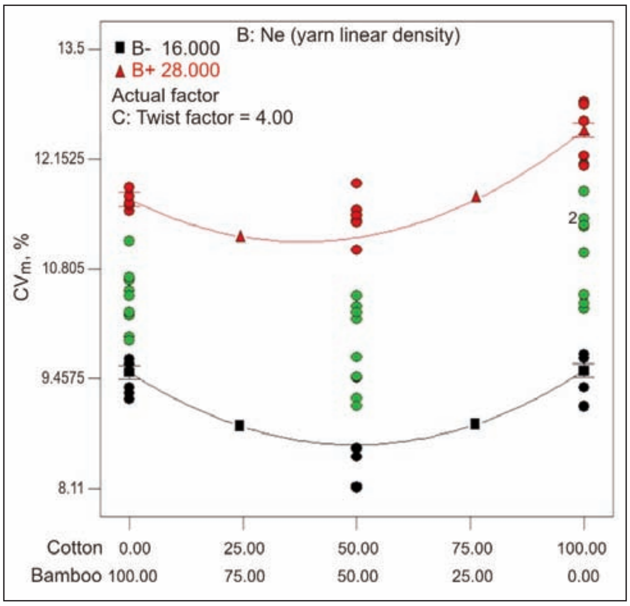
where, s is the standard deviation and $\bar{x}$ – the mean of a number of measured estimates of the mass per unit length of the yarn [21].
According to the F-test and lack of fit test, the quadratic model was suggested by the software. ANOVA table using quadratic model was obtained and given in table 2. The R^2 value is obtained as 90.9%, which indicates that the model explains the 90.9% of the response variable CV_m%. The model terms havig p-values of lower than 0.05 are considered to be significant. The contributions of the terms were also calculated. In the table, the yarn linear density (B) has the highest contribution with 70.61%. The sum of the linear and quadratic effect of the blend ratio (A) is the second in contribution as 17.68% (2.63+15.05). Other terms have relatively low effect on CV_m%. It can be inferred from the table that yarn linear density and blend ratio is the most important factors on CV_m%.
The regression curves for CV_m% are given in figure 3. In these figures, the experimental data is shown as dots or points and the curves are fitted by regression equations. Changing the blend ratio of cotton and bamboo from 0 to 100 can also be seen. In order to see the effect of twist coefficient, α_e = 3.5, 4.0 and 4.5

Table 2

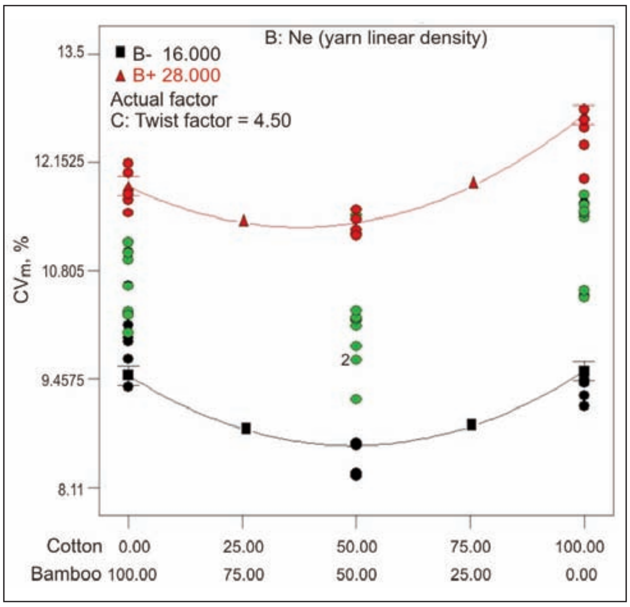
ANOVA for CVm%							
Source	**Sum of squares**	**Contribution (%)**	**Degrees of freedom**	**Mean squares**	**F value**	**p-value**	**Significance**
Model	309,11	90,90	9	34,35	303,12	< 0.0001	Significant
A	8,96	2,63	1	8,96	79,05	< 0.0001	Significant
B	240,10	70,61	1	240,10	2119,11	< 0.0001	Significant
C	0,53	0,16	1	0,53	4,67	0.0315	Significant
A²	51,18	15,05	1	51,18	451,72	< 0.0001	Significant
B²	0,02	0,01	1	0,02	0,18	0.6732	
C²	0,07	0,02	1	0,07	0,66	0.4173	
AB	4,33	1,27	1	4,33	38,17	< 0.0001	Significant
AC	0,03	0,01	1	0,03	0,23	0.6328	
BC	1,03	0,30	1	1,03	9,11	0.0028	Significant
Residuals	30,93	9,10	273	0,11			
Lack of Fit	8,12	2,39	47	0,17	1,71	0.0053	
Error	22,81	6,71	226	0,10			
Corrected total	340,04	100,00	282				



a



b



c

Fig. 3. CV_m% for cotton/bamboo blended yarns: *a* – α_e=3.5; *b* – α_e=4.0; *c* – α_e=4.5

was selected and given as figure 3, *a*, *b*, and *c*, respectively. It can be seen that CV_m% is high in finer yarns (Ne 28) for each twist levels. This situation may be related to the low number of fibres in the cross section of yarn finer yarns. Increased number of fibres in yarn cross section regulates the imperfections and unevenness regions on the yarn. As the cotton blend ratio in the yarn increases, the CV_m% decreases up to a certain level and further increasing cotton ratio increases the CV_m%. Pure cotton yarns show the maximum CV_m% value. This may be related to the fibre cross sections and fibre-to-fibre cohesion forces in the yarn. The optimum CV_m% value was seen between 40% cotton-60% bamboo and 50% cotton-50%50 bamboo blend. The cross sections of the fibres were shown in figure 1 and 2. The effective and maximum cohesion forces between curly bamboo fibre and bean-like cotton fibre may be obtained 50%/50% blend in the yarn. The fibre length variation in cotton fibres is higher than that of bamboo. Thus pure cotton yarns demonstrate high CV_m% than that of pure bamboo yarns.

Hairiness (H)

Hairiness (*H*) is defined as the length of protruding hairs per 1 cm yarn. According to the F-test and lack of fit test, the quadratic model was suggested. ANOVA table using quadratic model was obtained and given in table 3. The R^2 value is obtained as 65.24%. The model terms having p-values of lower than 0.05 are considered to be significant. The contributions of the terms were also calculated. The maximum contribution is obtained from blend ratio with 57.84%. The second contribution is achieved by twist factor with 4.44%. Other terms have relatively low effect on hairiness. It can be inferred from the table that blend ratio and twist factor are the most important factors on hairiness.

The regression curves for hairiness are given in figure 4. It can be seen that *H* is high in finer yarns (Ne 28) for each twist levels. The cohesion forces between fibres are low due to the low number of fibres in the cross section of finer yarns, hence the fibres tend to protrude from the yarn hairiness in fine yarns much more than coarse yarns. As the cotton blend ratio in the yarn increases, the hairiness also increases which can be related to the high length and fineness variation of cotton fibres compared to the bamboo fibres. Minimum hairiness was seen in pure bamboo yarns. Increasing the twist decreases the hairiness in the figures, as expected. While increasing the twist, fibre-to-fibre cohesion forces will increase which help to hold the fibre in the yarn body.

Friction coefficient (μ)

According to the F-test and lack of fit test, the quadratic model was suggested. ANOVA table using quadratic model was obtained and given in table 4. The R^2 value is obtained as 73.02%. The maximum contribution is obtained from blend ratio with 46.03% (sum of linear and quadratic effects $A+A^2$). The sec-

Table 3

ANOVA for hairiness (H)							
Source	**Sum of squares**	**Contribution (%)**	**Degrees of freedom**	**Mean squares**	**F value**	**p-value**	**Significance**
Model	102,43	65,24	9	11,38	56,71	< 0.0001	Significant
A	90,81	57,84	1	90,81	452,56	< 0.0001	Significant
B	1,55	0,99	1	1,55	7,72	0.0059	Significant
C	6,97	4,44	1	6,97	34,74	< 0.0001	Significant
A^2	1,35	0,86	1	1,35	6,71	0.0101	Significant
B^2	1,62	1,03	1	1,62	8,08	0.0048	Significant
C^2	0,07	0,04	1	0,07	0,33	0.5641	
AB	0,49	0,31	1	0,49	2,45	0.1185	
AC	0,16	0,10	1	0,16	0,80	0.3722	
BC	0,16	0,10	1	0,16	0,77	0.3802	
Residuals	54,58	34,76	272	0,20			
Lack of Fit	30,63	19,51	47	0,65	6,12	< 0.0001	Significant
Error	23,95	15,25	225	0,11			
Corrected total	157,01	100,00	281				

Table 4

ANOVA for friction coefficient μ							
Source	**Sum of squares**	**Contribution (%)**	**Degrees of freedom**	**Mean squares**	**F value**	**p-value**	**Significance**
Model	0,46	73,02	9	0,05	83,74	< 0.0001	Significant
A	0,26	41,27	1	0,26	425,88	< 0.0001	Significant
B	0,00	0,00	1	0,00	3,51	0.0621	
C	0,04	6,35	1	0,04	67,36	< 0.0001	Significant
A^2	0,03	4,76	1	0,03	53,49	< 0.0001	Significant
B^2	0,11	17,46	1	0,11	177,74	< 0.0001	Significant
C^2	0,01	1,59	1	0,01	19,44	< 0.0001	Significant
AB	0,00	0,00	1	0,00	0,22	0.6362	
AC	0,00	0,00	1	0,00	0,68	0.4120	
BC	0,00	0,00	1	0,00	7,32	0.0073	Significant
Residuals	0,17	26,98	271	0,00			
Lack of Fit	0,15	23,81	47	0,00	54,27	< 0.0001	Significant
Error	0,01	1,59	224	0,00			
Corrected total	0,63	100,00	280				

ond contribution is obtained by the quadratic effect of yarn linear density (B^2) with 17.46%. Twist factor is, contrary to the expectations, the third in importance for the friction coefficient of the yarns with 7.94% (sum of linear and quadratic effects $C+C^2$).

The regression curves for friction coefficient μ are given in figure 5. It can be stated that increasing twist factor increases friction coefficient, as expected (figure 5, *a*, *b* and *c*). Increasing twist increases the rigidity of the fibre and friction coefficient increases, as well. In figure 5, *a*, the finer yarns show higher friction coefficient; whereas in figure 5, *b* and *c*, coarser yarns have higher friction coefficient values than finer yarns. The critical twist coefficient is α_e = 3.77 in which the friction coefficient of finer and coarser yarns are almost equal. Increasing cotton blend in the yarn decreases the friction coefficient. This may be due to the high friction coefficient of bamboo fibre. The natural bamboo fibre are already can be used in brake composites and it is used for its improved wear characteristics [9–11]. Hence the increasing bamboo blend in the yarn increases the friction coefficient.

