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The effect of N-tetradecyl-N,N-dimethyl-3-ammonio-1-propanesulfonate addition on washing properties of liquid laundry detergents

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ABSTRACT – REZUMAT

The effect of N-tetradecyl-N,N-dimethyl-3-ammonio-1-propanesulfonate addition on washing properties of liquid laundry detergents

The use of colorimetric analysis based on a CIELab system to determine detergency of commercial liquid laundry detergents before and after modification with SB3C14 sulfobetaine (N-tetradecyl-N,N-dimethyl-3-ammonio-1-propanesulfonate) is presented. The EMPA 101 standard cotton fabric soiled with carbon black and olive oil was used in washing tests under the following conditions: temperature 40°C, rotational speed 200 rpm, 30 minute washing cycle, water hardness 5.35 mval/l, the concentration of liquid laundry detergents 1.25–50 g/l. The physicochemical analysis of colour, form, odour, pH, density, viscosity and content of anionic surfactants showed compliance with the manufacturers' declarations. The studies demonstrated that with increasing laundry detergent concentration a gradual increase in detergency occurred. At the highest tested concentrations of 50 g/L, detergency of 18.1% and 22.2% for cheaper L1 and more expensive L2 products was achieved, respectively. Modification with the 5% addition of the zwitterionic sulfobetaine SB3C14 led to an improvement of the washing properties by 4.7% on average. At a concentration of 50 g/l, the modified L1 and L2 solutions demonstrated the highest detergency equal to 22.8% and 35.3%, respectively. This proves the existence of synergistic effect by the interaction of all ingredients in the solutions with higher concentrations. Microscopic analysis of EMPA 101 fabrics before and after washing processes showed no serious damage to the fibres, only the presence of slight fraying of individual ones. The results suggest that the SB3C14 sulfobetaine can be successfully used in liquid laundry detergents due to its very favourable surface properties.

Keywords: *surfactants, zwitterionic sulfobetaine, detergency quality, liquid laundry detergents, colorimetric analysis*

Influența adaosului de N-tetradecil-N, N-dimetil-3-amonio-1-propanesulfonat asupra proprietăților detergenților lichizi pentru rufe

Se prezintă utilizarea analizei colorimetrice bazată pe un sistem CIELab pentru a determina capacitatea de curățare a detergenților lichizi comerciali pentru rufe înainte și după adăugarea de SB3C14 sulfobetaină (N-tetradecil-N, N-dimetil-3-amonio-1-propanesulfonat). Materialul textil din bumbac EMPA 101 impregnat cu negru de fum și ulei de măsline a fost utilizat în testele de spălare în următoarele condiții: temperatura 40°C, viteza de rotație 200 rpm, ciclul de spălare de 30 de minute, duritatea apei 5,35 mval/l, concentrația detergenților lichizi pentru rufe 1,25–50 g/l. Analiza fizico-chimică a culorii, formei, mirosului, pH-ului, densității, viscozității și conținutului surfactanților anionici a arătat conformitatea cu declarațiile producătorilor. Studiile au demonstrat că odată cu creșterea concentrației de detergent pentru rufe a avut loc o creștere treptată a capacității de curățare. La concentrații ridicate de 50 g/l, s-a obținut o capacitate de curățare de 18,1% și 22,2% pentru produsele L1 mai ieftine și, respectiv, pentru produsele L2 mai scumpe. Adăugarea de 5% a sulfobetainei zwitterionice SB3C14 a condus la o îmbunătățire a proprietăților de spălare cu o medie de 4,7%. La o concentrație de 50 g/l, soluțiile L1 și L2 modificate au înregistrat cea mai ridicată capacitate de curățare, egală cu 22,8%, respectiv 35,3%. Aceasta dovedește existența unui efect sinergic prin interacțiunea tuturor ingredientelor din soluțiile cu concentrații mai ridicate. Analiza microscopică a materialelor textile EMPA 101 înainte și după procesele de spălare nu a arătat nicio deteriorare gravă a fibrelor, ci doar prezența unei ușoare destrămări a celor individuale. Rezultatele sugerează că sulfobetaina SB3C14 poate fi utilizată cu succes în detergenții lichizi de rufe datorită proprietăților sale de suprafață.

Cuvinte-cheie*: surfactanți, sulfobetaină zwitterionică, capacitatea de curățare, detergenți lichizi pentru rufe, analiză colorimetrică*

INTRODUCTION

Surfactants are one of the most important organic substances, used in large amounts in domestic and industrial applications, such as topical pharmaceutical formulations, antiseptics, cosmetics, shampoos, detergents, creams or lotions. Surface active agents are for to their amphiphilic properties used as emulsifers, suspending, wetting, solubilizing and stabilizing substances. Both ionic and nonionic surfactants are used. In this paper we will focus on a particular group of the compounds – zwitterionic surfactants and their potential application in liquid detergents. They contain both positively and negatively charged hydrophilic groups and the property leads to large dipole moments for zwitterionic surfactant molecules with hydrophilicites intermediate between ionic and nonionic surfactants [1]. Zwitterionic surfactants are mild to eyes and skin, exhibit very low toxicity [2], have a high foam stability and resistance to hard water and to degradation by oxidizing and reducing agents than many ionic surfactants [3–5]. Moreover, the temperature and the addition of electrolytes have little influence on their solution properties. Due to these useful properties, zwitterionic surfactants are often combined with anionic or cationic surfactants in many consumer products [6–8]. One of the most interesting properties of the zwitterionic surfactants is a strong interaction or complex formation with anionic surfactants, which is significant for the practical applications. Anionic surfactants are the main component for their detergency and foaming properties, and additionally the zwitterionics can act as a booster [9, 10]. In recent years, mixed nonionic/ionic, nonionic/nonionic, and ionic/ionic surfactant mixtures have been studied and reported in the literature [11–13].

Betaine surfactants are an important kind of zwitterionic surfactants and they are widely used as boosters in hair conditioners or shampoos, because they can stabilize foams against the antifoaming action of oil droplets [14]. Compared to other surfactants, betaines have many excellent advantages, such as high interfacial activity at low concentrations [15–18]. They can reduce the interfacial tension to an ultralow value within a wide concentration range (0.005–0.3%) [19, 20]. Sulfobetaines belong to surfactants that contain both amino and sulfonate groups. The compounds are divided into several subgroups differing the length and structure of the hydrocarbon chain, which separates the quaternary ammonium centre from the sulfonate group [21, 22].

Sulfobetaines have higher surface activity than betaine ones [23] and exhibit amphoteric properties at all pH values, thus they adsorb to charged surface at all pH values without forming a hydrophobic film [24]. The literature shows that sulfobetaines are widely used in industries concerned with adhesives, textiles, coatings, flocculants, dispersion agents, surfactants, protective colloids, hair conditioners, shampoos, etc. [25–27].

In this study, zwitterionic sulfobetaine N-tetradecyl-N,N-dimethyl-3-ammonio-1-propanesulfonate (SB3C14) has been chosen to examine its washing properties when added to liquid laundry detergents. The interaction of the sulfobetaine with other surfactants and components has not been studied and reported yet. Especially it is necessary to investigate the synergistic effect of the combined substances to demonstrate positive or negative changes in their surface properties.

EXPERIMENTAL SECTION

Materials

Liquid laundry detergents were selected on the Polish market due to their price category: cheap (L1) and expensive (L2). Their composition and gross sales prices are presented in table 1.

In these studies, the liquid laundry detergents were modified with the amphoteric surfactant: sulfobetaine N-tetradecyl-N,N-dimethyl-3-ammonio-1-propanesulfonate (formula: $C_{19}H_{41}NO_3S$; abbreviation: SB3C14; molecular weight 363.6 g/mol; solubility in water is 50 mg/mL; melting point 245°C; flash point 110°C; topological polar surface area 65.6 $Å^2$) in the amount of 5% (m/m). The compound was synthesized in our laboratory [28] based on the literature [21, 22]. The crystalline substances were separated from the reaction mixture by filtration and next purified by the recrystallization process. Finally, white SB3C14 solids were obtained with high purity (99.9%) and yield and taken into this research. Thermodynamic and surface parameters of the SB3C14 sulfobetaine at different temperatures are listed in table 2 [29]. The surface tension at temperature 25°C (for critical micellar concentration (CMC) = 0.377 mmol/l) is 31.8 mN/m. The measurements of surface tension were conducted using the drop-volume method in a water thermostat control at temperature range 25–45°C in

Table 1

TESTED COMMERCIAL LIQUID LAUNDRY DETERGENTS

Liquid laundry detergents	Compositions based on manufacturer's information	The retail price range of detergents (euro/l)
L1	5–15% ethoxylated (EO 9) fatty alcohol (C_{12}–C_{18}), 5–15% sodium lauryl (C_{12}–C_{14}) ether (EO 2) sulfate, 5–15% soap, <5% phosphates, enzymes, fragrance (benzyl salicylate, hexyl cinnamal, butylphenylmethylpropional), preserving agents (1,2-benzisothiazolin-3-one, 2-methyl-4-isothiazolin-3-one)	1.7–2.0
L2	5–10% sodium dodecylbenzenesulfonate, 1–5% sodium dodecylpoly(oxyethylene) sulphate ($C_{14}H_{29}NaO_5S$), 1–5% (C_{10}–C_{16})alkyl benzenesulfonic acid - monoethanolamine salt, 1–5% ethoxylated (EO 7) fatty alcohol (C_{14}–C_{15}), <1% hexyl salicylate, phosphonates, soap, enzymes, preserving agents (1,2-benzisothiazolin-3-one, 2-methyl-4-isothiazolin-3-one), fragrance (α-isomethyllonone, butylphenylmethylpropional, citronellol, geraniol, linalool)	3.6–3.9

Table 2

THERMODYNAMIC AND SURFACE PARAMETERS OF MICELLIZATION FOR SB3C14					
Temperature (°C)	**ΔG°_{mic} (kJ/mol)**	**ΔH°_{mic} (kJ/mol)**	**ΔS°_{mic} (kJ/mol×K)**	**$-T\Delta S^{\circ}_{mic}$ (kJ/mol)**	**CMC (mmol/l)**
25	–29.505	–28.611	0.003	–0.894	0.377
30	–29.520	–16.333	0.044	–13.187	0.456
35	–29.940	4.265	0.111	–34.205	0.468
40	–30.630	15.090	0.146	–45.720	0.433
45	–31.400	17.595	0.154	–48.995	0.389

a time range of 5 to 50 minutes up to a state of equilibrium. Then, the surface tension (γ) was calculated according to the equation 1:

$$\gamma = \frac{F V \Delta p g}{R} \quad (1)$$

where R is the tip's radius, Δp – the difference of the two phases, g – the local gravity acceleration, V – the volume of one drop, $F(R/V)^{1/3}$ – a correction factor that takes into account the drop's non-sphericity. The CMC were signified from the sudden change in the slope of γ versus Log C plot. The thermodynamic values of micellization (free energy ΔG°_{mic}, enthalpy ΔH°_{mic}, entropy ΔS°_{mic}) were estimated according to the equations 2–4:

$$\Delta G^{\circ}_{mic} = RT \ln CMC \quad (2)$$

$$\Delta H^{\circ}_{mic} = \Delta G^{\circ}_{mic} + T\Delta S^{\circ}_{mic} \quad (3)$$

$$\Delta S^{\circ}_{mic} = (\delta \Delta G^{\circ}_{mic} / \delta T) \quad (4)$$

All the solutions of liquid laundry detergents applied in the research were prepared using deionized water at hardness 5.35 mval/l, which was prepared by mixing hydrated calcium chloride with hydrated magnesium sulphate(VI) in certain proportions in accordance with Polish Standard PN-C-77003. The EMPA 101 fabric (cotton soiled with carbon black and olive oil) and EMPA 210 (cotton fabric, pattern, bleached, without stains) were obtained from the company EMPA Testmaterialien AG plant (Switzerland). EMPA swatches were stored at room temperature (23±1°C) in dark polypropylene foil in an desiccator in order to keep samples dry and under normal pressure. EMPA fabrics meet all the requirements of the model fabrics and are suitable for washing tests. Carbon particles present in the fibres are chemically neutral and do not form any strong physical or chemical bonds with cotton fibres, which could interfere with their removal. The size of carbon particles is very small (~ 0.1 μm) and their diffusion coefficient for aqueous solutions (calculated from the Stokes-Einstein equation) is about ~10^{-12} m^2/s [30]. The construction parameters of the fabrics are shown in table 3.

Methods

Evaluation of colour, form and odour of liquid laundry detergents, determination of density by picnometry, pH measurements (pH meter HI 221, Hanna Instruments), viscosity using Höppler viscometer (KF-20, Brookfield) were carried out in accordance with the literature and Polish standards [31–35]. Determination of anionic surfactants content in liquid detergents was carried out using a direct manual two-phase titration method [36]. The structure analysis was performed by a Fourier transform attenuated total reflection (FT-IR ATR) using Spectrum 100 (Perkin-Elmer, Waltham, USA).

Detergency experiments were carried out using EMPA 101 cotton fabric soiled with carbon black and olive oil under the following conditions: 40°C, rotational speed 200 rpm, 30 minute washing cycle, water hardness 5.35 mval/l, the concentration of liquid laundry detergents ranged from 1.25 to 50 g/L, the concentration of SB3C14 added was 5% (m/m). During each process three EMPA 101 swatches (5×5 cm) were washed in detergent solutions (500 mL) under the same conditions [37–39]. After washing processes fabric samples were rinsed in deionized water and dried at room temperature (23±1°C) for 24 hours. The colour measurements were carried out in the CIELab (CIE – *Comission Internationale de l'Eclairage*) colour space using a colorimeter Minolta CR-300 (Konica Minolta). Calibration parameters for

Table 3

CONSTRUCTION PARAMETERS OF TESTED COTTON FABRICS EMPA 101 AND EMPA 210										
Cotton fabrics	**Sample mass 5×5 cm (g)**	**Thickness (mm)**	**Surface mass (g/m^2)**	**Linear mass of a single thread (g/m, tex)**	**Relative water absorption capacity (%)**	**Absolute water absorption capacity (g/m^2)**	**Mass of warp threads (g/m^2)**	**Count of warp (pcs/cm)**	**Mass of weft threads (g/m^2)**	**Count of weft (pcs/cm)**
EMPA 101	0.231±0.003	0.16±0.01	91.08±0.8	9±0.001	144.4±1.2	132.3±1.1	54.6±0.1	50	39.8±0.1	43
EMPA 210	0.468±0.002	0.29±0.01	180.2±0.7	33±0.04	129.4±0.9	231.9±1.3	104.6±0.1	27	78.5±0.1	22

a light source D_{65} were as follows: Y = 94.0, x = 0.3174, y = 0.3330. The system of coordinates was designated as L^*, a^* and b^*. The symbol L^* is the vertical coordinate of a three-dimensional system of colours, which has values from 0 (black) to 100 (for white). The symbol a^* is the horizontal coordinate the values of which range from –80 (green) to +80 (red), and b^* is the horizontal coordinate, the values of which range from –80 (blue) to +80 (yellow). Colour coordinates are calculated by the following equations 5–7:

$$L^* = 116(Y/Y_0)^{1/3} - 16 \quad (5)$$

$$a^* = 500\left[(X/X_0)^{1/3} - (Y/Y_0)^{1/3}\right] \quad (6)$$

$$b^* = 200\left[(Y/Y_0)^{1/3} - (Z/Z_0)^{1/3}\right] \quad (7)$$

The values X_0 = 94.81, Y_0 = 100.0 and Z_0 = 107.3 are standardized values, which are related to a theoretical ideally white specimen [40, 41, 44, 45].

The colour measurements were repeated 10 times for two sides of each sample. Colour differences ΔE between the sample (EMPA 101) and the reference (EMPA 210) was determined based on the measured L^*, a^*, and b^* values according to the equation 8:

$$\Delta E = \sqrt{(\Delta L)^2 + (\Delta a)^2 + (\Delta b)^2} \quad (8)$$

Depending on the parameter ΔE visible differences in change in the colour are described in table 4 [42]. Detergency D [%] was calculated according to the equation 9:

$$D = \left[\frac{(\Delta E - \Delta E_1)}{(\Delta E_0 - \Delta E_1)}\right] \times 100\% \quad (9)$$

Table 4

DEGREES OF COLOUR CHANGE DUE TO THE ΔE PARAMETER

Values of parameter ΔE	**Assessment of colour change by a standard observer**
$0 < \Delta E < 1$	A standard observer cannot see the colour difference
$1 < \Delta E < 2$	Only an experienced observer can see the colour difference
$2 < \Delta E < 3.5$	An inexperienced observer can see the colour difference
$3.5 < \Delta E < 5$	An observer (everyone) can see the colour difference clearly
$5 < \Delta E$	An observer can see two distinct colours

The values ΔE and ΔE_1 denote the average colour difference (degree of brightness) of the fabric sample after and before washing, respectively, and ΔE_0 is the average colour difference of the standard unsoiled fabric sample as a reference. Detergency D [%] means the efficiency of removing soil from fabrics.

The fabric swatches were observed before and after detergency processes using the Amplival microscope (Carl Zeiss Jena, Germany) and a EVO40 scanning electron microscope (SEM) (Carl Zeiss, Germany), which is equipped with a secondary electron (SE) detector and a backscattered electron detector–extended variable pressure (BSD–XVP).

RESULTS AND DISCUSSION

To begin with, the SB3C14 amphoteric sulfobetaine was synthesized and next characterized by FT-IR spectroscopy. The following peaks were observed at the FTIR spectrum: 914 cm^{-1}, 941 cm^{-1} (nitrogen group C–N, stretching), 1032 cm^{-1} (sulfonate group S–O, stretching), 1196 cm^{-1} (sulfonate group S=O, asymmetric stretching), 1468 cm^{-1} (nitrogen group CH_3–(N^+), bending), 2851 cm^{-1} (symmetric CH_2, stretching), 2918 cm^{-1} (asymmetric CH_2, stretching). Similar results were reported by Viana et al. and the following bands were shown: 2944 cm^{-1} (ν_{as} CH_3), 2873 cm^{-1} (ν_{sym} CH_3), 2954 cm^{-1} (ν_{sym} N–CH_3), 2920 cm^{-1} (ν_{as} CH_2), 1465 cm^{-1} (δ CH_2), 1378 cm^{-1} (CH_2 umbrella mode), 1402 cm^{-1} (δ_{sym} N–CH_3), 912 cm^{-1} (ν C–N stretching), 1133–1280 cm^{-1} (ν_{as} SO_2), 1038 and 1058 cm^{-1} (ν_{sym} SO_2) [43]. Based on the findings, there is no ν_{as} CH_3 vibration when the packing density is larger than 10^{17} molecules/cm^2. In case higher densities, only a band in 2954 cm^{-1} related to the ν_{sym}N–CH_3 is revealed. In our analysis a peak in 2918 cm^{-1} is present and it is an indicative of a crystalline conformation. The CH_2 asymmetric stretching and the CH_2 scissoring vibration are dependent on the SB3C14 packing density. On the other hand, the CH_2 symmetric feature is not linearly dependent on the sulfobetaine packing density. The 1300–1400 cm^{-1} region, in which peaks are related to the *d-g* and *e-g* conformation, is characterized by the CH_2 wagging deformations. The 900–1000 cm^{-1} region contains ν C–N stretching for packing densities larger than 10^{16} molecules/cm^2. The $\nu_{as}SO_2$ peaks are present for densities lower than 10^{16} molecules/cm^2 in the range of 1133–1280 cm^{-1}. The $\nu_{sym}SO_2$ bands in 1038 and 1058 cm^{-1} are noticed for densities larger than 10^{17} molecules/cm^2. Additionally, the interaction between the H_3O^+ ion and the sulfonate group may appear and consequently a split for the $\nu_{sym}SO_2$ mode is reported [43].

Selected physical and chemical properties were determined and the results are presented in table 5. The results proved to be in line with declarations of the detergents manufacturers. After the addition of SB3C14 (5%, m/m), a slight change in colour, odour, pH, density and viscosity was observed.

The standard EMPA 101 fabrics have been washed using liquid laundry detergents before and after modification with SB3C14. Based on the colorimetric measurements of colour change of EMPA fabrics, the calculated ΔE values were observed to be higher than 5. Thus, in accordance with table 4, the observer was able to see two distinct colours during comparative analysis of samples before and after washing processes. Nevertheless, modification did not cause changes to the extent enabling the observer to see the colour differences with unaided eye, hence only colorimetric measurements could provide this detailed information. The results showed that as the concentration of detergents solutions increases (form 1.25 to 50 g/l), detergency also increases (figure 1). However, no detergent was able to completely remove the carbon black and olive oil dirt from the fabrics. The applied dirt is difficult to remove and often used as a standard during the research on detergency at many research centres. At the highest tested concentrations of 50 g/l, only the detergency of 22.2% (L2) and 18.0% (L1) was achieved. The more expensive L2 product showed better washing properties than the less expensive L1 one.

Modification of commercial liquids with the SB3C14 sulfobetaine added improved detergency. Figure 1 shows a steady upward trend as concentration increases. The best washing performance (35.3%) was observed for the L2 solution modified with SB3C14 at a concentration of 50 g/l. The modified L1 liquid has better detergency in the initial concentration range from 1.25 g/l to 20 g/l. Only at the concentration greater than 20 g/l, the addition of SB3C14 had a more favourable effect on the efficiency of the L2 solution. The synergism of action of all the components of the liquid detergents was strengthened at a greater concentration in the washing solution. The addition of SB3C14 (5%, m/m) to the products resulted in an increase in detergency by 4.7% on average. It can be stated that enriching the detergent composition with the addition of an amphoteric surfactant has a positive effect on the efficiency of removing dirt from cotton fabric.

The process of removing dirt in a washing solution is divided into several stages. This starts with wetting and penetrating the fabric fibres along with the impurities present on it with a detergent solution that is able to reduce the interface tension. Wetting can occur quickly and efficiently if the interfacial tension is reduced by surfactants to 30 mN/m or lower value [50]. Thanks to surfactants, the dirt layer is well wetted and evenly covered with an aqueous solution.

Penetration of impurities is facilitated by solubilizing surfactants, sequestrants, alkaline compounds or acids by selective elution of dirt components, causing erosion of its compact layer and facilitating the penetration of the washing solution deep into dirt. Water, solubilizers and organic solvents, interacting with alkalines, increase the volume and softness of dirt as a result of penetrating the dirt structure, which facilitates the removal of dirt from the surface. In the second stage, the active ingredients are adsorbed on the surface of the fabric fibres and penetrate the structure of the impurities. Active ingredients, having a high affinity for active centres of the washed surface, adsorb more strongly than dirt, facilitating its removal. In the third stage, solid carbon black dirt is dispersed. Contaminants are thoroughly surrounded by surfactants and released from the adjacent surface (*"rolling-up"* phenomenon). The dirt sphere stays in the washing solution all the time and prevents it from settling on the fabric again. The surface of the fabric is also covered entirely by surfactants. This increases the negative electrostatic charge of dirt and fabric, making them more repulsive. The aqueous alkali solution penetrating deep into the impurities causes alkaline hydrolysis reactions. As a result, the cohesion decreases and the dirt solubility increases. The result is an emulsion/dispersion consisting of an aqueous solution and dirt particles surrounded by surfactants (the last stage). The solution is then removed and the fabric washed out of the emulsion/dispersion residues and detergent components [50, 51].

In the aqueous solution, the carbon black particles contain both hydrophobic and hydrophilic groups that can provide steric or electrostatic interaction with amphiphilic particles. The attraction of hydrophobic particles is stronger to the fibre surface than that of hydrophilic ones, probably due to coulombic attraction. Another important aspect of soil removal is the surface energy of the fabric substrate. Cellulose in cotton fabrics has high surface energy (as well as high critical surface tension) for wetting in air, however, it has low surface energy for wetting in water. Therefore, cellulose exhibits high resistance to wet soiling by hydrophobic dirt that also means its easy

Table 5

RESULTS OF PHYSICO-CHEMICAL MEASUREMENTS

Properties (T = 23±1°C)	**L1**	**L1 + SB3C14**	**L2**	**L2 + SB3C14**
Colour	white, milky, opaque	white brighter, more intense	green-blue, opaque	green-blue brighter, opaque
Physical state	liquid	liquid	liquid	liquid
Odour	less pleasant, slightly irritating	less pleasant, slightly irritating	pleasant	pleasant
pH	8.51 ± 0.03	8.87	8.26 ± 0.03	8.57
Density [g/ml]	1.01 ± 0.0006	0.93	1.06 ± 0.0004	0.95
Viscosity coefficient η (mPa • s)	349 ± 4,3	—	186 ± 3,8	—
Content of anionic surfactant (%)	6,62 ± 0.07	—	10.28 ± 0.08	—

removal during washing processes [52]. Carbon black has an acid-base character, hence the surface groups present on its surface may gain or lose a proton depending on the pH of the aqueous solution. Some investigators observed that the isoelectric point (IEP) of carbon particles in water is achieved at about pH 6.5 when the zeta potential $\zeta = 0$ (the net surface charge is zero) [53, 54]. At higher pH values the surface charge becomes negative. In the present studies, pH of L1 and L2 washing solutions was equal to 8.51 and 8.26, respectively. At this pH, the negatively charged surface of carbon particles attracted the head groups of cationic surfactants during the adsorption. Amphoteric sulfobetaine SB3C14 at pH > 8 takes on a negative electrostatic charge.

Thanks to this, in washing bath SB3C14 repels the negatively charged carbon black particles on the fibres in accordance with the *"roling-up"* mechanism. In addition, low interfacial tension of SB3C14 promotes the wetting and dirt removal process of the fibre surface. The above interpretation can probably explain the increased amount of carbon black removed after adding the sulfobetaine to the washing solution.

The assessment of the structure of fabric fibres before and after the washing process was carried out using an optical microscope and SEM. Figure 2 shows the fabrics EMPA 210 (100% cotton, white, not soiled) and EMPA 101 (100% cotton, soiled with carbon black and olive oil) before the washing process.

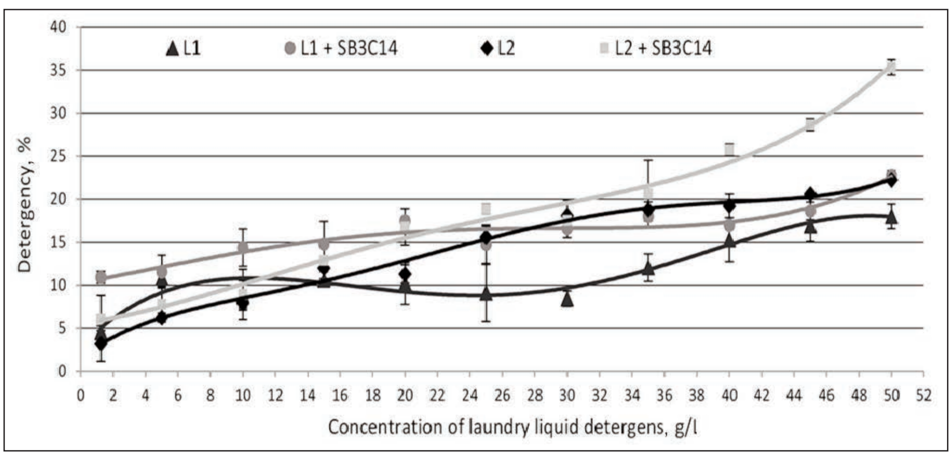
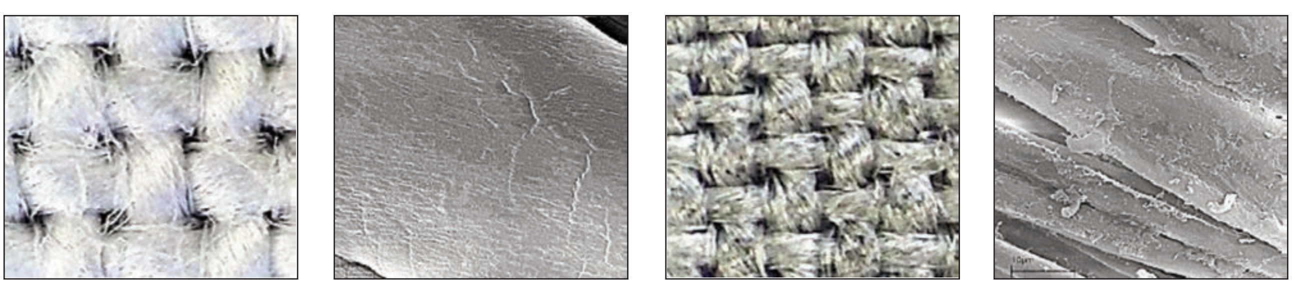


Fig. 1. Detergency of liquid laundry detergents (L1, L2) before and after modification with SB3C14

Weft and warp threads are arranged in an orderly manner and only slight pilling is visible. The SEM images showed no pilling or damage to individual threads. Figures 3 and 4 show samples of EMPA101 fabric after washing processes in L1 and L2 laundry liquids before and after modification (at concentrations of 1.25 g/l, 20 g/l, 25 g/l, 35 g/l, 50 g/l). At a microscopic approximation of 359x, no serious fabric damage was found in the concentration range tested. However, SEM images showed damage in the form of single fibre delamination. Moreover, it was observed with the unaided eye that few pilling appeared on the samples after washing processes. One reason may be the movement of the agitator blades, rubbing against the surface of the fabric during the process.

Figures 5 and 6 show FT-IR spectra of EMPA 101 cotton fabrics before and after washing processes using tested detergents. As it is seen, both spectra are very similar and typical bands of cellulose, lignin and hemicellulose are revealed. The strong peak at 3333.9 cm^{-1} is typical for the stretching vibration of hydroxyl groups present in cellulose, lignin and water [46]. The peak at 2899.8 cm^{-1} is related to the stretching vibration of C–H present in hemicellulose and cellulose [47]. The peak at about 1620 cm^{-1} is characteristic for water present in the fibres [48]. The peak at 1428 cm^{-1} refers to CH_2 symmetric bending in cellulose. Bending vibrations of the C–H and C–O groups of the aromatic rings in cellulose (polysaccharides) are associated with the peaks at 1360 and 1314.7 cm^{-1}, respectively. The peak at 1245 cm^{-1} corresponds to the stretching vibration of hydroxyl-bound carbon. The C–O bond stretching vibration occurred at 1165 and 1107.9 cm^{-1}. The intense bands at 1053.3 and 1028.8 cm^{-1} refer to the C–O and O–H stretching vibrations in hemicellulose and lignin (polysaccharides). β-glycosidic connections between



a *b* *c* *d*

Fig. 2. Cotton fabrics: before washing processes: *a* – EMPA 210, white, uncontaminated (magn. 1346×); *b* – EMPA 210 (15000×); *c* – EMPA 101 (359×); *d* – EMPA 101 (5000×)

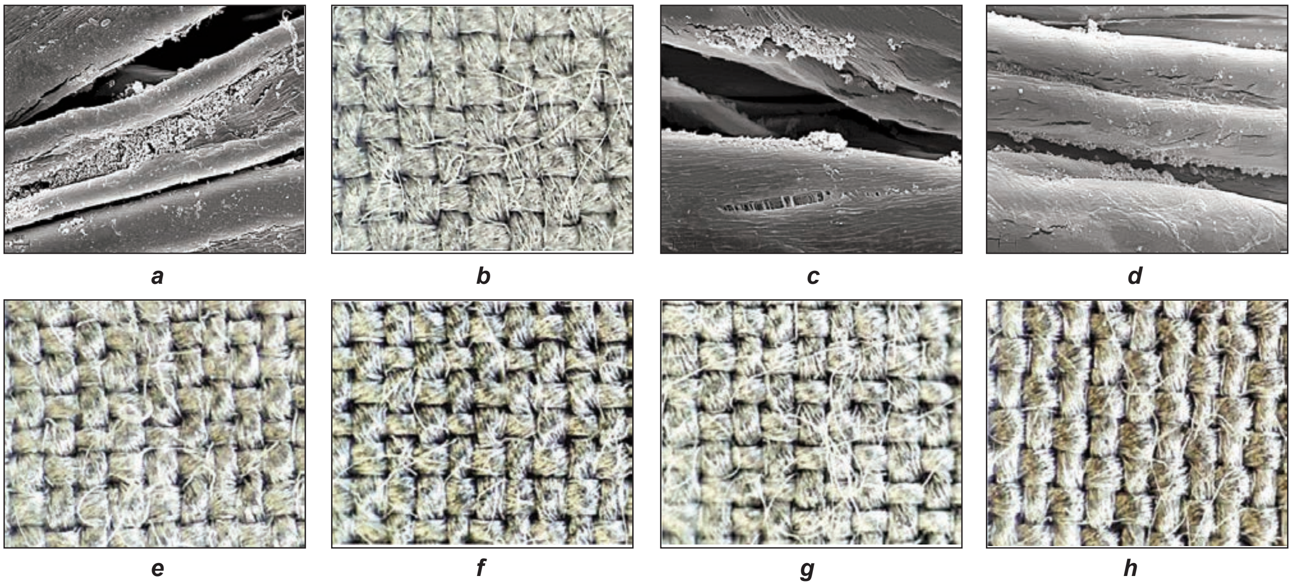


Fig. 3. The images of EMPA 101 cotton fabrics after washing processes at various concentrations of the L1 laundry detergent solutions: *a* – 1.25 g/l (magn. 10000×); *b* – 20 g/l (359×); *c* – 25 g/l (13750×); *d* – 50 g/l (10000×); L1 modified with SB3C14; *e* – 1.25 g/l; *f* – 20 g/l; *g* – 35 g/l; *h* – 50 g/l (359×)

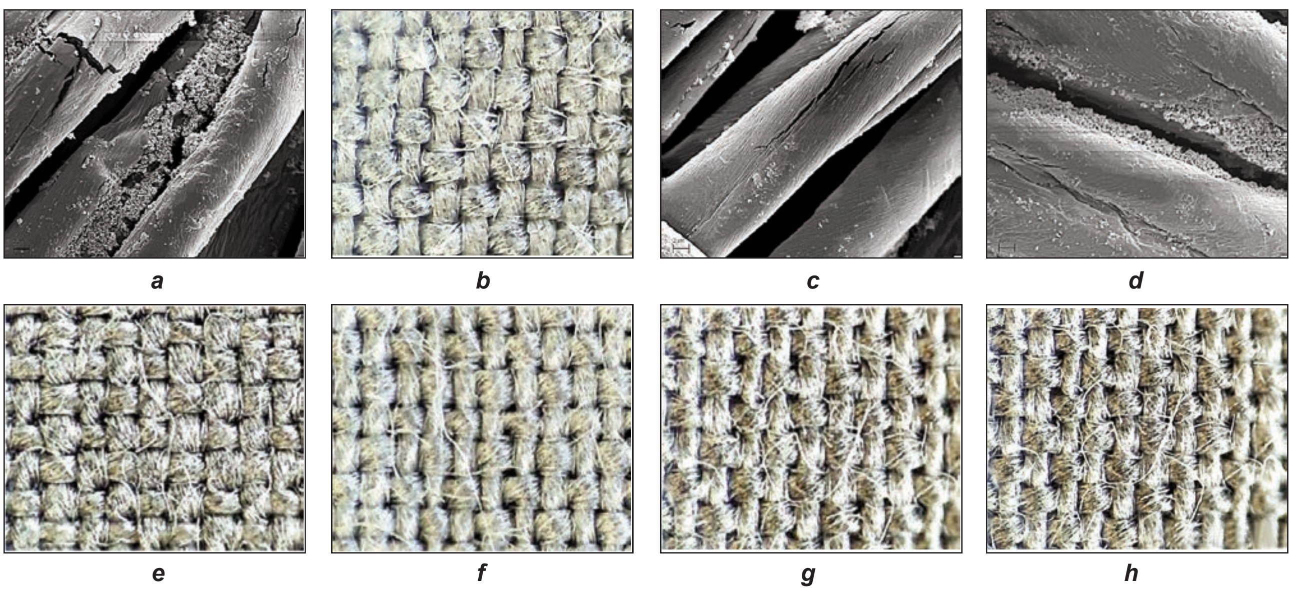


Fig. 4. The images of EMPA 101 cotton fabrics after washing processes at various concentrations of the L2 laundry detergent solutions: *a* – 1.25 g/l (magn. 10000×); *b* – 20 g/l (359×); *c* – 25 g/l (10000×); *d* – 50 g/l (10000×) L2 modified with SB3C14; *e* – 1.25 g/l; *f* – 20 g/l; *g* – 35 g/l; *h* – 50 g/l (359×)

monosaccharides are visible at 894 cm^{-1} [49]. The washing processes with L1 and L2 detergents and modified detergents with SB3C14 resulted in a slight change in the intensity of the peaks towards higher values of transmittance.

CONCLUSIONS

In this work, commercial liquid laundry detergents: cheaper L1 and more expensive L2 before and after modification with SB3C14 sulfobetaine (N-tetradecyl-N,N-dimethyl-3-ammonio-1-propanesulfonate, 5% m/m) were used for physicochemical and detergency tests. EMPA 101 cotton fabric soiled with carbon black and olive oil was tested for washing performance.

The assessment of colour, form, odour, pH, density, viscosity and content of anionic surfactants showed compliance with the declarations of detergent producers. The addition of SB3C14 did not cause significant changes in these properties. An increase in detergency was observed with increasing detergent solution concentration (1.25–50 g/l). At the highest tested concentrations of 50 g/L, detergency of 18.1% (L1) and 22.2% (L2) was achieved. Synergistic effect between all the components strengthened at a higher concentration in the washing solution. Modification of liquid compositions with the 5% addition of the amphoteric surfactant sulfobetaine SB3C14 resulted in an improvement of the washing efficiency by 4.7% on average. The best washing performance (35.3%)

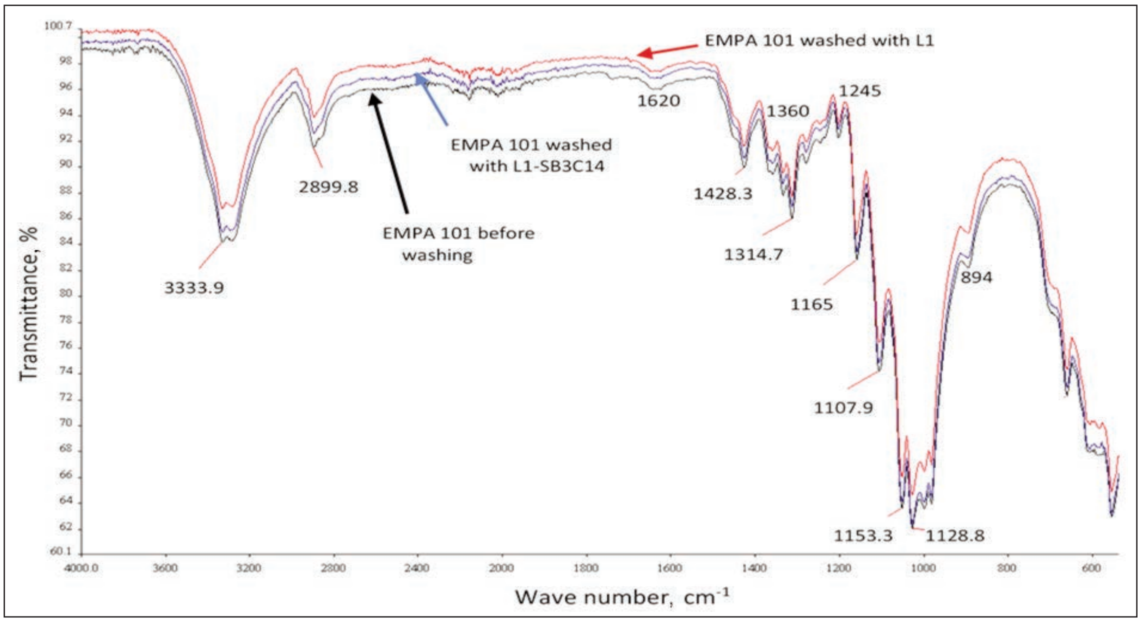


Fig. 5. FT-IR spectrum of EMPA 101 cotton fabric before and after washing processes using L1 detergent

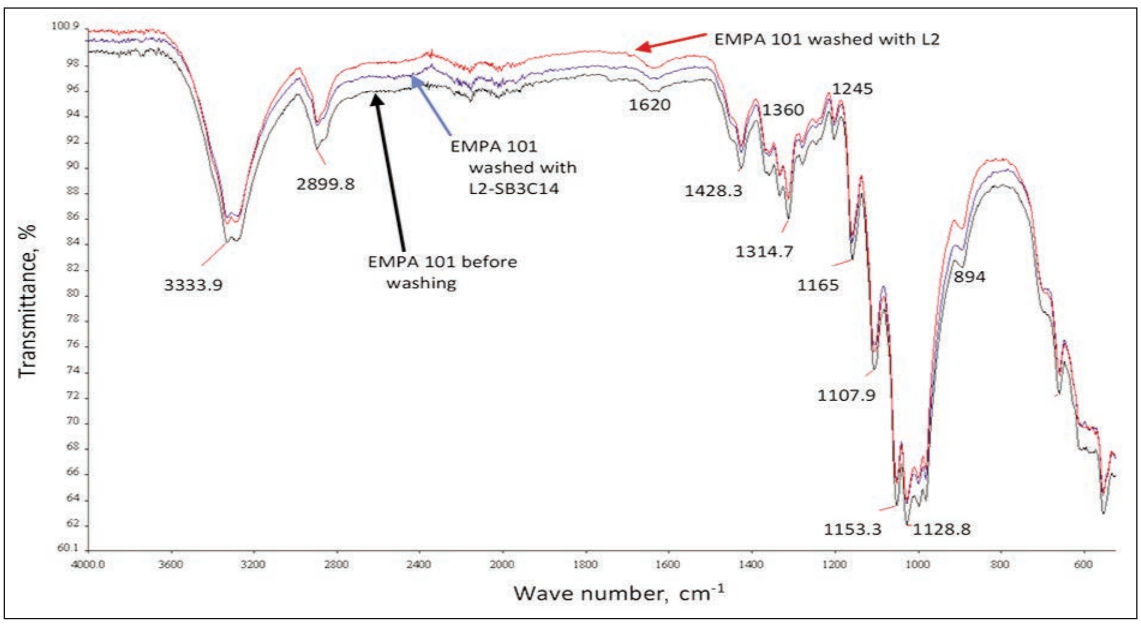


Fig. 6. FT-IR spectrum of EMPA 101 cotton fabric before and after washing processes using L2 detergent

was obtained with the L2 modified solution at a concentration of 50 g/l. The positive effect of the modification was too small for the observer to see colour differences with unaided eye, so changes can only be seen by colorimetric measurements. Microscopic analysis of images of EMPA 101 fabrics before and after washing processes showed only the occurrence of single ruffled fibres.