CONCLUSIONS

In this study, unevenness, hairiness and the frictional properties of cotton/bamboo blended yarns are

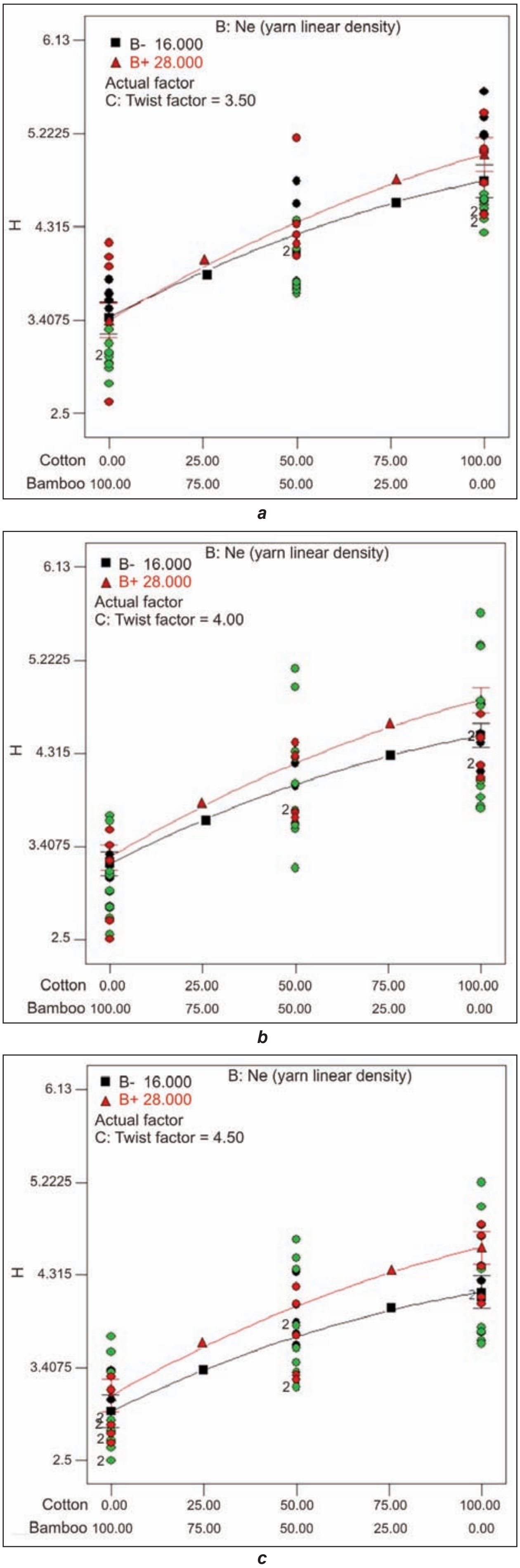


Fig. 4. Hairiness for cotton/bamboo blended yarns: *a* – $\alpha_e = 3.5$; *b* – $\alpha_e = 4.0$; *c* – $\alpha_e = 4.5$

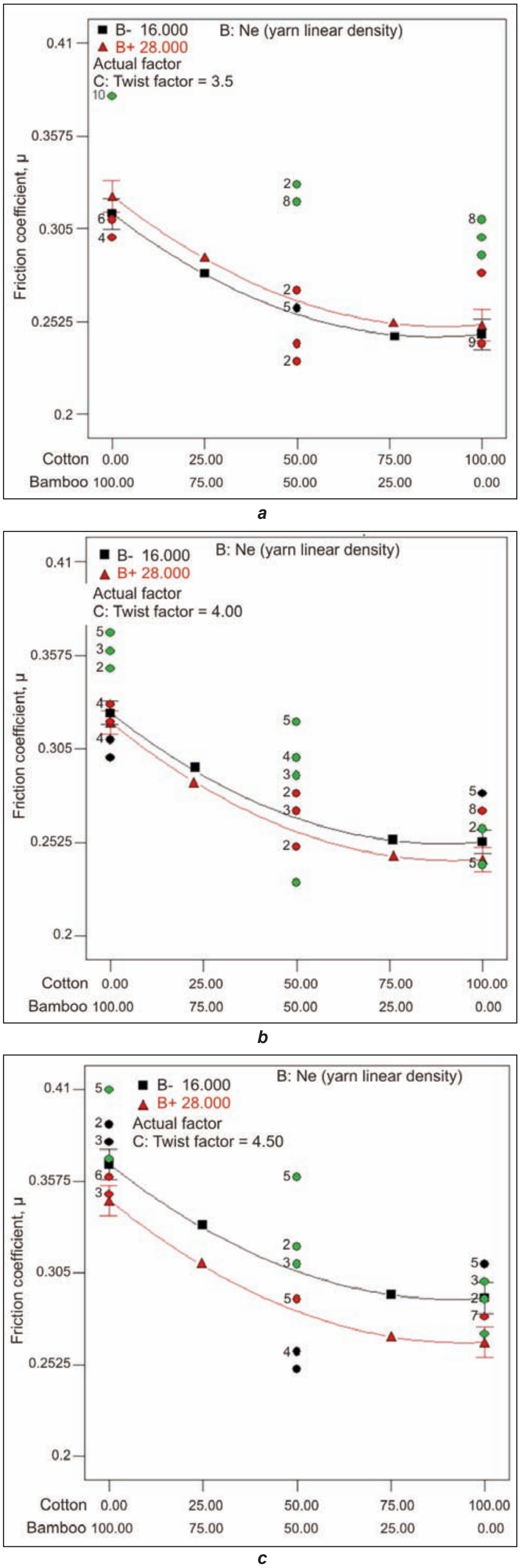


Fig. 5. Friction coefficient variation for cotton/bamboo blended yarns: *a* – $\alpha_e = 3.5$; *b* – $\alpha_e = 4.0$; *c* – $\alpha_e = 4.5$

investigated by statistical analysis. For this purpose pure bamboo and cotton yarns and 50%/50% cotton/bamboo blended yarns produced in four different yarn linear densities and five different twist coefficients. The conclusions arised from the study may be drawn as follows:

1. Yarn linear density is the most effective factor on the unevenness (CV_m%). CV_m% is high in finer yarns (Ne 28) for each twist levels since the low number of fibres in the cross section. Increased number of fibres in yarn cross section regulates the imperfections and unevenness regions on the yarn.
2. Since the fibre length variation in cotton fibres is higher than that of bamboo, pure cotton yarns demonstrate high CV_m% than that of pure bamboo yarns.
3. The optimum CV_m% value was seen between 40% cotton - 60% bamboo and 50% cotton - 50%50 bamboo blend.
4. Blend ratio is the most effective factor on the hairiness. The cohesion forces between fibres are low due to the low number of fibres in the cross section of finer yarns, hence the fibres tend to protrude from the yarn hairiness in fine yarns much more than coarse yarns
5. As the cotton blend ratio in the yarn increases, the hairiness also increases which can be related to the high length and fineness variation of cotton fibres compared to the bamboo fibres.
6. Minimum hairiness was seen in pure bamboo yarns. While increasing the twist, fibre-to-fibre cohesion forces will increase which help to hold the fibre in the yarn body.
7. Blend ratio is the most effective factor on the friction coefficient. The finer yarns show higher friction coefficient; whereas in figure 5, *b* and *c*, coarser yarns have higher friction coefficient values than finer yarns.
8. The critical twist coefficient is $\alpha_e = 3.77$ in which the friction coefficient of finer and coarser yarns are almost equal.
9. Increasing cotton blend in the yarn decreases the friction coefficient. This may be due to the high friction coefficient of bamboo fibre.

As an overall conclusion, increasing cotton ratio in the yarn structure increases unevenness and hairiness, whereas decreases friction coefficient, in general. One of the most influential reasons may be due to the contact surface area between yarn with metal. The yarn-metal friction coefficient will increase with increasing the effective contact area of the yarn to metal, as expected. The one end of the hairs is free from the yarn and these fibres are not in full contact with metal. In addition, increased unevenness results in increased variation in the diameter of yarn, which results in the lack of contact of yarn with metal during the yarn passing through testing device. Thus increased hairiness and unevenness decreases friction coefficient. These results are in accordance with the research of Altas and Kadoğlu [14].

The results of this study may be beneficial for yarn producers for characterizing the bamboo/cotton blended yarns. It may also be useful for determining the wax content for the yarns for further applications such as knitting and weaving in order to prevent from rupture of yarns during the process.

Acknowledgement

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Research on the possibilities of reducing the effects of shock waves in case of explosions in environments with dust and textile suspended particulate matter

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REZUMAT – ABSTRACT

Cercetări privind posibilitățile de reducere a efectelor produse de undele de șoc în cazul exploziilor în medii cu praf și particule textile în suspensie

În cadrul acestui articol se prezintă un sistem automat destinat reducerii undelor de șoc ce se obțin în urma unei explozii interioare într-un spațiu închis unde amestecul cu aerul, în condiţii atmosferice, al substanţelor inflamabile sub formă de praf sau fibre, după aprindere, arderea se propagă în tot amestecul neconsumat.
Sistemul automat realizează aerisirea spațiului închis în vederea reducerii efectelor produse de explozie. Sistemul este dezvoltat în jurul unui microcontroler și se bazează pe un algoritm predictiv. Alimentarea cu energie electrică a dispozitivelor de automatizare, utilizate în cadrul sistemului, se face de la un sistem fotovoltaic autonom cu stocare de energie electrică, situat în exteriorul spațiului închis.

Cuvinte-cheie: sistem automat, sisteme protectoare, algoritm predictiv

Research on the possibilities of reducing the effects of shock waves in case of explosions in environments with dust and textile suspended particulate matter

This article presents an automatic system designed to reduce shock waves resulting from an internal explosion in a closed space where mixing with air under atmospheric conditions of flammable substances in the form of dust or fibers after ignition, is propagated in the whole unconsumed mixture.
The automatic system provides ventilation of the enclosure in order to reduce the effects of the explosion. The system is developed around a microcontroller and is based on a predictive algorithm. The power supply of the automation devices used in the system is made from a stand-alone photovoltaic system with electrical storage located outside the closed space.

Keywords: automatic system, protective systems, predictive algorithm

GENERAL CONDITIONS

Industrial installations where flammable and/or combustible materials are processed, transported or stored are likely to have an explosive atmosphere.
Explosive atmosphere is defined as a mixture with air, under atmospheric conditions, of a flammable material in which, after ignition, the burning propagates throughout the whole unconsumed mixture.
Flammable and/or combustible materials must be considered creating/able to create an explosive atmosphere unless the situation where investigation of their properties has shown that they are incapable of spreading a self-sustained explosion in air mixtures.
Depending on the nature of the flammable material, explosive atmospheres can be:
– explosive gas atmospheres when the flammable material is in the form of gas or vapors;
– explosive dust atmospheres when the flammable material is in the form of dust or fibers.
In order for an explosion to occur, it is necessary to coexist with an explosive atmosphere and a source of ignition. Therefore, to reduce the risk of explosion, precautions must be taken to prevent explosions through:
– avoiding explosive atmospheres. This purpose can be achieved mainly by either changing the concentration of the flammable substance to a value that is outside the range of explosion or by bringing oxygen concentration to a value below the concentration limit of oxygen (LOC);
– avoiding any possible sources of ignition.
Measures may also be taken by limiting the effects of explosions to an acceptable limit by constructive protection measures.
Elimination or minimization of risk can be achieved by applying only one of the above prevention and protection measures. However, this is often not possible and therefore, in practice, we apply a combination of these.
In most cases, combustible dusts and vapors are a fire hazard, but mixed with air at certain concentrations and in the presence of a source of ignition are also an explosion hazard. The existence of this real danger was confirmed by the events that took place in economic units, for example: textile industry, forage factories, steel industry, etc.
Because in most cases fires and explosions cause damage with significant economic and social effects,

it is absolutely necessary to take appropriate measures to prevent such a hazard.
The risk of fire and explosion due to dust is less known than the one produced when using flammable gases or liquids. That is why, an erroneous assessment of the hazard might be obtained.
Regarding the explosion, it can only occur if the following conditions are met simultaneously:
- the existence of sufficient amounts of lint or combustible dust;
- their concentration combined with air should be at least the minimum explosive concentration;
- the existence of a dangerous potentially explosive mixture;
- the existence of a source capable of ignition.

To prevent the risk of explosion and/or fire, the following protective measures are recommended:
- avoiding or diminishing the flammable and combustible substances that may form explosive mixtures with air;
- prevent or reduce the possibility of forming explosive mixtures around electrical installations.

The ignition and explosion of dust requires simultaneous existence in the same place:
- of the oxidizable substances to the outside;
- of the oxidant (sufficient oxygen);
- of the efficient ignition source.

The explosion of dust only occurs if, in addition to the above conditions, the following are added:
- the fine grain size of the dust is less than 200 μm;
- the concentration of dust in the cloud is within the explosive limits.

According to industrial practice, ignition and explosion of dust can occur during the following technological operations:
- the mechanical transport of organic substances and their spillage;
- grinding and drying organic dust;
- suction and pumping of dust into separation and filtration installations;
- dry spraying of organic products;
- polishing light metals and their alloys.

Zoning needs to be done for both new and existing installations. In the first case, the responsibility lies with the technological specialists from the design institutes, in the latter case the plan can also be set up by technological specialists from the industrial units.
Zoning must be reviewed and updated whenever changes occur in installations and/ or technological process.
Electrical installations and equipment, located in areas with explosive atmosphere which may be a potential source of ignition, must meet certain conditions both in terms of construction and use.

FACTORS DETERMINING THE EXPLOSION RISK IN DANGEROUS AREAS WITH COMBUSTIBLE DUST AND LINT

Combustible dust and lint may be ignited by the following sources:
- by having contact with the surfaces of electrical devices which have a temperature above the ignition temperature of the dust;
- by arches or sparks produced by the electrical parts of electrical equipment (eg brushes, contactors, switches, etc.);
- by discharging an accumulated electrostatic charge;
- by radiant energies (eg electromagnetic waves, ionizing radiation, ultrasound, etc.);
- through mechanical friction and impact sparks or heating of the equipment.

THE PROPERTIES OF COMBUSTIBLE DUST

The nature of the dust is a decisive factor in the explosions, the characteristics of the dust (particle size, humidity, ignition temperatures in the cloud and in the layer, resistivity) influence both its dispersion in the medium, the particles size and also the explosive parameters.
In order to achieve security against combustible dust and lint, it is necessary to know the main explosive parameters of dust and lint which in combination with the air can generate explosive atmospheres. These features for the main combustible dust and lint are presented in literature [11–13].

THE QUANTITY OF DUST AND LINT EXISTING IN THE TECHNOLOGICAL FIELD

Dust and lint exist in the technological fields in two forms: dust and lint in suspension and dust and lint deposited.
Dangers due to dust and lint deposits occur in two closely related ways:
- Dust and lint deposited on/ in electromechanical devices and equipment having hot surfaces, as well as other hot surfaces such as heat-conducting pipes with improper insulation, etc., form a heat-insulating layer which prevents the dissipation of heat in the environment.
- Accumulation of heat in the layer of dust and lint leads to the sudden acceleration of the exothermic oxidation reactions, which end with the phenomenon of smolder, on the surface of dust and lint layer leading eventually to fire spots. These fire spots can migrate through a layer of dust at tens of meters distance and when they encounter a flammable substance they can trigger fires.

Most causes that determine whirling of the deposited dust also ensure the ignition source of the formed suspension.
Deposits of dust and lint that smolder represent a great danger. These, usually have a very low humidity around the fire spots, and at any movement they rise in suspension.

CHARACTERISTICS OF THE TECHNOLOGICAL FIELD

Being a factor that influences the danger of explosion, the technological space intervenes first of all through its volume. It is well-known from the research

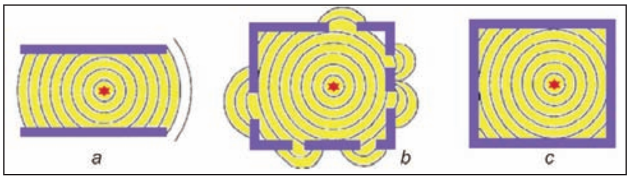

Fig. 1. Types of internal explosions according to the degree of ventilation [1]: *a* – complet ventilated; *b* – partially ventilated; *c* – fully closed

studies that a certain volume of explosive mixture of dust, lint and air produces effects on a 10 times higher volume.

This way results one of the security measures which requires removal of deposited dust and lint so that in the case of total whirling of the deposits, the concentration of the resulting mixture is less than the minimal explosive concentration. The volume of this mixture must not exceed 1/10 of the technological room volume.

When the explosion occurs inside a building, the pressures associated with the initial shock wave will be much higher than in the case of an explosion that occurs outside the building.

High temperatures as well as the accumulation of gases produced by chemical reactions make the explosions produced inside buildings require structural resistance over a longer period of time, depending on the degree of ventilation of buildings. This situation can be easily encountered in textile units that process and handle combustible materials such as raw material for yarn production, textile thread, dye solvents, combustible chemical substances used in technological processes, lubricants, textile dust.

Figure 1 illustrates the three types of interior explosions, depending on the ventilation degree of the building.

Internal explosions are characterized by three effects [2]:

- The effect of air compression around the explosion, the so-called "air shock wave" effect;
- Dynamic air pressure;
- Ground compression effect, the so-called ground shock wave effect.

After the explosion, the shock wave produces an instantaneous increase in air pressure (overpressure) over ambient atmospheric pressure at a certain distance from the source of the explosion (the positive phase of the explosion). Consequently, there is a difference in pressure between the combustion gases and the atmosphere, which causes a reversal of the flow direction (from a certain point to the center of the explosion). This stage is known as the negative phase of the explosion. The equilibrium point is reached when the air pressure returns to its original state. The above mentioned are highlighted in figure 2.

In figure 2, with t_d was noted the duration of the positive phase of the explosion, and with t_0 was denoted the initial time when the detonation took place. From figure 2 it is observed that the explosion has three phases: detonation, positive phase and negative phase. As a result of the practical experiments it was shown that the time variation of the air pressure within an enclosure after an explosion is described by an exponential function, given by the Friendlander equation [3].

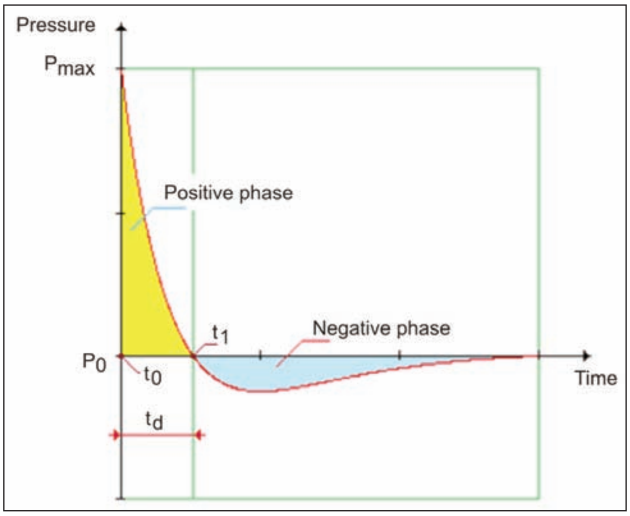

Fig. 2. Blast wave pressure plotted against time

$$p(t) = p_{max} \cdot \left(1 - \frac{t - t_0}{t_d}\right) \cdot e^{-\alpha \cdot \frac{t - t_0}{t_d}} \qquad (1)$$

Where $t_d = t_1 - t_0$, and α is a parameter of the waveform.

Based on the above-mentioned relationship, we can calculate the value of the shock wave pulse, which is defined by the area of function (1) in the positive phase of the explosion.

$$i_s = \int_{t_0}^{t_0+t_d} p(t)\,dt = \frac{p_{max} \cdot t_d}{\alpha^2} \cdot (\alpha - 1 + e^{-\alpha}) \qquad (2)$$

From relations (1) and (2) it is observed that with the decrease of the maximum pressure, the value of shock impulse decreases. A widespread method for reducing the effects of an explosion (reduction of maximum pressure) within a building is the method of aerating the space where the explosion occurred. The ventilation must be made to a safe location where combustion can not be sustained, away from crowded areas, other facilities or other buildings.

Among the most well-known venting devices in the spaces where explosions occur, we mention the following [4]:

- ventilation ducts covered with membranes made of weak material that breaks gently at contact with the explosion air flow (figure 3, *a*). These holes are designed according to NFPA 68 [5] and are designed to reduce overpressure and flame directional firing;
- ventilation devices that do not allow flame and dust particles to escape outward (figure 3, *b*). These devices have been able to evacuate excess pressure and hot gas from the explosion, consisting of a membrane and a filter. The ventilation design using these devices is based on the NFPA 68 standard.

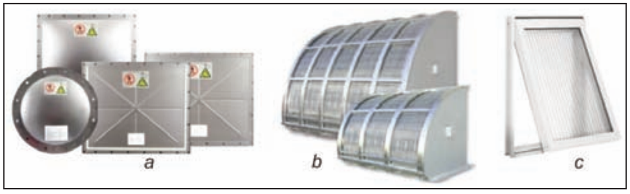

Fig. 3. Passive ventilation devices for spaces where explosions occur [6], [7], [8]

- steel hinged doors (figure 3, *c*). According to standard NFPA 68, the mass of the door should be less than 12.2 kg/m^2.

The ventilation devices in figure 3 are some passive ones being driven by the explosion air flow. The main concerns of researchers in recent years with regard to ventilation devices are largely intended to increase their effectiveness in the event of an explosion [9]. In view of the above, the primary objective of the article is to propose a new type of device designed to vent a space in which an explosion occurred. The proposed ventilation device is an active device, driving the device by means of an automatic system. The control system consists of one or more automatic transducers used in explosion detection (pressure transducers, flame transducers) whose information is transmitted to a performing microcontroller which, based on a program based on a predictive algorithm, performs the command the execution element conducting the ventilation of the space in which the explosion occurred.

AUTOMATIC SYSTEM AND VENTILATION DEVICE

The proposed ventilation device is shown in figure 4. The ventilation device consists of the following elements: 1 – steel panels (4 pieces); 2 and 3 – steel fastening bars; 4 – way, rigid, steel, clamp connectors (4 pieces); 5 – tension spring hinge and electromagnet (4 pieces).

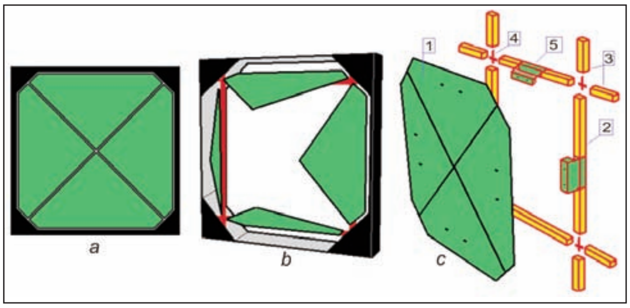

Fig. 4. Ventilation device

Each panel is hinged to the hinge by means of two screws.

The hinge of the hinge component can be adjusted manually, which is used to open the panel. The hinge is made up of an electromagnet used to hold a panel in a closed position.

The four panels of the ventilation device are closed as long as the coils of the 4 electromagnets are run-in. When powering the electromagnets is interrupted, the tensile springs in the four hinges will open the four steel panels very quickly.

The scheme of the ventilation control system is shown in figure 5.

In figure 5, have been using the following electronic devices:

- Resistances (denoted with R, R_1 and R_2). Resistance values are: R = 1 kΩ; R_1 = 220 Ω; R_2 = 10 kΩ.
- Protection diodes 1N4004 (denoted with D).
- BC301 transistors (marked with T).
- An opt coupler 4N25.
- Four PML-080AB electromagnets with a 45 kgf retaining force at 12 Vdc / 60 mA.
- A MEX-3.2HT pressure sensor.
- A processing unit with microcontroller, FAB-4.