To sum up, it can be stated that enriching the composition of the washing liquids with the addition of SB3C14 sulfobetaine has a positive effect on the efficiency of removing dirt from cotton fabric. The research results suggest that the tested sulfobetaine can be potentially used as an ingredient in liquid laundry detergents.

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Thermal comfort properties of cotton/spandex single jersey knitted fabric

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ABSTRACT – REZUMAT

Thermal comfort properties of cotton/spandex single jersey knitted fabric

Knitted fabrics are characterized by comfort compared to woven fabrics due to their high extensibility and air permeability, but they have lower dimensional stability after repeated washing especially single jersey knitted fabric (SJKF). Therefore, the spandex (Lycra) core-spun yarns are used to maintain the dimensions of knitted fabrics during use and after repeated stresses. In this study, nine elastic SJKF samples were produced at three levels of loop length and spandex percent using yarn linear density 30/1 Ne. For comparison, three 100% cotton knitted samples were produced with the same levels of loop length and yarn count. The dimensional and thermal comfort properties of the long-stretch samples were compared with the short-stretch cotton knitted fabric. The thermal comfort properties (thermal conductivity, resistance, absorptivity, and water vapour permeability), air permeability, and dimensional properties were measured and compared to 100% cotton samples. The results showed that the stitch density, fabric density, fabric thickness, and thermal resistance increased, whereas the air, water vapour permeability, and spirality angle decreased in cotton/spandex samples.

Keywords: *thermal comfort properties, spandex, stretchable knitted fabrics, core-spun yarn, spirality angle, thickness*

Proprietățile de confort termic ale tricoturilor glat din bumbac/spandex

Tricoturile prezintă propritӑți de confort comparabile cu cele ale țesăturilor, datorită extensibilității ridicate și permeabilității la aer, dar au stabilitate dimensională mai mică după spălarea repetată, în special tricotul glat (SJKF). Prin urmare, firele filate cu miez de spandex (Lycra) sunt utilizate pentru a menține dimensiunile tricoturilor în timpul utilizării și după solicitări repetate. În acest studiu, au fost realizate nouă probe elastice SJKF și trei probe 100% bumbac tricotate la trei niveluri de lungime buclă și procent de spandex, folosind densitatea liniară a firului de 30/1 Ne. Pentru comparație, au fost realizate trei probe tricotate din 100% bumbac cu aceleași niveluri de lungime a buclei și densitate liniară. Proprietățile de confort dimensional și termic ale probelor cu întindere ridicată au fost comparate cu tricotul din bumbac cu întindere redusă. Proprietățile de confort termic (conductivitatea termică, rezistența termică, capacitatea de absorbție și permeabilitatea la vapori de apă), permeabilitatea la aer și proprietățile dimensionale au fost măsurate și comparate cu probe din 100% bumbac. Rezultatele au arătat că desimea ochiurilor, grosimea materialului textil și rezistența termică au crescut, în timp ce permeabilitatea la aer și la vapori de apă, precum și unghiul de spirală au scăzut în probele din bumbac/spandex.

Cuvinte-cheie: *proprietăți de confort termic, spandex, tricoturi elastice, fire filate cu miez, unghi de spirală, grosime*

INTRODUCTION

Single jersey knitted fabrics (SJKF) are used for under- and outer-wear compared to woven fabrics because of their high extensibility (compression and elongation of individual stitch). If these fabrics were produced from 100% cotton yarns, they don't have the ability to recover the stitch rearrangement [1]. To enhance the recovery and dimensional stability of knitted fabric, the spandex yarns are incorporated with cotton yarns in weft circular machine. Spandex is used as a core in the core spun yarns with natural and synthetic fibres or additional yarn (full and half plated) in circular knitting machines. Spandex improves the dimensional stability, body fit of weft knitted fabric and freedom of body movements but it also has a negative effect on other important properties such as air permeability and thermal comfort properties. Thermal comfort is one of the most important parameter of clothing comfort. Thermal comfort is defined as a state of satisfaction with the thermal conditions of the environment. Most of studies focused only on either dry or wet state [2–4]. The thermal comfort properties depend on the temperature difference between environment and skin, yarns structure and material, fabric thickness, porosity, areal density, number of fabric layers, trapped air, and fabric structure [5].

There are many researchers investigated the effect of spandex on the dimensional and mechanical properties of different knitted fabric structures. The dimensional and physical properties of cotton/spandex single jersey fabrics were investigated and the results were compared with fabrics knitted from cotton alone [6]. The effect of extension increase percent of bare Lycra yarns during loop formation on the geometrical, physical and mechanical properties of plain jersey fabrics was investigated [1]. Half-plated, full-plated, and 100% cotton plain and rib knitted fabric structures were investigated for physical, dimensional, geometrical, and some comfort properties and compared to each other [7]. The relations between Lycra consumption and fabric dimensional and elastic behaviour were studied [8]. The influences of raw material, yarn count, pattern and elastomeric yarn ratio on the performance and physical properties of the plain, pique, double-pique, and fleecy patterned knitted fabrics were found out [9]. The dimensional and physical properties of cotton/elastane single jersey fabrics were measured and compared to 100% cotton knitted fabric [10]. Comfort properties such as stretch, recovery, air permeability, and wicking of SJKF of three different fibre contents (cotton/spandex, rayon/spandex, and polyester/spandex) were compared [11]. The effects of spandex brand, tightness factor of the base, and spandex yarn on the dimensional and physical properties of cotton/spandex single jersey fabrics were investigated [12]. The physical, dimensional, and mechanical properties of back plaited cotton/spandex SJKF were measured and compared to 100% cotton fabric [13]. Dimensional characteristics of core-spun cotton/spandex and cotton samples were studied [14]. The dimensional properties of single jersey fabric produced from Polyester/Lycra air-covered yarns with different loop lengths were tested [15]. The effect of spandex yarn input tension, yarn loop length, and spandex yarn linear density on the elastic properties of stretchable knitted fabrics were studied [16].

Based on the previous research [1, 7–16], spandex has a significant effect on the dimensional, physical, and mechanical properties of knitted fabrics. The fabric thickness, stitch density, and weight per unit area increased whereas the air permeability and spirality angle decreased. There is a limited research that studied the effect of spandex on thermal properties. The properties of the weft knitted fabrics with different structures (single jersey, rib 1×1, and full cardigan) produced from core and dual core-spun yarns at different levels of loop length were compared [17]. Results showed that the yarn type had a significant effect on fabric recovery, elasticity, and shrinkage. However, it had a nonsignificant effects on drapability, thermal resistivity, and air permeability. So, more research is required in this point.

The proposed research aims to investigate the effect of spandex rate on the dimensional and thermal comfort properties of SJKF and compare it with the properties of 100% cotton fabric without spandex.

EXPERIMENTAL

Materials

Nine elastic SJKF samples were produced on VIGNONI SJ-B at three levels of loop length and spandex percent with yarn count 30/1 Ne. For comparison, three 100% cotton fabric samples were produced at the same yarn count and levels of loop length. Circular knitting machine and samples specifications are listed in tables 1 and 2 respectively. All fabric samples were treated according to elastic knitted fabric finishing recipe. After finishing, all samples were washed three consecutive washing cycles at 40°C in laboratory washing machine.

Table 1

MACHINE SPECIFICATIONS				
Machine Type	**Model**	**No. of feeders**	**Diameter (inch)**	**Gauge**
Single jersey (Circular)	VIGNONI SJ-B	51	17	24

Table 2

SAMPLES' PRODUCTION SETTINGS					
Lycra percent %		**100% cotton**	**Cotton/Lycra core spun yarn**		
		0	**5.5**	**6**	**6.5**
Loop length level (mm)	2.7	✓	✓	✓	✓
	2.9	✓	✓	✓	✓
	3.1	✓	✓	✓	✓

Methods

Fabric thickness was measured according to ASTM D1777. The spirality angle is measured as the angle between the wale line and the line parallel to the machine running direction [6, 18]. The fabric bulk density is calculated by equation 1 [19]:

$$\textit{Bulk density}\left(\frac{\text{kg}}{\text{m}^3}\right) = \frac{W}{t} \qquad (1)$$

where W is fabric weight per unit area (g/m^2) and t – fabric thickness (mm).

Thermal conductivity, resistance, and absorptivity were measured using Alambeta tester [20, 21] according to ISO 8301.

Relative water vapour permeability was tested by Permetest according to ISO 11092. Air permeability was measured according to ASTM D737. The statistical multivariate analysis of variance (MANOVA) was performed for the experimental results using SPSS program.

RESULTS AND DISCUSSION

Fabric thickness

Figure 1 shows the effect of loop length on the fabric thickness of cotton/spandex and 100% cotton plain knitted fabric at three level of spandex percent (6.5, 6, and 5.5%). The thickness of cotton/spandex sample is higher than 100% cotton samples by 61% at 2.7 loop length. The fabric thickness is equal to twice of yarn diameter for jamming condition ($t = 2*d$ where t is fabric thickness, d – yarn diameter, wale spacing = $4*d$ and course spacing = $2\sqrt{3}*d$) as shown in figure 2, *a*. So we can interpret that because the spandex leads to stitch overlapping [1] which increases

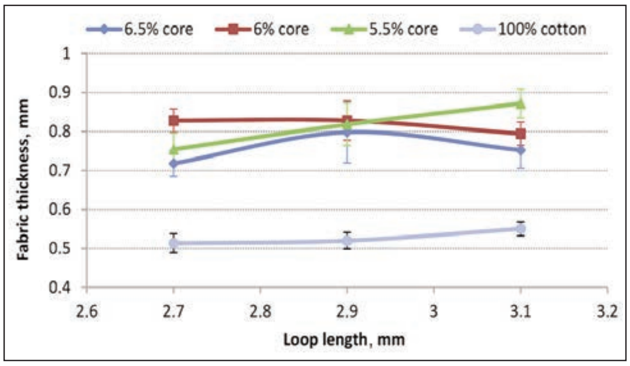
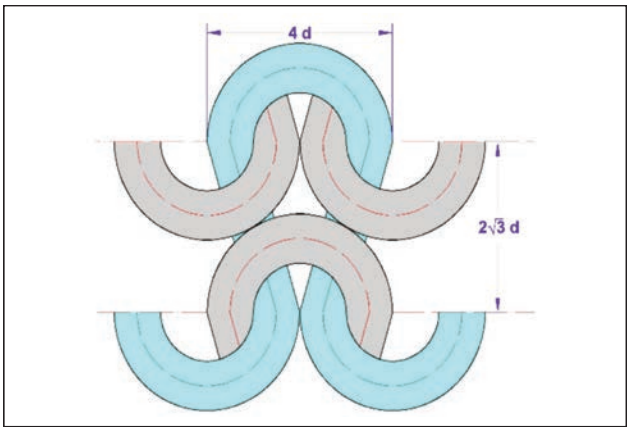
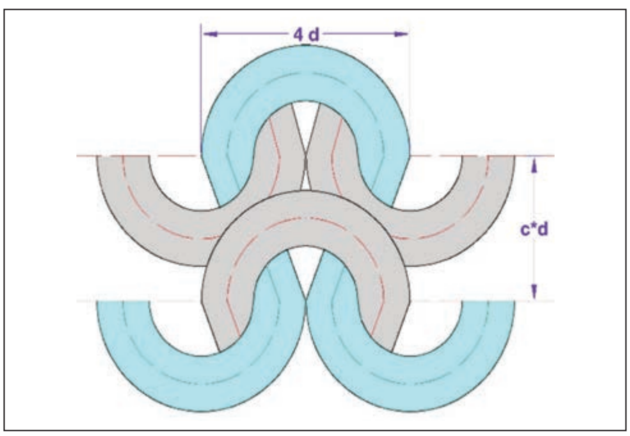


Fig. 1. Effect of loop length on the fabric thickness



a



b

Fig. 2. Theoretical geometry of single jersey loop structure: *a* – jamming condition; *b* – stitch overlapping, *d* is yarn diameter and *c* < $2\sqrt{3}$

the fabric thickness, as shown in figure 2, *b* (course spacing < $2\sqrt{3}*d$). There is a slight effect of loop length on the fabric thickness and there isn't obvious effect of spandex percent (from 5.5 to 6.5%). Therefore, the increase of fabric thickness may lead to increase of thermal resistance.

Stitch density

The stitch density per unit area was calculated by multiplying the course per unit length by the wales per unit length. Figure 3 shows the effect of loop length on stitch density of cotton/spandex and 100% cotton samples.

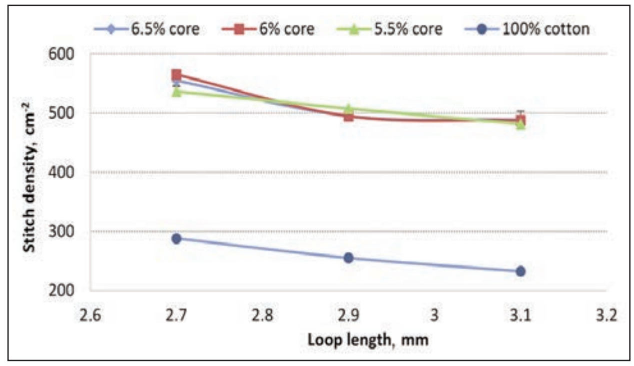


Fig. 3. Effect of loop length on the stitch density

In general, the stitch density decreases with increasing the loop length. The stitch density of elastic fabric is higher than 100% cotton fabric by 96% at loop length 2.7 mm because Lycra leads to convergence of wales and courses, so the fabric becomes more tight.

Thermal conductivity

The thermal conductivity of elastic knitted fabric is higher than 100% cotton by 17% and 36% at loop length 2.7, 3.1 mm respectively and went up when the spandex percent decreased from 6.5 to 5.5%, as shown in figure 4. This may due to the increase of stitch density and fabric density which means that the amount of fibres increased and the rate of heat transfer by conduction increased as well. The statistical analysis proved that the spandex percent and loop length had a significant effect on the thermal conductivity (table 3).

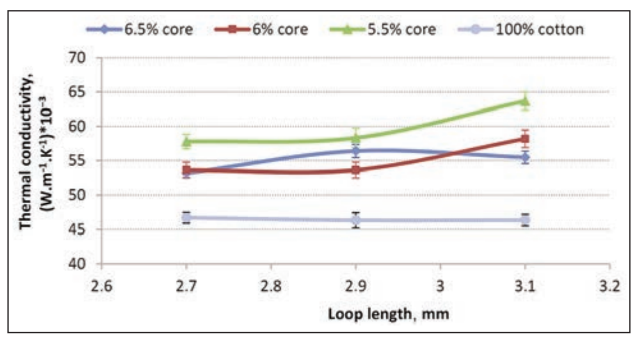


Fig. 4. Effect of loop length on the thermal conductivity

Thermal resistance

The thermal resistance of elastic plain knitted fabric increased by 47% compared to 100% cotton fabric although the cotton fabric density is lower than the elastic fabric, as shown in figure 5. So, the pores size and its distribution play an important rule to entrap air inside the fabric. The thermal resistance increases with fabric thickness increasing according to the equation 2 [22].

$$R = \left(\frac{t}{\lambda}\right) \quad (2)$$

where R is thermal resistance ($K \cdot m^2 \cdot W^{-1}$), λ – thermal conductivity ($W \cdot m^{-1} \cdot K^{-1}$), and t – fabric thickness (m).

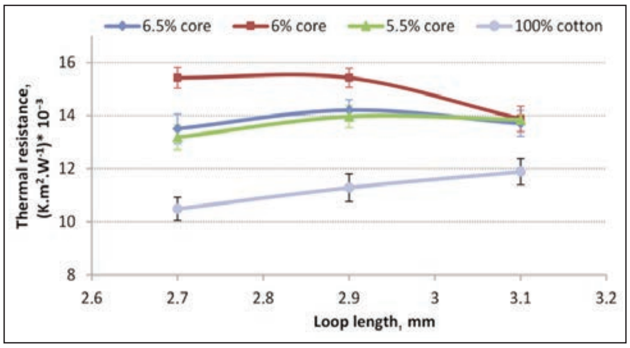


Fig. 5. Effect of loop length on the thermal resistance

So, the elastic fabric has the ability to maintain the body temperature if it is used as winter clothing. The statistical analysis showed that the spandex percent and loop length had an insignificant effect on the thermal resistance.

Thermal absorptivity

Thermal absorptivity is the objective measurement of warm cool feeling of the fabric. Fabrics with a lower thermal absorptivity value have warm feeling and vice-versa [23]. The thermal absorptivity increases with increasing the thermal conductivity and fabric density according to the following equation [21].

$$b = (\lambda \rho c)^{1/2} \quad (3)$$

where b is thermal absorptivity ($W \cdot S^{1/2} \cdot m^{-2} \cdot K^{-1}$), λ – thermal conductivity ($W \cdot m^{-1} \cdot K^{-1}$), ρ – fabric density (kg/m^3), c – specific heat capacity ($J \cdot kg^{-1} \cdot K^{-1}$). Therefore, the thermal absorptivity of elastic fabric is more than 100% cotton by 29% and 53% at the loop length 2.7 and 3.1 mm respectively and gives a cool feeling at first touch, as shown in figure 6. The spandex percent had a significant effect and loop length had an insignificant effect on the thermal absorptivity.

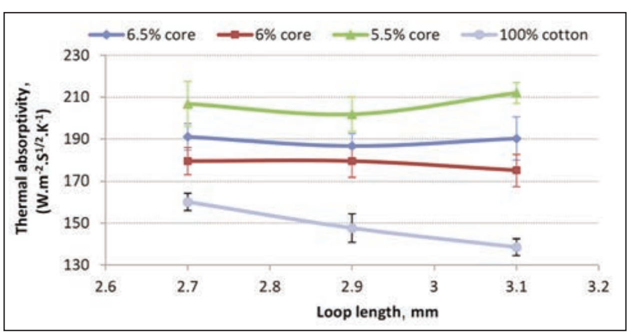


Fig. 6. Effect of loop length on the thermal absorptivity

Water vapour permeability

Figure 7 shows the relative water vapour permeability (RWVP) of elastic and 100% cotton SJKF at three levels of loop length and spandex percent. The RWVP of elastic fabric is less than 100% cotton fabric because the bulk density of 100% cotton is less than the elastic fabric. Therefore the 100% cotton fabric contain a large size of pores that can permit the water vapour transfer by convection. So, the elastic

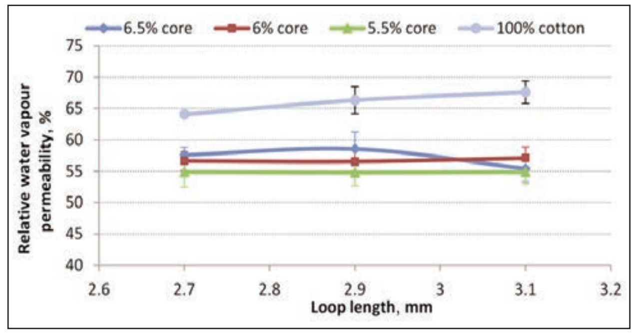


Fig. 7. Effect of loop length on the relative water vapour permeability

SJKF gives a discomfort feeling because it fails to transfer the water vapour compared to 100% cotton fabric and water vapour may convert to sweat. The RWVP slightly went up when the spandex percent increased. The spandex percent, rather than the loop length, had a significant effect on the RWVP.

Air permeability

Figure 8 displays the effect of loop length on the air permeability of SJKF at three levels of the spandex percent and loop length. In general, the air permeability increased by the increasing of loop length and the air permeability of elastic fabric is less than 100% cotton fabric by 94%. This is due to increasing of stitch density as shown in figure 3 and the elastic fabric becomes much tight. The statistical analysis showed that the loop length had a significant effect whereas the spandex percent had a nonsignificant effect on the air permeability.

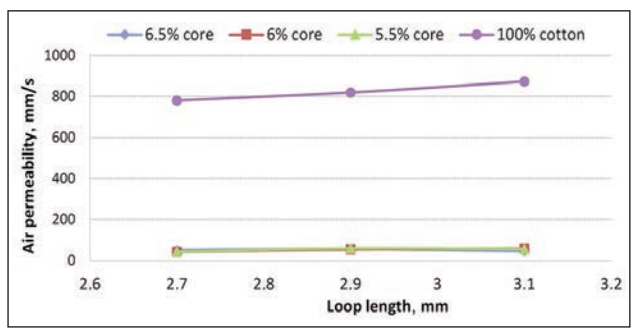


Fig. 8. Effect of loop length on the air permeability

Spirality angle

Spirality is the most common fabric defect that affects the single jersey knit wear fabric and it is the angle (θ) between the wale line and a line perpendicular to the course line [18] as shown in figure 9. So, the spirality angle depends on the wales spacing and using of cotton/spandex core sun yarn in SJKF decreases

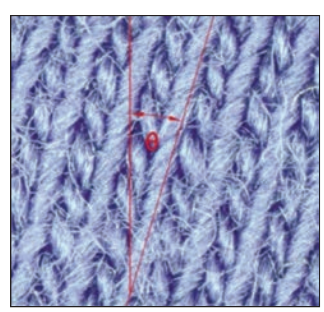


Fig. 9. Spirality angle (θ)

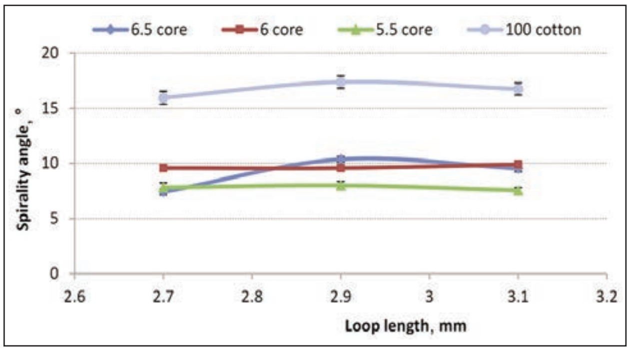


Fig. 10. Effect of loop length on the spirality angle

Table 3

THE RESULTS OF VARIANCE ANALYSIS (P VALUE AT CONFIDENCE INTERVAL 95%)		
Dependent property	**P value, Independent variable (spandex percent)**	**P value, Independent variable (loop length)**
Thermal conductivity	0.000	0.003
Thermal absorptivity	0.000	0.313
Thermal resistance	0.261	0.805
Air permeability	0.705	0.000
Water vapour permeability	0.009	0.528
Fabric thickness	0.025	0.616
Spirality angle	0.000	0.000

the wales spacing and then decreases the spirality angle. Therefore, the spirality angle of elastic knitted fabrics are higher than 100% cotton fabric as shown in figure 10.

The statistical analysis of the experimental results by variance analysis using SPSS software are listed in table 3.

CONCLUSIONS

The dimensional and thermal comfort properties of cotton/spandex plain knitted fabric are investigated and compared to the properties of 100% cotton without spandex. The experimental results proposed that:

- The thickness, stitch density, and density of elastic knitted fabric are higher than 100% cotton fabric.
- The thermal conductivity and resistance of cotton/spandex samples increased by 17 and 47% respectively compared to 100% cotton fabric. So, the elastic fabric has ability to maintain the body temperature and it will be perfect in winter clothing.
- The thermal absorptivity of elastic fabric is more than 100% cotton by 29% and 53% at the loop length 2.7 and 3.1 mm respectively, which could give a cool feeling at first touch.
- The RWVP of elastic fabric is less than 100% cotton fabric that might give a discomfort feeling because it failed to transfer the water vapour out of the body to the fabric surface.
- The air permeability of elastic knitted fabric decreased by 94% and the spirality angle decreased 49% compared to 100% cotton fabric.

So, the use of spandex has two different effects, it enhances the dimensional stability, but also affects other important properties such as the RWVP, thermal absorptivity, and air permeability.

ACKNOWLEDGEMENTS

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A study on detection of roving tension and fine control of yarn breakage

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CUI PENG XUE YUAN

ABSTRACT – REZUMAT

A study on detection of roving tension and fine control of yarn breakage

The fine control of yarn breakage is essential for the production of better yarn quality by reducing the tension fluctuation of roving. The detection of roving tension provides important information regarding the yarn formation during spinning. In the present work, we developed a device for roving-tension detection and regulation, which greatly reduces the yarn breakage rate and improves the production efficiency of ring spinning. By analysing the factors affecting the roving tensions, we used a signal acquisition system in conjunction with the tension detection device to regulate the spindle rotate speed to realize the fine control of yarn breakage. Our results indicate that the proposed method can ensure a uniform spinning tension of the yarn in ring spinning, which significantly reduces the yarn breakage rate, and boost the yarn production. Our work paves the way toward the rational production of high-quality yarn.

Keywords: *spinning frame, spinning tension, intelligent control, spindle rotate speed, breakage rate*

Studiu privind detectarea tensiunii semitortului și controlul fin al ruperii firelor

Controlul fin al ruperii firelor este esențial pentru producerea unor fire de calitate superioară, prin reducerea fluctuației tensiunii semitortului. Detectarea tensiunii semitortului oferă informații importante cu privire la formarea firelor în timpul filării. În lucrarea de față, s-a dezvoltat un dispozitiv pentru detectarea și reglarea tensiunii semitortului, care reduce foarte mult rata de rupere a firelor și îmbunătățește eficiența filării cu inele. Analizând factorii care influențează tensiunea semitortului, s-a folosit un sistem de achiziție a semnalului împreună cu dispozitivul de detectare a tensiunii pentru a regla viteza de rotație a fusului, pentru a realiza controlul fin al ruperii firului. Rezultatele indică faptul că metoda propusă poate asigura o tensiune uniformă de filare a firului în filarea cu inele, ceea ce reduce semnificativ rata de rupere a firelor și crește producția de fire. Lucrarea deschide calea către producția rațională de fire de calitate superioară.

Cuvinte-cheie: *mașină de filat, tensiune de filare, control inteligent, viteza de rotație a fusului, rata de rupere*

INTRODUCTION

The knowledge of spinning tensions is critical for improving yarn quality in a ring spinning frame. A suitable spinning tension is compatible with the strength of roving, which can improve the winding quality and reduce the breakage rate. On the one hand, an excessively large roving tension increases the occurrence of yarn breakage; on the other hand, if the roving tension is too low, it reduces the winding density and the yarn strength. Moreover, in the latter case, the size of the balloon is increased, which may increase the number of collisions between the balloon and anti-balloon plate and thus resulting in more hairiness and high breakage rates [1, 2]. Therefore, the detection of spinning tension is critical for the rational control of the yarn breakage in ring spinning.

In general, the tension test includes a contact measurement method and a non-contact measurement method. For the contact measurement method [3, 4], the interaction between yarn and measuring device brings in additional friction forces, which changes the yarn trajectory in ring spinning and thus bringing errors into the measurement. For the non-contact measurement method [5, 7], a detector monitors the yarn movement through the traveller. Once the yarn breakage occurs, the sensor generates electrical signals to stop the operation of the ring-spinning machine. However, it fails to detect the yarn breakage for the multi-channel drafted spun yarn [8, 9], in which the sensor cannot pick up the signal upon the breakage of one roving since another roving still moves through the traveller. Therefore, it is necessary to develop an effective method for detection and fine control of the breakage of ring spun yarn, since the currently existing theories and test means can hardly resolve the real-time dynamics of spinning tensions in overall spinning process, including twisting, ballooning and winding.

Two methods are commonly employed to regulate the spinning tensions to reduce yarn breakage, which are the based on single-phase two-speed pole-change servomechanism [10] and transducer-controlled servomechanism [11], respectively. In the former case, a low-speed operation is adopted in the initial spinning stage, which is switched to the high-speed operation later on. In the latter case, the motor speed is adjusted in accord with the pattern of end breakage distribution of spinning bobbin [12, 13].

However, the switch of rotor speeds in these two methods relies on the predetermined balloon height without taking into account the variation in winding radius as well as the dynamic changes of balloon height.

In the present work, we use a self-developed device to measure the roving tensions in ring spinning, in which the sensors are installed on the guide plate. The coupled physical-mathematical equations, which describe the evolution of the tensions, are solved to obtain real-time dynamics of roving tensions. Furthermore, we constructed a uniform tension control system, which proves to be an effective way to realize the fine control of roving tension.

THEORETICAL MODEL

Analysis of spinning tensions

The centre of the thread guide is denoted as *O*. *X*-axis, *Y*-axis and *Z*-axis pass through point *O*, in which *X*-axis is parallel to the plane that holds the guide plate; *Y*-axis is perpendicular to the plane that holds the guide plate; *Z*-axis is perpendicular to *X-O-Y* plane. Therefore, a three-dimensional coordinate system is built with the centre of the thread guide as the origin. Similarly, the *X´-Y´-Z* three-dimensional coordinate system is built for the ring rail where *O´* is set as the centre of ring rail. Both the upstream and top ballooning tensions acting on the thread guide generate the stress signals via the stress sensor. As shown in figure 1, T_f is the upstream tension of roving; T_q is the top ballooning tensions; *F* is the force acting on the thread guide and its projections on X-, Y- and Z-axis are F_x, F_y and F_z, respectively; μ is the dynamic friction coefficient between yarn and thread guide, and σ is the wrapping angle of yarn around thread guide. The stresses F_y and F_z can be measured through the bidirectional stress sensor. In addition, the perpendicular displacement of the guide plate can be measured through a displacement sensor installed on the guide plate.

According to figure 1, *a*, the stress on the thread guide can be decomposed as:

$$F_x = T_{q1} \sin\beta \cos\alpha \quad (1)$$

$$F_y = T_{q1} \sin\beta \sin\alpha + T_f \cos\gamma \quad (2)$$

$$F_z = T_{q1} \cos\beta - T_f \sin\gamma \quad (3)$$

where γ is denoted as the guide angle between the attenuated roving and the *X*-axis; β is denoted as the top ballooning angle between the tangent line to the top of yarn-ballooning and the *Z*-axis; α is the angle between the *Y´*-axis and the line passing through an arbitrary point in *X’-Y’* plane.

According to Euler’s formula:

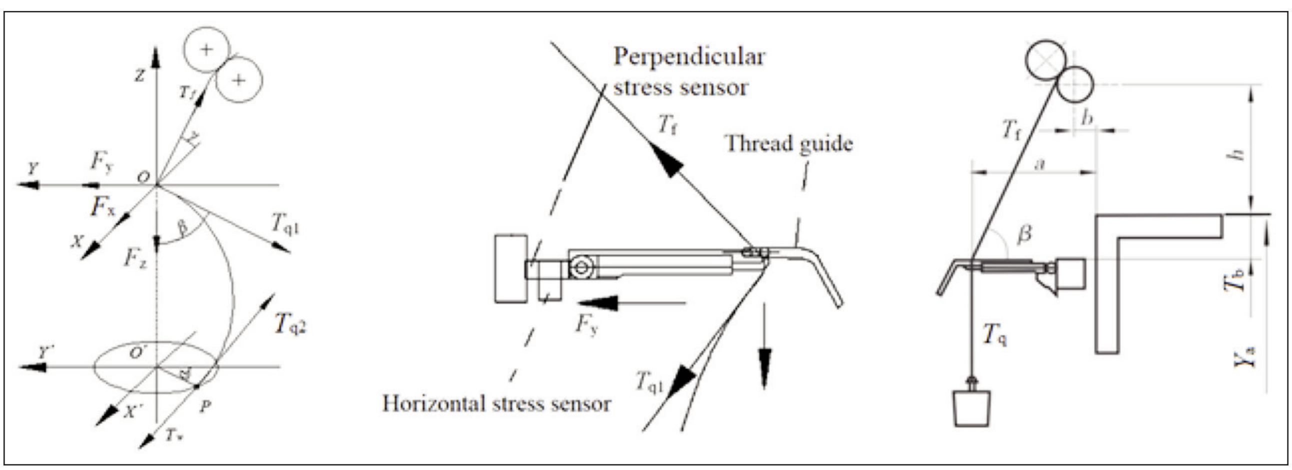
$$T_f = T_{q1} e^{-\mu\delta} \quad (4)$$

Substituting equation 4 into equation 3, the upstream tension T_f can be written as:

$$T_f = \frac{F_z}{e^{-\mu\delta} \cos\beta - \sin\gamma} \quad (5)$$

There are two independent sensors installed at the guide plate to detect the horizontal and perpendicular stresses, i.e., F_x and F_y, respectively, as shown in figure 1, *b*. For calibrating the sensors, the horizontal sensor was placed vertically without load, and the output current of the transmitter was adjusted to be 5 mA; then, a 150 g weight was added and the output current was adjusted to 20 mA. The calibration of the perpendicular sensor was the same as that of the horizontal sensor. After all the sensors were calibrated as described above, the guide plate was placed horizontally, and the horizontal and vertical forces were reset to zero.

To verify the accuracy and reliability of the self-developed detection device, one end of the yarn was attached to the jaw of the front roller and the other end is hanged with a 50 g weight. Under the static tension, $\gamma = 0°$, $\alpha = 0°$, $T_f = T_q = 50$ cN. The guide angle β can be calculated using the following equation:



a **b** **c**

Fig. 1. Graphical presentation of: *a* – analysis of the spinning tension; *b* – schematic diagram illustrating stress tensor; *c* – schematic diagram illustrating static tension test

$$\beta = \tan^{-1}\frac{h + Y_a + R_G - Y_b}{a - b - R_G} \qquad (6)$$

where a represents the distance from thread guide to the left side of ion plate (88.8 mm), b – the distance from front roller to the left side of ion plate (15 mm), h – the distance from the bottom roller to the top of iron plate (95 mm), R_G – the radius of thread guide (1.3 mm), Y_a – the height of iron plate (48.4 mm), and Y_b – the height of guide plate.

As shown in figure 1, *c*, when a 50 cN weight is added to the thread guide, the F_y is calculated to be 4.67 cN, and the F_x is calculated to be 21.09 cN, based on the equations 1 and 2, while F_y is measured to be 4.72 cN and F_x is measured to be 20.86 cN with the calibrated horizontal and perpendicular sensors. The measured values match with the calculated values very well, indicating the reliability of the self-developed tension detection device.

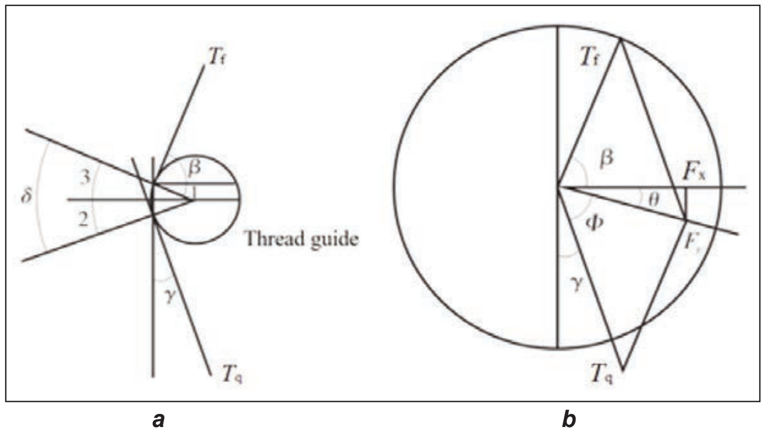


Fig. 2. Analysis of: *a* – the angles at the thread guide; *b* – the stresses at the thread guide

Since the top ballooning angle γ remains uncertain, so the equations 1–3 cannot be solved. The relation between the top ballooning angle and the wrapping angle is illustrated in figure 2, *a*.

According to the geometric relationship shown in figure 2, *b*, the relation between γ and θ can be expressed as followings:

$$\text{tg}\,\theta = \frac{F_y}{F_x} \qquad (7)$$

$$e^{\frac{\mu\pi\gamma}{180}}\cos(\theta+\gamma) = \frac{\sin(\beta+\theta)}{e^{\frac{\mu\pi(90-\beta)}{180}}} \qquad (8)$$

Thus, we can calculate θ by measuring F_x and F_y using the self-developed tension detection device. Then, we obtain the using equation 8.

Designing the fine control system of roving tension

In general, the relation between spinning tension T and spindle speed n can be expressed as:

$$T_1 = T_2\left(\frac{n_1}{n_2}\right)^2 \qquad (9)$$

The higher the spindle speed, the greater the spinning tension is. The frequency converter is used here to adjust spindle rotation speed to control the spinning tensions. On the one hand, during spinning, the dynamic stress signals are amplified and then converted by an A/D converter before being input into the CPU. On the other hand, the perpendicular displacement of the yarn guide plate is converted to analog signals by displacement sensor and then being input into CPU to compensate for the variation of tensions due to the up and down movement of the guide plate. Two analog signals are further processed via an operational amplifier to compare with the given tension value to produce deviation σ and deviation variation rate δ. In this way, the controlled quantity of tension can be figured out with a controller.

Subsequently, through D/A conversion, the output frequency of the converter can be controlled so that the rotate speed of the master motor in the spinning frame is adjusted and the goal of controlling spinning tension is finally realized. As demonstrated in figure 3, this is a closed-loop control system featuring rapid dynamic signal tracking for uniform tension control.

EXPERIMENTS

The yarn is made of cotton with a linear density of 18.5 tex. We recorded the variations of tension in one cycle, in which the ring rail is moving from the lowest position to the highest one and then going back again to the lowest position. The spindle speed was 11917 r/min, and one value was recorded per second. To study the effect of type of traveller on spinning tension, the spindle speed was set to be 11162 r/min.

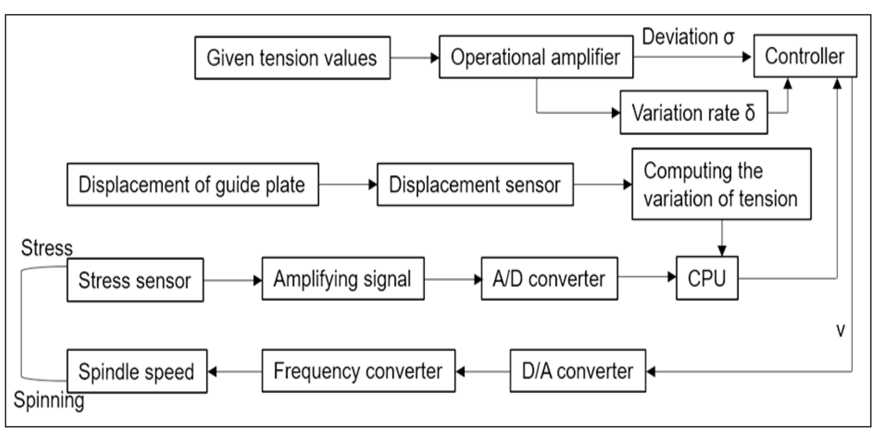


Fig. 3. Schematic diagram illustrating uniform tension control system

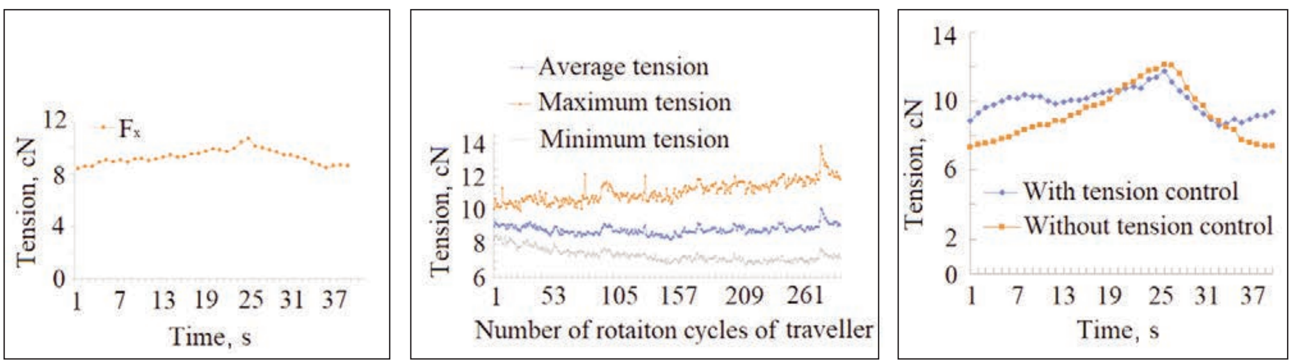
RESULTS AND DISCUSSION

Figure 4, *a* demonstrates the tension variation within one cycle. It gradually rises as the ring rail moves upward from the lowest position and declines when it moves downward. The tension reaches the minimum value when the ring rail approaches the lowest position and the maximum value when the ring rail is close to the highest position.