An autonomous photovoltaic system, used in the power supply of consumers, of the control system component of figure 5.

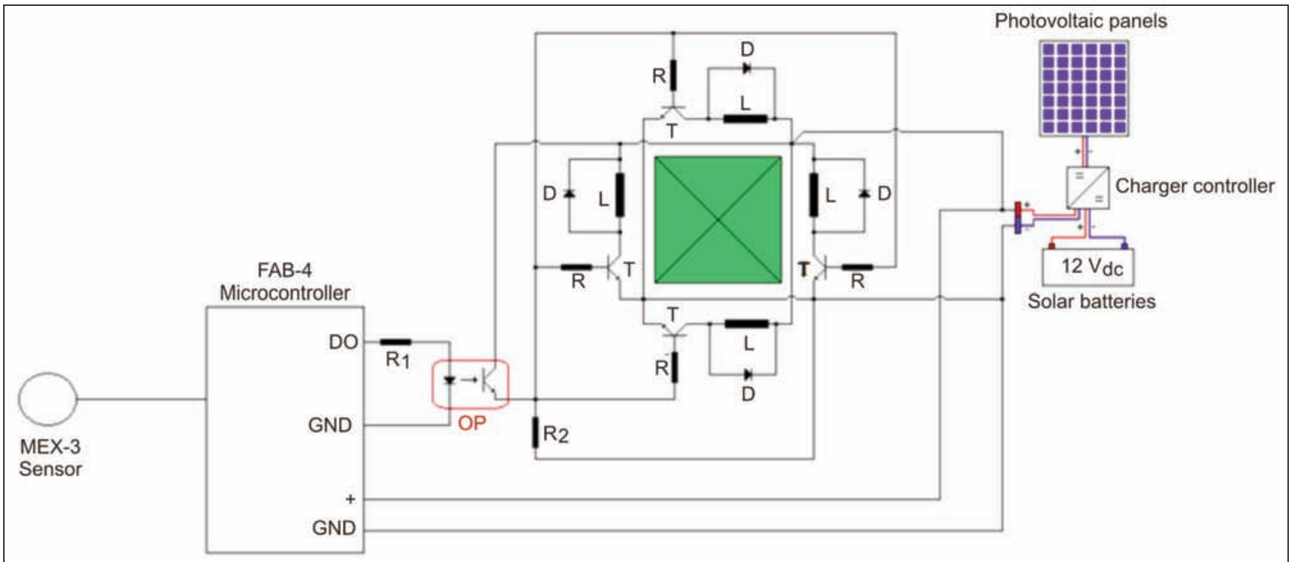

Fig. 5. Ventilation control system

In the scheme of figure 5, dynamic pressure is measured using the MEX-3.2HT sensor, manufactured by Germana, IEP Technologies GmbH [10]. This sensor is capable of measuring dynamic pressures ranging between 0 and 2 bar, under temperature conditions between –20 and 160 degrees Celsius. The MEX-3.2HT sensor is shown in figure 6.

Fig. 6. Pressure sensor MEX-3.2HT [10]

The sensor is KEMA 03 ATEX 1480 certified, protected by a stainless steel casing. The MEX-3.2HT sensor must be mounted inside the building. Data acquired by the MEX-3.2HT pressure sensor is processed by the FAB-4 microcontroller unit [10]. Within the microcontroller are implemented three predictive algorithms, working in parallel, to determine the rate of increase of the dynamic pressure from the positive phase of the explosion. The FAB-4 processing unit is manufactured by the same firm as the MEX-3.2HT pressure sensor. The FAB-4 processing unit connected to the MEX-3.2HT sensor is shown in figure 7.

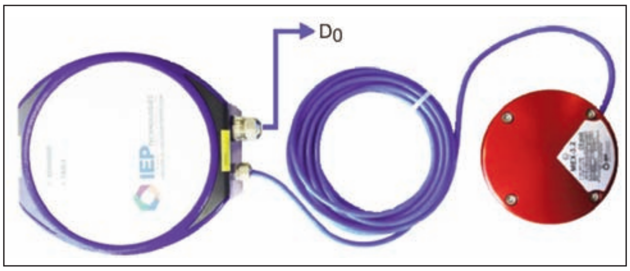

Fig. 7. FAB-4 Processing Unit [10]

The FAB-4 processing unit connects outside the building, powered by a stand-alone photovoltaic system with a 12 Vdc voltage. The FAB-4 processing unit has a 1.5 W power consumption and can operate in the following temperature range: –25 ... + 75 degrees Celsius.

The FAB-4 processing unit is certified SEV 15 ATEX 0120. This unit allows for the recording of the acquired values of the pressure and can thus carry out post-explosion analyzes. With the evaluation software, you can download event logs from the FAB-4, either in the short or long term.

On the other hand, it is known that the rate of pressure increase depends on concentration, explosive material and room volume. For this reason, the FAB-4 processing unit allows you to program and adapt the software to the process conditions.

CONCLUSIONS

In order to avoid the risk of ignition, it is necessary:

- the temperature of the surfaces to which dust, lint may deposit or may come in contact with dust and lint cloud, to be hold below the ignition temperature of the dust and lint taken into account.
- all electrical parts capable of producing sparks or all parts having a temperature above the ignition temperature of the considered dust and lint;
- to be contained in a capsule that conveniently prevents the penetration of dust and lint or has electric networks with limited energy in order to avoid arches, sparks and temperatures capable set fire to combustible dust and lint;
- all other sources of ignition should be avoided.

In order to prevent the explosion hazard, the essential security requirements are targeted to two basic directions, namely:

- preventing the accumulation of combustible dust and lint and maintaining their contents, in mixture with air, below the limit value considered as non-dangerous;
- limitation of ignition sources by using equipment and specifically constructed installations (all electrical parts capable of producing sparks or all parts which have a temperature above the dust and lint temperature must be protected or totally enclosed in capsules or must have electrical circuits with limited energy).

Preventive measures may be used to eliminate the risk of simultaneous occurrence of a source of ignition and an explosive atmosphere in the considered area. The problem can be addressed in one of the following ways, each having its own field of application:

a) suppressing or avoiding dangerous conditions;
b) the use of electrical equipment which is protected from explosion;
(c) control conditions applied to manual, automated or procedural means through which we prevent the simultaneous occurrence of an explosive atmosphere and a source of ignition.

Although each method of prevention can be a complete solution to a particular problem, it is allowed to use a combination of techniques to achieve the required degree of security.

In case the explosion cannot be avoided, a series of technical means can be introduced to alleviate the effects of shock waves from explosions produced in environments with dust and suspended particulate matter.

Both the proposed automatic system and the ventilation device require a comparative analysis with existing exhaust systems in terms of explosion efficiency. The hinges of the ventilation device require careful maintenance in operation (they must not be blocked, corroded, the spring should not be broken).

The automatic system together with the ventilation device reduces the maximum burst pressure as well as the effects of the shock waves both on the structure of the building and on the people.

The automated system together with the proposed venting device considerably reduces the disadvantages of membranes in the existing ventilation systems. Among the most important drawbacks are: fatigue damage, heat damage, damage due to bending of the membranes due to pulsating pressures.

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Some validation aspects on the analytical method for assaying carcinogenic amines from textile dyes

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REZUMAT – ABSTRACT

Aspecte privind validarea metodei analitice de determinare a aminelor cancerigene derivate din coloranți specifici industriei textile

Controlul siguranței chimice, precum și proprietățile ecologice au devenit o prioritate pentru industria textilă cu scopul de a evita efectele negative ale substanțelor chimice asupra oamenilor și asupra mediului înconjurător. Interesul crescut pentru toxicologia produselor textile este determinat de prezența compușilor periculoși în haine generați în urma proceselor de vopsire și de finisare. Pentru a proteja sănătatea umană, regulamentele europene, precum Oeko Tex Standard 100 și REACH, limitează prezența substanțelor chimice periculoase, cum ar fi aminele aromatice generate prin scindarea reductivă a coloranților azoici, la cel mult 30 mg/kg de material textil. Scopul principal al acestei lucrări de cercetare a fost elaborarea și validarea metodei cromatografice HPLC/MWD pentru identificarea și cuantificarea precisă și sigură a aminelor aromatice cancerigene derivate din coloranți azo specifici industriei textile. Determinarea simultană a 24 de amine aromatice reglementate a fost efectuată prin două metode cromatografice conform SR EN ISO 14362-1: 2017 pentru a evita interferențele matricei și erorile în identificarea compușilor din cauza prezenței izomerilor structurali. Analizele preliminare pentru a stabili lungimea de undă corespunzătoare absorbției maxime a fiecărei soluții standard de amine aromatice s-au efectuat simultan la patru lungimi de undă, 240, 280, 305 și 380 nm. Cu scopul de a demonstra siguranța, fiabilitatea și precizia datelor analizate, s-au validat atât metoda cromatografiei de lichide, cât și cea a cromatografiei de gaze. Au fost evaluați parametri ca: selectivitatea, precizia, limita de detecție și limita de cuantificare a celor două metode analitice. Certitudinea determinărilor a fost dovedită și de rezultatele testelor interlaboratoare efectuate de Institutul de Studii Interlaboratoare din Olanda asupra coloranților azoici din textile.

Cuvinte cheie: testarea competențelor, amine cancerigene, textile vopsite, textile ecologice, HPLC, GC-MS, validare

Some validation aspects on the analytical method for assaying carcinogenic amines from textile dyes

Chemicals safety control and ecological properties have become a priority for the textile industry in order to avoid the negative effects on humans and environment. The increasing interest for toxicology of textiles is determined by the presence of dangerous compounds in clothes generated from dyeing and finishing processes. In order to protect human health, European Regulations as Oeko Tex Standard 100 and REACH Regulation limit the presence of dangerous chemicals, such as aromatic amines, generated by reductive cleavage of azo dyes, by no more than 30 mg/kg of textile material. The main goal of this research work was to develop and validate a HPLC/MWD method for precise and reliable identification and quantification of carcinogenic aromatic amines derived from banned azo dye specific to the textile industry. The simultaneous determination of 24 regulated aromatic amines has been conducted by two chromatographic methods according to SR EN ISO 14362-1:2017 in order to avoid matrix interferences and compounds misidentification due to the presence of structural isomers. Preliminary analyses to establish the maximum absorption wavelength of each standard solution of aromatic amine were performed simultaneously at four wavelengths, 240, 280, 305 and 380 nm. With the scope of demonstrating the consistency, reliability and accuracy of the analysed data, both liquid and gas chromatographic method were validated. Parameters as selectivity, precision, limit of detection and limit of quantification of the analytical methods were evaluated. The certainty of the determinations was also proved by the results of proficiency testing conducted by IIS Netherlands on azo dyes in textiles.

Keywords: proficiency testing, carcinogenic amines, textile dyes, textile ecology, HPLC, GC-MS, validation

INTRODUCTION

Azo colourants are used to colour textile fibres, leather, plastics, papers, hair, mineral oils, waxes, foodstuffs and cosmetics [1–2]. ‘Azo dye’ is the collective term used to describe a group of synthetic that rose to prominence in the 1880s and are now comprise 70% of all organic commercial dyes [1]. The word ‘Azo’ signifies the presence of a chemical azo group (–N=N–) in the dye. Today, they are produced for the most part in China and India, followed by Korea, China and Argentina [1]. Azo dyes are popularly used, because they dye cloth at 60°C, while Azo-free dyes require a temperature of 100°C. Also, Azo dyes offer an extensive range of colours, better colour fastness and four times the intensity of the closest alternatives, making them invaluable to the textile industry.

In specific conditions, azo dyes produce by in vivo reductive cleavage of the azo groups primary aromatic amines (PAAs), that are considered by the international authorities to be toxic, and have mutagenic and carcinogenic effect. These specific reductive conditions are met in the digestive tracts and some organs of animals, including humans [3]. The main responsible for their toxicity is represented by the amino group bound to the aromatic system. 24 aromatic amines have been confirmed as or implicated to be, carcinogens in humans, and as many as 5% of Azo dyes can cleave to form these dangerous compounds [2]. They can be present in dyed product and in the environment due to incomplete synthesis or degradation of azo dyes.

There are three main routes of exposure to azo dyes: a) ingestion, mainly by babies and children, b) dermal absorption, the largest concern both for people wearing dyed clothing and for the staff from factories producing dyes and c) dye inhalation worrying for workers from factories but also for handling freshly dyed materials with azo dyes [1].

In one German dye plant, 100% of workers (15 people) involved in distilling 2-naphthylamine developed bladder cancer [4]. Aromatic amines are also present in tobacco smoke, which may explain why smoking seems to elevate the risk of bladder cancer. EU restricted aromatic amines have also been linked to splenic sarcomas and hepatocarcinomas [6].

Many strict government regulations worldwide limit the usage of azo dyes in textile and leather products. 22 aromatic amines are classified by the EU Commission as proven or suspected human carcinogens, and their concentration in textile materials is limited at 30 mg/kg [1]. Oeko-Tex Label, designed to protect the consumers is a voluntary label adopted by an increasing number of textile manufacturers, and regulates 24 aromatic amines, of which 22 overlap with the European legislation. The maximum amount of carcinogenic aromatic amines specified in Oeko Tex is 20 mg/kg [2].

The increasing need for less harmful chemicals used in textile industry, that have minimum of no harmful effects on human health justify the necessity for fast and accurate methods to test and quantify aromatic amines derived from azo dyes extracted from textile materials [2].

EXPERIMENTAL

Reagents and standards

Acetonitrile and methanol gradient grade from Merck KGaA (Germany), water for chromatography (resistivity min. 18.2 MΩ x cm, TOC max. 50 ppb).

Analytical standards of 24 aromatic amines from Sigma-Aldrich and Dr. Ehrenstorfer GmbH (Germany).

Instrumentation

HPLC separation was performed on Agilent 1100 LC System using an Agilent Zorbax Eclipse XDB C18 column and MWD detector. GC separation was performed on Agilent 6890 GC System coupled with Agilent 5973N transmission quadrupole mass spectrometer (table 1).

Table 1

Agilent 6890 GC/5973N MS Operating Conditions	
Capillary Column	DB-35MS (J&W), 35 m × 0.25 mm × 0.25 µm;
Injector System	splitless
Injector Temp.	260°C
Carrier gas	helium
Flow (mL/min)	1 mL/min
Temp. programme	100°C (2 min), 100°C – 310°C (15°C/min), 310°C (2 min)
Injection Volume	1.0 µl
Detection	MS / Full Scan
Acquisition Parameters	EI Positive Ion Mode, 70 eV

Agilent 1100 HPLC/MWD Operating Conditions		
Analytical Column	Zorbax Eclipse XDB C18 150 mm x 4,6 mm x 3.5µm	
Column Temp.	32°C	
Injection Volume	5.0 µl	
Mobile Phase	Eluent 1: methanol	
	Eluent 2: 0.68 g potassium dihydrogen phosphate in 1000 mL water, 150 mL methanol	
Run time	35 min	
Flow rate	0,6–2,0 mL/min (gradient)	
Quantification	at 240 nm, 280 nm, 305 nm and 380 nm	
Gradient profile	Time (minutes)	Gradient (% Eluent 1)
	0.00	10.0
	22.50	55.0
	27.50	100.0
	28.50	100.0
	28.51	100.0
	29.00	100.0
	29.01	10.0
	31.0	10.0
	35.00	10.0

Sample preparation

Stock solutions of each amine (according to – SR EN ISO 14362-1:2017 [2]) with the concentration of 300 µg/mL in ACN were prepared. From these stock solutions, 8 solutions for calibration curve were prepared, with the following concentration: 3, 4.5, 6, 12, 24, 28, 30, 36 µg/mL.

Selection of maximum absorption wavelength for each of 22 aromatic amines

Each standard solution of the target amines in concentration of 50 µg/mL was analysed using spectrophotometric detection simultaneously at four wavelengths, 240, 280, 305 and 380 nm. Thus, a classification of the 24 amines depending on the

Table 2

240 nm	280 nm	305 nm	380 nm
Amines 3, 4, 6, 7, 8, 9, 13, 14, 15, 16, 17, 18, 19, 20, 21*	Amines 2, 12, 1, 10	Amines 11	Amines 5, 22

* according to aromatic amines numbering from table 1 – ISO/FDIS 14362-1:2016(E) [8]

specific wavelength at which absorption is maximal was obtained (table 2).
The overlaid chromatograms of amines 3, 2, 11, and 22, solutions with concentration of 50 mg/L are shown in figures 1–4. Detection has been performed at 240, 280, 305 and 380 nm and the overlaid chromatograms indicate the detection wavelength for each amine.

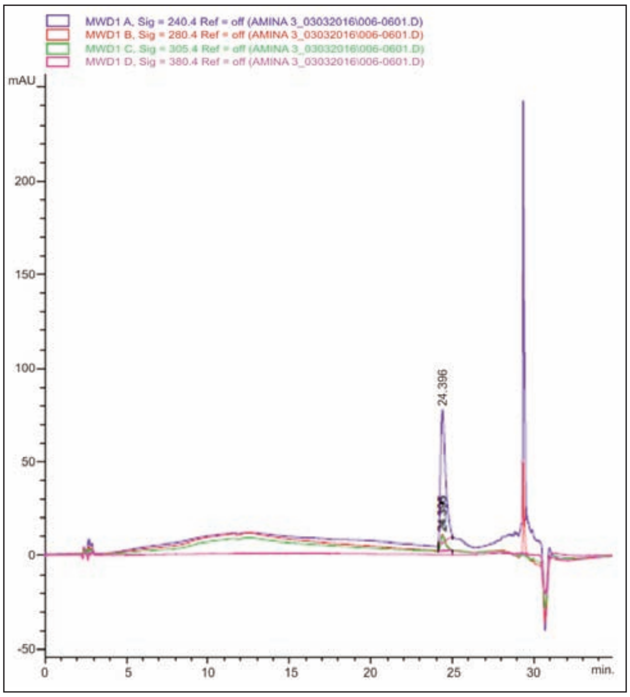

Fig. 1. Overlaid chromatograms of 4-chloro-o-toluidine, 50 mg/L, maximum absorption wavelength at 240 nm

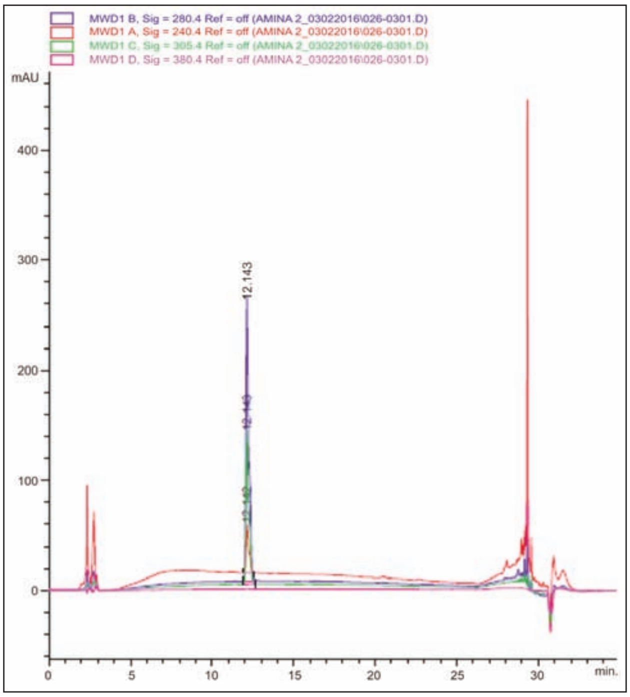

Fig. 2. Overlaid chromatograms of benzidine, 50 mg/L, maximum absorption wavelength at 280 nm

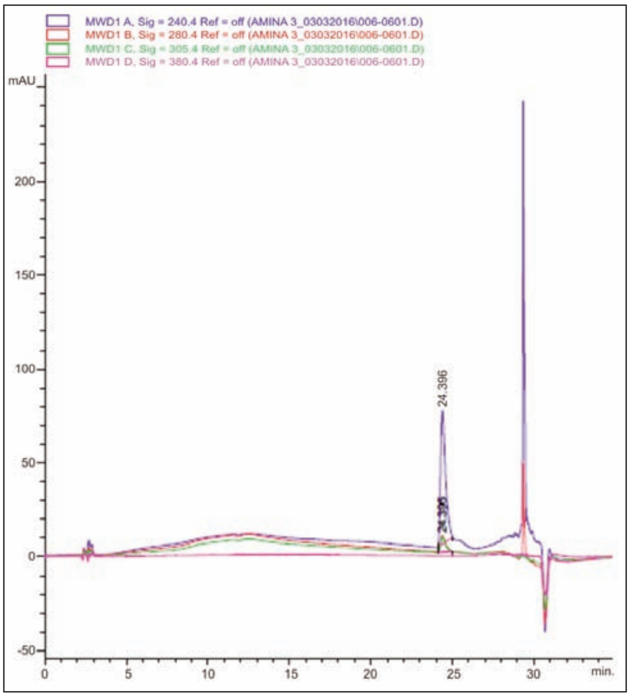

Fig. 3. Overlaid chromatograms of o-dianisidine, 50 mg/L, maximum absorption wavelength at 305 nm

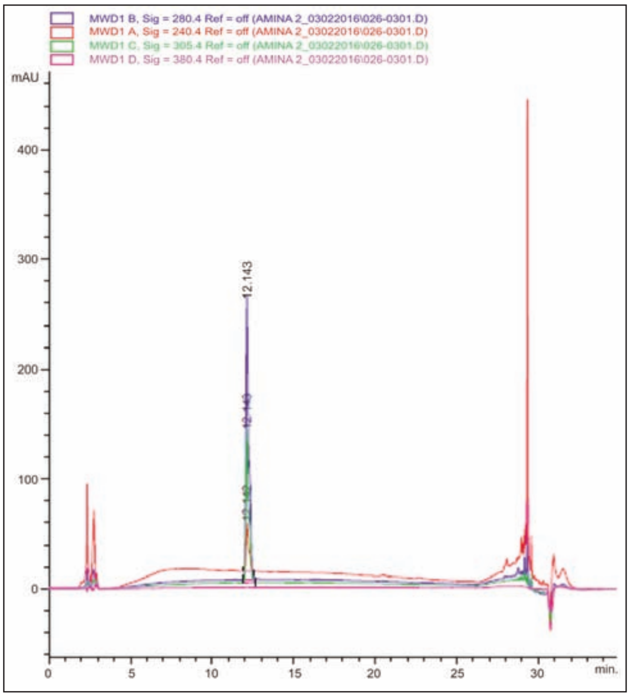

Fig. Overlaid chromatograms of 4-aminoazobenzene, 50 mg/L, maximum absorption wavelength at 380 nm

Performance characteristics of the analytical method

Selectivity

Selectivity is the ability of the analytical method to measure and differentiate analytes in the presence of components that are expected to be present in the sample. In the case of an HPLC method it must be demonstrated that the analyte of interest was very well separated from the other compounds in the sample and that the peak of interest did not overlap with other interfering peaks.