We collected 12,241 test data during one cycle of up and down movement of ring rail. To facilitate the analysis, the average, maximum and minimum tensions were recorded, as shown in figure 4, *b*. Table 1 summarizes the information about tension distribution and variation during the spinning process. According to figure 4, *b* and table 1, the average tension at the beginning of spinning is 9 cN, so this stage is called the small-yarn stage. The average tension starts to decline below 9 cN after 48 minutes, which is called the moderate-yarn stage. The average tension again increases above 9 cN after 122 minutes, which is called the large-yarn stage.

To study the effect of the fine control system of spinning tension on spun yarn, the uniform tension control system was turned off, in which the maximum value of tension was observed to be 12.1187 cN. When the tension reaches 10.0 cN, and the uniform tension system was turned on. The average spindle speed was 11,917 r/min and 12,505 r/min before and after initiating tension control, respectively. Figure 4, *c* shows the variations of tensions before and after initiating the uniform tension control system. After initiating tension control, the spindle speed was raised by 4.14%; the standard deviation was fell by 0.72 percent; the coefficient of variation (CV) of tension was declined by 52.49%. Table 2 lists the detailed experimental results. Table 3 lists the differences in yarn qualities before and after tension control. As revealed in table 3, no significant difference is found in yarning quality before and after the tension control, but the total number of broken ends is significantly reduced.

As illustrated by the experimental data above, spindle speed can be utilized to control the spinning tension effectively. The converted electric signal output from the tension detector was compared with the designated tension value to control the frequency converter. When the tension is higher than the given value,



a *b* *c*

Fig. 4. Graphical presentation of: *a* – variations of tension (F_x) during an up-down cycle of the ring rail; *b* – average, maximum and minimum F_x during an up-down cycle of the ring rail; *c* – comparison of tension F_x before and after tension control

Table 1

TENSION DISTRIBUTION AND VARIATION DURING ONE CYCLE OF UP AND DOWN RING RAIL MOVEMENT

Spinning process	Average tension F_x (cN)	Standard deviation	Tension CV	Maximum tension (cN)	Minimum tension (cN)	Range
Small-yarn stage	9	0.712	7.9	11.36	7.38	3.98
Moderate-yarn stage	8.75	1.159	13.5	12.56	6.70	5.86
Large-yarn stage	9.12	1.453	15.93	13.87	6.82	7.05
Overall process	8.97	1.32	14.66	13.87	6.7	7.17

Table 2

DIFFERENCES IN SPINNING TENSIONS BEFORE AND AFTER INITIATING TENSION CONTROL

Frequency (Hz)	Spindle rotation speed (r/min)	Average tension F_x (cN)	Maximum tension (cN)	Minimum tension (cN)	Range (cN)	Standard deviation	Tension (cN)
48	11917	9.23	12.12	7.33	4.79	1.49	16.08
50.37	12505	10.02	11.74	8.56	3.18	0.77	7.64

Table 3

YARNING QUALITY AND BREAKAGE BEFORE AND AFTER TENSION CONTROL								
Quality	**Evenness CV (%)**	**Thin sections (number/km)**	**Thick sections (number/km)**	**Nep (number/km)**	**Broken ends distribution/single yarn**			**Total number of broken ends**
					Small-yarn	Moderate-yarn	Large-yarn	
With tension control	17.34	42	140	286	4	10	2	25
Without tension control	17.27	30	114	284	13	23	5	60

Table 4

EFFECT OF DIFFERENT FREQUENCY SETTINGS ON TENSION							
Designated frequency (Hz)	**Actual frequency (Hz)**	**Average tension F_x (cN)**	**Maximum tension (cN)**	**Minimum tension (cN)**	**Range (cN)**	**Standard deviation**	**Tension (cN)**
6.7	51.19	6.89	7.32	6.48	0.84	0.21	2.96
6.9	50.89	6.95	7.36	6.03	1.33	0.32	4.62
7.1	51.49	7.32	7.89	6.82	1.07	0.30	4.03
7.3	51.77	7.40	8.74	6.19	2.55	0.23	3.06
7.5	52.08	7.51	8.01	6.92	1.09	0.41	5.27
7.7	51.76	7.72	8.21	7.27	0.94	0.24	3.06
7.9	52.16	7.89	8.26	7.26	1.00	0.29	4.22
8.1	53.68	8.01	8.54	6.37	2.17	0.39	5.35
8.3	53.68	8.12	8.44	7.65	0.79	0.27	3.28
8.5	54.61	8.46	9.44	7.77	1.67	0.42	4.98

the frequency is reduced to a lower speed until they are equal; when it is higher than the given value, the frequency is raised to reach the given value. The effect of different frequency settings on tension is shown in table 4.

According to the experimental results listed in table 4, the deviation of actual tension from the designated value during the spinning process is within the range of +0.22 cN ~ –0.18 cN. The tension variation remains insignificant, and its non-uniformity is controlled within 6%, which suggests the tension control system constructed hereby can alleviate the spinning tension fluctuation, and thus achieving uniform spinning tension.

Figure 5 shows the variation of tension against spindle rotation speed. During the tension test, the speed of spindle was set to be 7412 r/min (30 Hz), 8154 r/min (33 Hz), 8922 r/min (36 Hz), 9664 r/min (39 Hz), 11407 r/min (42 Hz), 11149 r/min (45 Hz), 11917

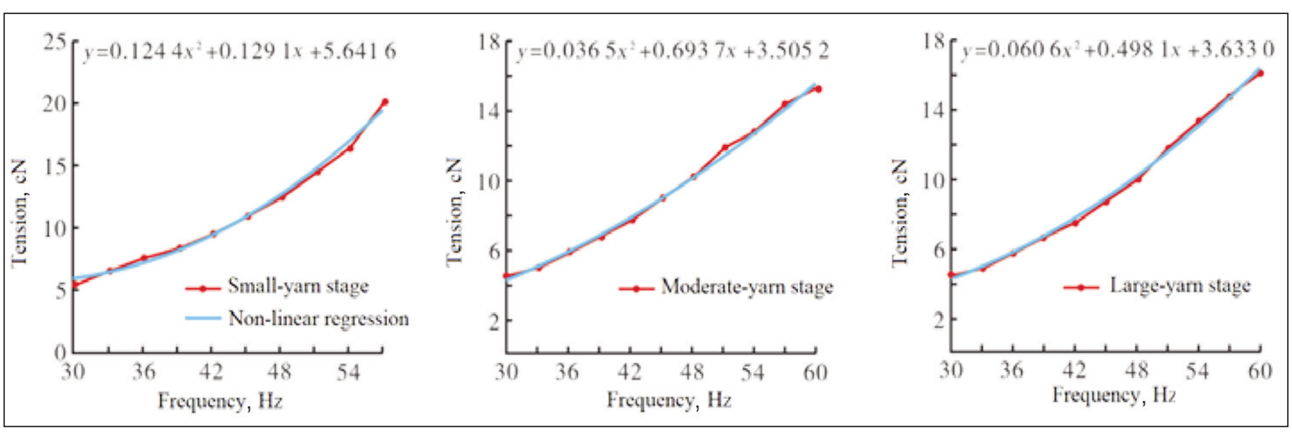


Fig. 5. Effect of spindle rotation speed on spinning tension F_x in: *a* – small-yarn stage; *b* – moderate-yarn stage; *c* – large-yarn stage

r/min (48 Hz), 12647 r/min (51 Hz), 13389 r/min (54 Hz), 14132 r/min (57 Hz), 14772 r/min (60 Hz), and the ring rail was moved from the lowest place to the highest one. It can be seen from figure 5 that the relationship between the tension and spindle rotation speed is nonlinear, and the tension is increased with the increase of spindle rotation speed.

The effect of the type of traveller on spinning tension is summarized in table 2. Under the same spindle rotation speed, the mass of the traveller has a significant effect on the tension and CV. In particular, the larger the mass of traveller, the greater the tension is. The CV and range corresponding to the 8/0 traveller are smaller than those of the other two travellers, suggesting that 8/0 traveller has better operating performance.

CONCLUSION

In the present work, we constructed a novel tension detection and control system for the ring-spinning frame. The system, composed of stress sensor, A/D and D/A converters, and data acquisition and processing systems, can be used to measure the dynamic stress on thread guide. The mechanical models are established and solved to obtain real-time dynamics of roving tensions. The spindle rotation speed can be regulated to control dynamics of roving tensions using the self-developed tension control system, which greatly reduces the fluctuation of spinning tension, alleviates the end breakage, and improves the yarning quality. Overall, the proposed spinning tension control method can be used for the intelligent control of spinning tension, which can effectively reduce the yarn breakage during ring spinning.

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Modelling of tension in yarn package unwinding

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ABSTRACT – REZUMAT

Modelling of tension in yarn package unwinding

Yarn unwinding from a package is an essential step in many textile processes. The quality of the yarn is numerically expressed mainly by values of mechanical quantities. In the unwinding process viscoelastic properties are the most important ones. They depend on how the yarn is stressed. The quality of the yarn that is being unwound should not be reduced, unless this reduction doesn't significantly lower the quality of the textile fabric. During unwind the yarn tension is not constant, but it oscillates within some interval. Even when the yarn is not strongly stressed, the yarn still can break sometimes. This is why we think that a cross-wound package is not an ideal form of a package and that such packages aren't always made without flaws. We strive to achieve as large warping and weaving speeds as possible, therefore our aim is to improve the theory of cross-wound package unwinding and to find the necessary modifications of the yarn unwinding process.

Keywords: *modelling, tension, dynamics of yarn, balloon theory, quasi-stationary approximation*

Modelarea tensiunii în derularea bobinei de fire

Derularea firelor dintr-o bobină este un pas esențial în multe procese textile. Calitatea firului este exprimată numeric în principal prin valori ale mărimilor mecanice. În procesul de derulare proprietățile viscoelastice sunt cele mai importante. Acestea depind de modul în care firul este solicitat. Calitatea firelor care se derulează nu trebuie redusă, cu excepția cazului în care această reducere nu scade semnificativ calitatea materialului textil. În timpul derulării, tensiunea firului nu este constantă, dar oscilează într-un anumit interval. Chiar și atunci când firul nu este solicitat puternic, acesta se poate rupe uneori. Acesta este motivul pentru care se consideră că o bobină încrucișată nu este o formă ideală și că astfel de bobine nu sunt întotdeauna realizate fără defecte. Se dorește obținerea de viteze cât mai mari de urzire și țesere, prin urmare, scopul este să se îmbunătățească teoria derulării bobinei încrucișate și să se identifice modificările necesare procesului de derulare al firului.

Cuvinte-cheie*: modelare, tensiune, dinamica firelor, teoria derulării firului, aproximare cvasi-staționară*

INTRODUCTION

The theory of yarn unwinding and the balloon theory has a long history. Different authors tried to develop it and influenced the theory through the certain period of time [1–7]. The theory as we know it today was heavily influenced by Fraser, Ghosh and Batra [8]. They applied perturbation theory to show how to eliminate time dependence from the equation of motion of a cylindrical packages in a mathematically correct way. They derived moving boundary condition for packages with small winding angles. Fraser also found out that for elastic yarn the tension in the balloon is smaller [9, 10]. However, it turns out that this effect is small for elastic constants encountered in typical yarns [11]. The theory of yarn movement on the surface of the package was developed simultaneously with the balloon theory. Both theories solved the simplified equations at stationary boundary conditions and so determined the length of the sliding yarn [3]. The computation was verified by Fraser et al. [9]. During unwinding from the package the yarn moves over the surface of the package. The point where the yarn leaves the package is called a lift-off point. The residual tension of the yarn from the interior of the package is released at this point. The equations of motion of the yarn are known. We derived them in our previous contribution [12]. As we will show here it is possible to obtain a partial analytical solution demonstrating the existence of the residual force.

GENERAL EQUATION OF MOTION FOR YARN

The yarn is unwinding from a fixed cylindrical package in horizontal direction with velocity V through the guide-eye O (figure 1). The origin of the coordinate system is at the guide-eye. Point Lp is the lift-off point, i.e., the point where the yarn leaves the surface of the packages to form the balloon. Angle ϕ is the angle of the winding on the package. We are interested in balloon motion, i.e., the time variation of the position radius vector $r(s,t)$ of the yarn in space.
The theory of yarn unwinding off a package and the balloon equations was derived in the previous work [12]:

$$\rho\left(D^2 r + 2\omega \times Dr + \omega \times (\omega \times r) + \dot{\omega} \times r\right) = \frac{\partial}{\partial s}\left(T\frac{\partial r}{\partial s}\right) + f \quad (1)$$

They can be partially analytically solved, as we show in the following. Fictitious forces on the left-hand side of the equation are: the Coriolis force $-\rho 2\omega \times Dr$, the centrifugal force $-\rho\omega\times(\omega\times r)$ and the Euler force $-\rho\dot{\omega}\times r$. D is the differential operator which follows the motion of a point on the yarn in the rotating reference frame [8]:

$$D = \frac{\partial}{\partial t}\bigg|_{r,\theta,z} - V\frac{\partial}{\partial s} \quad (2)$$

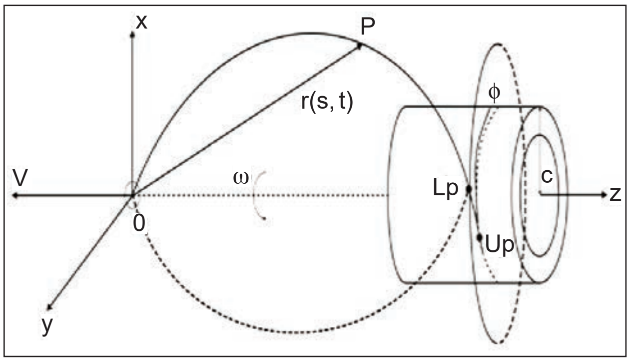

Fig. 1. Yarn unwinding from a cylindrical package

The fact that this operator "follows the motion of the point in the rotating frame" means, that the partial time derivative operator only operates on the coordinates of the point (r, θ, z), but it gives zero when applied on the base vectors e_z, e_θ, e_r. T is the mechanical tension and f is the linear density of external forces. In yarn which forms the balloon, f is the air resistance force [13, 14]:

$$f = -\frac{1}{2} c_u \rho d |v_n| v_n \quad (3)$$

where c_u is the effective air-drag coefficient, ρ – the mass per unit length of the yarn, d – the yarn diameter and v_n – the normal component of the yarn velocity. With the help of $D_n = 1/2 c_u \rho d$ we can write the air resistance force in a similar form as found in literature [12]:

$$f = -D_n |v_n| v_n \quad (4)$$

The equation of motion 1 expressed in the dimensionless form. We express all distances in units of package radius $\bar{r} = r/c$, $\bar{r} = r/c$, $\bar{z} = z/c$, $\bar{s} = s/c$, time is expressed in units of period of balloon rotation: $\bar{t} = t/\tau = \omega t$, velocitis are expressed in units of unwinding speed: $\bar{v} = v/V$, $\bar{v}_n = v_n/V$ and finally we find the following suitable combinations of quantities for forces and tension [15]:

$$\bar{f} = \frac{fc}{\rho V^2},\ \bar{n} = \frac{nc}{\rho V^2},\ \bar{T} = \frac{T}{\rho V^2} \quad (5)$$

Transforming the equantion of motion into the dimensionless form we get:

$$\bar{D}^2\bar{r} + 2\Omega\times\bar{D}\bar{r} + \Omega\times(\Omega\times\bar{r}) + \Omega\frac{\partial\Omega}{\partial\bar{t}}\times\bar{r} = \frac{\partial}{\partial\bar{s}}\left(\bar{T}\frac{\partial\bar{r}}{\partial\bar{s}}\right) + \bar{f} \quad (6)$$

where:

$$\bar{D} = \Omega\frac{\partial}{\partial\bar{t}} - \frac{\partial}{\partial\bar{s}},\ \Omega = \frac{c\omega}{V} \quad (7)$$

The dimensionless air resistance force is:

$$\bar{f} = -\frac{p_0}{16}|\bar{v}_n|\bar{v}_n \quad (8)$$

where:

$$\bar{v} = \bar{D}\bar{r} + \Omega\times\bar{r} \quad (9)$$

and

$$\bar{v}_n = \frac{\partial\bar{r}}{\partial\bar{s}}\times\left(\bar{v}\times\frac{\partial\bar{r}}{\partial\bar{s}}\right) \quad (10)$$

QUASI-STATIONARY APPROXIMATION

So far our derivation was entirely general. We took into account that the yarn has constant linear mass density and that it is unstretchable. The dimensionless equation 6 derived above enables to study arbitrary yarn motion. In the literature we can find two different approaches. In the first approach we simply assume that the motion is quasi-stationary with respect to the rotating coordinate system by setting all time derivatives on zero. In the second approach we attack the problem with perturbation theory [8]. Namely, it turns out that with a suitable choice of dimensionless variables the motion equations can be written in a form where all time derivatives are multiplied with a small parameter. Fraser estimates that for a typical package this parameter is between 0.007 and 0.103, which shows that time derivatives can be neglected in the first approximation. Perturbation theory is a systematic approach for founding such approximations. Fraser shows that the fundamental equation (the equation in the so called zero order) describes stationary motion et yarn in the rotating coordinate system. Boundary conditions however can be time dependent. Besides that it turns out that $\Omega = 1$ in the zero order of the theory. This corresponds to the winding angle $\phi = 0°$, which limits the generality of solutions if we work in the fundamental (zero) order perturbation theory as Fraser did. Unfortunately equations for corrections are time dependent which is not very helpful. The use of perturbation theory is more justified from a mathematical point of view but from the perspective of physics the first approach is also entirety satisfactory and it also allows greater generality. Therefore we have decided to use quasi-stationary approximation in the sequel. If we sent all time derivatives to zero and we omit writing ¯ for dimensionless quantities we get the following quasi-stationary equation of motion.

$$\frac{\partial^2 r}{\partial s^2} - 2\Omega\times\frac{\partial r}{\partial s} + \Omega\times(\Omega\times r) = \frac{\partial}{\partial s}\left(T\frac{\partial r}{\partial s}\right) + f \quad (11)$$

A DERIVATION OF COMPONENTE WISE EQUATIONS OF MOTION

The vectorial equation 11 will be written out in component form. This form is more suitable for solving the equations.

Firstly, we need the first and the second derivative of the position vector.

$$r(r,\theta,z) = r(s)\,e_r(\theta(s)) + z(s)\,e_z \tag{12}$$

We emphasize that the basis vector e_r depends on the angle θ. Therefore it indirectly depends also on the parameter s. To compute derivatives we use relations [12]:

$$\frac{\partial e_r}{\partial\theta} = e_\theta \qquad \frac{\partial e_\theta}{\partial\theta} = -e_r \tag{13}$$

For the first derivative we get that:

$$\frac{\partial r}{\partial s} = r'e_r + r\frac{\partial e_r}{\partial\theta}\frac{\partial\theta}{\partial s} + z'e_z = r'e_r + r\theta'\,e_\theta + z'e_z \tag{14}$$

We introduced notation $' = \partial/\partial s$ for derivatives with respect to parameter s.

For the second derivative we get that:

$$\frac{\partial^2 r}{\partial s^2} = r''e_r + r'\frac{\partial e_r}{\partial\theta}\frac{\partial\theta}{\partial s} + r'\theta'e_\theta + r'\theta''e_\theta + r\theta'\frac{\partial e_\theta}{\partial\theta}\frac{\partial\theta}{\partial s} + z''e_z$$
$$= r''e_r + r'\theta'e_\theta + r'\theta'e_\theta + r\theta''e_\theta - r'\theta'\theta'\,e_r + z''e_z$$
$$= (r'' - r\theta'^2)e_r + 2r'\theta'e_\theta + r\theta''e_\theta + z''e_z \tag{15}$$

To make bottle results more transparent we write them as column vector:

$$r' = \begin{bmatrix} r' \\ r\theta' \\ z' \end{bmatrix} \qquad r'' = \begin{bmatrix} r'' - r\theta'^2 \\ 2r'\theta' + r\theta'' \\ z'' \end{bmatrix} \tag{16}$$

We will also need the following results which are obtained from the rules for computing with vector products:

$$\Omega\times r = \Omega\begin{bmatrix} 0 \\ r \\ 0 \end{bmatrix},\ \Omega\times r' = \Omega\begin{bmatrix} -r\theta' \\ r' \\ 0 \end{bmatrix},\ \Omega\times(\Omega\times\bar{r}) = \Omega^2\begin{bmatrix} -r \\ 0 \\ 0 \end{bmatrix} \tag{17}$$

Considerably more work is required for the computation of the normal component of velocity. We will need this in expression for the density of the air resistance force. We start with the velocity which is by equation 9 equal to:

$$v = -r' + \Omega\times r = \begin{bmatrix} -r' \\ -r\theta' + \Omega r \\ -z' \end{bmatrix} \tag{18}$$

The normal component of velocity can be written as:

$$v_n = r'\times(v\times r') = \Omega\begin{bmatrix} -r^2\theta' r' \\ rz'^2 + rr'^2 \\ -r^2\theta' z' \end{bmatrix} = \Omega r\begin{bmatrix} -r\theta' r' \\ z'^2 + r'^2 \\ -r\theta' z' \end{bmatrix} \tag{19}$$

The square of the norm of this vector is:

$$|v_n|^2 = \Omega^2\left((r^2\theta' r')^2 + r^2(z'^2 + r'^2)^2 + (r^2\theta' z')^2\right)$$
$$= \Omega^2 r^2\left(r^2\theta'^2 r'^2 + z'^4 + 2z'^2 r'^2 + r'^4 + z'^2 r^2\theta'^2\right)$$
$$= \Omega^2 r^2\left(r'^2(\theta'^2 r^2 + z'^2 + r'^2) + z'^2(\theta'^2 r^2 + z'^2 + r'^2)\right)$$
$$= \Omega^2 r^2(r'^2 + z'^2)(r'^2 + r^2\theta'^2 + z'^2)$$
$$= \Omega^2 r^2(r'^2 + z'^2) \tag{20}$$

In the last step we used the inextensibility condition, $r'^2 + r^2\theta'^2 + z'^2 = 1$. Therefore the normal component of velocity is:

$$v_n = \Omega r\sqrt{r'^2 + z'^2} \tag{21}$$

It follows that the linear density of air resistance is equal to:

$$f_u = -\frac{1}{16}\,p_0 v_n v_n$$
$$= -\frac{1}{16}\,p_0 v_n \Omega\begin{bmatrix} -r^2 r'\theta' \\ r(r'^2 + z'^2) \\ -r^2\theta' z' \end{bmatrix} = \begin{bmatrix} 1/16\,p_0\,\Omega r^2 r'\,\theta' v_n \\ -1/16\,p_0/(\Omega r)\,v_n^3 \\ 1/16\,p_0\,\Omega r^2\theta' z' v_n \end{bmatrix} =$$
$$= -\frac{1}{16}\begin{bmatrix} p_0\,\Omega r^2 r'\,\theta' v_n \\ -p_0\,v_n^3/(\Omega r) \\ p_0\,\Omega r^2\theta' z' v_n \end{bmatrix} \tag{22}$$

By using the formula $\partial/\partial s\,(T\partial r/\partial s) = T'r' + Tr''$ we can write the equation of motion as

$$(1 - T)r'' - 2\Omega\times r' + \Omega\times(\Omega\times r) = T'r' + f \tag{23}$$

This is a vectorial equation with three components:

$$(1 - T)(r'' - r\theta'^2) + 2\Omega r\theta' - \Omega^2 r = T'r' + \frac{1}{16}\,\Omega p_0 r^2 r'\,\theta' v_n \tag{24}$$

$$(1 - T)(2r'\theta' + r\theta'') - 2\Omega r' = T'r\theta' - \frac{1}{16}\,p_0 v_n^3/(r\Omega) \tag{25}$$

$$(1 - T)z'' = T'z' + \frac{1}{16}\,\Omega p_0 r^2\theta' z' v_n \tag{26}$$

The fourth equation is the inextensibility condition:

$$r'^2 + r^2\theta'^2 + z'^2 = 1 \tag{27}$$

Therefore we have four equations for four variables, r, θ, z in T. We multiply the equation (24) with r', the equation (25) with $r\theta'$ and the equation (26) with z' to get:

$$(1 - T)\left(r''r' + r'r\theta'^2 + r^2\theta'\theta'' + z'z''\right) - rr'\Omega^2 =$$
$$= T'(r'^2 + r^2\theta'^2 + z'^2) +$$
$$+ \frac{1}{16}\,p_0 v_n\Omega\left(r^2 r'^2\theta^2 - \theta' v_n^2/\Omega^2 + r^2\theta' z'^2\right) \tag{28}$$

The expression between the round brackets on the right-hand side of the equation is equal to 1, by the inextensibility condition. The expressions between the square brackets are both equal to 0. The proof for the first expression is given by the following equation:

$$(r'r'') + (z'z'') + (r'r\theta'^2 + r^2\theta'\theta'') =$$
$$= \left[\frac{1}{2}(r'^2) + \frac{1}{2}(z'^2) + \frac{1}{2}(r^2\theta'^2)'\right]'$$
$$= \frac{1}{2}(r'^2 + z'^2 + r^2\theta'^2)'$$
$$= \frac{1}{2}(1)' = 0 \quad (29)$$

where we used the inextensibility condition in the next to last line.

In the second expression we first expand v_n^2 by using equation 21, we see that all terms cancel out. Therefore equation 28 simplifies to:

$$T' = -\Omega^2 rr' \quad (30)$$

If we write T_0 for the tension in the yarn passing through the guide (figure 1) we get that:

$$T = T_0 - \frac{1}{2}\Omega^2 r^2 \quad (31)$$

PARTIAL ANALYTICAL SOLUTION

When the yarn is unwinding from the package the lift-off point moves over a two-dimensional surface. We can use this in equation 31 to obtain another two-dimensional problem which can be solved more easily. It turns out that the tension of the yarn in the interior of the package can be expressed analytically. We will therefore assume that our package has a cylindrical shape (figure 2), which implies that the radius-vector to a surface point of the package is [12]:

$$r = ce_r + ze_z \quad (32)$$

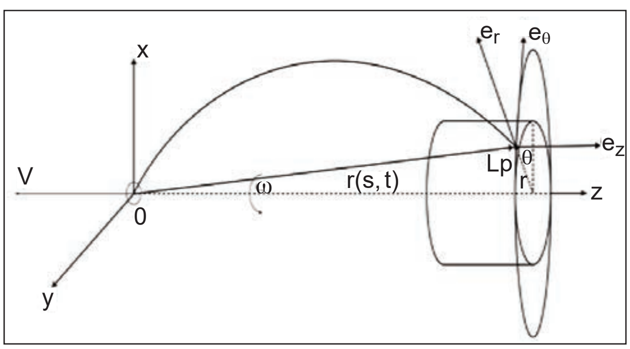

Fig. 2. Coordinate frame correspond to equation (31)

The quantity c is by definition equal to the constant distance of the point r from the axis of the packag, it is though equal to the diameter of the layer which is currently unwinding [12]. The eqaution 31 will now be used to find the residual tension at the lift-off point Lp. Therefore we are interested in the velocity with which the yarns leaves the package. This velocity doesn't have to be equal to the unwinding velocity V_1. Namely we have that

$$V_1 = V + \dot{s}_1 \quad (33)$$

where s_1 is the lenght of the yarn in the balloon i.e. the lenght of the yarn between the guide and the lift-off point Lp. In other woords we had to add time derivative of lenght to the velocity V to obtain the lift-off velocity. We take into account that:

$$\frac{ds_1}{dt} = \frac{ds_1}{dz_1}\frac{dz_1}{dt} \quad (34)$$

where z_1 is the z coordinate of the lift-off point.

At quasistationary movement we have that:

$$\frac{ds_1}{dz_1} = 1 \quad (35)$$

because the length of the yarn between the package and the guide is enlarged exactly by the enght corresponding to the displacement of the point Lp. If we insert the condition 35 for quasistationary movement into equation 32 we obtain boundary conditions at the lift-off point which we can express as $r=c$. The dimensionless boundary condition at the lift-off point becomes:

$$r(s_{Lp}, t) = 1 \quad (36)$$

Inserting condition (35) into equation 31 we get that the tension at the Lp is then equal to:

$$T - T_0 = \frac{1}{2}\Omega^2 \quad (37)$$

The equation 37 tells us that tension in the yarn drops from its value in the balloon (at the lift-off point) to its residual value, defined as the tension of the yarn inside the package. If we write $T_R = \Omega^2/2$ for the residual tension in the yarn (figure 3), we get that:

$$T - T_0 = T_R \quad (38)$$

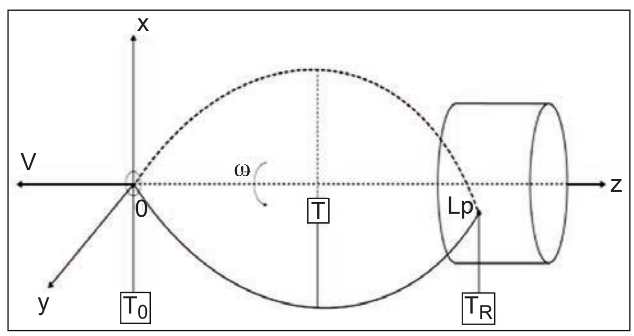

Fig. 3. View of the "balloon" (illustration of equations 38)

CONCLUSIONS

We saw how the equation for yarn tension in the balloon can be obtained from the general equation of yarn by replacing the usual perturbation theory approach with quasi-stationary approximation. The tension T of the yarn in the balloon consists of two points: from the tension T_0 in the yarn at the guide-eye and from the residual tension T_R in the yarn: $T - T_0 = T_R$. Analytical solutions enable a better understanding of interdependencies between various quantities. The residual tension in the yarn has not been studied enough so far. We showed that it enables a reduction of the yarn tension in the balloon. This is the first analytical proof of the existence of the residual force in the theory of yarn unwinding.

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Design of the detecting platform for the electronic control rotary dobby

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ABSTRACT – REZUMAT

Design of the detecting platform for the electronic control rotary dobby

In order to meet the factory detection requirements of the rotary electronic dobby, a new design of the detecting platform for the rotary electronic dobby was proposed in the present study. It was composed with three main modules to meet the different levels of detecting process all over the factory, including the embedded control system, human machine interface system and the information management system. For the information management system of the dobby workshop, the proposed platform performed the remote management, results monitor, and data analysis to the dobby manufactured at the factory. For the operators of the dobby detecting process, the human machine interface system realized the edit of pattern, the upload and download of the pattern data based through Wi-Fi, the control of motor speed, the test process record and the upload of the test results. Moreover, the embedded control system was developed and built to realize the real-time control to electromagnet and swing arms of dobby according to the pattern stored in flash chip and status display of the detecting results on the platform. The designed detecting platform in this article can be widely applied in the factory for detection of the rotary electronic dobby. The reliability and practicability of the proposed platform have been confirmed by the practical application of the dobby manufacturing enterprise.

Keywords: *detecting platform, dobby control, information management, pattern design, rotary electronic dobby*

Proiectarea platformei de detectare pentru comanda electronică a ratierei rotative

Pentru a îndeplini cerințele de detecție din producție ale ratierei rotative electronice, în prezentul studiu a fost propus un nou design al platformei de detectare pentru ratiera rotativă electronică. Acesta se compune din trei module principale pentru a îndeplini diferitele niveluri ale procesului de detectare în întreaga fabrică, inclusiv sistemul de control încorporat, sistemul de interfață om-mașină și sistemul de gestionare a informațiilor. Pentru sistemul de gestionare a informațiilor din secția cu ratieră, platforma propusă a efectuat gestionarea la distanță, monitorizarea rezultatelor și analiza datelor către ratiera. Pentru operatorii procesului de detectare a ratierei, sistemul de interfață om-mașină a realizat editarea modelului, încărcarea și descărcarea datelor modelului bazate pe Wi-Fi, controlul vitezei motorului, înregistrarea procesului de testare și descărcarea rezultatelor testului. Mai mult decât atât, sistemul de control încorporat a fost dezvoltat și construit pentru a realiza controlul în timp real al electromagnetului și brațelor oscilante ale ratierei în conformitate cu modelul stocat în cip și afișarea rezultatelor detectării pe platformă. Platforma de detectare proiectată în acest articol poate fi aplicată pe scară largă în producție pentru detectarea ratierei rotative electronice. Fiabilitatea și practicabilitatea platformei propuse au fost confirmate de aplicația practică a întreprinderii producătoare de ratieră.

Cuvinte-cheie: *platforma de detectare, controlul ratierei, gestionarea informațiilor, proiectarea modelelor, ratieră rotativă electronică*

INTRODUCTION

Rotary electronic dobby is a type of positive dobby, which has been mainly used with rapier and projectile weaving machines. In recent years, manufacturers have demonstrated their rotary dobby at the international exhibitions. This makes it possible to employ a rotary dobby on high speed air jet and water jet weaving machines. Today, it is a dominant type of dobby in industry that can be used on all types of weaving machines [1–3].

As an important part of the weaving machinery, the rotary electronic dobby plays an important role in improving the efficiency and quality of the weaving machine. The rotary electronic dobby is an advanced opening device of looms, which plays an irreplaceable role in the research and development of new fabrics and batch weaving. Excellent output motion characteristics and advanced control technology of the rotary electronic dobby provide the necessary foundation for the development of high-speed and flexible looms. Meanwhile, the performance of the rotary electronic dobby directly affects the yield and quality of the fabric.

However, reviewing the literature indicates that few publications have been conducted so far on the control and detection of rotary electronic dobby. On the other hand, it is a great challenge to control the rotary electronic dobby produced by the manufacturer company so that the quality of the rotary electronic dobby cannot be guaranteed and the quality of the rotary electronic dobby and non-systematic operation of key operating parameters cannot be guaranteed [4, 5]. This remarkable drawback hinders users to provide the required information for manufacturing enterprises, thereby seriously restricting the digital development in the textile industry.

The working condition of the rotary electronic dobby is complicated during the factory inspection process. The detecting items of the platform include electromagnet current, electromagnet temperature, electromagnet working state, running speed of dobby, working time, vibration, lubricating oil temperature, lubricating oil level motor running state, inverter running, fault signal, electromagnet current abnormal information, electromagnet execution abnormal information. It is necessary to determine whether the rotary electronic dobby can perform the relevant actions smoothly and orderly. Moreover, it is of significant importance to study the control methods and develop techniques for the rotary electronic dobby. The present article intends to present a factory detection platform for the rotary electronic dobby.

STRUCTURE OF THE DETECTION PLATFORM

In the present study, the principle of the rotary electronic dobby is combined with the loom [6, 7] to design and develop a rotating electronic dobby (hereafter called “dobby”) detecting platform. Figure 1 illustrates the structure of the proposed detecting platform. It indicates that the platform is mainly composed of three parts, including the embedded control system (ECS), human machine interface system (HMIS) and the information management system (IMS). The ECS controls the start and stop of the frequency converter /motor, provides the electromagnet pull-off signal in accordance with the pattern information and detects the running status of the dobby. Moreover, the HMIS realizes operational parameter setting, pattern management, selection of the detection mode, and presentation of the data detection in the dobby. Finally, the IMS manages the shop-level dobby detection process.

ECS OF THE DETECTING PLATFORM

The ECS hardware circuit of the designed dobby consists of an ATmega128 microcontroller, power management module, pattern storage module, optocoupler isolation module, power drive module, Wi-Fi module and RS485 communication module. Figure 2 illustrates the ECS structure for the proposed design. Figure 2, *a* shows the hardware connection diagram, which presents the dobby structure, the function of the detection board, and the communication relationship with the HMIS. Furthermore, figure 2, *b* shows the basic circuit principle diagram of the proposed scheme. It indicates that the ECS consists of an ATmega128 microcontroller for power management, data communication, dobby control and detection.

Communication and pattern storage

The ECS employs two communication methods, one is RS-485 wired and the other is Wi-Fi wireless communication. The structure diagram of these methods is shown in figure 2. RS-485 communication module forms the protocol analysis between ECS and frequency converter through the MAX485 chip under the action of the control signal. Moreover, it realizes the frequency converter and the motor control. On the other hand, the Wi-Fi communication module receives the pattern data and controls commands transmitted from the HMIS to the ECS, performs controlling and detection operations of the dobby, and returns the detected data to the HMIS.

The pattern storage part employs FM24C512 flash chip. In order to meet the system requirements, the proposed design uses two FM24C512 flash chips with 1 MB of storage space. This memory performs continuous reading and writing operations at the bus speed up to 1 MHz. It should be indicated that the read/write operation consumes only 250 μA at 100 KHz, which is an extremely low power consumption. Moreover, application of the two-wire interface TWI (I^2C) of the ATmega128 microcontroller is simple and convenient so that this feature is applied on the FM24C512 to meet the requirements of the ECS.

Frequency converter/motor control

The detecting platform uses Schneider frequency converter with rated power of 7.5 KW and Schneider three-phase AC motor with 5KW to drive the rotation of the dobby main shaft. The ECS performs the bidirectional communication with the frequency converter through RS-485 serial communication and adopts the MODBUS communication protocol of the frequency converter. Moreover, it performs the start/ stop operation, forward/reverse rotation, adjusts the speed and the fault alarm of the motor, and completes the dobby motion control during the machine detection.

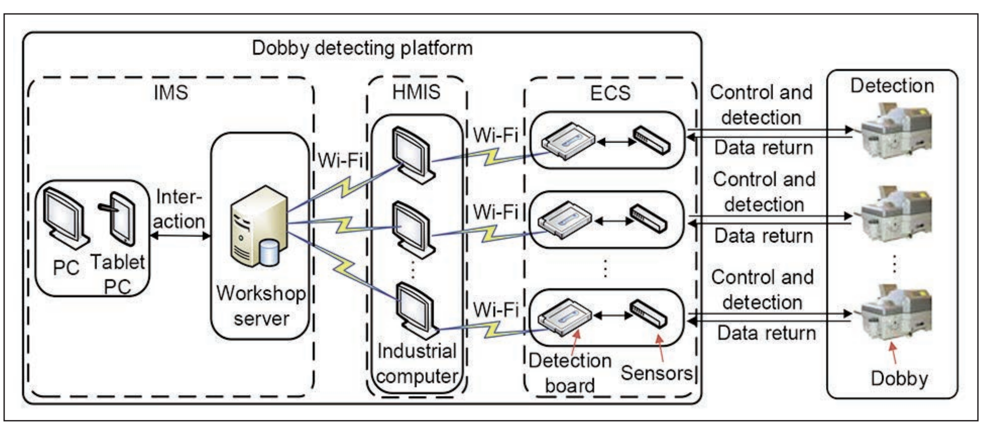

Fig. 1. Structure of the proposed detecting platform

Dobby control

The high-speed multi-channel electromagnet and swing arms

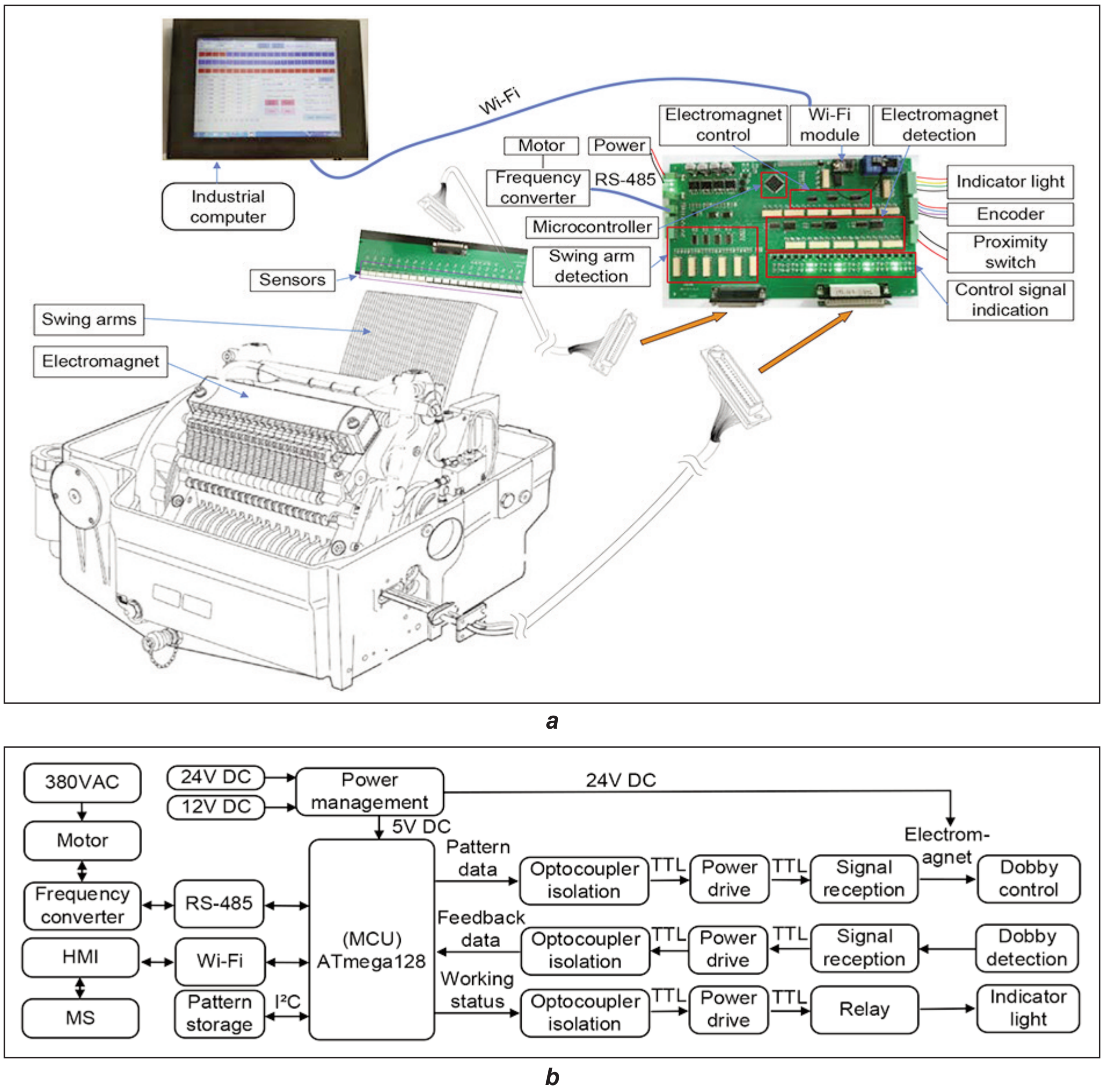

Fig. 2. ECS structure of the proposed scheme: *a* – hardware connection diagram; *b* – basic circuit principle diagram

act as the first-stage signal actuator of the dobby, which plays a vital role in the performance of the entire dobby. Therefore, it is of significant importance to control and detect the electromagnet and swing arms motion. The control items of the detecting platform include dobby operation control, pattern data storage, inverter and motor drive, electromagnet drive, electromagnet magnetic induction intensity acquisition, electromagnet current acquisition, swing arm motion state acquisition, oil temperature and liquid level information collection. Figure 3 schematically shows the control and detection module. It indicates that after reading the machine parameters of the selected pattern file, the pattern file is converted to the format required by the dobby ECS. In the process of control and detection, the electromagnet has two action modes, entitled by pull-in and release modes, which correspond to the logic "1" and logic "0" in the logic circuit, respectively. After reading the pattern file, the ECS determines whether the pattern data is "1" or "0". When the data is "1", the electromagnet energizes and it is pulled-in so that the corresponding swing arms move. Otherwise, when the data is "0", the electromagnet is powered off and it is released so that the corresponding swing arms remain stationary. Therefore, as shown in figure 3, *a*, a pattern drawn by the pattern file is formed on the fabric in accordance with the dobby ECS.

The electromagnet is controlled according to the control signal and the structural information. Figure 3, *b* illustrates the timing chart for the studied case. In A and B areas of the weaving machine, the microprocessor combines the pattern information to control the electromagnet. The working state of the electromagnet determines the movement of the heald frame of the loom during the weaving process. The working voltage of the electromagnet is set to 24 V DC. When the voltage is applied, the electromagnet is pulled-in and the swing arms move. On the other hand, the electromagnet is disconnected when the voltage is released. At this time, the swing arms are stationary. Since the electromagnet resistance of each path is approximately 230, ULN2803 microprocessor is required for power amplification during driving the swing arms. Since the number of electromagnets is large, while the Input/Output (I/O) of the ATmega128 is limited, the 74HC590 device is applied as the serial

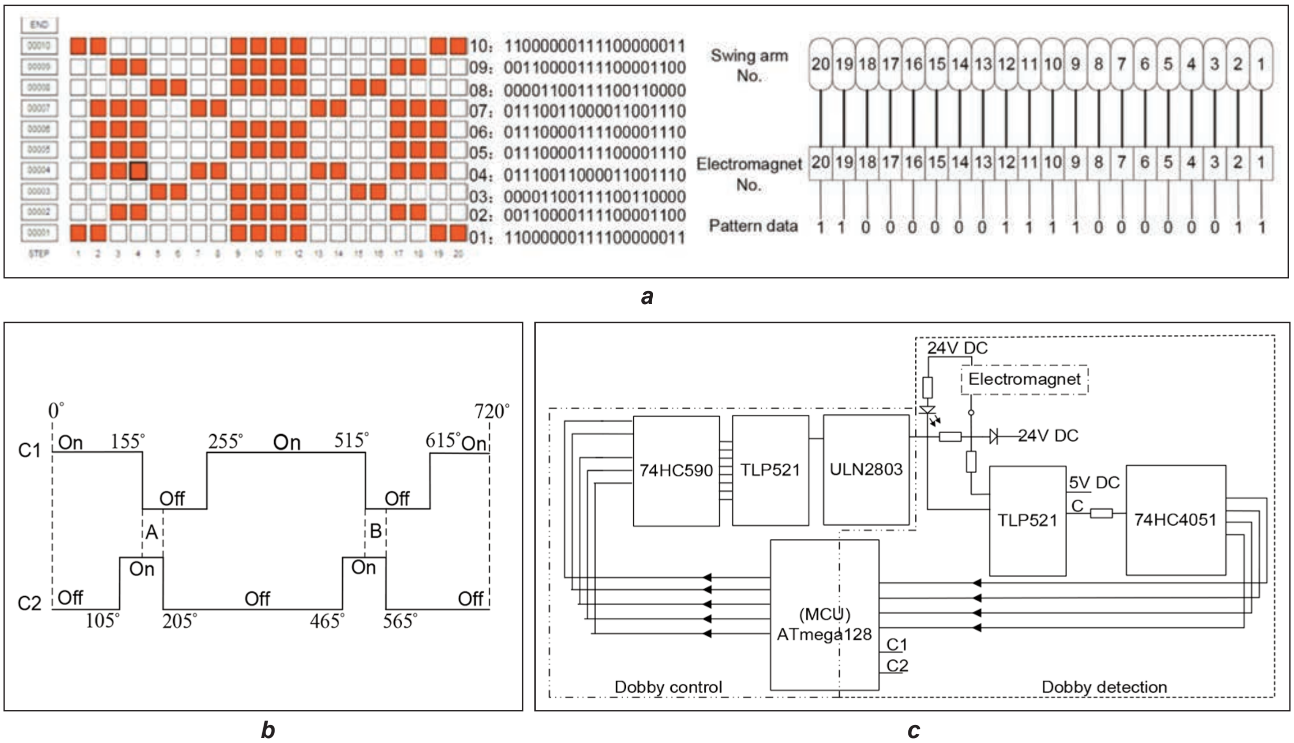

Fig. 3. Control and detection modules: *a* – pattern information and control signal conversion; *b* – timing chart of the control and detection operations; *c* – schematic of the control and detection modules

shift output control. Figure 3, *c* illustrates the control and detection schematic in this regard.

The signal plate is fixed on the main shaft of the dobby [8–11], and the rotational direction of the main shaft is detected by the photoelectric switch sensors. Meanwhile, two photoelectric switches can accurately detect the forward and reverse work of the dobby machine, which originates from the special shape of the signal disc.

Dobby detection

The principle of electromagnet and swing arms state detection is shown in figure 3, *c*. When the electromagnet is powered, the corresponding optocoupler (TLP521) input is turned on. Then the output end of the optocoupler is turned on in accordance with its working principle and the C terminal of the microcontroller generates a voltage of about 5 V, and the C port is connected to the I/O of the microcontroller. Based on this principle, it can be judged whether the electromagnet is attracted or not.

Similarly, photoelectric switch sensors are installed at the extreme position of the swing arms motion to detect whether the motion is consistent with the given pattern information, and determine whether the swing arms are in the correct state of motion. The obtained detection data is transmitted to the HIMS through the Wi-Fi wireless communication module.

Auxiliary function

The power management module provides Power supply with various voltages and amperes for the ECS of the entire dobby. Since the working voltage of the ECS microprocessor is inconsistent with that of the electromagnet, the electromagnet avoids the reverse impact of the controller and introduces electromagnetic interference when performing high-speed on-off operation. Moreover, the electromagnet adopts the optocoupler isolation design to effectively prevent spikes and various noise disturbances. Therefore, two power supplies are selected in the proposed design. The first one supplies 12 V DC, which is then turned into 5 V DC to supply power for the main controller through the buck and voltage regulation. The other channel is a 24 V DC power supply, which is powered by the filter and then it supplies the electromagnet.

When the dobby is working normally, the indicator light is green. When the dobby fails, the indicator light turns yellow. Moreover, when the dobby is powered off, the indicator light is red. The electromagnet indicator can be flashed according to the given pattern data so that the movement status and pattern data of the electromagnet are presented. The control circuit and program utilize a watchdog timer and a punctual interrupt to monitor the running status of the program. When the program runs out of order, the watchdog timer restarts the execution of the program through an internal interrupt.

HMIS OF THE DETECTING PLATFORM

In order to design an interactive interface that can directly perform the parameter setting, pattern management and the dobby detection, the HMIS of the dobby is programmed in the Visual Studio 2012 environment. Figure 4 illustrates the provided HIMS. Pattern film selection, input parameters of process, and reading/conversion parameters of the machine are obtained through interactive dialogue boxes. It

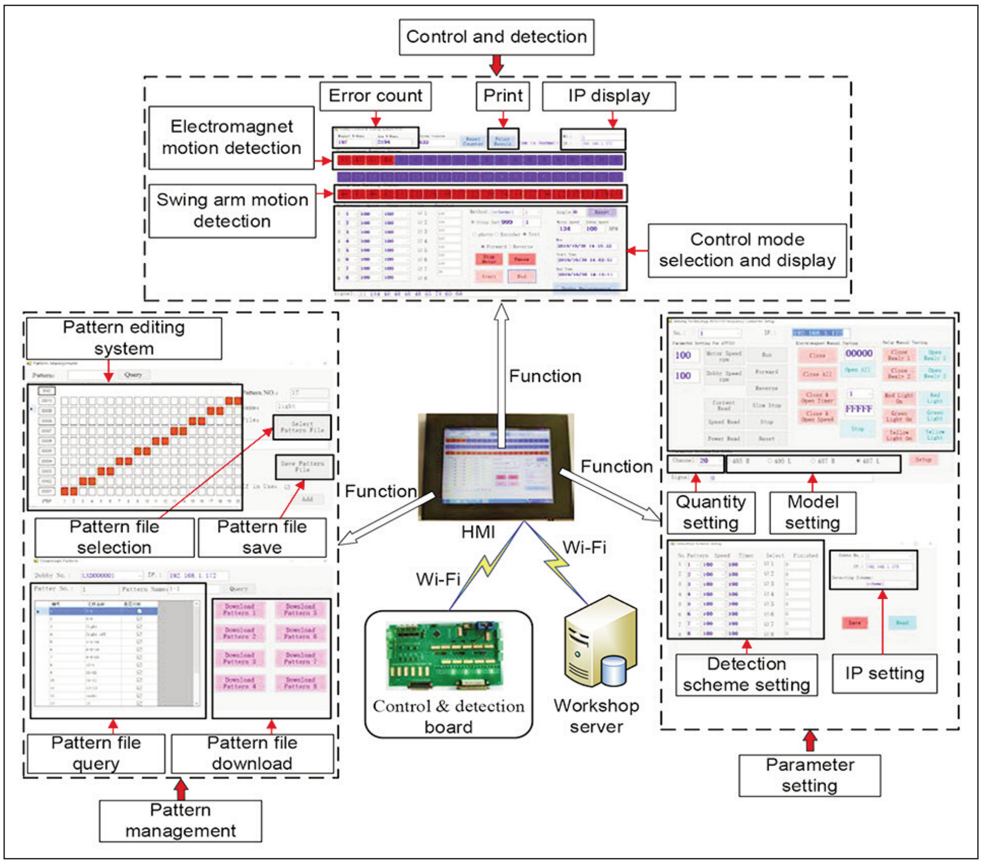

Fig. 4. HMIS structure

saved, queried, downloaded, renamed and deleted. The pattern design software can be applied simply and effectively to the ECS of the dobby. In the HMIS, a function is considered for the user to call the pattern design software. The user designs the pattern in accordance with the detection process, and can store the designed pattern in the database to create a pattern library. Since the interactive system of the dobby is installed on the industrial computer, multiple pattern information can be stored at the same time. In order to facilitate the created file management, each pattern file has a name. In the practical application, the user should only select the file list column of the basic pattern, and select the desired pattern according to the pattern name. Then the pattern will be called from the pattern library. Each pattern file obtains the pattern required for controlling and detecting the dobby.

should be indicated that the HMIS of the dobby has wireless communication capabilities with a Windows operating system. Furthermore, the HMIS of the dobby can debug, evaluate the dobby performance, analyze and store data. In order to overcome the challenges of field wiring in the dobby industry, the HMIS transmits data to the dobby ECS through the wireless communication. The transmitted data include the pattern information and control commands. In order to preserve data and perform the analysis on the data, the test data is transmitted to the workshop server through the Wi-Fi protocol.

Parameter setting

In this section, the control and detection parameters of the dobby, including the number of swing arms, dobby model, swinging speed, detection scheme and IP address settings, are set. It should be indicated that the number of swing arms of the dobby is generally a multiple of 8, such as 16, 24, 32, or a multiple of 4, such as 12, 16, 20, 24, 28. Therefore, the number of swing arms should be initially determined. Moreover, the dobby model is different and should be set. In the detection of the dobby, it is also necessary to set a detection scheme, and when the scheme is saved, the scheme is selected in accordance with the detection process.

Pattern management

Pattern management includes the function of the pattern design software [12], pattern files can be selected,

Control and detection

Control and detection include controlling the frequency converter/motor, dobby electromagnet and swing arms action, and checking whether the electromagnet and swing arms work normally. The control and detection modes are applied to determine the structure and model of the dobby.

When the on/off state of each electromagnet and the action state of the swing arms are the same as those of the given pattern, the action state of the electromagnet and the swing arms are detected. If they are the same, the blue color is displayed on the dobby HMIS, while if they are not the same, the HMIS displays a red color accordingly. The number of errors is recorded, and the number of downtimes with the number of errors is set. If the number of errors exceeds the set value, the detection process will automatically stop. The test report can be automatically printed when the test is completed.

IMS OF THE DETECTING PLATFORM

The IMS is applied for the factory inspection process of the dobby. The dobby manufacturing enterprise can obtain its running status and data, and realize centralized data management for all the dobby

a *b*

Fig. 5. Application of the detection platform: *a* – IMS structure; *b* – detecting platform layout

machines detected in the factory. On the one hand, the dobby to be detected is assigned to the detection platform, where the corresponding inspection plan is arranged. On the other hand, the technician can view demanded information, including the process data, detection scheme and detection results of the dobby. Figure 5, *a* shows the designed IMS structure.

The IMS helps dobby manufacturers obtain the health status of the product in the real time, evaluate the performance of the dobby, continuously improve the technical optimization equipment, and improve the product quality.

APPLICATION OF THE DETECTING PLATFORM

In the factory application process, the detection platform of the dobby overcomes the reliability problem of long-term operation, and solves operational problems such as control of the dobby and factory detection. The presented detection platform in figure 5, *b* has been applied in Jiangsu Jinlong Technology Co., Ltd. It should be indicated that the detection platform has superior characteristics, including convenient operation, friendly interface and comprehensive functions. Moreover, it meets the requirements of the dobby factory detection and it can be widely promoted in diverse aspects.

CONCLUSIONS

In the present study, a dobby detection platform is designed and developed, where the platform consists of ECS, HMIS and IMS. The ECS is designed to control the frequency converter/motor, electromagnet and the swing arms. Moreover, it can detect the action state of the electromagnet and the swing arms, and satisfy the control and detection design principles. The HMIS integrates a series of functions such as call design, pattern files selection and procession. In order to improve the efficiency of the designed pattern, the pattern information can be transmitted to the embedded system through a wireless communication. The management system displays the test results of the dobby so that the dobby manufacturers can obtain the health status of the produced dobby in the real-time.

The present study shows that the proposed platform satisfies the factory inspection requirements of the dobby, improves the digitization level of the dobby detection platform, and greatly reduces the cost of the pattern control. It can be widely used in the factory inspection of the dobby to perform the factory inspection of the dobby intelligently. The reliability and usability of the proposed platform has been proven by the practical application of the dobby manufacturers.

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Design of a TENS knee pad with integrated textile electrodes

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ABSTRACT – REZUMAT

Design of a TENS knee pad with integrated textile electrodes

Transcutaneous electrical nerve stimulation (TENS) is defined as the application of electrical current to the skin for pain control by the American Physical Therapy Association (APTA). The TENS treatment is extensively preferred since it is safe, not expensive and has no side effects when compared to drug therapy. TENS therapy is applied using clinical or portable type TENS devices and TENS electrodes. However, conventional electrodes are not hygienic because they are not washable and their sticky structure makes patients uncomfortable. Furthermore, they are not suitable to be integrated into a smart garment. In this study, a knee pad with integrated electrodes and textile transmission lines have been designed and developed to be used for TENS therapy. Electrical resistance values of textile electrodes and transmission lines which are integrated into the knee pad were measured. The developed knee pad was connected to a commercially available TENS device and electrical current transmission on subjects was tested. Furthermore, washing tests were conducted on the knee pad.

Keywords: *electronic textiles, smart garment, conductive yarns, conductive materials*

Proiectarea unei genunchiere TENS cu electrozi textili integrați

Stimularea electrică a nervului transcutanat (TENS) este definită de către Asociația Americană de Terapie Fizică (APTA) ca aplicarea curentului electric pe piele pentru controlul durerii. Tratamentul TENS este preferat pe scară largă, deoarece este sigur, nu este scump și nu are efecte secundare în comparație cu terapia medicamentoasă. Terapia TENS se aplică utilizând dispozitive TENS clinice sau portabile și electrozi TENS. Cu toate acestea, electrozii convenționali nu sunt igienici, deoarece nu sunt lavabili și structura lor nu le oferă confort pacienților. În plus, aceștia nu sunt potriviți pentru a fi integrați în îmbrăcămintea inteligentă. În acest studiu, o genunchieră cu electrozi și linii de transmisie integrate în materialul textil a fost proiectată și dezvoltată pentru a fi utilizată pentru terapia TENS. Au fost măsurate valorile rezistenței electrice ale electrozilor și liniilor de transmisie care sunt integrate în genunchieră. Genunchiera dezvoltată a fost conectată la un dispozitiv TENS disponibil comercial și a fost testată transmisia de curent electric pe subiecți. Mai mult, s-au efectuat teste de spălare pentru genunchieră.

Cuvinte-cheie*: textile electronice, îmbrăcăminte inteligentă, fire conductive, materiale conductive*

INTRODUCTION

Transcutaneous electrical nerve stimulation (TENS), one of the electrical pain treatments, is defined as the application of electrical current to the skin for pain control by the American Physical Therapy Association (APTA) [1]. In TENS treatment, all or some of the sensory, motor, sensory-motor-nociceptive nerve fibers are stimulated using electrodes to influence the neuro-hormonal, neuro-physiological and cognitive system. TENS treatments are based on different action mechanisms however the most commonly used one is the "Gate Control Theory" which was introduced by Melzack and Wall in 1965 [2]. According to this theory, substantia gelatinosa acts as a gate control system that modulates the synaptic transmission of nerve impulses from peripheral fibers to central cells. A schematic diagram of the gate control theory in pain mechanisms is given in figure 1 [3]. The fundamental indications of TENS treatment are acute and chronic pain syndromes. It is known that TENS therapy, which was tested and still being tested by many researchers, is used in cases such as rheumatoid arthritis, osteoarthritis, low back pain, neck pain, neuropathic pain, labor pain, dysmenorrhea, after multiple rib fractures and so on [2]. The effect of TENS treatment varies depending on the source of the pain, the pain threshold of the individual, the electrode location, the intensity of stimulation

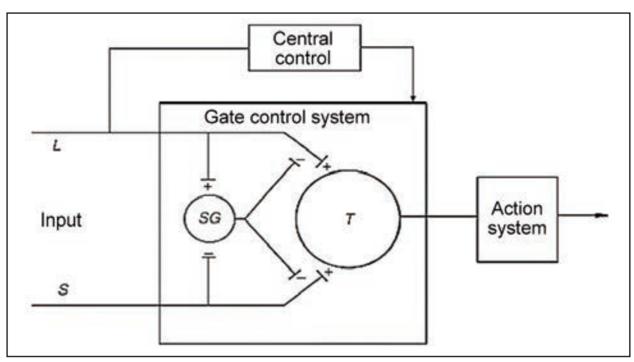

Fig. 1. A schematic diagram of the gate control theory in pain mechanisms: *L* – the large-diameter fibers; *S* – the small-diameter fibers; *SG* – substantia gelatinosa; *T* – transmission cells; + excitation; – inhibition [3]

and the electrical characteristics of the stimulation applied [4]. The TENS treatment is extensively preferred since it is safe, not expensive and has no side effects when compared to drug therapy [5].

TENS therapy is applied using clinical or portable type TENS devices and TENS electrodes. Metal plate electrodes covered by fabric tissue, carbon electrodes, and self-adhesive hydrogel electrodes are used as TENS electrodes up to this point [6]. The performance of these electrodes is very good. However, they are not hygienic because they are not washable and their sticky structure makes patients uncomfortable [7]. Furthermore, they are not suitable to be integrated into a smart garment. For these reasons, many type of research about textile electrodes is performing by researchers from all over the world recently. Most of the studies on textile electrodes focused on physiological monitoring and ECG, EMG and EEG measurements [8–15]. However, some of them concentrate on other fields such as electrical stimulation [16–20].

Prochazka et al. developed a functional electrical stimulation (FES) glove that improves hand function in people with spinal cord injury. The glove has conductive areas that contact with self-adhesive electrodes previously placed on the skin [21]. Lee et al. designed smart wear with built-in thermotherapy and TENS device for relief of dysmenorrhea [22]. Nisar et al. developed a rechargeable therapeutic wearable with embedded electrical stimulation device and skin adhesive electrodes for the prevention of pressure ulcers [23]. Keller et al. presented a transcutaneous electrical stimulation (TES) system consisted of a garment sleeve holding 60 textile embedded electrode pads and other electronic equipment. The developed system allows dynamic real-time adjustments of the electrode size and location for multiple regions on a single garment [24]. Li et al. designed and developed an intelligent garment with TENS function based on intarsia knitting technique. Silver conductive yarn was knitted into the garment to be used as electrodes and conducting wires [7]. Kim and Cho developed an e-textile-based smart glove with embedded textile electrodes. One side of the electrodes is a conductive snap which was used to combine with one end of a transmission line [16]. Goncu Berk presented the design process of a wearable pain management system with embroidered textile electrodes [25].

In this study, a knee pad with integrated electrodes and textile transmission lines have been designed and developed to be used for TENS therapy. Optimum electrode connections and electrode locations on the knee pad have been investigated. The electrical resistance values of textile electrodes and transmission lines which are integrated into the knee pad were measured. The developed knee pad was connected to a commercially available TENS device and electrical current transmission on subjects was tested. Furthermore, washing tests were conducted on knee pad and washing effect on textile electrodes and transmission lines were examined.

MATERIAL AND METHOD

Sample production

Knee pad is produced from two layers of 100% polyester laminated fabric with a weight of 150 g/m^2. Flame lamination of 1.7 mm thickness was applied to the base fabric with warp knitted fabric weighing 30 g/m^2. The raw material of the sponge used in lamination is polyurethane and its density is 26 kg/m^3. Since the bonding of the sponge to the fabric is done by melting the sponge in the flame machine, it is insoluble in the contact of the fabric with water. Electrodes and transmission lines were machine embroidered on one layer. The second fabric layer was used for providing a more aesthetical look. In this way, the sides of the electrodes which are not in contact with the skin and the transmission lines were concealed between two fabric layers. An empty area with 5 cm in diameter was formed on the patella to be used as a reference point for patients. The fabric layers were assembled using piping. Front and back views of the knee pad can be seen in figure 2.

Totally four textile electrodes were embroidered on the knee pad. Electrode locations were chosen according to the opinions of physical therapy and rehabilitation experts and doctors and previous studies about this subject [2]. In TENS therapy, three different electrode localization methods are determined. The first one is to position the electrode on pain region or its surroundings. The second one is to position the electrode on dermatome regions which are related to pain and the last one is to position the electrode on some special points on human body like acupuncture or trigger points [2]. Based on these

a *b*

Fig. 2. Graphical presentations: *a* – front view of knee pad; *b* – back view of knee pad

localization methods, patella was chosen as the center of the knee pad and electrodes were positioned on lower and upper corners. Electrodes, in size of 5 cm × 5 cm, and transmission lines, in sizes of 16 cm × 0.5 cm and 3 cm × 0.5 cm, were directly machine embroidered on the fabric with Tajima TFGN embroidery machine. For a better conductivity, conductive yarns were preferred as both top thread and bobbin thread.

Two different conductive yarns (X-Silver and X-Static) were used for the production of conductive parts. Overlapped high-density patterns were used for the production of electrode regions and transmission lines based on previous studies [26, 27]. Transmission lines and electrodes were embroidered at once to prevent disconnections between electrodes and TENS device. Female banana plug connectors were used by being fastened to the one end of textile transmission lines. Connectors were 2.54 cm in diameter, noncorrosive, and commercially available products. Totally 2 knee pad samples were produced and tested.

Testing of samples

Since one of the main aims of this study is to develop an integrated and washable product, washing tests were applied to the knee pads for ten times. Washing tests were carried out using 4 g/lt household detergent at 30°C main washing temperature in a domestic washing machine with reference to TS 5720 EN ISO 6330-2002 6A standard. After washing processes, samples were dried flat at room temperatures.

In order to evaluate the performance of textile electrodes and textile transmission lines, two different tests were applied. Firstly, electrical resistance values were measured before washing and after 1st, 5th and 10th washing cycles with a Thurlby 1503 digital multimeter. Before the measurements, knee pad samples were conditioned for 24 hours in laboratory conditions with a relative humidity of 20 ± 2°C and 65 ± 2%. Then, knee pad samples were connected to a Stimtec 2 model commercially available TENS device and current transmission was tested subjectively. Subjective trials were performed on 3 subjects (2 females, 1 male) which vary in ages from 28 to 52, from 165 to 187 cm in length and from 60 to 88 kg in body weight. Volunteers do not have any health problems. Subjective trials were repeated before washing and after 1st, 5th and 10th washings.

RESULTS AND DISCUSSION

The measured resistance values were evaluated with IBM SPSS Statistics 22 software and presented in figures 3 and 4 for knee pads produced using X-Silver and X-Static yarn, respectively. Electrical resistance values of electrodes and transmission lines were measured together and entitled as electrode number.

When figures 3 and 4 were examined, it is seen that electrical resistance values of the first and fourth electrodes are quite smaller when compared to second and third electrodes for both knee pads. The reason is that the first and fourth electrodes are located at the upper part of the knee pad and have shorter transmission lines, while other electrodes are located at the lower part and have longer transmission lines. All electrodes have the same dimensions and theoretically have the same electrical resistance values. Under these circumstances, it can be said that the difference between electrodes arises from the length of the transmission lines. An increase in the length of transmission lines causes an increase of electrical resistance values. When the figures are evaluated separately, it is observed that the electrical resistance values for the knee pad produced using X-Static yarn are higher especially electrodes with longer transmission lines.

When figures 3 and 4 were taken into consideration in the way of electrical resistance values before and after washing, it is observed that washing cycles give similar results for both knee pads. After washing processes, the electrical resistance values of electrodes and transmission lines are slightly increased. This

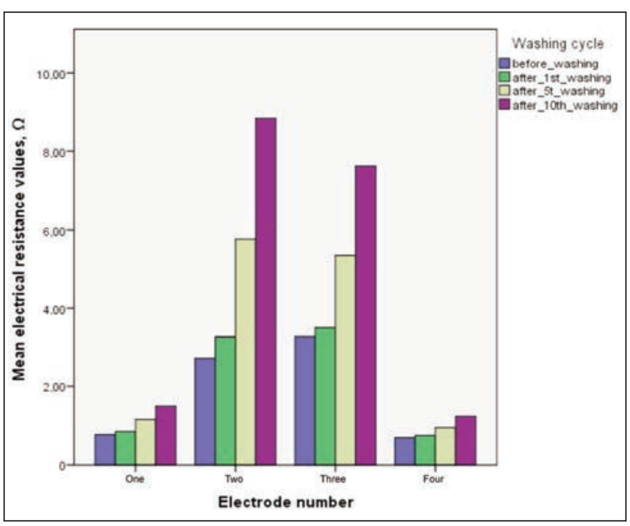

Fig. 3. Electrical resistance measurement results of knee pad produced using X-Silver yarn

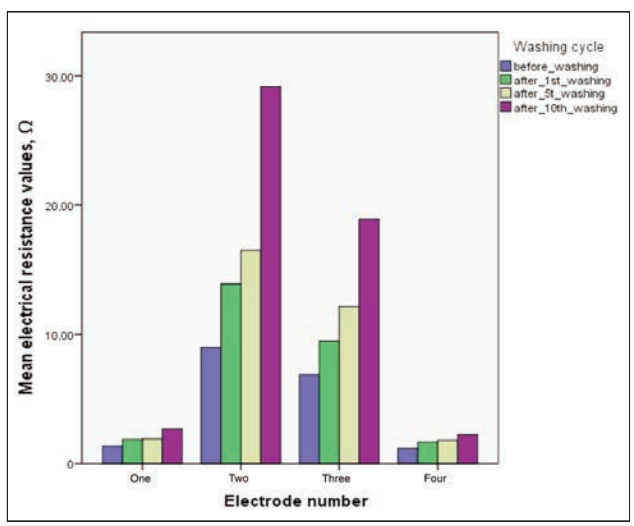

Fig. 4. Electrical resistance measurement results of knee pad produced using X-Static yarn

Table 1

MEAN CURRENT TRANSMISSION RESULTS OF KNEE PAD USING X-SILVER YARN								
Yarn type	**X-Silver Yarn**				**X-Static Yarn**			
Position	**Sitting position**		**Standing position**		**Sitting position**		**Standing position**	
Electrode type	**Upper electrodes (mA)**	**Lower electrodes (mA)**	**Upper electrodes (mA)**	**Lower electrodes (mA)**	**Upper electrodes (mA)**	**Lower electrodes (mA)**	**Upper electrodes (mA)**	**Lower electrodes (mA)**
Before washing	4.8	5.2	3.2	3.6	3.2	3.2	4.2	4.0
After 1st washing	3.8	5.0	3.2	5.0	3.0	3.2	2.6	2.6
After 5th washing	6.0	2.8	2.8	4.2	2.2	3.2	2.8	2.6
After 10th washing	6.8	3.8	4.0	3.4	3.0	3.8	2.2	2.6

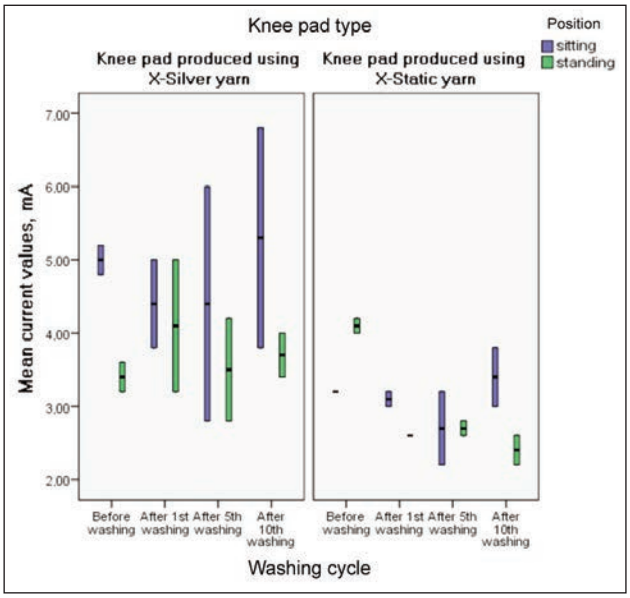

Fig. 5. Subjective trial results of knee pads

increase is followed by an increasing trend in direct proportion to the washing processes. It is concluded that after washing processes, the increase of electrical resistance values of longer lines is bigger than shorter lines.

In addition to electrical resistance measurements, subjective tests were also performed on the developed knee pads. The knee pads were connected to the StimTec brand TENS device and experiments were carried out while subjects were in standing and sitting positions. Subjective trials were repeated before washing and after 1st, 5th and 10th washings. Mean current transmission results of subjective trials were presented in tables 1 and 2, general results were presented in figure 5.

When table 1 and figure 5 were examined, it is seen that the mean current values of the knee pad produced using X-Static yarn distribute more homogeneously. This result shows that the entire electrodes and transmission lines of the knee pad produced using X-Static yarn have similar electrical resistance values. Current values recorded in the experiments in standing position were lower than those recorded in sitting position for both knee pads. However, the difference is between 0 and 0.8 mA and it is negligible. According to these results, standing or sitting position does not affect current transmission.

CONCLUSIONS

In this paper, knee pads with integrated textile electrodes and textile transmission lines have been designed and produced for use in TENS therapy and the effectiveness of the knee pads have been investigated by preliminary tests. These preliminary tests were washing tests, electrical resistance measurement, and subjective trials. In preliminary work cables were used for electrical transmission, however, cables were broken especially after washing processes. In this study, textile transmission lines and banana plug connectors were used to solve this problem and products that are more resistant to washing processes were developed.

When electrical resistance measurements were taken into consideration, it is observed that different yarns cause different electrical resistance values. In our example, electrodes and transmission lines of knee pad produced using X-Static yarn have higher electrical resistance values than the knee pad produced using X-Silver yarn. Washing cycles give similar results for both knee pads. After washing processes, the electrical resistance values of electrodes and transmission lines are slightly increased.

In trials with TENS device and designed knee pads on the subjects, it is noted that subjects had electrical stimulation from knee pads. Also, according to these subjects' feedback, there is not any discomfort feeling. In consequence of first trials, it is concluded that produced knee pads can be used for pain relief and it is planned to test the effectiveness of knee pads on knee osteoarthritis patients after taking ethical committee permission. In this study only sitting and standing positions were examined, in further studies, it is planned to test the knee pad in a state of motion. Furthermore, in this study, only the effect of 10 washing cycles to electrical resistance values was examined. In further studies, it is planned to investigate the effect of more washing cycles and laundry processes.

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Research status and prospect of intelligent fibres and textiles

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ABSTRACT – REZUMAT

Research status and prospect of intelligent fibres and textiles

Intelligent fibre is a kind of fibre that integrates sensing and information processing. It is similar to biological materials and has intelligent functions such as self-perception, self-adaptation, self-diagnosis, and self-repair. Intelligent textiles refer to textiles that have sensing and responding functions to the environment. Intelligent fibres and their textiles not only have the ability to perceive and respond to external stimuli but also have the ability to adapt to the external environment. In recent years, the research on intelligent fibres has achieved many results in the world, and it is widely used in textiles and clothing industry. Therefore, this paper summarized the research status of intelligent fibre and intelligent textile worldwide, and put forward the research direction in the future. This paper introduced the properties and research status of five kinds of main intelligent fibres, including phase change fibre, shape memory fibre, smart hydrogel fibre, optical fibre and electronic intelligent fibre, and summarized their application in textiles. This paper also introduced the research status of five important intelligent textiles, including intelligent temperature control textile, shape memory textiles, waterproof and moisture permeable textile, intelligent antibacterial textile and electronic intelligent textile. Moreover, it forecasted the development prospects of intelligent fibres and textiles, and pointed out development direction in three aspects of performance optimization, green and safety, industrialization. It provided research reference and guidance for future intelligent fibre and intelligent textile.

Keywords: *intelligent fibres, intelligent textiles, phase change fibre, shape memory fibre, smart, hydrogel fibre*

Stadiul cercetării și perspectiva fibrelor și textilelor inteligente

Fibrele inteligente sunt un tip de fibre care integrează detectarea și procesarea informațiilor. Sunt similare cu materialele biologice și au funcții inteligente, cum ar fi auto-percepția, autoadaptarea, auto-diagnosticarea și auto-repararea. Textile inteligente se referă la materialele textile care au funcții de detectare și răspuns la mediul exterior. Fibrele și materialele textile inteligente nu numai că au capacitatea de a percepe și de a răspunde la stimulii externi, dar au și capacitatea de a se adapta la mediul extern. În ultimii ani, cercetările privind fibrele inteligente au obținut multiple rezultate la nivel mondial și sunt utilizate pe scară largă în industria textilă și a îmbrăcămintei. Prin urmare, această lucrare a rezumat stadiul cercetării fibrelor și materialelor textile inteligente la nivel mondial și a prezentat direcția cercetărilor viitoare. Această lucrare a prezentat proprietățile și stadiul cercetării a cinci tipuri principale de fibre inteligente, incluzând fibra cu schimbare de fază, fibră cu memorie a formei, fibră inteligentă de hidrogel, fibră optică și fibră electronică inteligentă și a prezentat domeniile lor de aplicare. Această lucrare a prezentat, de asemenea, stadiul cercetării a cinci materiale textile inteligente importante, inclusiv materiale textile cu control inteligent al temperaturii, materiale textile cu memoria formei, materiale textile impermeabile și permeabile la umiditate, materiale textile inteligente antibacteriene și materiale textile inteligente electronice. Mai mult, a prognozat perspectivele de dezvoltare a fibrelor și textilelor inteligente și a subliniat direcția de dezvoltare din punctul de vedere al optimizării performanței, ecologiei și siguranței, industrializării. Aceasta a furnizat referințe de cercetare și îndrumări pentru studiul viitoarelor fibre și materiale textile inteligente.

Cuvinte-cheie*: fibre inteligente, textile inteligente, fibre cu schimbare de fază, fibre cu memorie a formei, inteligent, fibre hidrogel*

INTRODUCTION

Intelligent fibre refers to the fibre that can sense the change of external environment (machinery, heat, chemistry, light, humidity, electromagnetism, etc.) or internal state and respond to it [1]. And intelligent textile means a new type of textile which simulates the living system and meanwhile [2], has the dual function of both sensation and reaction, and retains the inherent style and technical characteristics of the textile. Intelligent fibre and intelligent textile possess or partly possess the following intelligent functions and life characteristics: sensor function, feedback function, information recognition and accumulation function, respond capability, self-repairing ability self-repair ability and self-adaptation ability [3]. For the last few years, with the development and application of nanotechnology, microcapsule technology, electronic information technology and other cutting-edge technologies, the exploitation of intelligent fibre has been rapidly developed, and a series of emerging intelligent textiles have appeared, thus meeting some specific needs of people.