In order to demonstrate the method selectivity, apparent resolution and relative standard deviation (RSD %) of retention time between each two analytes with consecutive elution have been determined (table 3). 6 chromatographic separation of mixture of 24 amines by HPLC-MWD and GC-MS techniques have been performed. For calculation of relative standard deviation, average values of retention times were used.

As can be seen in table 3, the chromatographic resolutions between each 2 consecutive compounds exceed in all cases the value of 1.5 and in many cases have increased values (amine 12: R_s = 47.128), indicating very good separation capacity of the amine mixture on the Zorbax Eclipse XDB C18 column.

The relative standard percentage deviation calculated for average retention time is in all cases less or very close to the value of 1, showing a good selectivity of the separation method of aromatic amines [11].

As it can be observed in figures 5–8 and table 3, all amines were evaluated at the wavelength corresponding to their maximum absorption; compounds are well separated at their baseline, with no fronting, tailing or overlapping peaks.

Precision

Measurement precision express the closeness of the results obtained from a series of multiple measurements of aliquots from the same homogeneous sample in specific conditions.

Reproducibility, component of precision, was addressed in the present study by participating in the

Table 3

Wavelength corresponding to maximum absorption	Amine	HPLC Results		
		t_R (average)	R_S (average)	RSD%
240 nm	Amine 8	3.955	3.19	0.59
	Amine 19	4.890	29.93	0.50
	Amine 16	12.284	5.58	0.86
	Amine 21	13.624	4.46	0.77
	Amine 18	14.901	9.90	0.73
	Amine 9	17.617	3.65	0.46
	Amine 7	18.618	1.06	1.43
	Amine 6	18.922	3.57	0.85
	Amine 14	20.090	1.73	0.60
	Amine 23	20.837	1.36	0.54
	Amine 24	21.209	5.43	0.61
	Amine 4	22.553	6.02	0.97
	Amine 3	24.207	4.11	0.96
	Amine 13	25.272	1.42	0.82
	Amine 20	25.603	16.81	0.69
	Amine 15	28.670	16.81	0.07
280 nm	Amine 2	11.601	37.75	0.85
	Amine 12	19.680	47.12	0.66
	Amine 1	27.727	5.43	0.51
	Amine 10	28.306	5.43	0.23
305 nm	Amine 11	19.362	1.53	0.64
380 nm	Amine 5	28.605	12.25	0.13
	Amine 22	29.173	12.25	0.09

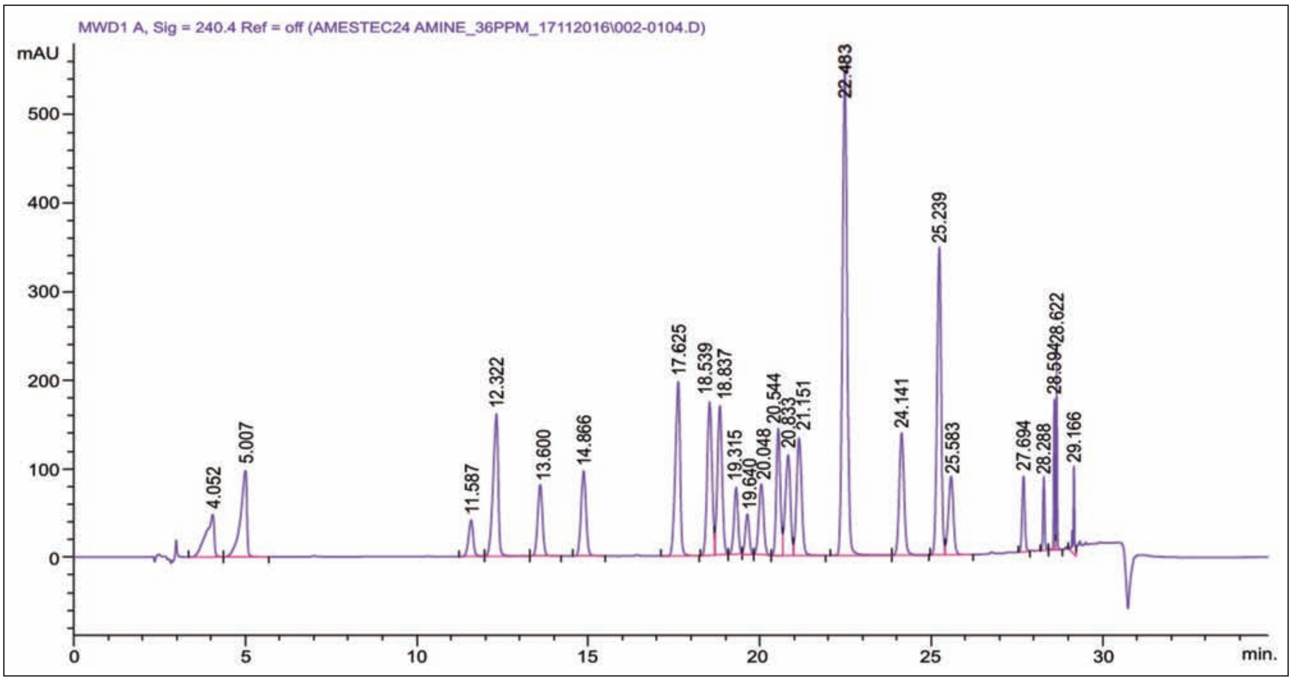

Fig. 5. Chromatogram of 24 amines mixture, concentration 36 ppm, detection at 240 nm

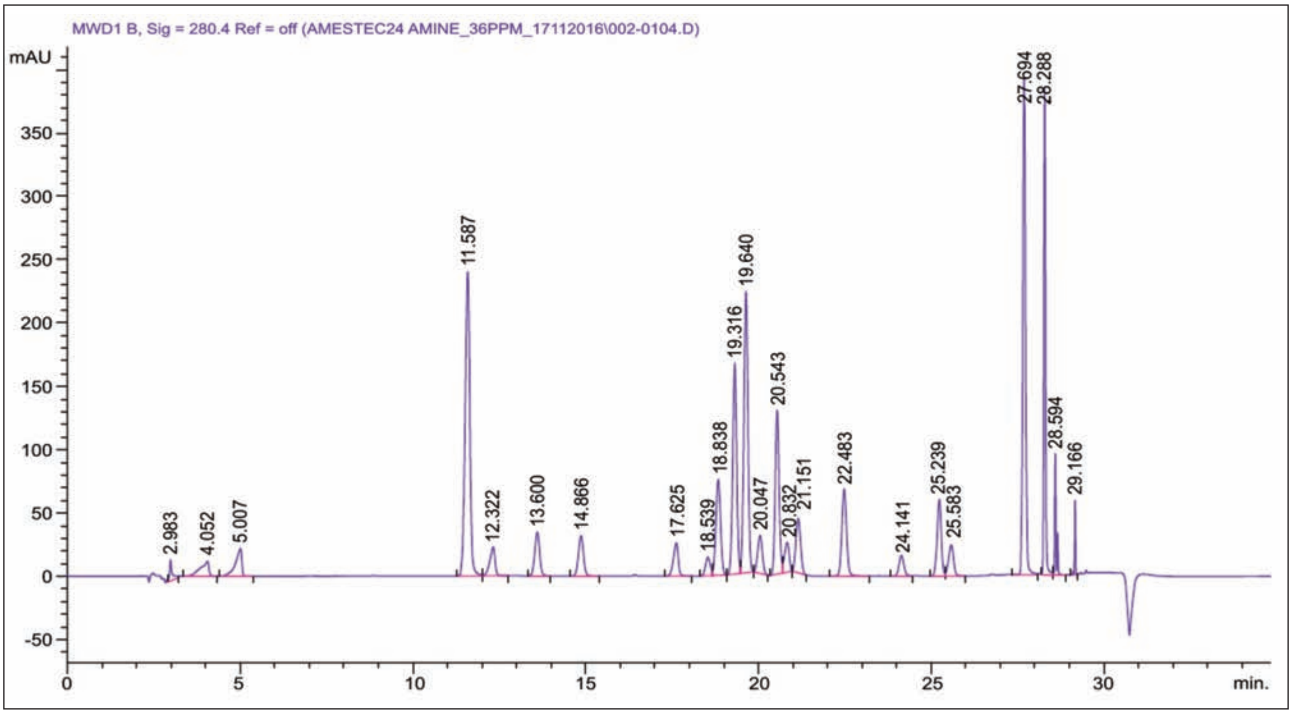

Fig. 6. Chromatogram of 24 amines mixture, concentration 36 ppm, detection at 280 nm

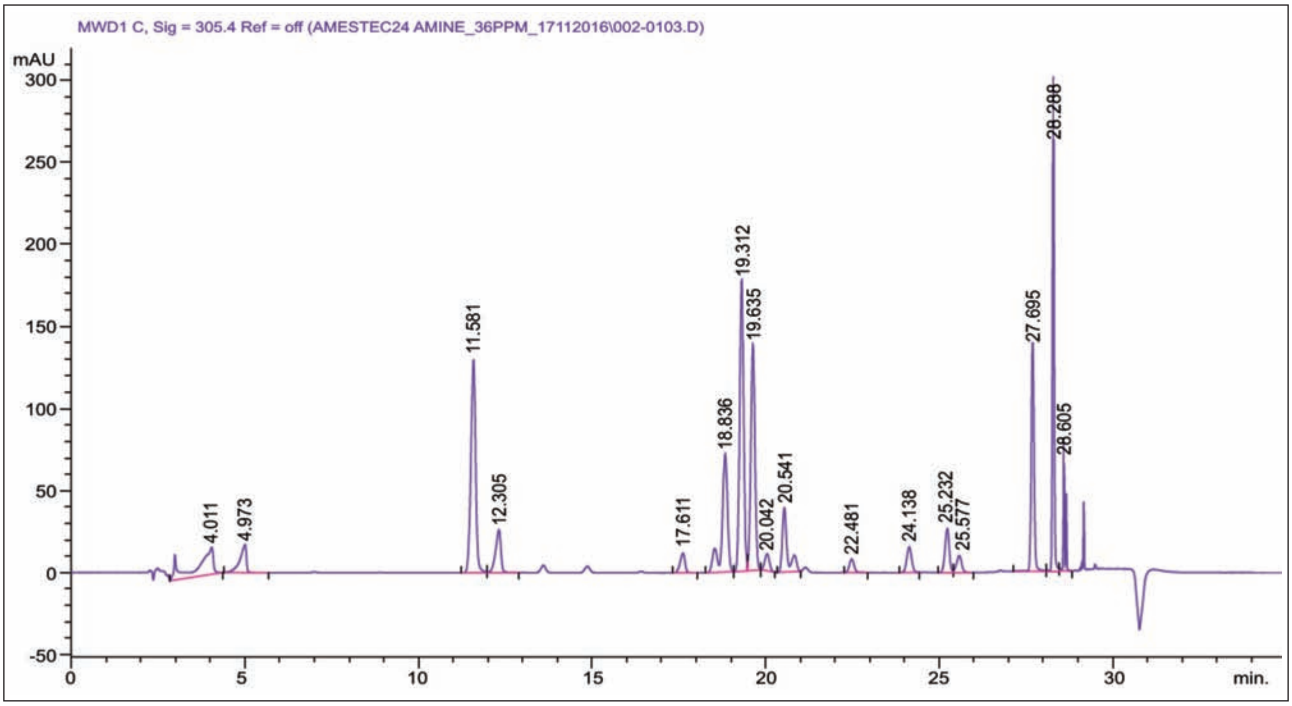

Fig. 7. Chromatogram of 24 amines mixture, concentration 36 ppm, detection at 305 nm

interlaboratory comparison with the Institute for Interlaboratory Studies in Spijkenisse, the Netherlands. In this study, 170 laboratories from 34 different countries participated. Two different samples of fabric were made available – a sample of cotton and a sample of polyamide, each dyed with azo dyes. In the cotton sample, 3,3'-dimethoxybenzidine aromatic amine was identified by the laboratory that organized the study, and in the polyamide sample the aromatic amines 3,3'-dimethylbenzidine and 2,4-xylidine were found.