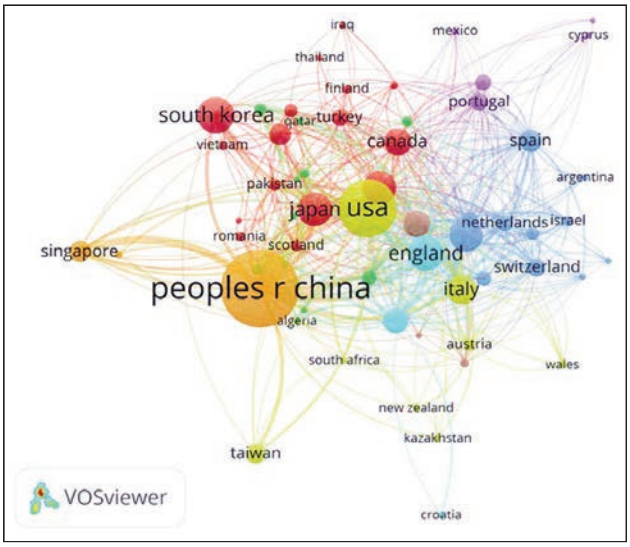

Fig. 1. VOSviewer country/region co-occurrence knowledge map of intelligent fibre

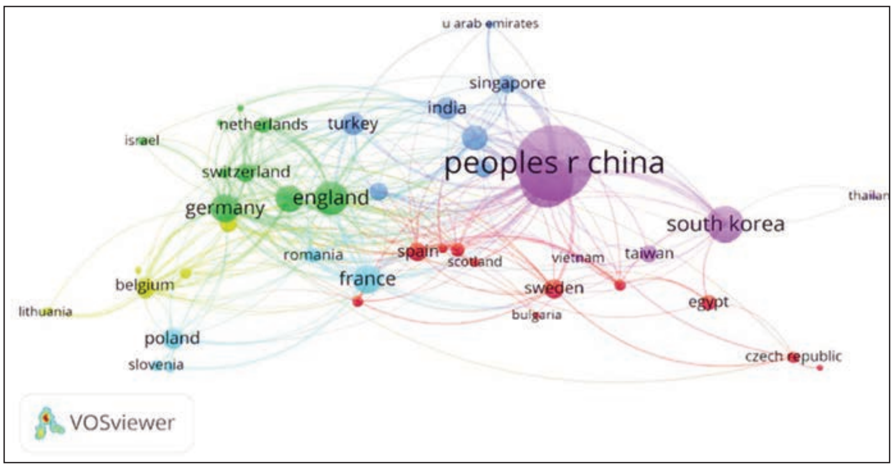

Fig. 2. VOSviewer country/region co-occurrence knowledge map of intelligent textile

We use VOSviewer visualization tool, and the relevant literature in the web of science core collection database is used as the data source to carry out statistical and visual analysis on all relevant literature in the field of intelligent fibre and intelligent textile. Using "Intelligent fibre" or "Smart Fibre" as intelligent fibre's search terms, and "intelligent textile" or "smart fibre" as intelligent textile's search terms, the retrieval date is October 24, 2020, and the time span is from 1985 to now. A total of 4660 literatures related to intelligent fibre and 1957 literatures related to intelligent textiles were retrieved. Figure 1 shows that the main research power of intelligent fibre comes from about 61 countries and regions in the world, and the distribution of research power is uneven. China is far ahead with 1442 papers, belonging to the first group. Followed by the United States, with 802 papers is the second group. The third group is South Korea (320 papers), England (293 papers), Japan (276 papers), India (259 papers), Germany (248 papers) and Italy (202 papers), the number of their papers is 200–350 and the strength is equal. Figure 2 shows that the main research power of intelligent textiles comes from about 46 countries and regions in the world. China still has the largest number of papers with 540 papers, followed by the United States (272 papers), and the remaining two countries with more than 100 publications are South Korea (152 papers) and England (130 papers). The distribution of intelligent fibre research organization is shown in figure 3. There are about 220 research institutions, and there are two institutions with more than 100 papers, namely Chinese Acad Sci (135 papers) and Donghua University (129 papers). Combined with the timeline, it can be seen that Donghua University is also the earliest institution to study intelligent fibres. There are 4 institutions with 50–100 articles, which are Hong Kong Polytech University (89 papers), Harbin Institute of Technology (84 papers), Dalian University of Technology (63 papers) and Nanyang Technology University (57 papers). The distribution of intelligent textile research organization is shown in figure 4. There are about 161 research institutions, only Donghua University with 101 papers and has published more than 100 papers. Chinese Acad Sci (68 articles) ranked second, Hong Kong Polytech University (61 articles) ranked

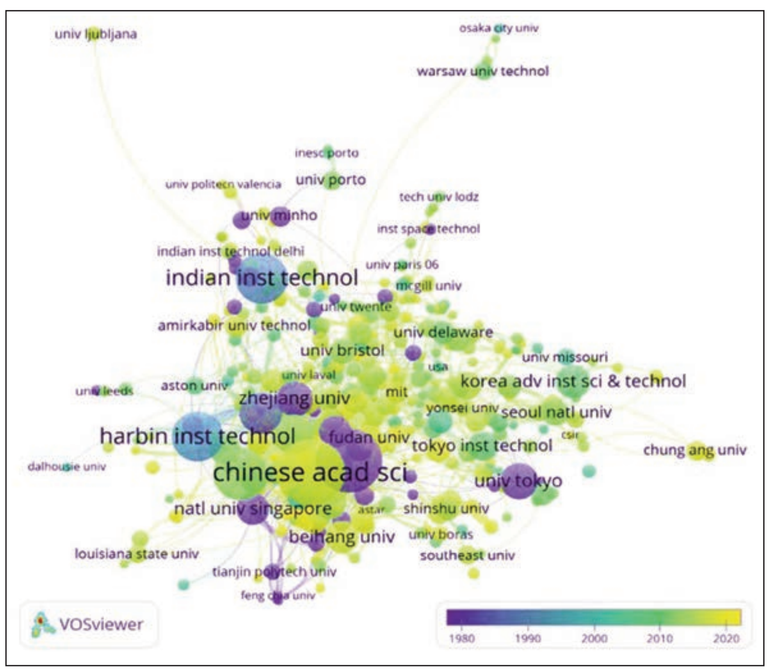

Fig. 3. VOSviewer organization co-occurrence knowledge map of intelligent fibre

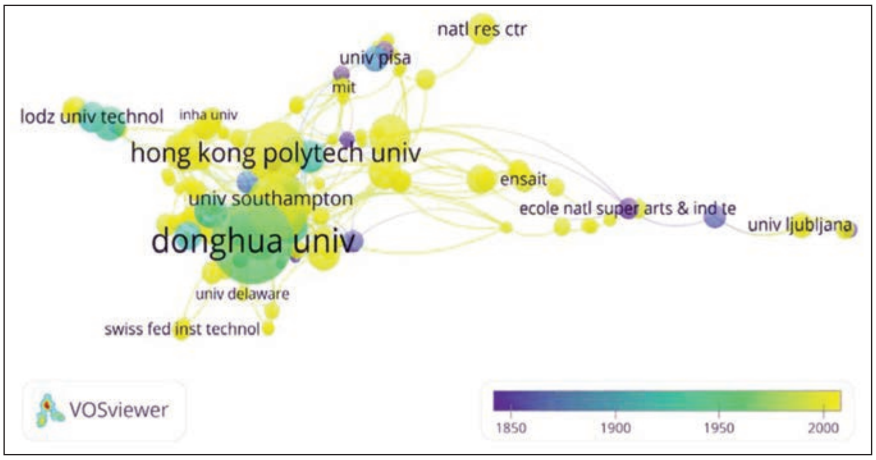

Fig. 4. VOSviewer organization co-occurrence knowledge map of intelligent textile

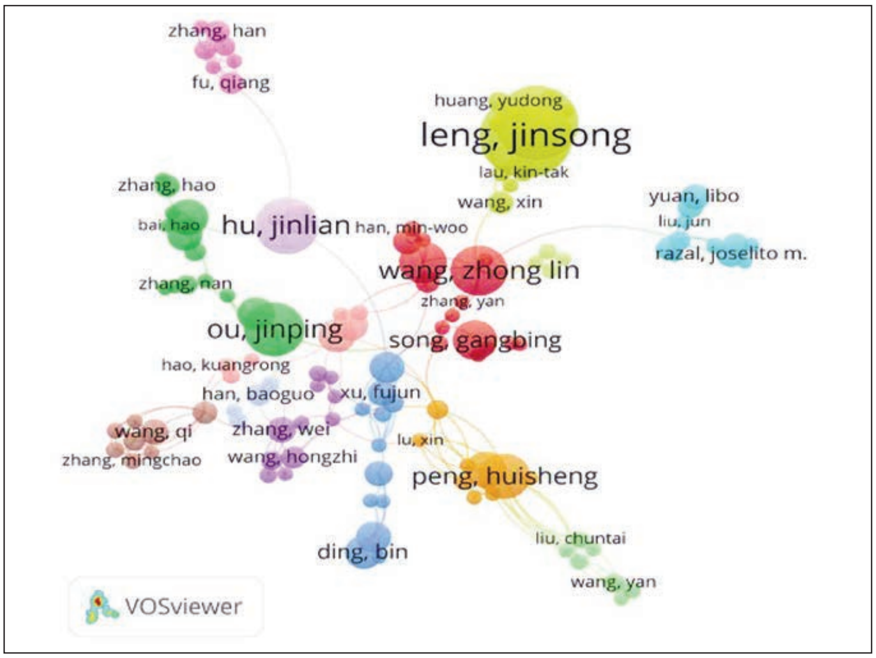

Fig. 5. VOSviewer author co-occurrence knowledge map of intelligent fibre

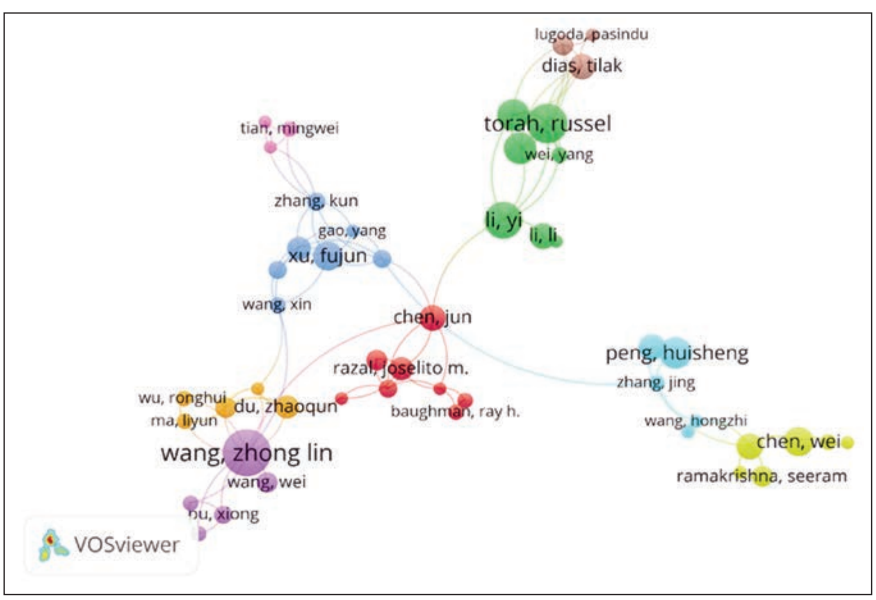

Fig. 6. VOSviewer author co-occurrence knowledge map of intelligent textile

third. The number of other articles published was less than 50. The author distribution of intelligent fibre research is shown in figure 5. There are 1372 authors in total; only 96 authors with more than 5 papers are shown in the figure 5.

There are 6 authors with more than 10 papers. Among them, Leng Jinsong (29 papers) and Liu Yanju (26 papers) are the most. The rest are Peng Huisheng (16 papers), Ubertini Filippo (15 papers), Sun Xuemei (13 papers) and D'alessandro Antonella (13 papers).

The papers of other authors are in 5 to 10. The authors' distribution of intelligent textile research is shown in figure 6. There are 7278 authors in total, only 140 authors with more than 5 papers are shown in the figure 6. There are 6 authors with more than 10 papers, the most is Koncar Vladan (27 papers), the rest are Wang Zhong Lin (18 papers), Torah Russel (15 papers), Beeby Steve (12 papers), Tudor John (12 papers), Schena Emiliano (10 papers). The rest of other authors' papers are 5 to 10.

At present, the research on intelligent fibre and intelligent textile is a hot hotspot in the field of textile and garment. Shen Xinyuan et al. [4] made a general statement for intelligent fibres from three aspects of ph-responsive gelatinous fibre, photosensitive fibres and temperature-sensitive fibres. Yao Lianzhen et al. [5] expound the preparation, function and application of five typical intelligent fibres, namely shape memory fibre, chameleon fibre, thermal-storage and temperature-regulated fibre, intelligent gelatinous fibre and electronic intelligent fibre, which are of certain reference value for this paper. However, in recent years, some scholars believe that the change in colour of existing chameleon fibres is blind and unavailable to be intelligently adjusted in the light of changing circumstances, so it is of some reasonability to regard them as functional materials. Neunham R.E. divides intelligent materials into three categories of negative, positive and high intelligence materials, which have been accepted by many scholars. However, negative intelligent materials are similar to functional materials and do not reach true intelligence, so the intelligent fibres and textiles described in this paper are mainly the latter two categories. He mainly introduces intelligent fibre from five kinds of fibre, such as phase change fibre, shape memory fibre, intelligent gelatinous fibre, optical fibre and electronic intelligent fibre, and sets forth the research status of intelligent textile, and prospects the development trend of intelligent fibre and intelligent textiles.

INTELLIGENT FIBER

Research status of intelligent fibre

Phase change fibre

Phase change fibre is a sort of high-tech fibre product developed by combining phase-change material technology and fibre manufacturing technology [6], which can automatically perceive the variation of environment temperature so as to intelligently regulate the temperature. The phase-change material contained in it can make the fibre have bidirectional temperature regulation and adaptability through solid-liquid or solid-solid reversible conversion: When the ambient temperature is higher than a certain threshold, the material phase transformation absorbs heat to have refrigeration effect. When the ambient temperature is lower than a certain threshold, the material phase transformation releases heat to have heat preservation effect. At present, some representative phase change fibre products in the market include Outlast Comfortemp Thermasorb and Cool Vest [7], which can be used repeatedly in the environment of temperature oscillation, and the frequency of thermal cycles generally reaches more than 1000. Figure 7 shows the preparation method of phase change fibre, the properties of phase change fibres have been greatly optimized by continuous breakthroughs in preparation methods. In recent years, breakthroughs have been made in composite spinning and microencapsulation, for example, Limei

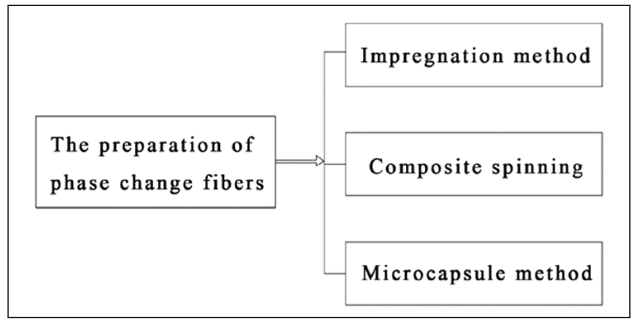

Fig. 7. Preparation method of phase change fibre

Shi et al [8] prepared composite phase change materials by vacuum melting adsorption method, and then obtained composite PET phase change fibres with skin and core. The prepared composite phase change fibres have better temperature regulation performance. The novel sodium alginate/feather keratin-g-allyloxy polyethylene glycol (SA/FK-g-APEG) composite phase change fibre was designed and fabricated via centrifugal spinning for the first time by Xueyong Gong et al. [9]. Hongyun Fu [10] prepared soybean wax phase change microcapsules by in-situ polymerization method, and then obtained coaxial composite fibres by electrostatic spinning method, which improved the leakage, chemical instability and poor processing performance of simple phase change materials in practical applications.

Shape memory fibre

Shape memory fibre refers to a kind of fibre that can recover its initial shape under certain conditions (stress temperature, etc.) after plastic deformation and stimulation in specific conditioned stimulus, whose original shape can be designed as straight line, wave, spiral or other shapes [11], which mainly includes three categories: shape memory alloy fibre, shape memory polymer fibre and shape memory functional fibre processed by finishing agent [12]. At present, the common shape memory alloys are TiNi system, Cu-base and Fe-base alloys. The preparation process of shape memory fibre is shown in figure 8, the types of shape memory fibre raw materials

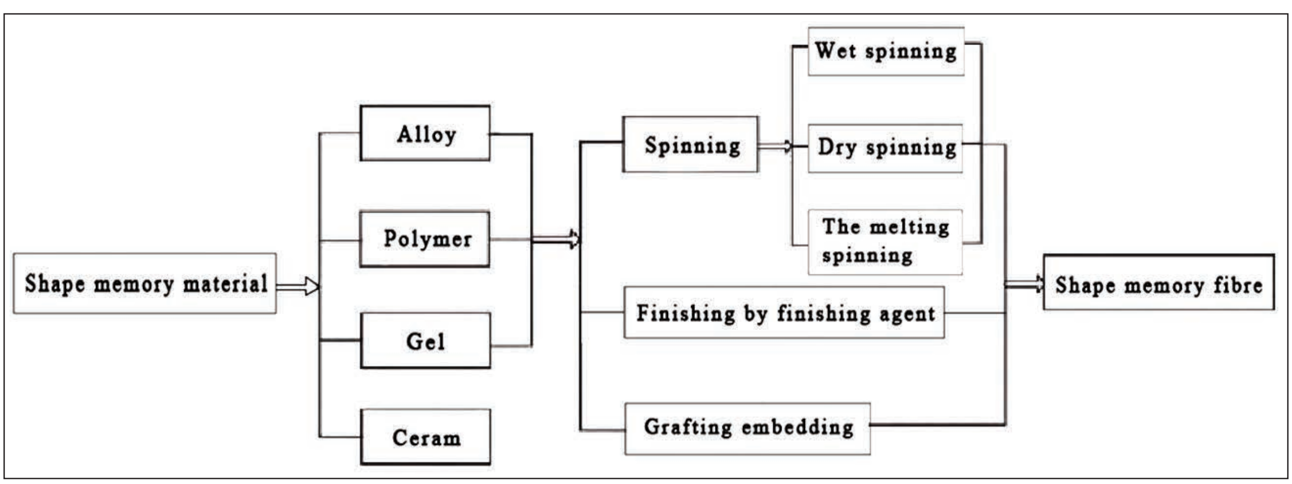

Fig. 7 Preparation process of shape memory fibre

continue to increase, from the initial shape memory alloy to a variety of shape memory fibres, such as Fangyuan chemical fibre company of China successfully developed the PTT shape memory fibre, and put it into large-scale production, named Fineyarn, which reached the international leading level.

Smart hydrogel fibre

Intelligent gelatinous fibre refers to gelatinous fibre that can change in volume or shape with external stimulation (temperature, pH value, light, electricity, etc.) According to different stimulus conditions, intelligent gelatinous fibres can be principally divided into pH-responsive gel fibres, temperature-sensitive fibres, photosensitive fibres and electro sensitive fibres, among which pH-responsive gel fibres are the most common. Intelligent gel fibres have adaptability and biocompatibility and are often used in the development and design of intelligent textiles in recent years. Suzhou nanometre of China has made important progress in the field of graphene aerogel smart fibres in 2018, the aerogel team of the Chinese academy of sciences cleverly combined graphene aerogel fibres, phase change materials and super hydrophobic coating to get a flexible and self-cleaning graphene aerogel intelligent phase change fibre, realizing multiple stimulus response functions including energy conversion and storage, self-cleaning, intelligent temperature regulation and heating [13].

Optical fibre

Light-guide fibre is a kind of optical composite fibre that can seal the light energy in the fibre and transmit it in the way of waveguide. It has excellent performance on transmission as well as provides accurate information describing the state of the system at any time, so it is recognized as the preferred sensing material. It has been proverbially used in the production of various types of sensors, in smart clothing, safety clothing and other new garment applications, to realize the understanding of the external environment temperature, pressure, displacement and other conditions as well as the body temperature, heartbeat, blood pressure, and other physiological indicators monitoring. In the past decade, optical fibre has been used in the research of intelligent clothing. For example, Furao Guo developed a human temperature warning system based on optical fibre in smart clothing [14], Guopeng Zhou developed a clothing pressure sensing system based on micro-bending optical fibre [15], Xinyu Tian developed a fibre grating intelligent clothing which can be used for human pulse detection and so on [16].

Electronic intelligent fibre

Electronic intelligent fibre is a new type of fibre developed based on electronic technology, fusing sensor, communication, artificial intelligence and other high-tech means. With people's increasing demand, they have higher requirements on electronic intelligent fibres. At present, the electronic intelligent fibres on the market mainly include antistatic fibres, conductive fibres, etc., among which conductive fibres are the most representative. Conductive fibre refers to a fibre whose specific resistance is lower than 107 $\Omega \cdot$cm at standard condition (relative humidity 65%), mainly used for static elimination, electromagnetic wave absorption and electrical signal detection and transmission. After three generations of development, the latest technology is carbon black composite organic conductive fibre [17].

According to the comparative analysis of the five mainstream intelligent fibres mentioned above, the advantages and disadvantages of various intelligent fibres are shown in table 1.

Table 1

ADVANTAGES AND DISADVANTAGES OF INTELLIGENT FIBERS

Name	Advantages	Disadvantages
Phase change fibre	With bidirectional temperature regulation and adaptability, it can be used repeatedly in the temperature oscillation environment.	It is difficult to control the temperature of excitation point because of the low energy of solid-liquid phase change or solid-solid phase change.
Shape memory fibre	It has shape memory effect, high recovery deformation, good earthquake resistance and adaptability.	It is hard to handle, and it can't achieve complete lossless bending deformation and recovery under the bending state of some specific external forces.
Smart hydrogel fibre	It is adaptive and biocompatible.	At present, there are differences in mechanical properties between intelligent gel fibres and organisms.
Optical fibre	With excellent transmission performance, fine diameter, good flexibility and easy processing, it is recognized as the preferred sensor material.	There is inherent loss.
Electronic intelligent fibre	It has excellent conductivity and can eliminate static electricity by electron conduction and corona discharge.	The comfort and softness are poor, and the safety, durability and power supply continuity need to be further studied.

Design thinking of intelligent fibre

As with other smart materials, bionics is the starting point of intelligent fibre. People can use the principle of bionics, take the cell as the blueprint of intelligent material, and develop the intelligent biological material which is close to the multiple functions of the organism, close to or even more than the organism in function [18].

The main way to develop intelligent fibre is molecular design. According to its stimulus response mechanism, intelligent fibre can be designed to produce only one response to the change of one factor, or to produce only one response to the change of multiple factors, or to produce different responses to the change of different factors [19]. Molecular design here, including polymer structural design and functional group design.

Many substances or materials are inherently intelligent, For example, the properties of some substances or materials (such as colour, shape, size, mechanical properties, etc.) can change with the environment or the conditions of use, also have the ability of self-diagnosis, self-learning and prediction, stimulus response and signal recognition [20]. The optical properties, electrical properties and other physical or chemical properties of some substances or materials can change with different external conditions, so in addition to recognizing and distinguishing signals, self-diagnosis, self-learning and anti-stimulation ability, they can also be developed into substances or materials with dynamic balance and self-maintenance functions. The structure or composition of some materials can change with the working environment and have the function of self-adaptation and self-adjustment to the environment. Therefore, intelligent fibres can be obtained by combining these existing substances or materials (including blending, addition and hybridization technologies as described later).

Preparative technique of intelligent fibre

Forming polymer direct spinning

Intelligent fibres can be spun directly by synthesizing intelligent fibre forming polymers through molecular design.

Graft copolymerization

It is one of the main methods to prepare intelligent fibres to graft some groups with special effects or functions onto the side chains of polymers or one or both ends of polymers.

Crosslinking

The crosslinking reaction mainly occurs during the polymerization of monomers with a function greater than 2. It can also trigger chains of macromolecules to produce reactive radicals and functional groups, leading to the formation of new chemical bonds between macromolecules. Crosslinking is the main method to prepare adaptive gel fibres.

Blend and add

By mixing the polymers, inorganic substances or low-molecular organic compounds with the fibre forming polymers, the traditional single-component processing method can be used to prepare the fibres, which can be endowed with intelligent functions without affecting the original properties of the fibres as much as possible.

Composite spinning and hybridization

Composite spinning and hybrid composite spinning are two kinds of polymer fluids which are mixed at the inlet of spinneret through their respective flow channels and extruded together. Because the liquid flow quickly solidified, so do not mix, forming a clear interface of the composite fibre.

Polymer chemical reaction

As mentioned above, the existing natural fibres, artificial fibres or synthetic fibres can be endowed with intelligent functions by conducting polymer chemical reactions through molecular design.

Post-processing

It can also be endowed with intelligent functions by post-processing existing fibres with materials that have intelligent functions of their own.

INTELLIGENT TEXTILES

Textile fibres are processed and woven into products, which are called textiles. Currently, in the development process of the intelligent textile, the insisting philosophy is that aiming at some particular functional requirements, the corresponding one or several intelligent fibres and other materials are combined, processed or introduced into the textile by means of weaving or finishing, and thus the textiles are developed to meet users' corresponding demand, rather than simply weave one or several types of intelligent fibres into textiles. Therefore, this paper introduces intelligent textile and intelligent fibre separately.

Intelligent temperature control textile

Intelligent temperature control textile is a kind of textile which can intelligently control fabric temperature to improve its comfort. In accordance with the stimulus-response way to the outer circumstance temperature, it can be split into three categories: thermal insulation textile, cooling textile and temperature-regulating textile. At present, the manufacturing technology of temperature-regulating textile mainly includes coating finishing, composite spinning and microcapsule spinning, and has been developed comparatively mature. In recent years, the research of temperature-regulating textile has made prominent achievements at home and abroad. The United States is the first country to study temperature-regulating textiles. It originally mainly aimed at the Lunar Probe Project, and successfully developed Outlast phase-change material in 1988. After 1994, temperature-regulating textiles were gradually commercialized and their property was constantly improved. Currently, Ureatech "air conditioning" fabric developed by Polytech Company in the United States is relatively advanced, which is a kind of polyurethane coating and temperature-regulating fabric. The research on temperature-regulating textile is relatively late in China. In 2003, Baoding Xiongya Textile Group and American Embers International Group successfully developed phase change thermoregulation Loko wool with the "space technology", and produced "warm in winter and cool in summer" clothing for the first time in China. Although many of these products have been industrialized at present, their processing difficulties, poor wearability and durability are still salient.

Shape memory textile

Shape memory textile usually refers to a kind of textile with superior performances such as shape memory, high recovery deformation, good shock resistance and adaptability, etc., by processing or introducing materials with shape memory function into textiles in the form of weaving or finishing. There are two major processing methods: one is to weave with shape memory fibre the other is to proceed shape memory finishing for textiles. And the methods of shape memory finishing include resin finishing, shape memory polymer finishing, collagen finishing, grafting, embedding and so on. At present, the common finishing means is to press polyurethane film on the upper layer of fabric or apply polyurethane coating. Shape memory textiles can be developed into multitudinous categories, functions of costumes, such as thermal insulation resistance clothing, waterproof and moisture permeable clothing, which are especially used in the parts with high requirements of shape maintenance, back swing of coat, knee of trousers and other parts of clothes to meet the requirements of restoring, and the knitwear and other materials with poor shape preserving to improve fabric performance.

Waterproof and moisture permeable textile

Waterproof and moisture-permeable textile refers to a kind of functional textile that water cannot infiltrate into the fabric under certain pressure, but the sweat gas emitted by the human body can be diffused or transmitted to the surrounding through the fabric and does not accumulate condensation between the body surface and the fabric, making people subjectively feel no tightness. At present, the processing methods of waterproof and moisture permeable textiles can be summarized into three main methods: ultra-high density structural approach, microporous technology and dense hydrophilic membrane technology. Therefore, waterproof and moisture permeable textiles can be divided into 4 categories: waterproof and moisture permeable high-density textile, micro-porous film waterproof and moisture permeable textile, non-porous film waterproof and moisture permeable textile and intelligent waterproof and moisture permeable textile [21]. But what can be called intelligent textile truly is intelligent waterproof and moisture permeable textile, the typical product is shape memory polyurethane and its waterproof and moisture permeable fabric Diaplex produced by Mitsubishi Heavy Industry in Japan, whose waterproof performance can reach 20,000~40,000 mm, the water pressure resistance can reach 196.13~392.26 kPa, and the moisture penetration can reach 8,000–12,000 g/(m·24 h). In addition, its moisture permeability can be adjusted correspondingly with the change of temperature to achieve intelligence. Therefore, it can be suitable for wearing under different conditions, so as to adjust the microclimate inside human clothing, which is mainly used in mountaineering suit, ski suit, sportswear, immersion suit and other clothing now.

Intelligent antibacterial textile

Waterproof Antibacterial is a process that kills bacteria or inhibits the growth and reproduction of bacteria and their activities by physical or chemical methods. After anti-bacterial treatment, textiles can exert two functions: one is to protect users; the other is to prevent fibre from damage. Antibacterial textiles are mainly acquired by two means: making all kinds of fabrics with antibacterial fibres; the fabric is after treated with antibacterial agents. At present, the latter antibacterial textile is in the majority in the market. Intelligent antibacterial textile is a kind of textile with selective control function to bacteria, which can maintain the growth and reproduction of certain microorganisms on the skin surface at a normal level no matter under mild or intense activity conditions, used in towels, underwear, bed sheets and children's cloth toys, etc. The manufacturing methods of intelligent antibacterial textiles include blending silk method, composite spinning method, grafting modification method, ion-exchange method, wet spinning method and post-finishing method, etc., which are majorly developed on the basis of intelligent gel fibre. For example, gel phase fibre in wet spinning is immersed in the solution of antibacterial agent to seal the solution into the fabric so as to possess antibacterial effect. But the endurance quality of intelligent fight bacterium textile is poor, the mould resistance of the fabric after washing will decline, even disappear, the wash frequency of this kind of product on the market is controlled in 30 times commonly now.

Electronic intelligent textile

Electronic intelligent textile is a new type of textile developed on account of electronic technology by applying high-tech means such as sensing, communication and artificial intelligence to textile technology. The addition of electronic components provides a new solution for textiles, but meanwhile, it also brings new security loopholes and processing problems, so different from other textiles, the research on electronic intelligent textiles has formed an independent theoretical and practical system. The study on electronic intelligent textiles is relatively late compared with other textiles, but in recent years, it has become a research hotspot in the field of textile and apparel, and is regarded as one of the important trends in the future research. At present, sensing device is a common element in the development of electronic intelligent textiles, whose application makes textiles have the function of perceiving the external environment and the internal state of human body. The clothing safety design centre of Jiangnan University has

Table 2

ADVANTAGES AND DISADVANTAGES OF INTELLIGENT TEXTILES			
Name	**Advantages**	**Disadvantages**	**Application**
Intelligent temperature control textile	It can control the temperature of fabric intelligently.	It is difficult to process, poor wearability and durability.	For mountaineering clothing, skiing clothing, fire clothing, etc.
Shape memory textile	It has shape memory, high recovery deformation, good earthquake resistance and adaptability.	It can't achieve complete lossless bending deformation and recovery under the bending state of some specific external forces.	It can be used in heat insulation clothing, waterproof and moisture permeable clothing, lazy shirt, anti-immersion thermal insulation clothing, etc.
Waterproof and moisture permeable textile	It can intelligently adjust and control the microclimate in the clothing, and has the functions of waterproof and moisture permeability.	The coating method has rough handle and poor performance; the lamination method is difficult to biodegrade and has high combustion temperature, which has a great impact on the environment.	For mountaineering clothing, skiing clothing, sports clothing, life-saving clothing, etc.
Intelligent antibacterial textile	It can protect users and prevent fibre damage.	Generally speaking, the durability is not good. After washing, the antibacterial property of the fabric will decline or even disappear. At present, the washing times of such products on the market are usually about 30.	For towel, underwear, bed sheet and children's cloth toys, etc.
Electronic intelligent textile	It provides a new solution for textiles and upgrades the user experience.	It has potential safety hazards and processing problems, and its comfort and softness are limited.	It can be used in medical, aerospace, national defence and military fields.

developed a series of safety clothing with sensing devices, such as traffic safety, medical safety, etc., which is particularly outstanding in the research of safety children's clothing. At the same time, some countries, including the United States, Finland, Japan, Germany, Italy and other countries, the researches in this area have been growing vigorously, and have achieved remarkable results. However, the integration of electronic components and textiles is still the key and difficult points in the development of such textiles.

According to the comparative analysis of the five mainstream intelligent textiles mentioned above, the advantages and disadvantages of all kinds of intelligent textiles are shown in table 2, and their application directions are listed.

PROSPECT

The study and development of intelligent fibres and intelligent textiles have expedited the upgrading of textiles. In the future, interdisciplinary application will become more and more prevalent in the territory of textile and clothing, thus to improve its core competence. The following tendencies are mainly presented:

Performance optimization

The prominent feature of intelligent fibre and textile is intelligentization, but because of the limitation of current technical level, the function of a lot of such products is not mature, the phenomenon of simplification is more obvious. In the future, the development and cross-application of multidisciplinary knowledge will promote its development towards the direction of differentiation, compound and systematization, that is, the property is constantly optimized. There are not only products with highlighted functions for specific demands, but also products that meet people's various needs. Simultaneously, the integration means of intelligent materials and textiles are becoming increasingly abundant, which strengthens the systematization of products, among which, intelligent fibres and intelligent textiles that focus on optical properties, thermal properties, electrical properties and electronic information will have broad application prospects, and electronic elements in intelligent fibres and intelligent textiles of electronic information will be more miniaturized and flexible to accommodate the development needs of such products.

Green security

The launch of a new product must be evaluated to guarantee its safety and reliability. At present, in the development of intelligent fibre and intelligent textile is primarily technology-cantered and pays attention to the realization of functions, but undervalues evaluation. So the security and dependability of the intelligent fibres and intelligent textiles cannot get effective guarantee, which is especially evident in the electronic product. With the constant deepening of the concept of green security, the future development of intelligent fibre and intelligent textile will be user-cantered and emphasize the evaluation of products to ensure their green and safety, among which technology is still a crucial part.

Industrialization

Industrialization can propel the exploitation of a product into a virtuous cycle, so industrialization is the assurance of the progress of intelligent fibre and intelligent textile. If a product wants to achieve the requirement of industrialization, it must satisfy numerous conditions, such as cost, appearance, practicability and so on. Although many of these products have been commercially available at present, most of them are still in the experimental stage, particularly in the electronic intelligent fibre and its textile, there are many difficulties that have not yet been overcome. In the future, the development of intelligent fibre and intelligent textile will be more professional and commercial. On the other hand, the technological multi-function integration will be stressed, especially in the fields of military industry and aerospace; On the other hand, the mass consumers will be taken as the centre, and the products design will be directed at the needs of the target group, so as to meet the needs of the market.

CONCLUSION

The development and application of intelligent fibre and intelligent textile are the research hotspots in the field of textile and garment nowadays, and also the growing trend in the future. The study and development of such products will benefit the development of military industry, medical care, recreation, entertainment, decoration and other multiple industries, which is concerned with the national economy and people's livelihood. This paper analyses the research status and trend of intelligent fibres and intelligent textiles, and used the VOSviewer visualization tool to perform statistical and visual analysis of all relevant literature in the field of intelligent fibre and intelligent textile in the Web of Science database, and compared the advantages and disadvantages of different types of intelligent fibre and intelligent textile by table, and summarizes the design ideas and preparation technologies of intelligent fibres, hoping to sort out the ideas for future research in this direction and provide a basis for future research.

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Heritage ethnographic objects – antimicrobial effects of chitosan treatment

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ABSTRACT – REZUMAT

Heritage ethnographic objects – antimicrobial effects of chitosan treatment

Chitosan is a natural polymer, which presents, according to studies made up to present, low toxicity and good biocompatibility. Recent studies are focused not only on its antimicrobial effects on textiles, because this polysaccharide leads to improvements such as: shrink resistance, dye uptake etc.
Two Romanian traditional shirts were non-invasively tested by applying Chitosan and by investigating the SEM images, before and after applying the chitosan. The paper underlines the surface modifications of tested textiles using chitosan. The odd agents on the fibres surfaces were removed and the limitation of the number of microorganisms was observed.

***Keywords:** chitosan, ethnographic textiles, SEM images*

Obiecte etnografice de patrimoniu – efecte antimicrobiene ale tratamentului cu chitosan

Chitosanul este un polimer natural care, conform studiilor realizate până în prezent, prezintă o toxicitate scăzută și o bună biocompatibilitate. Studii recente, care se concentrează nu doar pe efectele sale antimicrobiene asupra materialelor textile, au evidențiat că această polizaharidă conduce la îmbunătățiri din punctul de vedere al rezistenței la contracție, precum rezistența la contracție, absorbția coloranților etc.
Două cămăși tradiționale românești (ii) au fost testate neinvaziv prin aplicarea chitosanului și prin investigarea imaginilor SEM, înainte și după tratamentul cu chitosan. Lucrarea evidențiază modificările de pe suprafața țesăturilor testate folosind chitosan. După îndepărtarea agenților de pe suprafața fibrelor, s-a remarcat reducerea numărului de microorganisme.

***Cuvinte cheie:** chitosan, textile etnografice, imagini SEM*

INTRODUCTION

Heritage objects, especially textiles, depending on their composition and environmental conditions subjected to or stored in, can be contaminated with fungi, bacteria, etc., which may lead to their physical, chemical or biological deterioration, sometimes even to their destruction and negative impact upon the health of people manipulating them [1–8]. Biodeterioration generated by microorganisms requires proper remedy measures: mechanical, physical, respectively chemical; however, they should not endanger the workers' health and they should not affect or modify the features of the heritage object or those of the environment [9–17].

In this paper, two heritage ethnographic pieces were taken into analysis, out of cotton and flax fibres, both over 100 years old; one is in a private collection (figure 1), while the other one is in the care of the Tarii Crisurilor Museum from Oradea (figure 2).

It was proven once more [8; 13; 18–31] that Chitosan treatment is very useful for removing the odd agent on the fibres surface and as antibacterial effect against the microorganisms.

The paper explores the use of Chitosan for the treatment of aged cotton and linen fabrics to enhance its physical and antimicrobial characteristics. Scanning electron microscope (SEM) photographs showed that the surface of the chitosan coated cotton yarn was slightly changed after the series reaction.

MATERIAL AND METHOD

The two traditional shirts (ii) belonging to the Romanian cultural heritage were non-invasively tested

Fig. 1. Traditional shirt "ie", Alba County, Romania

Fig. 2. Traditional shirt "ie", Hateg area, Hunedoara County, Romania

by applying Chitosan and investigating SEM images. SEM images for the Hateg area shirt (figure 2), enlarged 250 times (figures 3 and 4), allowed the determination of the tested fibres condition, which presented certain longitudinal fractures. 500 times magnification images (figures 5 and 6) show the mechanical deterioration of fibres. The successive size of images, × 1,000 (figures 7 and 8) emphasize the presence of fine dust and dirt particles and possibly of certain microorganisms [32–34]. The conducted tests, published in Ilies et al., 2020 [35], for the other traditional shirt, from Alba County (figure 1), confirmed the presence of *Aspergillus nigger*, *Penicillium spp.*, *Cladosporium spp., Alternaria spp.* and *Candida spp.*

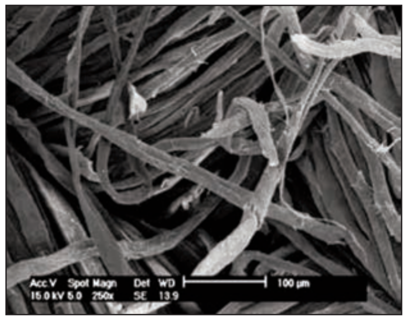

Fig. 3. SEM image of the fibres form traditional shirt "ie" from Hateg County, at 250× magnification

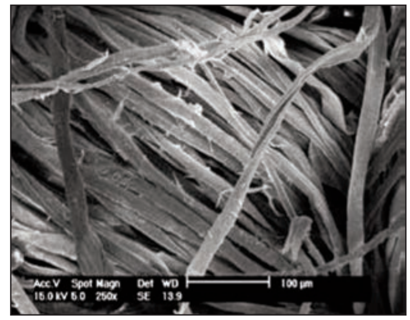

Fig. 4. SEM image of the fibres form traditional shirt "ie", from Hateg County at 250× magnification

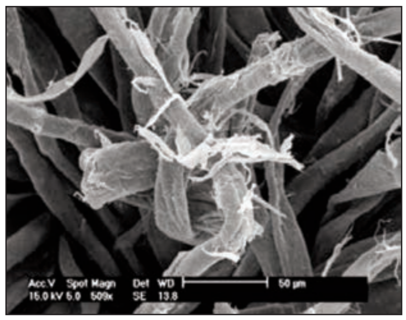

Fig. 5. SEM image of the fibres form traditional shirt "ie", from Hateg County, at 500× magnification

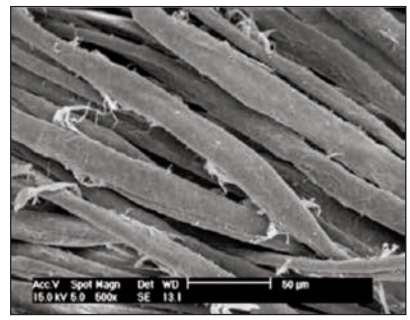

Fig. 6. SEM image of the fibres form traditional shirt "ie", from Hateg County, at 500× magnification

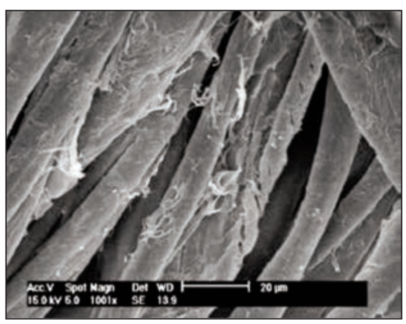

Fig. 7. SEM image of the fibres form traditional shirt "ie", from Hateg County at 1000× magnification

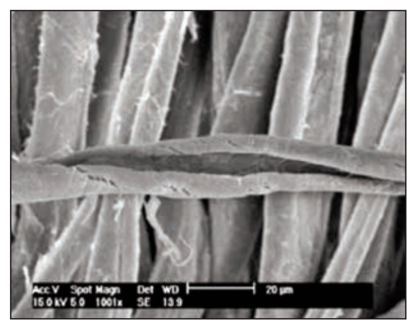

Fig. 8. SEM image of the fibres form traditional shirt "ie", from Hateg County, at 1000× magnification

Method

Chitosan Medium Molecular Weight was purchased from Sigma Aldrich. Acetic Acid was supplied by Panreac. Chitosan was prepared with the concentration 10 g/l. Because of the solubility of Chitosan in water at acid pH, 5 ml/l acetic acid was added. The solution was magnetically stirred for 24 hours [29]. The samples were dipped into the chitosan solution and dried flattened at room temperature.