The z score is calculated to evaluate the performance of the participating laboratories. For this determination, the calculated z score was our laboratory was –1.92, which is satisfactory according to literature [3] (figure 9).

For this determination, the calculated z score was –0.01 (good), indicating a good reproducibility of the method for determining the aromatics of textile materials (figure 10).

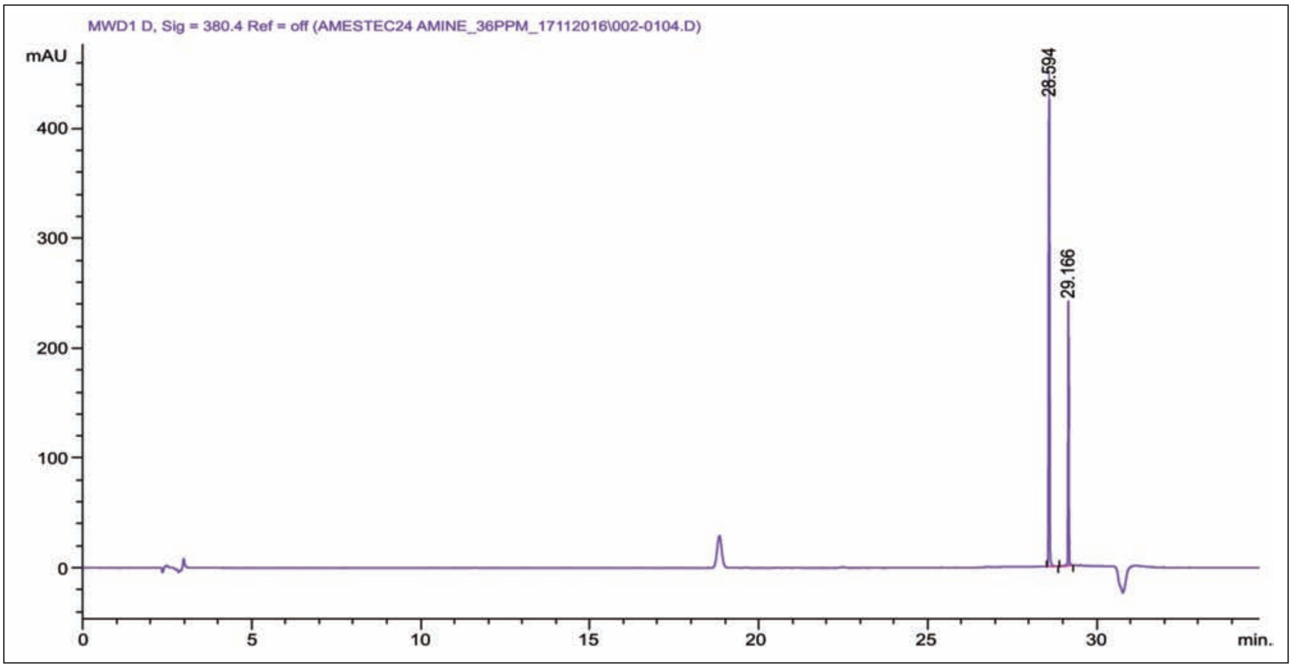

Fig. 8. Chromatogram of 24 amines mixture, concentration 36 ppm, detection at 380 nm

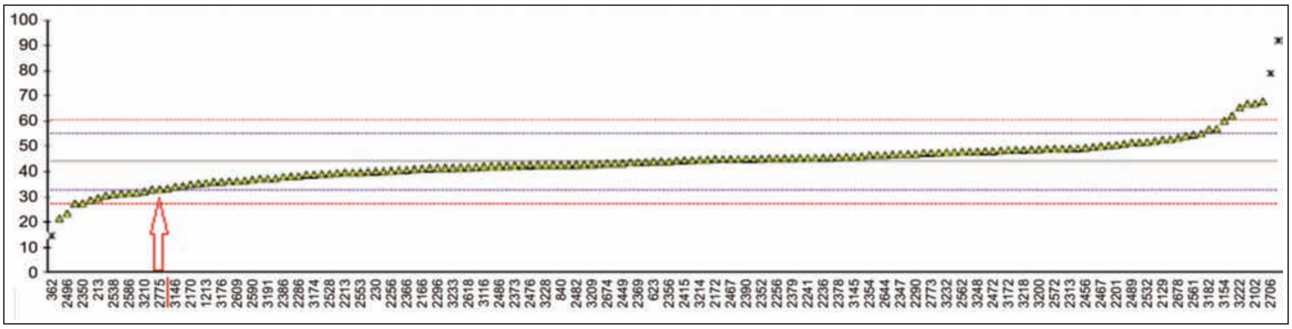

Fig. 9. Concentrations determined by the participating laboratories for 3,3'-dimethoxybenzidine in the cotton sample and positioning of our laboratory (code 2775) in the graph

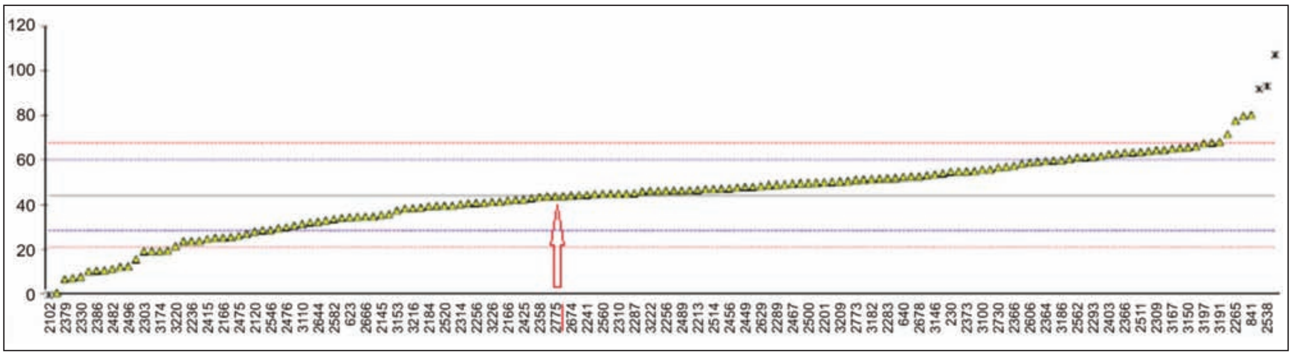

Fig. 10. Concentrations determined by the participating laboratories for 3,3'-dimethylbenzidine in the poliamide sample and positioning of our laboratory (code 2775) in the graph

The limit of detection (LOD) and limit of quantification (LOQ)

The limit of detection is the lowest value of the analyte concentration providing a signal (a chromatographic peak) at least equal to 3σ (σ – the standard deviation of the noise in the chromatogram baseline) [3].

The limit of quantification is the value of the concentration determined in the sample under well-specified measurement conditions with acceptable repeatability and accuracy.

To determine the detection limit, an injection of the 24 amine mixture was performed by both gas and liquid chromatography, of 6 independent blank samples fortified at the lowest acceptable concentration (3 ppm), measured once each. The values obtained for the detection limits of the 24 individual amines for the two

Table 4

Amine	Average conc. – HPLC [ppm]	s $_{HPLC}$	LOD $_{HPLC}$	Average conc. – GC [ppm]	s $_{GC}$	LOD $_{GC}$
Amine 8	2.9533	0.0404	**0.12**	3.7920	0.1809	**0.54**
Amine 19	2.1981	0.0316	**0.09**	4.0280	0.1859	**0.55**
Amine 16	2.9898	0.0298	**0.08**	4.0480	0.1571	**0.47**
Amine 21	3.0051	0.0137	**0.04**	3.3360	0.2140	**0.64**
Amine 18	3.0085	0.0143	**0.04**	3.4840	0.1534	**0.46**
Amine 9	2.9956	0.0281	**0.08**	3.9360	0.2459	**0.73**
Amine 7	2.9743	0.0176	**0.05**	3.5020	0.1480	**0.44**
Amine 6	2.9752	0.0178	**0.05**	3.8700	0.1339	**0.40**
Amine 14	2.9676	0.0169	**0.05**	3.4780	0.1770	**0.53**
Amine 17	2.9412	0.0239	**0.07**	4.1000	0.0780	**0.23**
Amine 23	3.0019	0.0188	**0.05**	4.4200	0.6325	**1.89**
Amine 24	2.9923	0.0198	**0.05**	4.3600	0.3145	**0.94**
Amine 3	3.0118	0.0364	**0.10**	3.4000	0.1476	**0.44**
Amine 13	2.9890	0.0191	**0.05**	4.3820	0.0538	**0.16**
Amine 20	3.0447	0.0217	**0.06**	3.7820	0.1541	**0.46**
Amine 15	2.9335	0.0150	**0.04**	4.3480	0.0567	**0.17**
Amine 2	2.9857	0.0212	**0.06**	3.9800	0.0738	**0.22**
Amine 12	2.9313	0.0479	**0.14**	4.2060	0.0550	**0.16**
Amine 1	2.9785	0.0265	**0.07**	4.2440	0.1183	**0.35**
Amine 10	2.9795	0.0202	**0.06**	4.2420	0.0412	**0.12**
Amine 11	2.9900	0.0226	**0.06**	3.8860	0.0898	**0.26**
Amine 5	2.9773	0.0169	**0.05**	3.9180	0.0979	**0.29**
Amine 22	3.0718	0.0213	**0.06**	3.9360	0.1179	**0.35**

Table 5

Amina	Average conc. – HPLC [ppm]	s $_{HPLC}$	LOQ $_{HPLC}$	Average conc. – GC [ppm]	s $_{GC}$	LOQ $_{GC}$
Amina 8	2.9533	0.0404	**0.40**	3.7920	0.1809	**1.80**
Amina 19	2.1981	0.0316	**0.31**	4.0280	0.1859	**1.85**
Amina 16	2.9898	0.0298	**0.29**	4.0480	0.1571	**1.57**
Amina 21	3.0051	0.0137	**0.13**	3.3360	0.2140	**2.13**
Amina 18	3.0085	0.0143	**0.14**	3.4840	0.1534	**1.53**
Amina 9	2.9956	0.0281	**0.28**	3.9360	0.2459	**2.45**
Amina 7	2.9743	0.0176	**0.17**	3.5020	0.1480	**1.47**
Amina 6	2.9752	0.0178	**0.17**	3.8700	0.1339	**1.33**
Amina 14	2.9676	0.0169	**0.16**	3.4780	0.1770	**1.77**
Amina 17	2.9412	0.0239	**0.23**	4.1000	0.0780	**0.77**
Amina 23	3.0019	0.0188	**0.18**	4.4200	0.6325	**6.32**
Amina 24	2.9923	0.0198	**0.19**	4.3600	0.3145	**3.14**
Amina 3	3.0118	0.0364	**0.36**	3.4000	0.1476	**1.47**
Amina 13	2.9890	0.0191	**0.19**	4.3820	0.0538	**0.53**
Amina 20	3.0447	0.0217	**0.21**	3.7820	0.1541	**1.54**
Amina 15	2.9335	0.0150	**0.14**	4.3480	0.0567	**0.56**
Amina 2	2.9857	0.0212	**0.21**	3.9800	0.0738	**0.73**
Amina 12	2.9313	0.0479	**0.47**	4.2060	0.0550	**0.54**
Amina 1	2.9785	0.0265	**0.26**	4.2440	0.1183	**1.18**
Amina 10	2.9795	0.0202	**0.20**	4.2420	0.0412	**0.41**
Amina 11	2.9900	0.0226	**0.22**	3.8860	0.0898	**0.89**
Amina 5	2.9773	0.0169	**0.16**	3.9180	0.0979	**0.97**
Amina 22	3.0718	0.0213	**0.21**	3.9360	0.1179	**1.17**

chromatographic methods are shown in table 4. We determined the values for limits of detection of aromatic amines according to the standard SR EN ISO 14362-1:2017 (table 4); by liquid chromatographic method with spectrophotometric detection HPLC-MWD, values are in the range of 0.04–0.14 mg/L and by the gas chromatographic method with mass selective detector GC-MS are in the range of 0.2–1.9 mg/L, which allows a precise detection of amines in the range of 2–50 mg/L (specified in standard method). The values of the limits of quantification for aromatic amines by liquid chromatographic method HPLC-MWD according to SR EN ISO 14362-1: 2017 are in the range of 0.1–0.5 mg/L, and by gas chromatography method are in the range of 0.4 to 2.5 mg/L, which allows quantification of amines at low levels of concentration (table 5).

CONCLUSION

In this study, some aspects relating to validation of a precise and reliable method for determining aromatic amines derived from banned azo dyes specific to the textile industry are presented; specific UV absorption wavelength for each compound has been identified and the performance characteristics for both HPLC-MWD and GC-MS methods specified in standard SR EN ISO 14362-1:2017 [10] have been determined for an accurate and reliable detection and quantification of multicomponent aromatic amines.

ACKNOWLEDGEMENTS

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Harness/container assembly for sport parachutes – A new concept

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REZUMAT – ABSTRACT

Ansamblul ham/container pentru parașute sport – Un nou concept

Lucrarea prezintă un nou concept de proiectare al ansamblului ham/container pentru parașute sport. Acest ansamblu poate fi folosit cu parașute de rezervă și parașute principale de diferite volume. Ansamblul va fi multifuncțional. Containerul este subansamblul care păstrează în cele două compartimente parașuta principală și parașuta de rezervă în stare pliată, împreună cu suspantele, dispozitivul de deschidere și parașuta extractoare. Hamul sau sistemul de suspensie asigură legătura dintre parașutist și voalură, susținand greutatea parașutistului.
În prezent, producătorii de containere pentru parașute sport realizează containere ale căror compartimente au un volum bine definit și sunt dedicate unui anumit tip de parașută cu același volum, în stare pliată, al compartimentului în care va fi introdusă.
Noul concept propune proiectarea și dezvoltarea unui ansamblu ham/container cu compartimente ce pot avea un volum variabil. Astfel este posibil să avem un container multifuncțional utilizabil cu voaluri de volume diferite în stare pliată.
„Această lucrare a fost realizată prin Programul-nucleu, derulat cu sprijinul ANCSI, proiect nr. PN 16 34 03 01”

Cuvinte cheie: container (capotă), compartiment, volum, parașută principală, parașută de rezervă.

Harness/container assembly for the sport parachute – A new concept

The paper presents a new design concept of the harness/container assembly for sport parachutes. It can be used with reserve parachutes and main parachutes of different volumes. So the assembly will be multifunctional. The container is the subassembly that keeps the main and reserve parachute canopies in a folded condition, together with the suspensions lines, the deployment device and the pilot chute in the reserve and main compartments. The harness, or suspension system, ensures the link between the parachute jumper and the canopies and supports the weight of the parachute jumper.
Currently, container parachute manufacturers produce containers whose compartments have a well-defined volume and dedicated to a particular type of parachute with the same volume in folded state.
The new concept consists in the design and development of a harness/container assembly with variable volume compartments. Thus it is possible to have a multifunctional container usable with canopies of different volume in a folded state.

Keywords: container, compartment, volume, main parachute, reserve parachute

INTRODUCTION

The ham/container assembly is an individual equipment for parachutist, representing the parachutist's safety system, controlling the deployment and opening of the parachutes. The harness/container assembly includes all the parts necessary to make the parachute to be able to fly. The basic harness/container assembly is what remains when all detachable subassemblies (without sewing) are removed. The container is the subassembly that holds the main and reserve parachutes in a folded state together with the suspension lines, the deployment device, if used, and the pilot chute. Containers for sport parachutes have 2 compartments each for each type of parachute: main and reserve. The main parachute is connected to the bottom compartment and the reserve parachute is connected to the top compartment.

The harness (suspension system) is the subassembly consisting of webbings, which is designed to conform to the shape of the body, it makes the connection between parachutist and the canopy, supports the weight of the parachutist, ensures the safety of the parachutist at the parachute opening force and uniformly distributes the weight of the load during the opening and descent. The sport parachute assemblies have the harness and containers integrated into one assembly [1].

Currently, the dimensions of the container compartments are designed and manufactured in different sizes to accommodate with the folded volume of the canopies. For example, ICON containers are designed and manufactured in 9 sizes for 9 different volumes of the reserve parachute and 9 different volumes of the main parachute, both in folded state [2]. Quasar II containers are designed and manufactured for 9 different volumes of the reserve parachute in folded state and for each reserve parachute between 1 and 4 volumes of the main parachute in folded state [3]. The container must be rigid, molded on the body and small enough to be circumvented by the airflow and allow complete freedom of movement.

The reserve parachute compartment is generally smaller, close-fitting, and especially in a cone trunk shape. The design of the reserve compartment must be made in such a way that, in the event of an incident, the reserve opens quickly. Designing the reserve parachute compartment can be done in two ways: with the pilot chute inside the container or outside. The design of the main parachute compartment is less restrictive than that of the reserve parachute. The main parachute compartment is in the parallelepiped shape. It is preferable to design a container that does not matter the order of closing the flaps or one in which the flaps cannot be closed incorrectly.

Container compartments must include the parachute opening bags. In these bags are folded in the "Free Bag" state parachutes, that is, they are extracted from the pilot chute, fall freely above the parachutist and keep locked up until the complete deployment of the suspension lines. Only after the suspensions lines are deployment, allows the parachute to start the swelling process.

A parachute assembly, in conformity with AC 105-2D, normally but not exclusively, consists of the following major components: a canopy, a deployment device, a pilot chute and/or drogue, risers, a stowage container, a harness, and an actuation device (ripcord).

EXPERIMENTAL WORK

Development of the harness/container assembly

When designing the container we considered the requirement for the correct opening of the parachute when the ripcord, the static line and the pilot chute or the AAD (opening device of the reserve parachute) are activated and the uninterrupted unfolding of the canopy.

In the design and construction of the harness the following requirements were imposed: to be comfortable to wear; to fit all people between 150 cm and 200 cm and 50 kg to 120 kg weight with winter clothing; the ripcord device to operate quickly and safely at an effort of up to 10 kg; body adjustments to be simple, visible and minimal; to support the body safely; the straps should not interfere with the flexible metal cable with any adjusting or automatic opening reinforcement button.

All assemblies and stitches have been designed to support the weight test.

The materials used in the manufacture of the assembly are standardized as parachute materials. In the assembly the main materials used were: 1000 denier Cordura fabric with 300 g/m^2, breaking strength of 300 daN and abrasion resistance of at least 50,000 cycles Martindale (MIL-C-43734, class 3) and for harness webbing with 43 mm width and 2700 daN breaking strength (PIA-W-4088).

Figure 1 shows the harness/container assembly developed and its subcomponents.

Calculation of container compartments volume

The aim of this research was to design and develop a harness/container multifunctional assembly with the variable volume compartments that can be used with reserve and main parachutes of different volumes and different types. More than 200 main canopies are available on the market, which implies an enormous challenge for container manufacturers about container size. Containers must be sized for

Fig. 1. The harness/container assembly and its subcomponents

Table 4

Parachute type		Producer	No. cells	Certified volume, cm^3
Reserve parachute	Swift 200	PARA-FLITE	5	6769
	Smart 220	AERODYNE RESEARCH	7	7572
	Smart 250	AERODYNE RESEARCH	7	7752
Main parachute	Skylark SK 190	SKYLARK	7	6785
	Solo 270	AERODYNE RESEARCH	9	8637
	Manta 290	ZP MANTA	9	9340

the canopies that enter them. Over dimensioning and under dimensioning can cause problems. Oversize can cause faster stitching and eyelets, and undersize can lead to premature openings caused by pins entering loops that are too slightly loaded.
The volume of the deployment bags and, implicitly, of the compartments of the container shall be calculated as follows:
a) the rectangular bag of the main parachute

$$A_B \cdot h \quad (1)$$

b) the truncated cone bag of the reserve parachute

$$h / 3(A_B + A_b) + \sqrt{(A_B \cdot A_b)} \quad (2)$$

where:
A_B is the large base area of the parallelepiped or truncated cone;
A_b – the small base of the truncated cone;
h – the height of the parallelepiped and the truncated cone.
To achieve the proposed aim, the main parachute compartment was designed with the possibility of a variable h, and for the reserve parachute compartment the variation of the length of the reserve parachute closing loop. To be noted that the volumes of parachutes with the same surface, in the folded state, may vary depending on the type of canopy fabric and the type of the suspension lines. So, for the same surfaces 15.77 m^3, different canopies have different volumes, e.g. 6,064 cm^3 (Micron 175), 6,146 cm^3 (Laser 5) and 6,425 cm^3 (Bogy 178-R). The difference comes from the type of suspension lines, e.g. Kevlar (Micron 175), Dacron (Laser 5) and Spectra (Bogy 178-R) and from the fabric type (weight per square meter, air permeability, soft or stiff handling).

Materials and volume testing method

For the testing of the variable volumes of the multifunctional container we used reserve parachutes and main parachutes of different volumes, provided by the Romanian Air club. The volume of the parachute compartment was tested using Swift 200 [4], Smart 220 and Smart 250 [5], with manufacturer certified volumes. Skylark MA 190 [6], Solo 270 [7] and Manta 290 [8] were used as main parachutes.
The characteristics of the parachutes used in testing the volumes of the multifunctional container compartments are shown in table 1.

RESULTS

The container compartment for reserve parachute was closed correctly with all three types of parachutes that were tested. The length of the closing loop, figure 2, of reserve compartment for each type of reserve parachute is the following:
Swift 200 parachute: 10,5 cm.
Smart 220 parachute: 12,5 cm.
Smart 250 parachute: 14,5 cm.
The handle command works correctly and the reserve parachute opens easily and correctly.
The container compartment for the main parachute was closed correctly with all three types of parachutes. The volume of the main compartment can be easily varied by using the extra volume from the created pocket.
At the flight testing the reserve parachute and the main parachute were correctly opened. There was no damage to the fabric and stitches of the container and harness.

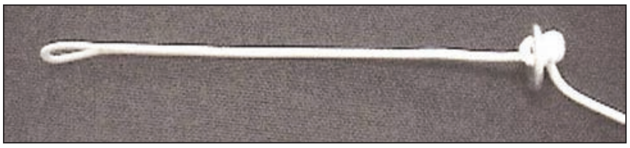

Fig. 2. The reserve closing loop

CONCLUSIONS

The new concept of the multifunctional container is functional. It allows:
– equipping with reserve parachutes of different types and with volumes within the limits 6769 cm^3 minimum and 7752 cm^3 maximum;
– equipping with main parachutes of different types and volumes within the limits 6785 cm^3 minimum and 9340 cm^3 maximum.
The advantage is quantified in the parachute clubs/schools that purchase the multifunctional container that can be used with different parachutes in the endowment.
The proposed solution is patented pending.

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