The samples were observed with a Field Emission Microscope FESEM (ULTRA 55, ZEISS). Each sample is placed on a surface and covered with a layer of gold and palladium in order to make them into conductive by using a Sputter Coater and covering them with gold. The samples were analysed with the appropriate magnification and with an acceleration voltage of 10 kV.

RESULTS AND DISCUSSION

Every sample studied has been observed by FSEM and comparisons were established, in order to determine the effect of Chitosan treatment. From the comparison, it can be stated that some foreign substances are placed on the fibres. Those strange particles on some occasions can be appreciated as a coating that covers the fibres and keeps them stacked together.

Chitosan treatment has shown efficiency in removing the odd agent from the fibres surfaces. Therefore, it can be concluded that it fits with the presence of some microorganisms on the fibres. Due to the antibacterial effect attributed to chitosan, the microorganisms have disappeared. The effect of chitosan treatment for this case study can be observed on figure 9.

For Sample 1, the SEM images show that some of the fibres are stacked together because of the presence of some strange agent (figure 9, *a*). Once the fibres have been padded with chitosan solution and dried, it can be noticed that the odd agent is not present any more on the fibres' surface (figure 9, *c*). The particles which agglomerate the fibres (figure 9, *b*) are present on the original fabric of the sample 2, but they have been removed by the Chitosan treatment (figure 9, *d*).

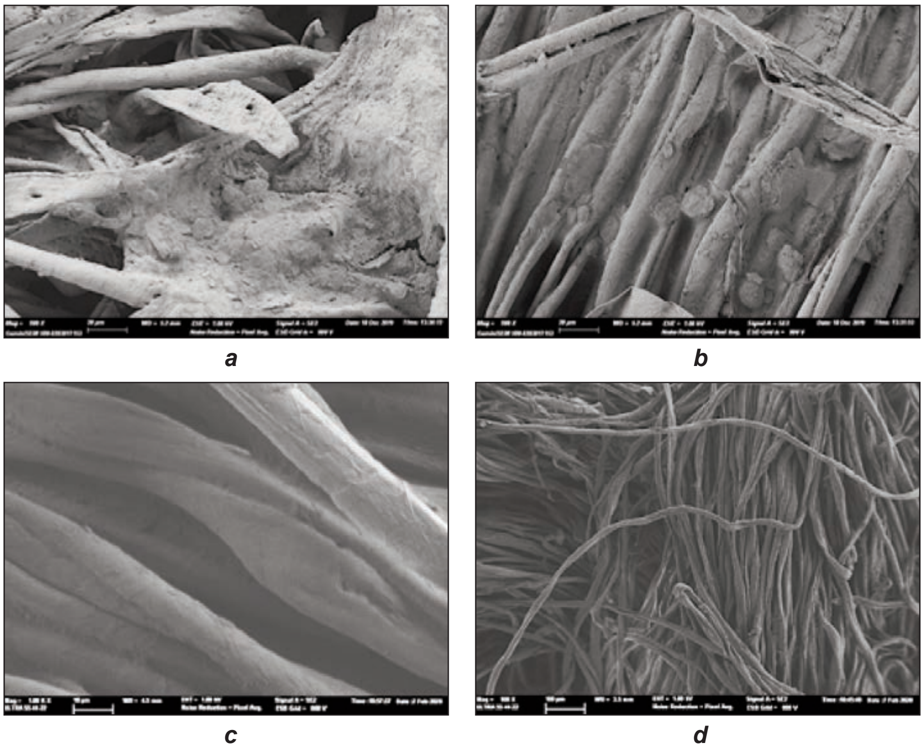

Fig. 9. SEM images of: *a* – untreated fabric, sample 1 at 500×; *b* – untreated fabric, sample 2 at 500×; *c* – treated fabric, sample 1; *d* – treated fabric, sample 2 at different magnifications ×1000, ×500 and ×100

CONCLUSIONS

The use of chitosan, which is very economical [29] and biodegradable, with characteristics which make it non-toxic for fabrics and for the people who handle them, provides favourable perspectives regarding using it on a large scale in the sustainable industry of fibre production and fabric treatments, with antimicrobial and antifungal effects on aged textiles from museums and other collections.

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Criteria for sportswear preference of Turkish runners

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ÖZGE URAL

ABSTRACT – REZUMAT

Criteria for sportswear preference of Turkish runners

Nowadays, while the importance of doing sports for a healthy life is spreading all over the world, consumers expect some performance and functional properties from sports products. It is expected that the sportswear must be in harmony with the body, do not create discomfort and do not affect the performance. The comfort of sportswear is an important criterion that affects the performance and motivates the athlete. There are dynamic and fundamental changes in the preferences of sports people with the change in the context; type of sports, the geography they live in, season, climate, their cultural, demographic and anthropologic characteristics, etc. While offering sportswear products to the market, brands should pay attention not only to quality parameters, but also to these criteria.

This article aims to determine Turkish runners' sportswear preference criteria and expectations that are evaluated against past experiences and present desires. For the study, data were collected from 195 runners and statistically analyzed. With the data obtained from the questionnaires, the runner and running habits were analyzed, the perspective of sportswear shopping and purchasing preference criteria, sportswear size and fit issues, evaluation of the fabric properties, and the demands of the runners for sportswear were determined.

This research gives resourceful information for sportswear manufacturers and comfort researchers since the compiled consumer feedback from runners provide tools for product improvement to enhance utility.

Keywords: *sportswear, runner, preference criteria, shopping behaviour*

Criterii pentru alegerea îmbrăcămintei sport a sportivilor din Turcia

În prezent, importanța practicării sportului pentru o viață sănătoasă este cunoscută în toată lumea, iar consumatorii se așteaptă la anumite performanțe și caracteristici funcționale pentru produsele sport. Îmbrăcămintea sport ar trebui să fie în armonie cu purtătorul, să nu creeze disconfort și să nu influențeze negativ performanța. Confortul îmbrăcămintei sport este un criteriu important, care influențează performanța și motivează sportivul. Există schimbări dinamice și fundamentale în preferințele sportivilor în funcție de tipul de sport, mediul geografic în care trăiesc, sezonul, clima, caracteristicile lor culturale, demografice și antropologice etc. Atunci când brandurile oferă pe piață produse de îmbrăcăminte sport, ar trebui să acorde atenție nu numai parametrilor de calitate, ci și acestor criterii.

Acest articol își propune să stabilească criteriile și preferințele, în ceea ce privește îmbrăcămintea sport a sportivilor din Turcia, care sunt evaluate în funcție de experiențele anterioare și dorințele prezente. Pentru acest studiu, au fost colectate date de la 195 de sportivi și analizate statistic. Pe baza datelor obținute din chestionare, au fost analizate obiceiurile sportivilor și cele ale practicării sportului, fiind identificate perspectiva achiziției de îmbrăcăminte sport și criteriile preferențiale din procesul de cumpărare, dimensiunea îmbrăcămintei sport și problemele de corespondență dimensională, evaluarea proprietăților materialelor textile și cerințele sportivilor pentru îmbrăcăminte sport.

Această cercetare oferă informații utile pentru producătorii de îmbrăcăminte sport și pentru cercetătorii în materie de confort, întrucât feedback-ul de la utilizatorii sportivi oferă instrumente pentru îmbunătățirea produselor și extinderea domeniului de utilizare a acestora.

Cuvinte-cheie: *îmbrăcăminte sport, sportiv, criterii de preferință, comportament de cumpărare*

INTRODUCTION

Usually used in extreme physical and environmental performance conditions, along with the requirements of covering and "supporting" the active body, sportswear is about functionality, comfort and safety, with the specification developed and designed to provide a product that fits the athlete's performance needs [1, 2].

The functional performance of the sportswear is determined according to different conditions such as the physical structure and mechanical properties of the material, thermal and moisture regulating properties, as well as the athlete's body sizes and shapes, physiological variations, comfort perception, sports type, environmental conditions and activity level [3–5].

Since the main purpose of sportswear design is function, fabrics and cuts are selected by taking performance characteristics into account [6]. The wear comfort of sportswear is an important quality criterion that affects efficiency, well-being and has considerable impact on the individual physical and cognitive performance [7, 8]. Besides thermal comfort, sensory skin-feel comfort, comfort due to fit, or the psychological comfort of clothing, external environments (physical, social and cultural) have great impact on the comfort status of the wearer [8, 9].

Some aspects to consider when designing sportswear for a particular sport can be listed as follows [4, 10–12].

Functional aspects:

- The protection/insulation/safety functions to protect wearers from air, water & adverse weather (wind, rain, snow, cold etc.);
- The comfort function which gives wear comfort (thermophysiological comfort, skin sensorial comfort, ergonomic comfort, and psychological comfort) to wearers;
- The exercise function, performance and movement needs (to improve athletic records positively and achieve athletes' goals).

Aesthetics aspects:

- Aesthetic appeal (subjective perception of clothing to the eye, hand, ear, and nose which contributes to the overall wellbeing of the wearer); from the sensitivity or aesthetic point of view, softness, surface texture, handle, lustre, colour variation and comfort in wear are important factors;
- High fashion ability;
- Appropriate fit.

Some desirable characteristic of functional sportswear are identified as follows [4, 10, 13, 14]:

- Maintain a comfortable microclimate (temperature & humidity in the skin sensor zone);
- Optimum heat;
- Moisture regulation;
- Good absorption of moisture & ability to transmit moisture vapour (fast drying & vapour permeability);
- Good air permeability;
- Low water absorption of the layer of clothing just positioned to the skin;
- Good extensibility without restriction mobility;
- Dimensional stability even when wet;
- Durability;
- Easy care;
- Lightweight (low intrinsic weight, not impairing physical performance);
- Coolness effect;
- Pleasant to skin, soft, non-abrasive and nonchafing;
- Water repellent & dirt repellent;
- Thermal absorptivity;
- UV resistance;
- Absence of unpleasant odour (perspiration);
- Compatibility with skin;
- Good fit stability & give relaxation without fatigue;
- Smart and functional design;
- Higher Drapability & graceful luster.

In running sport, due to extremely high sweat rate, moisture transmission is the most important requirement for microclimatic condition. The sensorial comfort of sportswear is also crucial as it prevents from skin abrasion, chafing, and skin injury. In high-speed games, ergonomic comfort that affects air entrainment is also a vital requirement [11]. Because considerable movement of body parts occurs during running, sportwear must have sufficient degree of mobility so that runner can move freely [13].

Runner sportswear must be proper fit for move and balance well on active body. It has to provide proper ease and set so the interaction of gravity and frictional properties of the fabric do not displace the garment [5]. Sportswear fabrics and cuts are carefully chosen to enhance the silhouette [6]. Besides protection against climate extremes like wind, rain, and snow, ultraviolet (UV) rays also become an important functional requirement for runners spending long hours at outdoor [11].

LITERATURE REVIEW

There have been many studies and researches in the literature regarding comfort parameters of sportswear products. However, there are few researches that investigate consumer satisfaction in depth and whether the products that meet the comfort parameters in theory are sufficient for the runners. Studies on sports wear aimed at developing and improving the comfort and performance of the athlete were carried out in different areas such as fabric characteristics of the running clothes, model/design features and consumer evaluations.

In one of the studies in the literature on the fabric properties of running clothes and their effects on comfort and performance, the researchers investigated the influence of sportswear fabric properties on the physiological responses and performance of athletes in sports conditions. They found a statistically significant effect on physiological responses and performance parameters of athletes for the different types of sportswear tested [7]. In another study, the physiological and psychological responses of athletes who wear t-shirts with different fabrics during and after high-intensity sports in hot and humid environments investigated, the results obtained were evaluated according to the fabric properties [15]. In a study, the effects of functional t-shirts with different fiber composition on thermoregulation and wearing comfort during an average intensity treadmill walking in well-trained runners were investigated and also sweat loss, heart rate, and subjective comfort perception were determined [16].

In one of the studies on the design of innovative runner clothes in the literature, the researchers realized a new running t-shirt prototype and compared it with the standard one. Effectiveness of prototype has been evaluated in terms of ergonomics and comfort with subjective ratings expressed by the participants [17].

In a study on smart textile and a smart jersey design for athletes, researchers focused on the wearable technology and implemented some of the technologies together to propose an idea of smart jersey which will help the athletes to maintain their health. Researchers identified the issues faced by the athletes in relation to their health while they were in active mode and proposed wearable skin sensors for respiratory, muscle strain, hydration level of body, body temperature regulation [18]. Participant design sessions were held in a study in which runners were involved in developing innovative product concepts. The aim of the study was to develop and test a base layer concept that helped thermal comfort while running in cold weather. This research, in which the design session, concept voting and wear trials were conducted, aimed to understand the runner's needs correctly and clearly [19].

In the literature, in one of the studies on the perception and evaluation of sportswear and runner clothing, clothing fit and perceived fitness level was investigated, and the effect of clothing fit on the perceptions of running performance was examined. It was determined that the participants believed the positive effects of tight-fitting clothing on their performances and self-confidence [20]. In another study, consumers' purchase intention for green sportswear was examined by investigating the effects of their expectation, perception, subjective norm, perceived behavior control, and attitude on purchasing green sportswear [21]. Another study aimed to determine the key factors influencing the US consumers' intent to purchase activewear for casual use [22]. In another study that examined the perception of activewear of women consumers, drawing upon brand association theory and the functional, expressive, and aesthetic model, the researchers identified important attributes of activewear brands and how attributes led to benefits pursued by female activewear consumers. They revealed three product-related attributes (functional design, colour, and size and fit) and two non-product-related attributes (price and model imagery) influenced the fulfillment of four benefits (mood enhancement, exercise facilitation, healthy and active lifestyle, and physical fit body image) [23]. In the research in which running clothes were evaluated by users, the problems encountered within the scope of thermal, sensual, physical and aesthetic factors and the features contributed to the performance were tried to be determined. Researchers have determined that athletes most pay attention to physical comfort and lightness in their jogging suits and define those two features as features that affect performance most [24].

The knowledge and methodology developed in clothing comforts research can be applied in a number of ways to conduct consumer research by utilizing the research techniques developed to understand what consumers want and need, and to identify a market gap for new product development [12].

STUDY OBJECTIVES

This research aims to contribute to the knowledge and experience required for effective design in running clothes. The study was carried out on Turkish runners in order to have similarity in the consumer characteristics. Conducting the research on a certain population is important in terms of both the reliability of the data and the use of the findings in marketing techniques appropriate to the consumer profile.

Current study provides feedback on Turkish runners' perspectives, demands and expectations regarding sportswear. The specific objectives of the research include the following:

- to understand runners' sportswear shopping behaviors
- to determine shopping reasons and the effective criteria for purchasing,
- to determine the expected and important criteria in running sportswear fabrics,
- to understand main fit issues (for example, in which parts of the body the runner sports clothes cause size and fit problems).

METHOD

This study contains data from 195 runners, who are members of running communities in Istanbul, Ankara and Izmir provinces, in Turkey. A questionnaire was applied to the runners and the obtained data were evaluated statistically.

The questionnaire was prepared in the light of the information obtained from the literature research, and was developed through interviews with coaches and runners actively involved in running sports. The questions in the first section include the demographic characteristics of the participants, information about their commitment to running (the number of years as a regular runner) and running frequency per week, in order to understand their running habits.The questions in the second section are about runners' running clothes shopping and purchasing behaviors, most preferred fabric properties in sportswear, fit issues with the running sportswear, optional feature preference in running sportswear.

In order to determine the reliability of the scale used in the research, the results of Cronbach Alpha (α) statistics were examined. The result of the Cronbach Alpha (α) statistics is 0.871. According to this result, a high degree of reliability and internal consistency was provided for the data collection scale used in the study. Descriptive statistics of gender, age, body type and monthly income are shown in frequency and percentage. In addition to frequencies, total score was obtained for some questions by giving points (between 1 and 5; 1 is the lowest and 5 the highest value). Total scores were calculated by multiplying the scores given by the participants with the frequencies. Total scores were calculated for the questions about runner sportswear shopping reasons, criteria effective in shopping, and evaluation of fabric properties, (evaluations are given in mentioned questions in result and dicussion section with its figures). Pearson Chi-square test was used to evaluate the relationship between the frequency of upper & lower body garments shopping and age, monthly income, and body type. Kruskal-Wallis test was used to evaluate the effect of age, monthly income and body type on shopping reasons. Mann-Whitney U test was used to evaluate the effect of gender on the criteria effective in shopping. Kruskal-Wallis test was used to evaluate the effect of age, monthly income and body type on the criteria effective in shopping. In case of determining the effect among these, the results of binary comparison were examined. The Pearson chi-square test was used to evaluate the relationship between the optional feature preference (about fabric quality, color alternative, design and pattern/cut) and gender, age, monthly income, and body type. In cases where the relationship between the groups is determined, the results of the binary comparison are examined.

IBM SPSS Statistics 22.0 (IBM Corp. Released 2013. IBM SPSS Statistics for Windows, Version 22.0. Armonk, NY: IBM Corp.) and MS-Excel 2007 programs were used for statistical analysis and calculations. Statistical evaluations were made by taking Type-I error level $\alpha = 0.05$.

ANALYSIS AND RESULTS

Questionnaire results consist of items under two main categories. The first category concerns analyzing runners and their running habits. The second category provides a perspective about running sportswear shopping and purchasing preference criteria, fit issues with the running sportswear, fabric characteristics evaluation and runners' optional feature preference demands.

Runners and running habits

Demographic information of participants is shown in table 1. In addition to the demographic information of the runners participating in the survey, information on body types was obtained. In accordance with the scope of the research, the effects of demographic features, body types, and sports habits on the reasons of shopping and purchasing behavior of the runners were investigated.

According to the frequency results of body types; It was determined that 28 people (14.4%) had ectomorphic body type (characterized as skinny, weak, with small muscles, and usually tall), 59 people (30.3%) had endomorphic body type (characterized as fat, usually short, rounded stocky body and having difficulty losing weight) and 108 people (55.3%) had mesomorphic body type (characterized as hard, muscular, and as having good posture, well-defined muscles, large bones, and a torso that tapers to a well-defined waist). The table 2 shows body type distribution by gender.

In order to understand their running habits, participants were asked about the number of years as a regular runner. It was determined that 117 runners (60%) were doing less than 3 years, 78 runners (40%) were doing sports for 3 years and longer. According to the data obtained on the frequency of running sports, it was concluded that 129 people (66.2%) were doing sports twice a week at most, while 66 people (33.8%) were doing sports at least 3 times a week.

Table 1

DEMOGRAPHIC INFORMATION		
Gender	**Number**	**Frequency (%)**
Male	85	43.6
Female	110	56.4
Total	195	100
Age	**Number**	**Frequency (%)**
19–29	26	13.3
30–39	104	54.4
40–50	65	33.3
Total	195	100
Income (monthly)	**Number**	**Frequency (%)**
Low (< 2500TL)	69	35.4
Middle (2501–10000TL)	94	48.2
High (>10000 TL)	32	16.4
Total	195	100

Runners' sportswear shopping behaviours

The frequency of shopping of participants was examined for upper and lower body sportswear. In the related question, the option of "less frequent" for the purchase of 3 or less sportswear per year, and "very frequent" for the purchase of 4 or more garments is offered. The results of data analysis are shown in the table 3.

The relationship between the frequency of shopping for upper and lower body garments, gender, age, monthly income and body type was examined by Pearson's chi-square test. The analysis results of the variables that have significant relationship with the frequency of shopping are shown in tables 4 and 5. It was found that the frequency of upper body sportswear shopping was significantly related to the frequency of running ($\chi^2 = 7.937$; $p = 0.005$) and monthly income ($\chi^2 = 23.166$; $p < 0.001$).

Table 2

BODY TYPE DISTRIBUTION ACCORDING TO THE GENDER							
Gender	**Ectomorphic**		**Endomorphic**		**Mesomorphic**		**Total**
	Number	**Frequency (%)**	**Number**	**Frequency (%)**	**Number**	**Frequency (%)**	
Male	15	17.6	30	35.3	40	47.1	85
Female	13	11.8	29	26.4	68	61.8	110
Total	28	14.4	59	30.3	108	55.3	195

Table 3

SHOPPING FREQUENCY				
Product type	**Less frequent**		**Very frequent**	
	Number	**Frequency (%)**	**Number**	**Frequency (%)**
Upper body sportswear	110	56.4	85	43.6
Lower body sportswear	118	60.5	77	39.5

Table 4

THE RELATIONSHIP OF UPPER BODY SPORTSWEAR SHOPPING FREQUENCY WITH THE RUNNING FREQUENCY AND INCOME

Shopping frequency	**Running frequency**						**Test statistics**	
	twice a week at most				**at least 3 times a week**			
	n		**%**		**n**	**%**	**χ^2**	**p**
Less frequent	82		63.6		28	42.4	7.937	0.005
Very frequent	47		36.4		38	57.6		
Shopping frequency	**Income (monthly)**						**Test statistics**	
	Low		**Middle**		**High**			
	n	**%**	**n**	**%**	**n**	**%**	**χ^2**	**p**
Less frequent	54	78.3	38	40	18	56	23.166	<0.001
Very frequent	15	21.7	56	60	14	44		

Table 5

THE RELATIONSHIP OF LOWER BODY SPORTSWEAR SHOPPING FREQUENCY WITH THE FREQUENCY OF RUNNING, INCOME, AND BODY TYPE

Shopping frequency	**Running frequency**						**Test statistics**	
	twice a week at most				**at least 3 times a week**			
	n		**%**		**n**	**%**	**χ^2**	**p**
Less frequent	88		68.2		30	45.5	9.468	0.002
Very frequent	41		31.8		36	54.5		
Shopping frequency	**Income (monthly)**						**Test statistics**	
	Low		**Middle**		**High**			
	n	**%**	**n**	**%**	**n**	**%**	**χ^2**	**p**
Less frequent	52	75.4	51	54	15	47	10.399	0.006
Very frequent	17	24.6	43	46	17	53		
Shopping frequency	**Body type**						**Test statistics**	
	Ectomorphic		**Endomorphic**		**Mesomorphic**			
	n	**%**	**n**	**%**	**n**	**%**	**χ^2**	**p**
Less frequent	18	64.3	43	73	57	53	6.648	0.036
Very frequent	10	35.7	16	27	51	47		

It has been determined that gender, age and body types do not have a significant relationship with the frequency of shopping in upper body garments. It was found that the frequency of lower body sportswear shopping was significantly related to the frequency of running (χ^2=9.468; p=0.002), monthly income (χ^2=10.399; p=0.006), and body type (χ^2=6.648; p=0.036). It has been determined that gender and age do not have a significant relationship with the frequency of shopping in lower body garments.

In addition to shopping frequencies, participants were asked to evaluate the reasons for shopping by scoring 1 to 5 points. Total scores were calculated by multiplying the frequencies by the scores given by the participants.

Considering the 195 participants, the total score would range from 195 (least effective criterion) to 975 (most effective criterion). The reasons for shopping were shown in figure 1.

The effect of age, monthly income and body type on the reasons for shopping was investigated with the Kruskal-Wallis test. The analysis results of the groups that have significant relationship with the shopping reasons are shown in table 6.

It was determined that gender had no effect on the reasons for shopping.

When the effects were determined between the reasons and groups, the results of the binary comparison were examined. It was concluded that age groups had an effect on the discomfort (χ^2=7.598; p=0.022) and functionality criteria (χ^2=10.626; p=0.005). Runners between the ages of 19 and 29 gave lower scores for the discomfort criterion than runners between the ages of 40 and 50 (p=0.023). Runners between the ages of 19 and 29 gave relatively lower scores for functionality criteria than runners between the ages of 30 and 39 (p=0.005). Likewise, runners between the ages of 19 and 29 scored relatively lower for functionality criteria than runners between the ages of 40 and 50 (p=0.009).

It was concluded that monthly income status had an effect on the functionality (χ^2=9.109; p=0.011), unpleasant odour (χ^2=8.548; p=0.014), size and fit issues (χ^2=12.127; p=0.002), deformation (χ^2=7.103;

Table 6

THE EFFECT OF AGE, MONTHLY INCOME AND BODY TYPE ON SHOPPING REASONS					
Shopping reasons	**Age**			**Test statistics**	
	19–29	**30–39**	**40–50**	χ^2	**p**
	Mean±S.D.	**Mean±S.D.**	**Mean±S.D.**		
Discomfort of current sportswear	2.19±1.30	2.68±1.44	3.08±1.43	7.598	0.022
The functionality of current sportswear is insufficient	2.27±1.25	3.13±1.34	3.12±1.14	10.626	0.005
Shopping reasons	**Monthly income**			**Test statistics**	
	Low	**Middle**	**High**	χ^2	**p**
	Mean±S.D.	**Mean±S.D.**	**Mean±S.D.**		
The functionality of current sportswear is insufficient	2.96±1.48	3.23±1.24	2.50±0.76	9.109	0.011
Unpleasant odour of current sportswear	2.99±1.67	2.62±1.51	1.97±1.33	8.548	0.014
Size and fit issues of current sportswear	2.16±1.43	2.43±1.24	1.56±0.80	12.127	0.002
Dimensional deformation of current sportswear	2.64±1.47	2.39±1.39	1.78±0.91	7.103	0.029
Follow the fashion	2.93±1.47	3.83±1.14	3.53±1.24	15.758	<0.001
Shopping reasons	**Body type**			**Test statistics**	
	Ectomorphic	**Endomorphic**	**Mesomorphic**	χ^2	**p**
	Mean±S.D.	**Mean±S.D.**	**Mean±S.D.**		
Size and fit issues of current sportswear	1.46±0.79	2.58±1.43	2.17±1.23	14.374	0.001
Follow the fashion	2.57±1.32	3.47±1.38	3.69±1.24	14.309	0.001

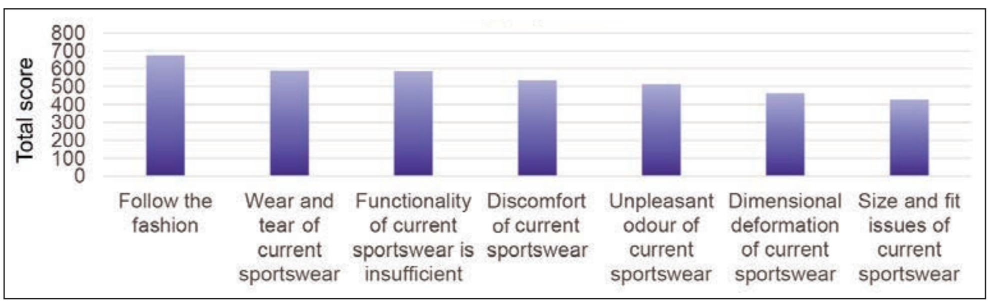

Fig. 1. Runners' sportswear shopping reasons

$p = 0.029$), and fashion ($\chi^2 = 15.758$; $p < 0.001$) criteria. Those with high monthly income scored relatively higher for functionality criterion than those with middle monthly income ($p = 0.009$), with relatively higher scores for unpleasant odour than those with low monthly income ($p = 0.010$). Likewise, those with higher monthly income scored relatively higher for fit and size issue than those with middle monthly income ($p = 0.002$), and relatively higher scores for deformation than those with low monthly income ($p = 0.009$). The scores of those with middle monthly income had relatively higher values for fashion criterion than those with low monthly income ($p < 0.001$).

It was concluded that body types had an effect on the criteria of size and fit issue ($\chi^2 = 14.374$; $p = 0.001$) and fashion ($\chi^2 = 14.309$; $p = 0.001$). It was determined that for the size and fit issues, those with ectomorphic body type gave a lower ($p < 0.001$) score compared to those with endomorphic body type and relatively lower ($p = 0.018$) than those with mesomorphic body type. It was concluded that those with ectomorphic body type for fashion criterion had relatively lower scores compared to those with endomorphic body type ($p = 0.011$) and likewise lower than those with mesomorphic body type ($p < 0.001$).

The most problematic body parts that have size and fit issues in runner sportswear were investigated. It was found that most upper body problems were neck area (*f*: 58; %29.7), abdomen (*f*: 44; %22.6) and arm (*f*:38; %19.5), upper body length (*f*:33; %16.9). The most problems with lower body were the crotch area (*f*:46; %23.6), leg (*f*:41; %21) and waist (*f*:25; %12.8). The body parts with size and fit problems were shown in figure 2.

Participants were asked about the level of importance of the parameters that were effective in the purchase decision. Participants evaluated the effective parameters in purchasing decision by scoring 1 to 5 points (calculation of the total scores are explained in method section). The total score would range from 195 (least effective parameter) to 975 (most effective parameter). When the total score was calculated for parameters according to the preferences of all participants, comfort was considered the most important parameter, which was followed by performance, fabric quality, functionality, design, price, brand and fashion, respectively. The effective parameters in purchasing decision were shown in figure 3.

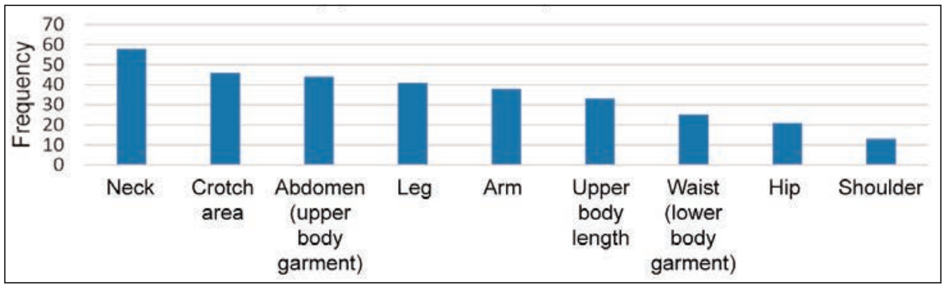

Fig. 2. Size and fit problems for running sportswear considering body parts

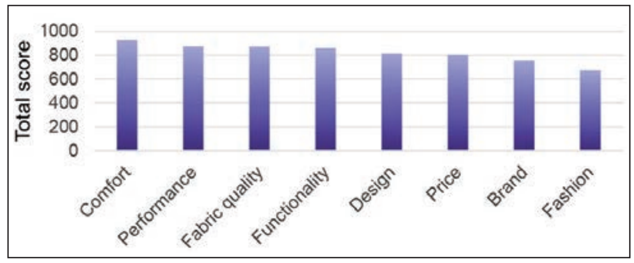

Fig. 3. The effective parameters in purchasing decision

The effect of gender on the parameters that affect the purchasing decision was examined with the Mann-Whitney U test and the existence of age, monthly income and body type effect on the parameters were examined by Kruskal-Wallis test.

When the effects were determined between the effective parameters and the groups, the results of binary comparison were examined. Analysis of the effect of gender, age, monthly income and body type on the parameters that affect the purchasing decision is shown in table 7.

It has been determined that the effect of gender on fabric quality ($z = –3.297$; $p = 0.001$) and functionality ($z = –3.532$; $p < 0.001$) parameters is important. It was determined that women's evaluation scores were higher than those of men for fabric quality and functionality criteria.

It has been determined that the effect of monthly income on brand, fabric quality, fashion, functionality, performance and comfort parameters is important. According to the binary comparison results:

Table 7

EVALUATION OF THE EFFECT OF GENDER, AGE, MONTHLY INCOME AND BODY TYPE ON THE PARAMETERS THAT AFFECT THE PURCHASING DECISION

Effective parameters	**Gender**			**Test statistics**	
	Male		**Female**	**χ^2**	**p**
	Mean±S.D.		**Mean±S.D**		
Fabric Quality	4.29±0.81		4.61±0.67	–3.297	0.001
Functionality	4.14±1.15		4.61±0.84	–3.532	<0.001
Effective parameters	**Monthly income**			**Test statistics**	
	Low	**Middle**	**High**	**χ^2**	**p**
	Mean±S.D.	**Mean±S.D.**	**Mean±S.D.**		
Brand	4.01±1.17	3.97±0.99	3.38±1.29	6.99	0.03
Fabric Quality	4.62±0.71	4.46±0.62	4.19±1.06	8.071	0.018
Fashion	3.07±1.45	3.81±1.02	3.19±1.28	12.803	0.002
Functionality	4.52±0.96	4.53±0.85	3.78±1.29	17.163	<0.001
Performance	4.55±0.87	4.55±0.85	4.09±0.93	13.887	0.001
Comfort	4.86±0.46	4.73±0.71	4.63±0.55	7.783	0.02
Effective parameters	**Body type**			**Test statistics**	
	Ectomorphic	**Endomorphic**	**Mesomorphic**	**χ^2**	**p**
	Mean±S.D.	**Mean±S.D.**	**Mean±S.D.**		
Price	4.32±0.95	4.44±0.77	3.91±0.99	13.992	0.001
Functionality	4.29±1.36	4.08±1.18	4.61±0.72	8.344	0.015
Performance	4.75±0.80	4.32±1.01	4.49±0.82	6.375	0.041
Comfort	4.96±0.19	4.59±0.87	4.80±0.47	6.525	0.038

- The effect on the brand; those with high monthly income scored higher than those with low monthly income ($p = 0.028$).
- The effect on the fabric quality; those with high monthly income scored higher than those with low monthly income ($p = 0.036$).
- The effect on the fashion; those with middle monthly income scored higher than those with low monthly income ($p = 0.003$).
- The effect on the functionality parameter; those with high monthly income scored higher than those with middle monthly income ($p = 0.001$) and those with low monthly income ($p < 0.001$).
- The effect on the performance; those with high monthly income scored higher than those with middle monthly income ($p = 0{,}002$) and those with low monthly income ($p = 0.002$).
- The effect on the comfort; those with high monthly income scored higher than those with low monthly income ($p = 0.001$).

It has been determined that the effect of body type on functionality ($\chi^2 = 8.344$; $p = 0.015$), price ($\chi^2 = 13.992$; $p = 0.001$), performance ($\chi^2 = 6.375$; $p = 0.041$) and comfort ($\chi^2 = 6.525$; $p = 0.038$) parameters is important. The evaluation scores for the price parameter of those with body type mesomorphic have relatively higher values than individuals with endomorphic body type ($p = 0.001$). For the functionality parameter those with mesomorphic body type had relatively higher values than individuals with endomorphic body type ($p = 0.012$). Those with endomorphic body-type had relatively higher scores for performance parameter compared to individuals with ectomorphic body types ($p = 0.036$) and relatively higher scores for comfort parameter ($p = 0.033$).

Participants evaluated the fabric properties they preferred in sportswear fabrics by giving a score of 1–5 (calculation of the total scores are explained in method section). Considering that 195 participants, the total score would range from 195 (least preferred property) to 975 (most preferred property).

When the total scores for the fabric properties were examined, it was determined that the air permeability was the most important feature, followed by flexibility, fast drying, dimensional stability, durability, heat and moisture regulation, soft and pleasant touch, waterproofness. Evaluation results were shown in figure 4.

In order to understand the specific demands of the runners on the quality, color, design and model/cut of the sportswear, the participants were asked if they would like to have options for the mentioned features of the sportswear if customized production was made. Optional feature preference in running sportswear evaluation is shown in table 8.

The relationship between the demand for optional features in sportswear products and gender, age, monthly income and body type was examined by Pearson chi-square test. Test results are shown in table 9. The relationship between the fabric quality options request and gender ($\chi^2 = 16.684$; $p < 0.001$) and age ($\chi^2 = 14.593$; $p = 0.001$) was found to be significant.

It was found that the relationship between the color options request and gender ($\chi^2 = 4.561$; $p = 0.033$), age ($\chi^2 = 7.155$; $p = 0.028$) and monthly income ($\chi^2 = 20.080$; $p < 0.001$) is significant. It was concluded design options request were not significant in relation to gender, age, monthly income, and body type. It has been found that the relationship between

Table 8

OPTIONAL FEATURE PREFERENCE IN SPORTSWEAR

Optional feature	No		Yes	
	Number	Frequency (%)	Number	Frequency (%)
Model/Cut	60	30.8	135	69.2
Fabric Quality	65	33.3	130	66.7
Design	74	37.9	121	62.1
Colour	107	54.9	88	45.1

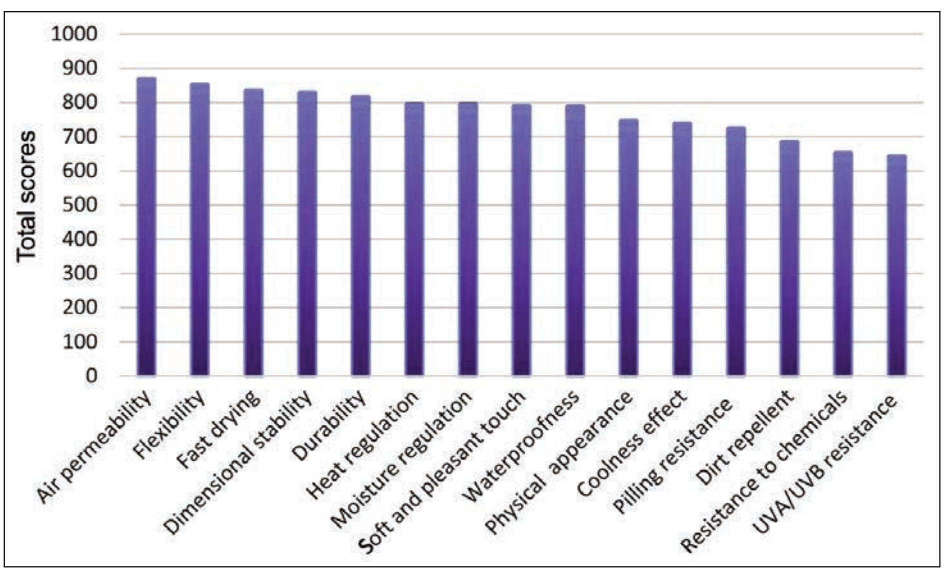

Fig. 4. Most preferred fabric properties in sportswear

Table 8

THE RELATIONSHIP BETWEEN OPTIONAL FEATURE PREFERENCE IN SPORTSWEAR AND GENDER, AGE, AND MONTHLY INCOME

	Answer	Gender				Test statistics	
		Male		Female			
		n	%	n	%	χ^2	p
FABRIC QUALITY OPTION REQUEST	No	15	17.6	50	45.5	16.684	<0.001
	Yes	70	82.4	60	54.5		

	Answer	Age						Test statistics	
		19-29		30-39		40-50			
		n	%	n	%	n	%	χ^2	p
FABRIC QUALITY OPTION REQUEST	No	17	65.4	27	26	21	32.3	14.593	0.001
	Yes	9	34.6	77	74	44	67.7		

	Answer	Gender				Test statistics	
		Male		Female			
		n	%	n	%	χ^2	p
COLOUR OPTION REQUEST	No	54	63.5	53	48.2	4.561	0.033
	Yes	31	36.5	57	51.8		

	Answer	Age						Test statistics	
		19-29		30-39		40-50			
		n	%	n	%	n	%	χ^2	p
COLOUR OPTION REQUEST	No	8	30.8	62	59.6	37	56.9	7.155	0.028
	Yes	18	69.2	42	40.4	28	43.1		

	Answer	Income (monthly)						Test statistics	
		Low		Middle		High			
		n	%	n	%	n	%	χ^2	p
COLOUR OPTION REQUEST	No	23	33.3	62	66	22	68.8	20.08	<0.001
	Yes	46	66.7	32	34	10	31.2		

	Answer	Gender				Test statistics	
		Male		Female			
		n	%	n	%	χ^2	p
MODEL/CUT OPTION REQUEST	No	34	40	26	23.6	6.027	0.014
	Yes	51	60	84	76.4		

model/cut options request and gender is significant (χ^2=6.027; p=0.014).

DISCUSSION

This article aims to determine sportswear preference criteria and expectations that are evaluated against past experiences and present desires. The analysis of quantitative data obtained from the questionnaires answered by the runners themselves shed light on issues related to the runner sportswear preference criteria.

Regarding the shopping habits; of the runners participating in the survey, 43.6% of them frequently shop for upper body sportswear and 39.5% of them frequently shop for lower-body sportswear. It has been determined that as the frequency of running and monthly income increases, the frequency of shopping of upper and lower clothing increases and those with mesomorphic body type shop more frequently. Fashion, wear and tear, and performance are the leading reasons for shopping. Gender has no effect on the reasons for shopping. As the age of the athletes participating in the survey increases, the score given by the participants to discomfort and functionality criteria increases. As the income level increases, the scores given by the runners for functionality, unpleasant odour, deformation and fashion criteria also increase. It was determined that those with endomorphic body type gave higher scores to fit and fashion criteria.

When the fitted body parts and body problems related to sportswear were examined, it was determined that these parts were collar, crotch, abdomen, leg, upper body length and waist according to the frequency order.

Regarding the purchase decisions of the runners, comfort, performance, fabric quality, functionality and design are determined to be important in the purchase decision. The fashion, which takes the first place in the reasons for shopping draws attention as the least effective parameter in the decision to purchase. It has been determined that the effect of gender on fabric quality and functionality parameters is important. Women's evaluation scores were higher than men's for fabric quality and functionality criteria. The effect of monthly income on brand, fabric quality, fashion, functionality, performance and comfort parameters are important. As the monthly income level increases, the scores given for these parameters increase. Those who are mesomorphic have higher scores for price and functionality parameters, while those who are endomorphic have higher scores for performance and comfort parameters.

According to the ranking of the most preferred fabric properties in sportswear; air permeability was considered as the most important property, which was followed by flexibility, fast drying, dimensional stability, durability, heat and moisture regulation, soft and pleasant touch, waterproof.

The participants stated that they would like to have model/cut, fabric quality and design options in sportswear products. 82.4% of male participants and 54.5% of women want to have fabric quality options. 74% of participants in the 30-39 age group want to have fabric quality options. 51.8% of women, 69.2% of participants between the ages of 18–29, and 66.7% of participants with low salaries wanted to have colour option. 76.4% of women asked for the model/cut option to be offered. Here, the results draw attention to the importance of customization. Customer requests and suggestions should be taken into consideration with the aim of eliminating size and fit issues, meeting quality expectations as well as increasing the level of satisfaction.

CONCLUSIONS

In the light of the information obtained from the literature, it can be said that there are dynamic and fundamental changes in athletes' preferences along with contextual changes; type of sport, geography, season, climate, cultural, demographic and anthropological characteristics etc. While offering sportswear products to the market, brands should pay attention not only to quality parameters, but also to these criteria.

This research gives resourceful information for sportswear brands and comfort researchers, as the compiled consumer feedbacks from runners provide tools for product improvement to enhance utility. Because it will be more efficient for the brands to offer sportswear products to the market by paying attention not only to the quality parameters, but also to the criteria preferred by the athletes and consumer feedback.

When designing sportswear, manufacturers should consider criteria such as customer profile, demographic and anthropological features, sports habits, and shopping behaviors.

The finding of this research obtained from Turkish runners should be evaluated by the manufacturers producing for Turkish market in terms of demographic, anthropological, cultural and geographical features. The data obtained from this study drew attention to the criteria effective in shopping and purchasing, as well as to customer demands and expectations.

This study can be developed and conducted with different populations and international comparison can be made. Thus, important feedback is provided for effective and efficient marketing and sales techniques for sportswear brands.

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The role of financial literacy and risk tolerance: an analysis of gender differences in the textile sector of Pakistan

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ABSTRACT – REZUMAT

The role of financial literacy and risk tolerance: an analysis of gender differences in the textile sector of Pakistan

This research explores the effect of financial literacy and risk tolerance on decisions making for investment by men and women in the textile sector of Pakistan. It examines the role of risk tolerance as mediator in relation between financial literacy and individual's investment decision making. It also examines the moderating effect of gender difference between financial literacy and risk tolerance. Collection of research data was done from the 300 respondents in the textile sector of Faisalabad through the self-administered questionnaire by using convenient sampling. This research work represented the facts that financial literacy has a positive and significant relationship with risk tolerance, and investment decisions are significantly influenced by it. Risk tolerance has a positive and insignificant impact on investment decisions.

In contrast, the mediation role of risk tolerance is insignificant between the financial literacy level of individuals and decisions made by them for investment. The purpose of a moderator as gender differences is significant. This study empowers managers to provide basics financial services to employees. Management might be guided that what should be highlighted and what has to be improved to enhance the financial literacy level of textile workers. Employers can play a vital role in building awareness and to educate their employees on fiscal wellness, investment planning, and retirement. Financial literacy can also help employees to achieve commercial success, and it is fruitful in providing benefit plans at work and in their financial affairs.

Keywords: *financial literacy, risk tolerance, investment decisions, innovation, PLS-SEM, textiles application*

Rolul alfabetizării financiare și al toleranței la risc: o analiză a diferențelor de gen în sectorul textil din Pakistan

Acest studiu explorează influența alfabetizării financiare și a toleranței la risc asupra deciziilor privind investițiile de către bărbați și femei în sectorul textil din Pakistan. Acesta analizează rolul toleranței la risc în calitate de mediator în relația dintre alfabetizarea financiară și luarea deciziilor de investiții ale individului. De asemenea, analizează efectul moderator al diferenței de gen între alfabetizarea financiară și toleranța la risc. Colectarea datelor de cercetare a fost realizată de la cei 300 de respondenți din sectorul textil din Faisalabad, prin intermediul chestionarului autoadministrat prin utilizarea de eșantioane convenabile. Această lucrare de cercetare a demonstrat faptul că alfabetizarea financiară are o relație pozitivă și semnificativă cu toleranța la risc, iar deciziile de investiții sunt influențate semnificativ de aceasta. Toleranța la risc are un impact pozitiv și nesemnificativ asupra deciziilor de investiții. În schimb, rolul de mediere al toleranței la risc este nesemnificativ între nivelul de alfabetizare financiară a persoanelor și deciziile luate de acestea pentru investiții. Scopul unui moderator ca diferență de gen este semnificativ. Acest studiu sprijină managerii în oferirea angajaților de servicii financiare de bază. Managementul ar putea fi ghidat cu privire la ceea ce ar trebui evidențiat și ce trebuie îmbunătățit pentru a spori nivelul de alfabetizare financiară a lucrătorilor din industria textilă. Angajatorii pot juca un rol vital în creșterea gradului de conștientizare și în educarea angajaților cu privire la bunăstarea fiscală, planificarea investițiilor și pensionarea. Alfabetizarea financiară poate ajuta, de asemenea, angajații să obțină succes comercial și este utilă în furnizarea de planuri de beneficii la locul de muncă și în rezolvarea problemele lor financiare.

Cuvinte-cheie*: alfabetizare financiară, toleranță la risc, decizii de investiții, inovație, PLS-SEM, aplicații textile*

INTRODUCTION

Households and individuals make different financial decisions in their routine life. Their decisions may be holding money for children's education and emergency funds, financial planning, insurance, retirement planning, choice of pension plans, and mortgage financing or refinancing, etc. Financial literacy has a deep concern with households' behaviour as it helps them to plan their future and participate in attaining a suitable lifestyle during workdays and after retirement. Financial literacy of employees is a critical factor as it stressed that employees might cause loss of productivity and profit because of high turnover rates, absenteeism, and healthcare claims. Research shows that almost one in five employees' unpredictability remained absent from work in the past year to deal with a financial issue. These employees concerned about their finance as they spend a minimum of three hours at work each week thinking about or dealing with their financial matters. With the help of financial education, employees can develop and manage their financial plans, which help them to support their distinct needs such as health insurance, budgeting, building an emergency fund, improving credit, and retirement planning, etc. [1]. Individuals' ability to understand financial concepts are enhanced by financial literacy and assist them in understanding financial facts to make familiar financial decisions. Financial education is associated with the prosperity of people. Earlier studies found that individuals, who have less financial literacy, face problems of personal finance such as retirement planning, savings, investments, borrowings, etc. Over the current years, new financial products have introduced, and the financial landscape has significantly become multifaceted. The risk is linked with the financial products, and a person finds difficulties to recognize the risk. The minimal level of knowledge about the handling of financial matters is required to acknowledge the uncertainties and return related to those products. The financially literate individuals can efficiently use those products and selecting the best by analysing the risks and returns associated to them [2]. We spread this literature as first; we studied the impact of financial literacy on investment decisions of households of the textile sector in the form of retirement planning, children's education, emergency funds, insurance, real estate funds, etc. Second, we measured the effect of the level of an individuals' financial literacy on risk tolerance to find noticeable perceptions about risk and examined the mediating role of risk tolerance on financial literacy and investment decisions. Third, we studied the gender differences as a moderator in relation between risk tolerance and financial literacy. According to Grable [3, 4], risk tolerance is peoples' desire to achieve a specific aim wherever consequences of activities are unsure; it generally accomplished with a probability of inevitable loss. Kimball states that typically, the term risk tolerance has derived from the economic psychology field where almost it linked contrarily to the economic term risk aversion. From the past half-century, extensive research has been done to understand the behaviour associated with the financial risk tolerance of individuals and factors affecting the risk-averse attitude. Riley [5] shows that educational achievements are linked to the financial risk tolerance of people. This research work will investigate the financial literacy level of textile employees and analysed their investment choices.

The reason for this study is to explore the risk tolerance level of men and women and its link to investment decisions. The study also examined the differences in risk tolerance behaviour between both gender decision-makers. Females are poor risk-taker than males. Risk-taking behaviour is an essential element for crucial decisions in many fields. However, it participates in understanding the genders' risk preferences [6]. This study was concerned about financial literate households who display higher financial risk tolerance or gender can truly affect investment decisions due to financial literacy. The goal of current research is to measure whether the literacy about financial matters of a household affects financial risk tolerance. The key objective was to find out in what way gender influences risk tolerance because of financial literacy.

Problem statement

Financial literacy has great importance. It is difficult to make perfect financial decisions without financial knowledge because of the complex nature of financial markets these days. In Pakistan, the need for financial literacy is high for those having limited resources because inadequate knowledge may cause problems in investment. Financial knowledge is essential for persons to gain awareness to perform financial tasks with proper financial planning [7].

This study finds the effects of financial literacy on risk-taking behaviour as well as the investment decisions taken by households in the textile sector of Pakistan.

Research questions

- Do households differ in their financial literacy abilities while making decisions about investments?
- Do households have different capacities for risk tolerance because of financial literacy?
- Does risk tolerance mediate the relationship between financial literacy and investment decisions?
- Does gender effectively moderate the relationship between financial literacy and risk tolerance?

Objectives

The research work has the following primary objectives to:

- Discover the influence of financial literacy on investment decisions;
- Check the mediating role of risk tolerance between financial literacy and investment decisions;
- Study the moderating influence of gender differences on the relationship between financial literacy and risk tolerance.

THEORETICAL FRAMEWORK

Every individual keeps a distinctive perception of risk while making the financial decision in daily life. Thus, they face difficulties to establish an optimal portfolio for savings strategies, for instance, emergency savings, planning for children education, or retirement planning etc. Therefore, households have different financial decisions and may act irrationally while comparing with an optimal portfolio, which the rational economic theory proposes [8].

Underlying figure 1 represents the conceptual model which is studied in this research. In this model, financial literacy is the independent variable, the dependent variable is investment decisions, risk tolerance as the mediator and gender differences are moderator. This model is developed with the help of previous studies [9], which have studied that financial literacy is related to the 'individual's risk tolerance in different ways. Financial literacy and investment decisions are previously described by Janor et al. [11], and mediation of risk tolerance is defined according to Awais et al. [12]. The current study focuses on investment decisions impacted by different level of financial decisions. It was projected that financial literacy has a significant positive influence on investment decisions. According to Stolper and Walter [13], low financial literacy of an individual investor has long-lasting consequences as it results in suboptimal financial behaviour. The second aspect of research work is about analysing the effect of the financial literacy level of people on risk-taking behaviour and to what extent risk tolerance mediates the association of financial knowledge and investment decisions. Follow a line of investigation by Brooks et al. [14] provided the evidence that men have more ability to take risk than women when they interact in the decision making process. However, the evidence by Mishra [15] shows that providing awareness to the households about financial concepts through financial education programmes enhance their investment decision-making ability. The last aspect of the current study is about analysing the moderation effect of gender differences in relation to financial literacy and risk behaviour. This will be the main contribution of this study. Figure 1 shows the connection of these relationships.

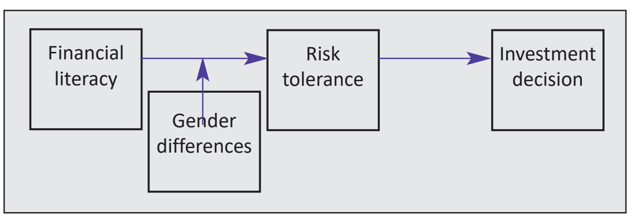

Fig. 1. Conceptual model

Hypothesis development

H1: Financial literacy affects risk tolerance.

H2: Financial literacy affects investment decisions.

H3: Risk tolerance affects investment decisions.

H4: Risk tolerance mediates the relationship between financial literacy and investment decisions.

H5: Gender differences moderates the relationship between financial literacy and risk tolerance.

METHODOLOGY

Sample and sampling procedure

From the literature, it examined that the most common approach for the collection of data in current research is the quantitative approach. Thus, it has been decided to use the quantitative approach in this research.

The target population for the present work is households who work in textile sector of Pakistan and concerns to make investments in the form of real estates, insurance, retirement plan, etc. The research work was conducted in city Faisalabad of province Punjab, to examine the financial knowledge of males and females and its effect on investment decisions and the risk tolerance. Thus, we target the households of the textile sector in Pakistan. It has been decided to choose convenience sampling that is a non-probability sampling. In the current study, it has been decided to choose the sample of 300 households' men and women of textile workers who concern to make investment decisions as to insurance, real estates, etc. for the data collection purpose.

Data collection

By considering all possible restraints (time, cost and population), for collection of data, the self-administered questionnaire was used from Pakistani households. Subsequently, as the main data was obtained through the questionnaire in this research, the data source was primary.

Measures

Financial literacy

The current study has adapted the items from [16] to measure the literacy about financial concepts. Research survey contained 10 items of financial knowledge about saving income, spending money, monthly budget, financial markets etc. However, households are asked to assess the financial literacy on 5-point Likert scale where 1 represents strongly disagree, and 5 denotes strongly agree.

Financial risk tolerance

Households were asked to check their desire of risk-taking about financial matters on (5-point Likert scale). It is considered as a risk tolerance score. The items are adopted from [17]. The options ranging from 1 mean strongly disagree to 5 means strongly agree to examine the risk-taking behaviour of households. The actual scale was changed a little by adding a neutral option due to further scales used as 5-point Likert scale. The low scores denote less risk-taking while more scores show more risk-taking.

Investment decisions

Our study includes questions on investment decisions as retirement planning to check the households plan for retirement questions about real estate to indicate the degree to which each item influence the households and also asked to assess their insurance behaviour. All these items were adapted from Boon and Naseem [18, 19]. The households were asked to give answers on the 5-point Likert scale where 1 show strongly disagrees and 5 represents strongly agree. We also use questions about emergency funds adapted from [20, 21]. Items about Children's Education are adapted from Chatterjee and Mittal [20, 22].

ANALYSIS AND RESULTS

Data analysis

Processing of data was started when the data from respondents was completed. SPSS and Smart PLS data analysis tool was used to present our results in descriptive statistics to weight each variable. The SPSS is a statistical tool in which results are shown in graphs, tables, charts etc. and it is helpful to conduct Chi 2-tests to find the difference between expected and observed frequencies. The PLS-Multi group analysis was also used to measure the moderation effect of gender differences.

Assessment of measurement model

For the current research work, financial literacy, the tolerance level for risks and also decisions for investments were analysed. To evaluate the model of reflective measurement for their reliability and level of validity, PLS-algorithm was run (figure 2). According to evaluation, the reliability of the most of indicators is valid as indicators have more than 0.7 outer loadings as shown in the figure 2 and tables 1 and 2.

There were 7 indicators of financial literacy, 4 indicators from the total of 7 indicators have reliable outer loading as it exceeds from the minimum acceptable level, which is 0.50 and 0.70. In investment decisions, 5 decisions were used in this study as insurance, retirement planning, real estate, emergency funds and children education, 9 indicators from the total of 14 indicators of investment decisions were considered for reliability. All the indicators show reliable loading which exceeds their satisfactory level, which is 0.5 and 0.7. For risk tolerance, 3 out of 4 indicators were used, and all the

Table 1

EVALUATION OF THE MEASUREMENT MODEL

Constructs	Items	Loading	AVE	CR	Cronbach's Alpha
Financial Literacy	Item 1	0.857	0.503	0.799	0.685
	Item 2	0.673			
	Item 3	0.575			
	Item 4	0.703			
Investment Decisions	Item 1	0.506	0.336	0.818	0.772
	Item 2	0.516			
	Item 3	0.689			
	Item 4	0.604			
	Item 5	0.641			
	Item 6	0.646			
	Item 7	0.502			
	Item 8	0.527			
	Item 9	0.548			
Risk Tolerance	Item 1	0.557	0.509	0.751	0.530
	Item 2	0.863			
	Item 3	0.687			

Notes: AVE stands for Average Variance Extracted and CR (Composite Reliability).

Table 2

DISCRIMINANT VALIDITY OF MODEL: FARNELL-LACKER CRITERION

Constructs	CR	AVE	FL	ID	RT
Financial Literacy	0.799	0.503	0.709	-	-
Investment Decisions	0.818	0.336	0.332	0.579	-
Risk Tolerance	0.751	0.509	0.409	0.248	0.713

Notes: Square root of Average Variance Extracted (AVE) is denoted in the diagonal, and the residual entries are Correlation values; CR (Composite Reliability).

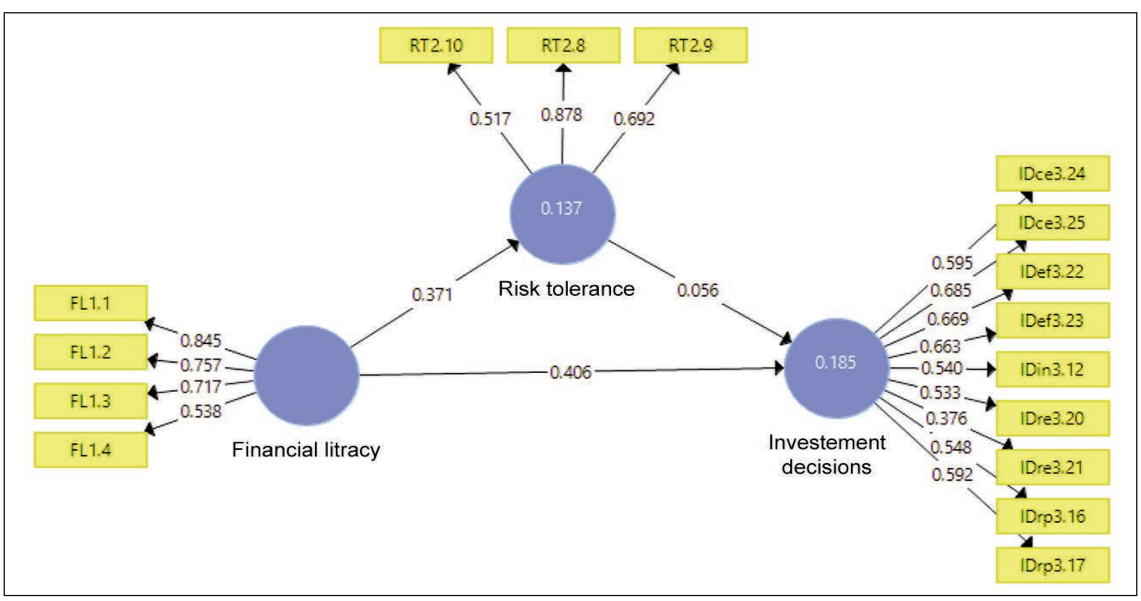

Fig. 2. PLS-Algorithm

values exceed their satisfactory level, which is 0.50 and 0.70, which shows the reliable outer loading. According to Nunnally [23], the reflective measurement model recommended the composite reliability level 0.885 and higher, which presents the confirmation about internal consistency reliability of constructs. For this research work, all the figures of CR were higher than the minimum level, which satisfies the safety of the model. In the table given below the standards of Average Variance extracted (AVE) are 0.5 which is higher than the benchmark level, which supports the convergent validity of the outer model.

Reliability and validity analysis

Evaluation of measurement model is done by sign its validity and reliability. Reliability of this model is assessed by factor loading and composite reliability. According to Nunnally [23] factor loading for all the constructs and their composite reliability must go above their minimum acceptable level, which is 0.7. As shown in the table 2 figures of factor loading and the result of composite reliability approve the reliability of measurement models. The validity of the model was determined by discriminate and convergent validity. The average variance extracted (AVE) and composite reliability (CR) determines the convergent validity, all the values of average variance extracted and composite reliability will have to exceed the threshold level 0.7 and 0.5 respectively.

Discriminant validity

To evaluate the discriminate validity of this model, two techniques are used. Initially, discriminate validity for this model is assessed by cross-loadings; it indicates that loading of all indicators with its construction should be higher than the cross-loading of other constructs. The cross-loadings of indicators were checked that displayed that there was no greater loading of indicators on the opposed constructs. Secondly, Fornell Larcker's criterion was used. The square root of AVE must be greater than the inter-correlation of constructs in discriminate validity, which assures discriminate validity [24]. Benchmark for the level of AVE is greater than 0.50 diagonally. The square root of AVE of all values shown in table 10 is higher than the threshold level, which denotes that all the values are valid and reliable that assures the discriminant validity of constructs. Table 2 showed the discriminant validity of all the constructs.

Evaluation of structural model

According to Chin [25], the Model's quality is assessed by R^2 of endogenous variable, which based upon some guidelines with an acceptable level of R^2 as 0.25, 0.50 and 0.75 respectively, that denotes weak, moderate and significant levels. R^2 of endogenous variables in table 3 denotes that sufficient predictive accuracy as the values exceed the threshold level that is 0.1 [26] and having weak predictive accuracy. Thus results represent that there is an 18% variance in investment decisions, while risk tolerance shows a 13% variance.

Table 3

PREDICTIVE ACCURACY

The goodness of fit indices	R-Square (R^2)
Investment Decisions	0.185
Risk Tolerance	0.137

Testing hypothesis

Table 4 illustrated the path coefficients of constructs, which denotes that all the values represent a strong positive significant relationship. Risk tolerance is significantly positively influenced by financial literacy as (β = 0.371, S.D = 0.061, t-value = 6.116). Investment decisions are insignificantly positively influenced by risk tolerance as (β = 0.056, S.D = 0.071, t-value = 0.791). These results support the hypothesis.

In SEM Analysis, PLS-algorithm was run, and PLS-bootstrapping conducted for testing the hypothesis (figure 3). The path is developed by entering latent variables in the model, financial literacy used as an exogenous variable, investment decisions as an endogenous and mediator variable is taken as risk tolerance.

As shown in table 5 to determine how much investment decisions and risk tolerance are effected by financial literacy, it was hypothesized that the FL enhances the RT level of households. These findings support the (H1) as Financial literacy has a positive and significant relationship with risk tolerance (β = 0.371, t = 6.116, p = 0.000). Hypothesis 2 evaluates that financial literacy level of people has a positive and significant influence on investment decisions (b = 0.406, t = 6.954, p = 0.000). These results support the (H2) and denote that the financial literacy level of individuals has an essential role in making effective investment decisions. It is hypothesized that

Table 4

PATH COEFFICIENT AND T-STATISTICS

Hypothesis links	Path Coefficients	Standard Deviation	t-values
Financial Literacy → Investment Decisions	0.406	0.058	6.954
Financial Literacy → Risk Tolerance	0.371	0.061	6.116
Risk Tolerance → Investment Decisions	0.056	0.071	0.791

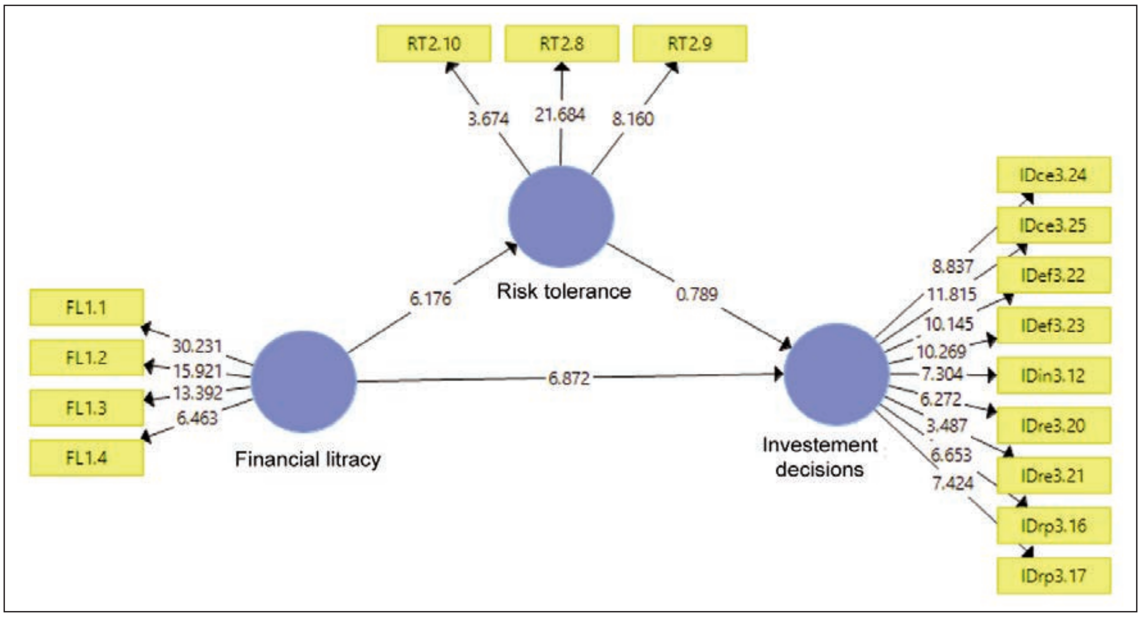

Fig. 3. PLS-Bootstrapping

Table 5

EMPIRICAL FINDINGS AND HYPOTHESIS SUMMARY					
Hypothesis	**Path coefficients**	**t-values**	**P Values**	**Expected impact**	**Decision**
H1	0.371	6.116	0.000***	+	Support
H2	0.406	6.954	0.000***	+	Support
H3	0.056	0.791	0.429 $^{n.s}$	+	Not support

Notes: Path coefficients *** p = 0.001 level, ** p = 0.01 level, * p = 0.05, n.s – non-significant; to simplify the illustration, control variables are not shown in the model.

risk tolerance has a positive and insignificant impact on investment decisions (β = 0.056, t = 0.791, *p* = 0.429), H3 is not supported. The findings signify that risk tolerance level contributes insignificantly to making investment decisions.

Mediator analysis

The direct and indirect effect of dependent and independent variables is also an estimation of a structural model [27]. This effect is measured through mediation or moderation analysis. Hypothesis 3 and 4 evaluate that investment decisions are significantly influenced by risk tolerance, and RT mediates the association between FL and ID. In this study, the effect of financial literacy on investment decisions is completely absorbed by risk tolerance that acts as a mediator (H4). Through indirect effect, financial literacy has a significant impact on investment decisions (β = 0.406, t = 6.954, *p* = 0.000) and has a positive and significant influence on risk tolerance as (β = 0.371, t = 6.116, *p* = 0.000). The investment decisions have indirect effect of financial literacy that displayed insignificant mediation and not supported hypothesis 4 (β = 0.021, t = 0.759, *p* = 0.448), as shown in table 6. According to Zhao et al. [28], a full mediation occurs when direct effect shows non-significant,

Table 6

DIRECT AND INDIRECT EFFECTS-MEDIATION					
Hypothesis	**Relationship**	**Direct effects**	**Indirect effects**	**Total effects**	**Result**
H4	FL → RT → ID	β = 0.406 t = 6.954 p = 0.000	β = 0.021 t = 0.759 p = 0.448	β = 0.427 t = 8.331 p = 0.000	Not supported
H1	FL → RT	β = 0.371 t = 6.116 p = 0.000	-	β = 0.371 t = 6.116 p = 0.000	Supported
H3	RT → ID	β = 0.056 t = 0.791 p = 0.429	-	β = 0.056 t = 0.791 p = 0.429	Not supported

Table 7

MODERATION PATH ANALYSIS				
Hypothesis	**Combined data set n = 300**	**Path coefficients Female (n = 128)**	**Path coefficients Male (172)**	**MGA-Diff female vs. male**
FL → RT	β = 0.371 t= 6.116 p=0.000	β = 0.469 t = 6.160 p = 0.000	β = 0.372 t = 5.055 p = 0.000	β = 0.097 P = 0.179
RT → ID	β = 0.056 t = 0.791 p= 0.429	β = 0.295 t = 0.981 p = 0.327	β = 0.356 t = 5.593 p = 0.000	β = 0.060 P = 0.355

while indirect effect shows significant, that signifies indirect effect only by the mediator occurs.

Multi-group analysis

Hypothesis 5 evaluates that gender differences moderates the relationship between literacy level and mediating variable risk tolerance. Table 7 represents the fact that the influence of financial literacy on risk tolerance is stronger for females (β = 0.469) than males (β = 0.372). It shows the significant relationship for both male and female, where the differences between gender by multi-group analysis is β = 0.097. The moderation test represents that the investment decisions are affected by risk tolerance which is greater for males β = 0.356 as compared to females β = 0.295, and it is significant for male and insignificant for female where the MGA-Difference in genders is β = 0.355.

CONCLUSIONS

This research work explored the role of financial literacy and risk tolerance with gender differences as moderators for analysis in the textile sector of Pakistan. First, this work analysed that to what extent investment decisions and risk tolerance being affected by financial literacy as to insurance, retirement planning, real estate, emergency funds, and children's education. The findings of the current study showed that financially literate households had more desire to take the risk, and financial literacy increases the tendency to invest. For instance, they invest in risky assets, and men showed more risk tolerance in making investment decisions while women showed less risk tolerance. In this study, financial literacy was expected to impact risk tolerance. The risk is connected with the commercial products, and a person finds difficulties to recognize the risk. The minimum level of financial literacy is essential for understanding the risk and return linked to those products. The study represented that financial literacy is significantly positively related to risk tolerance. It indicates that those households who have more knowledge of financial concepts are more risk-tolerant as an increase in financial literacy will increase in risk tolerance. Furthermore, a rise in financial literacy, the financial ability of households with higher risk tolerance, these results are consistent with previous studies [9, 20, 29–32]. The current study proposed that financial literacy must have a positive relationship and investment decisions making and found that investment decisions are positive as well as significantly affected by financial literacy. Financial literacy has great significance. Due to financial literacy, households get an understanding of financial services, products, and in-depth concepts to make effective investment decisions. This study concluded that houses that have not financial literacy have a low desire for making financial decisions as the planning of retirements, insurance, real estate, emergency funds, and children education and households having financial knowledge are further prepared to make decisions about investments. A higher level of financial literacy moves toward the exact decisions associated with saving and investment [33]. Current research work also investigated the control of risk tolerance has over the 'individuals' investment decision making and found that there is a positive and insignificant relationship between risk tolerance and investment decisions. Risk perception is essential in the financial decision-making process. The decisions about different investments are affected by the risk tolerance level of households. The households who are less risk-tolerant have less desire to involve in risky investments, while those who are more willing to take a risk, can gain more returns by handling the finances effectively. The other studies also showed a positive relationship with investment decisions [34]. The current study proposed that risk tolerance acts as mediator in the relationship between financial literacy and risk tolerance. Thus findings showed that the mediating role of risk is positive but insignificant. The other studies showed the positive and significant mediation of risk tolerance [12]. Moreover, the role of the moderator as gender differences is vital positively between financial literacy and risk tolerance. Risk tolerance is more influenced by financial literacy when celebrated for females than males, and it shows a significant relationship for both males and females. Whereas investment decision making is more significantly influenced by risk tolerance for males as compared to females, and it is vital for males, and it is insignificant for females. It signifies that men can bear more risk than women investors in making investment decisions [4]. This study suggests that there is a need to enhance the financial literacy level of employees by providing financial literacy programs to dissolve their economic issues. Through financial literacy, employees can manage their business plans and fulfil their financial needs. The households have to face the risk of making investment decisions. By enhancing the financial literacy level, they can improve the ability to invest in risky assets to gain higher returns through running investments effectively. This research is helpful for the households as by gaining financial knowledge they would be able to face the risky conditions and manage the risky investments efficiently. This research can be expanded for complete industrial sector in future research. It will help to elaborate the financial literacy level and boost up the financial performance as per global requirement in industrial sector.

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Investigation of ergonomic working conditions of sewing and cutting machine operators of clothing industry

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ABSTRACT – REZUMAT

Investigation of ergonomic working conditions of sewing and cutting machine operators of clothing industry

The textile industry is a very labour intensive industry which mainly comprises of small and medium enterprises (SMEs). In developing countries, usually occupational health and safety programs are focused on large-scale organisations. A cross-sectional study on evaluating ergonomics risk factors associated with task performing strategies has been carried out at cutting and sewing units of a garment industry organisation. A reliable direct observational ergonomics risk assessment method Rapid Entire Body Assessment (REBA) was used to find out the risk associated with working postures adopted by the workers. Data was collected through physical observations, walkthrough, interviews, and video recordings. Data analysis was carried out on 180 selected postures by using REBA method. It concluded that overall working strategies were poorly designed as more than 30% of postures highlighted a high level of risk of MSDs that necessitates immediate investigation for improvement. Major causes of risk were linked with the postural movements attached with the wrist, lower arm, and neck. The findings of the study add to the understanding of working conditions of cutting and sewing activities at garment manufacturing industries, these could help in the design of ergonomics interventions for reducing musculoskeletal symptoms and improving job quality which eventually increases work productivity.

Keywords: *musculoskeletal disorders, textile industry, sewing and cutting machine operators, REBA*

Investigarea condițiilor ergonomice de lucru ale operatorilor de mașini de cusut și croit din industria de îmbrăcăminte

Industria textilă este o industrie care implică muncă fizică intensivă, fiind compusă în principal din întreprinderi mici și mijlocii (IMM-uri). În țările în curs de dezvoltare, programele de sănătate și securitate ocupațională se concentrează de obicei pe organizații la scară largă. Un studiu transversal privind evaluarea factorilor de risc ergonomici asociați cu strategiile de îndeplinire a sarcinilor a fost realizat în secțiile de croire și de asamblare ale unei organizații din industria de îmbrăcăminte. S-a folosit o metodă fiabilă de evaluare a riscului ergonomic prin observare directă, respectiv "Evaluarea rapidă a întregului corp" (REBA), pentru a afla riscul asociat posturilor de lucru adoptate de lucrători. Datele au fost colectate prin observații fizice, inspecție, interviuri și înregistrări video. Analiza datelor a fost efectuată pe 180 de posturi selectate utilizând metoda REBA. S-a concluzionat că strategiile generale de lucru au fost concepute necorespunzător, deoarece mai mult de 30% din posturi au evidențiat un nivel ridicat de risc privind tulburările musculo-scheletice (MSD), care necesită măsuri imediate pentru îmbunătățire. Cauzele majore ale riscului au fost legate de mișcările posturale la încheietura mâinii, brațul inferior și gât. Rezultatele studiului facilitează înțelegerea condițiilor de lucru în secțiile de croire și de asamblare în industria de îmbrăcăminte, putând ajuta la proiectarea ergonomică pentru reducerea tulburărilor musculo-scheletice și la îmbunătățirea calității locului de muncă, ceea ce crește în cele din urmă productivitatea muncii.

Cuvinte-cheie: *tulburări musculo-scheletice, industria textilă, operatorii de mașini de cusut și croit, REBA*

INTRODUCTION

Background and objectives of the study

Economic worth of textile and clothing sector is estimated as 439.1bn $, where Pakistan is ranked as the 8th largest exporter of textile related products, and the sector supports about 8% to the gross domestic product (GDP). According to ILO, Garment, Textile, and Footwear industry employ more than 43 million people in developing Asia. At Pakistan, the textile industry has considerable employment contribution, i.e. 30% of the 49 million workforces of the country and have a competitive edge nationally [1–3]. MSDs are very commonly observed health issue, not only in the textile sector but also in many other sectors all over the world. These affect the quality of work-life and performance of individuals and organisations [4, 5]. Jobs in garment industry involve prolonged standing or sitting positions, repetitive movements of hands and arms, poor working postures and bad workplace design [6-8]. Sewing machine operators are engaged in repetitive actions of both hands while leaning forward to getting the focus that leads to MSD in the upper limb, back, and neck [5].

Currently, there is no study to understand the risk factors attached to the work practices adopted by the sewing and cutting operators of garment industries in Pakistan. To fill this gap, this study aims at examining the working conditions of sewing and cutting machines' operators of the garment industry. To achieve this objective, evaluation of ergonomics risk factors associated with existing working strategies has been carried out through Rapid Entire Body Assessment (REBA) tool.

Work-related musculoskeletal disorders are considered as a major health and safety concern which affects workers' life [9]. The cost of work-related accidents, injuries and illnesses is considerable (3.9% of global GDP) whereas according to WHO and ILO, WRMSDs is an international health concern which is found as the third major reason of disability and early retirement [10]. Similarly, European Foundation for the Improvement of Living and Working Conditions (EUROFOUND) concluded that about 60 million workers reportedly suffer from WRMSDs in Europe [11]. WRMSDs have significant economic impact because of lost working days, medical expenditures, and lost productivity [12, 13]. Additionally, WRMSDs result in injuries, symptoms of pain, and stress at work [14, 15].

Prevalence of WRMSDs in the textile industry, especially garments manufacturing sector has been reported because of the nature of job and working conditions [16]. Based on the working requirements, different body parts like neck, shoulders, back and lower extremities are usually affected because of sitting in a fixed position for prolonged hours, high paced repetitive tasks, difficult gripping positions and [15]. Symptoms of pain in the lower back, shoulder, wrist, elbow, and neck have been reported frequently [17–19]. Previously, the genesis of WRMSDs concluded that there were three sets of risk factors associated with these: physical; psychosocial/organisational and individual factors [20]. In general, occupational health and safety have been highlighted as an area of concern in the textile industry of Pakistan, and R&D need in the textile industry has been emphasised [21, 22]. Above discussion concludes that symptoms of WRMSDs among the workers of the garment industry are common due to multiple reasons and require the attention of researchers so that suitable interventions could be designed and implemented. At present, there is no study to understand the prevalence of MSDs and related risk factors among sewing and cutting machine operators working in the garment industry of Pakistan.

Techniques used for the assessment of risk factors are broadly categorised into three major domains: self-reports; observational techniques; and direct methods known as instrumental techniques. These techniques are used to analyse working postures, load or force being applied during work, frequency of movement, time duration, exposure to vibration, etc. [23]. The selection of an appropriate method depends upon the requirement and purpose of the study. Some methods like RULA (Rapid Upper Limb Assessment) [24], LUBA (Postural Loading on Upper Body Assessment) [25] and ULRA (Upper Limb Risk Assessment) [26] can only assess the upper limb or upper body load while others like REBA (Rapid Entire Body Assessment) [27], OWAS (Ovako Working Posture Analysis System) [28], NIOSH Lifting Equations [29] can be used to assess the entire body. REBA is a valid and reliable pen-paper based observation technique that has been frequently used to assess entire body posture along while considering other factors like force, repetitions, and coupling, etc. [27, 30].

RESEARCH METHODOLOGY

The study was conducted in one of the largest garment manufacturing unit located in Lahore, the provincial capital of Punjab, Pakistan. Cutting and sewing activities (containing 34 sub-tasks) of basic 5-pocket denim jeans emphasised for ergonomics risk assessment. As a first step, walk-through investigations, along with the interviews and focus group discussions were carried out for collecting information about work processes, job requirements, workstation design, and feelings of workers about their job. Then working strategies against selected activities (34 sub-tasks) were video recorded. Videos were analysed by the experts and selected snapshots were used for further analysis. The REBA sheet [30] was used to evaluate the selected postures for finding the level of risk. Final REBA scores were calculated based on the severity of the risk, and action categories were determined. Figure 1 and table 1 further explain the research process and REBA action categories.

Table 1

REBA SCORES AND ACTION CATEGORIES

Level	REBA Score	Action required
0	1	Negligible risk
1	2–3	Low risk: changes may be needed
2	4-7	Medium risk: further Investigation. Change soon
3	8-10	High rsk: investigate and implement change
4	11+	Very high risk: implement change NOW

DATA ANALYSIS

The feedback provided by the workers during walk-through, interviews and focus group discussions concluded the presence of the symptoms of musculoskeletal disorders. Sitting position workers complained about pain at their neck, back, wrist and shoulders; whereas standing position workers complained pain at their trunk, legs, and feet. It was also observed that injuries at fingers were a widespread problem. Some other work organization and workspace design-related issues were also highlighted by the workers; for example, long working hours,

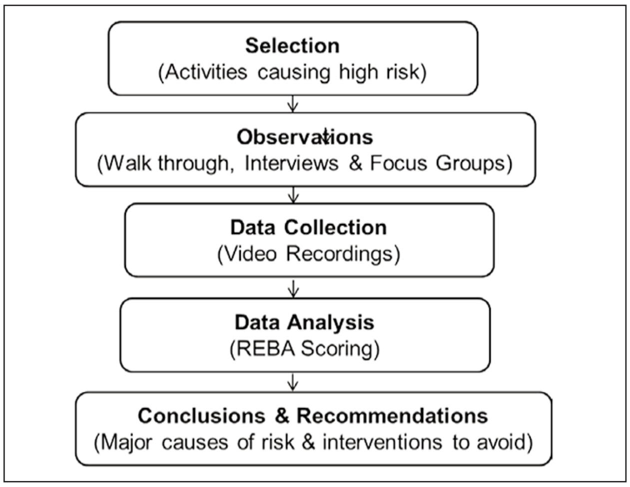

Fig. 1. Research process

repetition of tasks and congested workspace. Especially for sitting workers, workstation design had been found very poor where seats were provided without back support and movement of products were not on a streamlined path. Workers were to move the whole body for picking the material. All these findings helped in selecting appropriate tasks/activities which are physically strenuous for which video recordings were carried out.

Recorded videos were observed by the experts carefully, and snapshots were selected for further analysis. Finally, 180 snapshots were selected for final data analysis. In the REBA score chart, postural codes are assigned against the positions of different body parts like the neck, trunk, leg, upper arm, lower arm, and wrist. Posture score A was calculated with the help of table A and posture score B was calculated with the help of table B. Final score A and B were calculated after incorporating load/force score and coupling score to posture scores A and B respectively. Combining score A and B in table C gives score C, which is finally converted into final REBA score after adding activity score. Details about REBA score calculation can be seen in the literature [27, 30]. Final REBA score provides information regarding the severity of the level of risk in a working posture (table 1). It's important to mention that the selection of posture scores against the neck, trunk, leg, upper arm, lower arm, and wrist are based purely on the degree of flexion, extension, abduction, adduction, bending, side flexed, twist and their combinations. Postural movements containing combinations, for example, bent and twist have a relatively higher level of risk and scored high in the scheme.

Figure 2 shows a worker performing the task. It can be seen that the worker is picking up the bundle from the basket placed at the ground. The neck is flexed greater than 20˚ with a twist, so according to REBA risk assessment worksheet, the score for the neck will be 3. Scores against trunk and leg can be found as 4 and 1 respectively. Posture score A can be calculated by combining scores against the neck, trunk, and leg; whereas final Score A will be calculated by adding load/force score in posture score A, which is 6. Posture code B can be calculated by finding scores against the movements of upper-arm (2), lower-arm (2) and wrist (2). Score B can be calculated by adding a coupling score (1) into posture score B, found to be 4. Final REBA score is found to be 8 in this case after combining score A and B and adding activity score (1). As per the given picture, REBA score 8 will fall under the category of 'High Risk' where an immediate investigation is required.

RESULTS AND DISCUSSION

The analysis concluded that the majority of postures fall in the categories of medium, high and very high risk, where more than 30% fall in the category of high and very high risk. Postures falling under high risk categories (action categories 3 and 4) were further analysed so that a more in-depth insight about possible causes of risk could be investigated. Results concluded

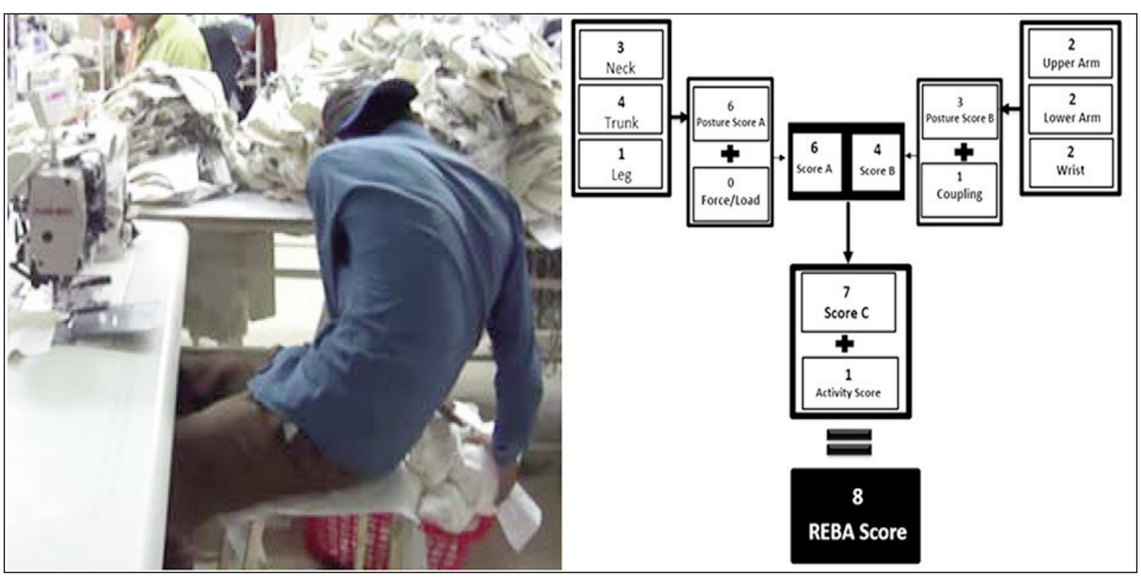

Fig. 2. Calculating REBA score against adopted working posture

that body parts like wrist, lower arm and neck were more vulnerable to risk as significant percentage of postures (84.41%, 79.31%, and 67.24% respectively) falling under action categories 3 and 4 belong to these body parts, shown in figure 3. Postural positions of the trunk and upper arm also played an important role. Complete summary of the analysis is shown in table 2. Descriptions of the code (in table 2) describe the postural position of a specific part of the body. For example, neck posture (code 3 for the neck as per REBA scores) caused high risk is a combination of >20˚ in extension or flexion with twist or side flexed movement. Some sample postures for the trunk, arm and unprotected fingers are shown in figure 4 respectively.

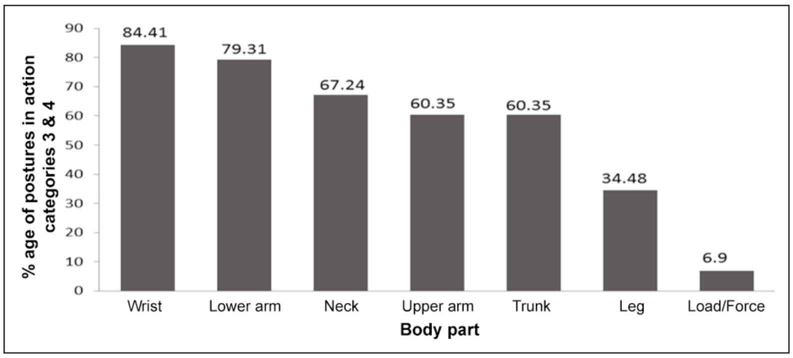

Fig. 3. Role of different body parts as a cause of risk (REBA action categories 3 & 4)

The problem of injuries at fingers was investigated and found that this was because of unguarded cutting blades and lack of the use of protective equipment for fingers. In light of the above results in which primary causes of MSDs have been determined, further recommendations have been developed. It's clear that in garment sewing and cutting activities, major causes of risk are the postural positions of the wrist, lower arm, neck, upper arm, and trunk.
Workers usually adopt awkward working postures that include simultaneous bend and twist movements. Additionally, injuries at fingers are caused due to improper design of cutter and unavailability of protective equipment specific to the cutting activity.
From all this, we may conclude recommendations for avoiding injuries and symptoms of MSDs of garment industry workers performing sewing and cutting operations. For example, improvement in workplace design by providing adequate supports for sitting and standing positions, ergonomically designed chairs, the appropriate height of the table, etc. Simultaneous twist and bend movements of different body parts like neck, trunk, arms, and wrist can be avoided by the smooth flow of materials among the workstation. Proper provision for the placement of materials must be

Table 2

POSTURAL DESCRIPTION OF DIFFERENT BODY PARTS (REBA ACTION CATEGORIES 3 & 4)		
Posture	**Code**	**Postural description**
Neck	3	Combinations of >20˚ in extension or flexion with twist or side flexed
Trunk	4,5	Different combinations of 20˚ – 60˚, >60˚ in flexion or extension and twist or side bending
Leg	3,4	Bilateral or unilateral weight-bearing with knee flexion 30˚ – 60˚ or >60˚
Load/Force	3	>10 kg
Upper Arm	4,5	Combinations include 45˚ – 90˚, >90˚ flexion with abduction, rotation or shoulder in raised position
Lower Arm	2	<60˚ flexion or >100˚ flexion
Wrist	2,3	Combinations of 0 –15˚ or >15˚ flexion or extension with deviation or twist

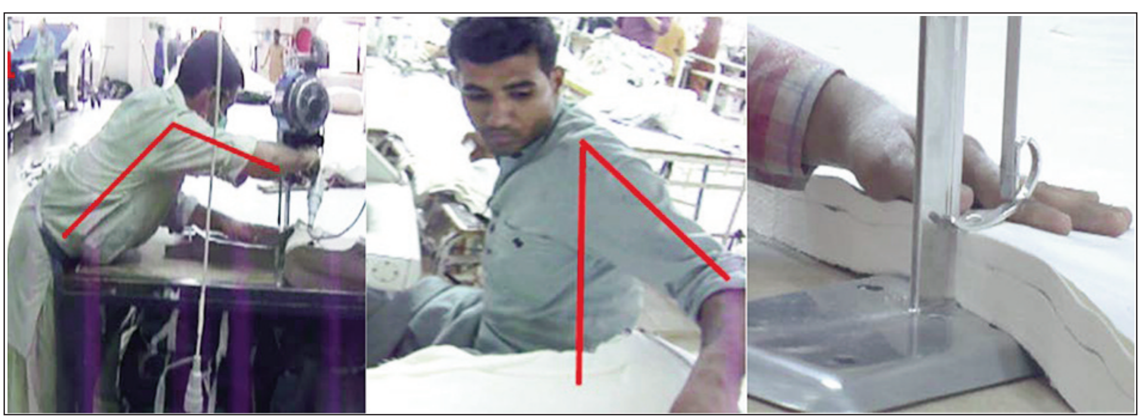

Fig. 4. Captured working strategies showing postural positions

ensured. Protective equipment for fingers must be ensured along with guarding the cutters. Other issues being highlighted during interviews and focus group discussions might be resolved through flexible working hours and job rotation.

CONCLUSIONS

The findings of this research highlighted that a significant number of working strategies adopted by sewing and cutting machine operators of garment industry showed a high level of risk for MSDs. The findings revealed that postural positions of the wrist, lower arm, upper arm, trunk, and neck are highly vulnerable to risk. Workers had to adopt working strategies that include simultaneous bend and twist movements due to poor workstation design. Cutting machine operators were exposed to injuries at their fingers because of unguarded cutters and unavailability of customised protective equipment. This research improves the understanding of ergonomics risk factors linked with the working conditions of sewing and cutting machine operators of the garment industry. Moreover, the study helps the managers and designers to consider associated risk factors while designing workplaces and assigning tasks to workers. Furthermore, some interventions have also been discussed for improving overall working conditions and well-being at work.

This study also has some limitations. For example, data has been collected from one industry, and results may differ for other industries. The study can be further extended to consider the impact of work organization, organizational culture, and environmental issues on the well-being in general and musculoskeletal disorders in particular. Further research can be carried out to conduct a comprehensive empirical study for multiple garment industries so that the most reliable significant ergonomics risk factors could be identified.

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Optimizing content of Pyrovatex CP New and Knittex FFRC in flame retardant treatment for cotton fabric

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ABSTRACT – REZUMAT

Optimizing content of Pyrovatex CP New and Knittex FFRC in flame retardant treatment for cotton fabric

In this study, the flame-retardant treatment for cotton fabric has been done by using the commercial organophosphorus compounds labelled Pyrovatex CP New (PR). Knittex FFRC (K), a formaldehyde-free crosslinking agent, has been used to enhance the link between Pyrovatex CP New and Cellulose molecules. The flame-retardant treatment process for cotton fabric has been done by the pad-dry-cure technique. The purpose of the study is to predict the optimal Pyrovatex CP New and Knittex FFRC concentrations with the highest fire resistance efficiency, minimum loss for mechanical properties and minimum formaldehyde release for the treated fabric. To achieve this goal, the response surface methodology (RSM) was used to find the relationship between the controlled experimental factors and the observed results. The central composite design type face centred (CCF) was applied as experimental design. According to this experimental design, 10 experiments were carried out. The chemical uptake rate, vertical flammability characteristics, LOI value, tensile strength and formaldehyde-free content of the untreated and treated samples were determined. Four response models between the reagent concentrations and the add-on amount, LOI value, warp and weft tensile strength of the treated fabric were obtained by the assistance of software Design-Expert V 10.0.8. The R-squared values of these models were above 80% confirming their significances. The optimal conditions when combining three parameters (LOI, warp tensile strength and weft tensile strength) were selected as 450 g/l Pyrovatex CP New and 107,575 g/l Knittex FFRC with the assistance of Design-Expert software.

Keywords: *cotton, Pyrovatex CP New, Knittex FFRC, durable flame retardant, response surface methodology, central composite designs*

Optimizarea conținutului de Pyrovatex CP New și Knittex FFRC în tratamentul de ignifugare al țesăturii din bumbac

În acest studiu, tratamentul de ignifugare al țesăturilor din bumbac a fost realizat prin utilizarea compușilor organo-fosforici comerciali Pyrovatex CP New (PR). Knittex FFRC (K), un agent de reticulare fără formaldehidă, a fost utilizat pentru a îmbunătăți legătura dintre moleculele de Pyrovatex CP New și cele de celuloză. Procesul de tratare ignifugă a țesăturii din bumbac a fost realizat prin tehnica de fulardare-uscare-condensare. Scopul studiului este de a identifica concentrațiile optime de Pyrovatex CP New și Knittex FFRC, cu cea mai mare eficiență de rezistență la foc, pierderi minime pentru proprietățile mecanice și eliberare minimă de formaldehidă pentru țesătura tratată. Pentru a atinge acest obiectiv, metodologia suprafeței de răspuns (RSM) a fost utilizată pentru a găsi relația dintre factorii experimentali controlați și rezultatele observate. Tipul de proiectare a compozitului central (CCF) a fost aplicat în proiectarea experimentală. Conform acestui plan experimental, au fost efectuate 10 experimente. S-au determinat rata de absorbție chimică, caracteristicile de inflamabilitate verticală, valoarea LOI, rezistența la tracțiune și conținutul de formaldehidă din probele netratate și tratate. Patru modele de răspuns între concentrațiile de reactiv și cantitatea suplimentară, valoarea LOI, rezistența firelor de urzeală și de bătătură ale țesăturii tratate au fost obținute cu ajutorul software-ului Design-Expert V 10.0.8. Valorile pătratice R ale acestor modele au fost de peste 80%, confirmându-le semnificația. Condițiile optime la combinarea a trei parametri (LOI, rezistență firelor de urzeală și de bătătură) au fost selectate cantitățile 450 g/l Pyrovatex CP New și 107.575 g/l Knittex FFRC, cu ajutorul software-ului Design-Expert.

Cuvinte-cheie*: bumbac, Pyrovatex CP New, Knittex FFRC, ignifugare durabilă, metodologie de suprafață de răspuns, modele compozite centrale*

INTRODUCTION

Cotton is one of the most abundantly used fibres. But it is one of the most flammable fibres as well with low limiting oxygen index (LOI) of 18.4% and onset of pyrolysis at 350°C [1]. Therefore, cotton is burn with hot flames and light smoke [2, 3]. Hence, the application of flame-retardant (FR) products on cotton is an important textile issue.

Durable flame-retardant cotton fabric is required in many uses such as home textiles; uniforms for fire-fighters; apparels and garments. Among the durable flame retardants, phosphorus-based flame retardants have been a major source of interest because of their environmentally friendly products and their low toxicity [4]. Durable flame-retardant finishes of cotton using phosphorus-based flame retardants are classified into two types depending on the way of the covalently bond flame retardant reacts to cellulose. One is the reactive finish that reacts with cellulose hydroxyl groups and forms covalent bond. These are mainly based on N-methylol dimethyl phosphonopropion amide (MDPA). The other is non-reactive finish that forms insoluble crosslinked polymer network inside the cellulose fiber. However, it requires the complex application method due to the use of special ammonia chamber and it is not compatible with sulphur dyes [5]. While the reactive finish based on MDPA is also durable, and the application method is simple. Therefore, MDPA-based FRs have been used until present days.

MDPA has methyl group which reacts with cellulose. Furthermore, crosslinking agents are used to improve the durability of the finish and to improve the phosphorus nitrogen synergistic effect [5–8]. MDPA with the trade names of "Pyrovatex CP" or "Pyrovatex CP New" have been the most useful approach to obtain durable flame-retardant finishes for cotton [2, 6, 9]. To improve the durable fire resistance of the treated cotton, MDPA has been used with TMM [2, 10]. There has been a great debate about the environmental impacts related to the use of organophosphorus MPDA product because of the high level of formaldehyde release when combining MDPA and TMM [6, 10].

To reduce the formaldehyde-free content of the flame retardant treated fabric, in our previous study [11], Pyrovatex CP New (PR) has been used as flame retardant agent, Citric acid (CA) and Knittex FFRC (modified DHEU) have been used as formaldehyde-free cross-linking agents [12]. The previous results [11] showed that the use of CA was more favourable than using Knittex FFRC (K). Because CA created the ester bond with PR and cellulose, while Knittex FFRC (DHEU) created the ether bond. However, ester bonds are more susceptible to hydrolysis in water than ether bonds [13], resulting in less durable fire resistance to washing. Beside the impact of DHEU on the tensile strength of the cotton fabric was also lower in comparison with CA. For these reasons, Knittex FFRC (K) was chosen for further research. However, how much of this substance should be used to get the best results?

In reality, there is a very limited research on the formulation and optimization of FR application processes, especially there is no study on optimal concentration of PR and K. Therefore, a study of the effect of PR and K concentrations on the properties of treated cotton fabrics is necessary to obtain their optimal content. In the traditional methodology, each factor is changed in turn to observe their impacts on the properties of the treated fabric as in the study of Mengal N [7]. Therefore, this method does not allow observing the simultaneous effects of factors and their interactions on the fabric properties. In recent years, several studies have applied the response surface methodology (RSM) to find the relationship between the controlled experimental factors and the observed results [1, 14]. Before applying the RSM, it is necessary to select an experimental design, which provides information on the number of experiments that need to be performed in the experimental region being studied. Experimental design for first-order models like factorial design can be used when the data set does not display curvature. If the response function cannot be described by linear functions, the other designs for quadratic response surfaces should be used such as three-level factorial, Box–Behnken, central composite and Doehlert designs etc. [14–16]. This method allows observing the simultaneous and interactive effects of many factors on the results. Moreover, it also allows achieving the optimal value of technological parameters with a minimum number of experiments.

In this study, a central composite designs type face centred (CCF) with RSM was used to optimize the PR and K concentrations in flame retardant finishing for cotton fabric. The flame retardancy, tensile strength and formaldehyde-free content of the treated fabric were measured as the functions of Pyrovatex CP New and Knittex FFRC (DHEU) concentrations. The purpose of the study is to predict the optimal Pyrovatex CP New and Knittex FFRC concentrations with the highest fire resistance efficiency, minimum loss for mechanical properties and minimum formaldehyde release for the treated fabric.

The news of this study is application of the CCF design with RSM to get the optimal concentrations of Pyrovatex CP New and Knittex FFRC in flame retardant finishing for cotton fabric.

MATERIALS AND METHODS

Materials

The 100% cotton twill fabric with surface mass of 190 g/m^2 was supplied by Hanoi Dyeing Joint Stock Company, Vietnam. The fabric was desized, scoured, bleached and mercerized. Pyrovatex CP New (PR), Knittex FFRC (K), Invadine PBN were supplied by Huntsman. Pyrovatex CP New (PR) is an N-methylol dimethylphosphonpropionamide, in this study, it was used as a flame-retardant agent. Knittex FFRC is a modified dihydroxy ethylene urea, it was used as a cross-linking agent. Invadine PBN was used as tenside surfactant.

Methods

Flame retardant treatment for cotton fabric

The pad-dry-cure technique was applied to finish fabrics with different finishing formulations that contain Pyrovatex CP New (PR), Knittex FFRC (K) and Invadine PBN. The reaction mechanism describes the link between cellulose (cotton) and Pyrovatex CP New through DHEU (Knittex FFRC) as cross-linking agent was presented in [11].

In this work, the concentration of Invadine PBN was 5 g/l for all experiments, while the concentrations of Pyrovatex CP New (PR) and Knittex FFRC (K) have been varied according to the options presented in table 1 (they were determined according to the selected test design, it was central composite designs type face centred (CCF)).

All experiments were carried out under the same conditions: the samples were padded with a wet pick-up of approximately 80% by padder SDL D394A, then dried at 110°C for 5 minutes and cured at 180°C for 2 minutes by stenter SDL D398. Next, the samples were washed under running water for 5 minutes and dried in the stenter at 110°C for 3 minutes. The detail of the characteristics of cotton fabric, chemical formulas of the main agents and the flame-retardant treatment process was presented in our previous study [11].

Assessment of fabric's properties

The fire-retardant effect of treated fabric was assessed through the following characteristics: The real uptake of recipe chemicals (add-on %) on fabric, the characteristics of the vertical flammability test and the limiting oxygen index (LOI).

The real uptake of recipe chemicals (add-on %) on the treated fabric was calculated using equation 1 and the results are presented in table 2.

$$\text{Add-on } (\%) = \frac{W_F - W_0}{W_0} \cdot 100 \quad (1)$$

In equation 1, W_F is the standard condition weight of the treated sample, and W_0 is the standard condition weight of the untreated sample. The test was repeated six times for each experiment. The final result is an average of the 6 measures.

The Vertical flammability test method ASTM D 6413-2015 [17] was used for evaluating the flammability of untreated and finished samples.

The LOI value of the control and finished samples were measured in accordance with the ASTM D 2863-97 standard method [18].

Tensile strength of the un-treated and treated samples was determined according to the ISO 13934-1: 2013 standard method [19] to assess the loss of mechanical strength of the fabric due to the flame retardant treatment.

The formaldehyde-free content of flame retardant finished specimens was tested to control the ecological property of the treated fabrics. It was measured with the reference to the guidelines given in the EN ISO 14184-1:1998 standard [20].

Experimental design

In this work, the statistical design was carried out considering two factors: PR concentration and K concentration as process parameters to maximize add-on amount, LOI value, warp tensile strength (Warp TS), weft tensile strength (Weft TS) and to minimize the formaldehyde-free content (FFC) of the treated fabric.

Based on the results of the works [6, 7] and our previous study [11], in this study, the variation range of the concentration of PR was chosen from 350 g/l to 450 g/l, and the concentration of K was changed from 80 g/l to 120 g/l.

According to the face-centred central-composite designs, axial points are located at a distance 1 from the centre point, i.e., factors are tested at 3 levels minimum, middle and maximum, equivalent to levels −1, 0 and +1 (which are called coded units) [16]. If X_{min} and X_{max} are respectively minimum and maximum absolute, i.e., un-coded values of a factor, the absolute values X corresponding the respective coded values can be obtained by a simple linear transformation of the original measurement scale, namely [16]:

$$X = \Delta_X \cdot \text{coded value} + X_0 \quad (2)$$

where $X_0 = (X_{min} + X_{max})/2$, $\Delta_X = (X_{max} - X_{min})/2$.

The relationship between the coded variables and un-coded variables is described by the following equations:

$$A(B) = (X_i - X_0)/\Delta_X \quad (3)$$

where X_i are the un-coded variables and $A(B)$ are the coded variables. Obviously, un-coded factors have their own units. By introducing coded variables, we make the factors dimensionless [16].

According to the CCF, the total number of experimental trials, based on the number of design factors $k=2$, was equal to $N = 2^k + 2k + n_c = 10$ [16]. Where k is number of factors studied in the experiment, 2^k – factorial trials, $2k$ – axial trials and n_c – centre point trials ($n_c = k$). Table 1 shows the experiments designed with PR and K concentrations determined according to CCF.

Table 1

DESIGNED EXPERIMENTS USING CCF

Exper. no.	A	B	X_1 (g/l)	X_2 (g/l)
1	+1	+1	450	120
2	–1	0	350	100
3	+1	0	450	100
4	–1	+1	350	120
5	–1	–1	350	80
6	0	+1	400	120
7	0	–1	400	80
8	+1	–1	450	80
9	0	0	400	100
10	0	0	400	100

The influence of the variables on the results including real uptake of recipe chemicals (add-on%) on fabric, limiting oxygen index (LOI value), the tensile strength of the treated fabric were adjusted using equation 4 [15].

$$Y = b_0 + \sum b_i X_i + \sum b_{ij} X_i X_j + \sum c_i X_i^2 \quad (4)$$

In this equation, $i \geq j$, $i, j = 1, 2, 3$, Y is add-on (%) on fabric, limiting oxygen index (LOI value), fabric tensile strength in the warp and weft directions.

X_i ($i = 1, 2$) and X ($j = 1, 2$) are independent variables, and b_0, b_i, and b_{ij} ($i = 1, 2$), and c_i ($i = 1, 2$ and j = 1, 2) are the coefficients of the model obtained using polynomial regression. The Design Expert V 10.0.8

(US, Stat-Ease Inc.) software was used to evaluate these relationships.

RESULTS AND DISCUSSION

The experimental results according to the CCF design are presented in the table 2. In the table 2 Y1, Y2, Y3 and Y4 are the anticipated responses for the add-on (%), LOI value, warp tensile strength, weft tensile strength.

Model determination

From the experimental results, the equations Y1, Y2, Y3 and Y4 respectively were output by the Design Expert V 10.0.8, they are linear equations for Y1, Y2 and Y4 and quadratic equation for Y3. The equations of Y1, Y2, Y3, Y4 and their statistical parameters are shown in table 3. The shorted ANOVA related to the Y1, Y2, Y3, Y4 models are given in table 4.

Model fitting and analysis of variance (ANOVA)

The coefficient of determination (R^2) is a measure of the degree of fit of the models. Sohail et al. [9] suggested that model with R^2 values above 0.6 is viewed as legitimate or a valid model. While Qiu et al. [21] proposed that a good model fit should yield an R^2 of at least 0.8. In addition, the variety of probability (p) > F estimations of a model also demonstrate the significance of the model: The lower the p-value is, the higher the model's significance becomes. Qiu et al. [21] proposed that a p-value lower than 0.05 indicates that the model is statistically significant, whereas a P-value higher than 0.1000 indicates that the model is not significant. Pure error lack-of-fit test is also used to assess whether the model is adequate

Table 2

THE CCF EXPERIMENTAL DESIGN AND RESULTS

Run	Variable factor: X_1 PR conc. (g/l)	Variable factor: X_2 K conc. (g/l)	Y_1 add-on %	Y_2 LOI %	Vertical flammability: After-flame times (s)	Vertical flammability: After-glow times (s)	Vertical flammability: Char length (mm)	Tensile strength: Y_3 warp tensile strength (N)	Tensile strength: Y_4 weft tensile strength (N)	Formal-dehyde-free content (mg/kg)
Control	-	-	-	14.9	23	44	Completely burned	899.3	532.8	-
S1	450	120	15.54	26.3	0	0	59 ± 6	631.69	435.19	290.86
S2	350	100	12.94	23.2	2 ± 1	0	69 ± 6	588.72	407.04	249.13
S3	450	100	14.99	25.9	0	0	70 ± 2	622.68	421.22	236.1
S4	350	120	13.67	23.7	5± 2	0	104 ± 16	603.55	400.33	266.03
S5	350	80	12.55	23.2	5 ± 2	0	100 ± 22	528.52	415.57	213.32
S6	400	120	14.36	24.1	2	0	59 ± 5	630.11	406.05	244.17
S7	400	80	12.80	23.7	0	0	66 ± 4	581.32	439.66	282.93
S8	450	80	13.94	25.0	2	0	64 ± 6	579.65	448.48	205.76
S9	400	100	13.01	24.1	4 ± 2	0	107 ± 30	628.23	421.88	292.35
S10	400	100	13.14	24.6	-	-	-	622.15	424.99	-

Table 3

MODEL FITTING OF TEST RESULTS

Test responses	R-squared	Adj R-squared	F-value	P-value	Response equation in actual variable
Add-on	0.8573	0.8165	21.02	0.0011	$Y1 = 3.04733 + 0.017700X_1 + 0.035667X_2$ (Y1)
LOI	0.8944	0.8642	29.63	0.0004	$Y2 = 13.08000 + 0.023667X_1 + 0.018333X_2$ (Y2)
Warp tensile strength	0.9895	0.9764	75.43	0.0005	$Y3 = -1655.30619 + 7.25710X_1 + 13.60843X_2 - 0.0057475X_1X_2 - 0.00788114X_1^2 - 0.049220X_2^2$ (Y3)
Weft tensile strength	0.8065	0.7513	14.59	0.0032	$Y4 = 364.55767 + 0.27317X_1 - 0.51783X_2$ (Y4)

Table 4

SHORTED ANOVA OF THE MODELS		
Source	**F-value**	**p-Value Probe > F**
Model	**Y1**	
A-PR CONTENT	25.48	0.0015
B-K CONTENT	16.56	0.0048
Lack of Fit	25.29	0.1510
Model	**Y2**	
A-PR CONTENT	54.07	0.0002
B-K CONTENT	5.19	0.0568
Lack of Fit	1.28	0.5886
Model	**Y3**	
A-PR CONTENT	83.99	0.0008
B-K CONTENT	202.59	0.0001
AB	5.19	0.0849
A^2	35.60	0.0040
B^2	35.55	0.0040
Lack of Fit	1.50	0.5257
Model	**Y4**	
A-PR CONTENT	18.53	0.0035
B-K CONTENT	10.65	0.0138
Lack of Fit	14.41	0.1990

to describe the functional relationships between the experimental factors and the response. Low p-value for lack-of-fit in ANOVA table means that the analysed model does not fit to the experimental data [16]. Table 3 shows that the coefficients of determination (R^2) of all four responses are higher than 0.8. Furthermore, their p-values are less than 0.05 in all responses indicating that all four models are highly significant. Besides, in the table 4, the calculated p-values for lack-of-fit are greater than 0.05 for all modes Y1, Y2, Y3, Y4. Therefore, there is no statistically significant evidence that these models do not represent the data at a 95% confidence level.

Statistical significance of the terms of the models

The statistical significance of the terms of the model defined by equation 4 can be evaluated using the analysis of variance (ANOVA). A statistical F-test is employed to identify statistically significant terms of the model. One can obtain p-values from this test for each term of the model, which are a measure of the probability of obtaining data at least as extreme as the data from the model. The lower the p-values for the analysed terms are, the greater the effect these terms have on the response predicted by the model [16]. As well as for the model, a p-value of the terms lower than 0.05 indicates that the term is statistically significant, whereas a p-value higher than 0.1000 indicates that the term is not significant [16, 21]. Table 4 shows that, all the p-values of the terms of Y1 and Y4 are less than 0.05, which means that the coefficients of the terms in these models are significant. Meanwhile, one p-value of Y3 and one p-value of Y2 are higher than 0.05, but they are less than 0.1, so, according to the above-mentioned principle, they can be accepted. As such, all terms of these four models are accepted.

All these four models are significant for the further analyses

Effect of PR and K concentrations on the properties of the finished fabric

Effect of PR and K concentrations on the real uptake of the finished fabrics

The fitted model of the add-on in un-coded variables is presented in equation Y1 (table 3) and in coded variables is showed in equation y1. Figure 1 shows the response surface curve of the add-on.

$$\text{add-on} = 13.69 + 0.88A + 0.71B \qquad \text{(y1)}$$

From the equation y1, it can be seen that, in the studied range of the factors, the relationships between both factors and the add-on on the treated samples are linear. The concentrations of PR and K used in the finishing solution are effective factors on the add-on of the treated fabric. The higher the concentrations of PR and K are, the higher the add-on on the samples is. However, the coefficient of factor A is slightly higher than the coefficient of factor B indicating that the effect of the PR factor on the add-on amount is greater than that of the K factor. Figure 1 and equation y1 indicate that the highest add-on amount is related to the sample treated with 450 g/l of PR and 120 g/l of K.

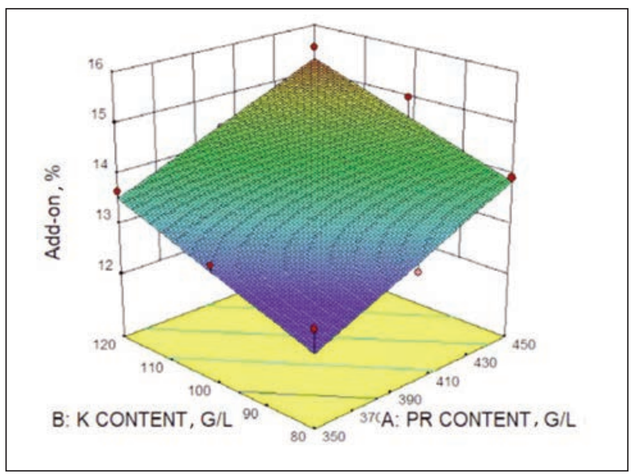

Fig. 1. Surface response curve related to add-on of samples

Effect of the chemical content on LOI value of the treated fabric

The fitted model for describing the relationship between the LOI value of the treated fabric and the PR and K concentrations in un-coded variables is presented in equation Y2 (table 3) and in coded variables is equation y2. Figure 2 shows the response surface curve of the LOI.

$$\text{LOI} = 24.38 + 1.18A + 0.37B \qquad \text{(y2)}$$

Equation y2 and figure 2 show that, similar to the value of add-on, LOI of the treated fabrics has a linear relationship that is directly proportional to both

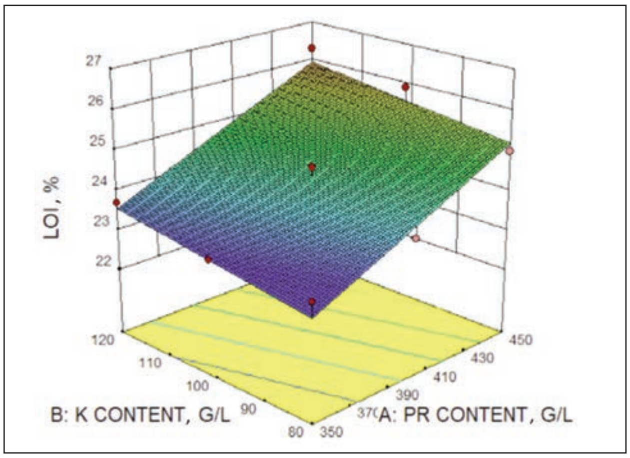

Fig. 2. Surface response curve related to LOI value of treated samples

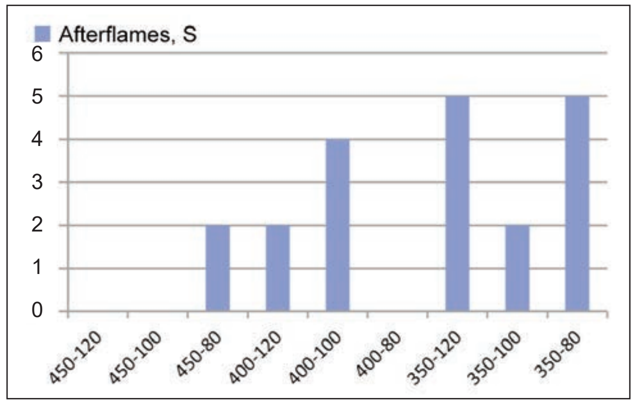

Fig. 3. After-flame time of the treated samples under ASTM D6413 test

PR and K. Thus, the highest LOI value is also related to the sample treated with the highest concentrations of PR (450 g/l) and K (120 g/l). However, in the equation y2, the coefficient of factor A is 1.18 while the one of factor B is only 0.37 indicating that the effect of PR to LOI is much greater than that of K.

Effect of the chemical content on the flammability of finished fabric

The results of flammability test of samples according to the test method ASTM D 6413-2015 are presented in table 2 (after-flame time, afterglow time and char length). Figure 3 shows the after-flame time of the samples treated with the different finishing formulations and figure 4 shows the images of the samples after the vertical flammability test.

The results show good effect of flame-retardant treatment on the cotton fabric. There is a clear difference in combustion behaviour between untreated and treated samples in the vertical flammability testing. The control sample (figure 4) burned vigorously in directly exposure to the ignition source. After removing the combustion source, the sample continued to burn until it had burned out and no char at all. Furthermore, there was 44 seconds of afterglow. While all the treated fabrics were self-extinguished after removing the combustion source. Moreover, there were char-forming on the sample areas exposed to the flame (figure 4). Besides, the burning behaviour of the treated samples under the vertical flammability test also varied depending on the formulation of their finished solution. The graph of figure 3 shows that the samples treated at the highest concentration of PR (450 g/l) have the shortest after-flame time (zero, zero and 2 seconds), the samples treated at the lowest concentration of PR (350 g/l) have the longest after-flame time (5, 2 and 5 seconds), that of samples treated at 400 g/l of PR are 2, 4 and zero seconds. Although there is no fitted model between after-flame time and 2 factors A and B, but their values have also varied relatively according to the changes of these factors.

The best vertical flammability characteristics are also related to the samples treated with the PR concentration of 450 g/l and K concentration of 120 or 100 g/l.

Influence of the chemical content on tensile strength of cotton fabric

Firstly, the fabric density was tested in the treated samples, the result showed that the density of the treated fabrics stays unchanged in comparison with the control fabric. Therefore, the tensile strength of fabric samples that presented in the table 2 was used to assess the influence of flame-retardant treatment on the tensile strength of cotton fabric.

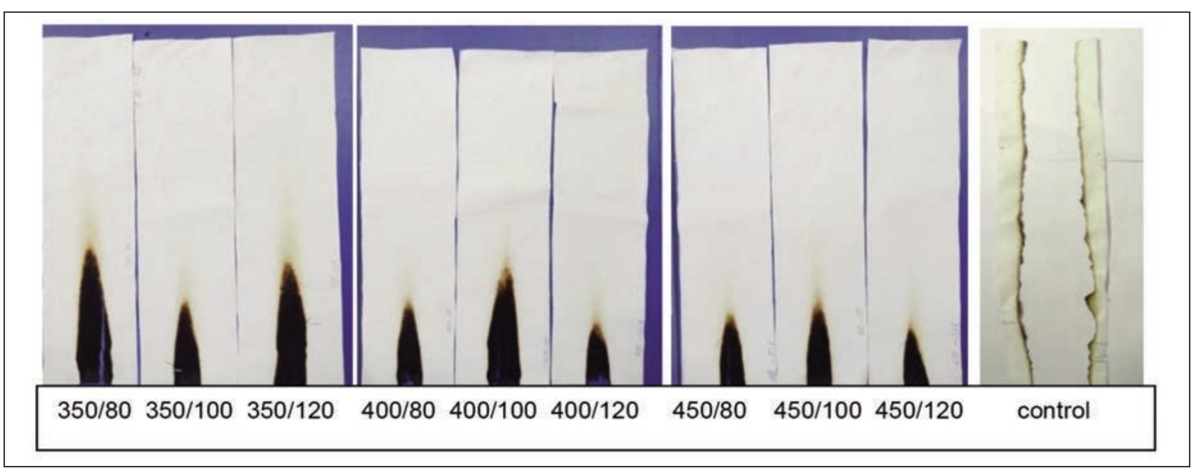

Fig. 4. Treated and control samples after vertical flammability test

The results of table 2 show that the tensile strength of the treated samples was significantly reduced compared to the untreated samples. This mechanical strength loss in the direction of warp yarn is in the range of 30 to 41%, while, in the direction of the weft, it is lower, from 18 to 25%.

Based on the values of tensile strength of the treated samples and the data of experimental design, the Design Expert software V 10.0.8 has been found the fitted models between two factors and the tensile strength of the treated fabric in warp and weft yarns direction, which are the equation Y3 and Y4 (table 3). The fitted model of the warp tensile strength in coded variables is presented in equation y3. The response surface curve of warp tensile strength of the samples is showed in figure 5.

$$\text{Warp TS} = 625.30 + 18.87A + 29.3 - 5.75AB - - 19.7A^2 - 19.69B^2 \quad (y3)$$

Equation y3 is a fully quadratic equation, the model takes into account linear effects, quadratic effects and two-way interactions between the studied factors. This means that the model has the maximum point within the studied range of these two variables. First, when the concentrations of PR and K increased, the warp tensile strength of the treated fabric increased. Then, it decreased while these two factors continued to increase. The highest warp tensile strength can be 638.63 N, it is related to the sample treated with 413.75 g/l of PR and 112.5 g/l of K.

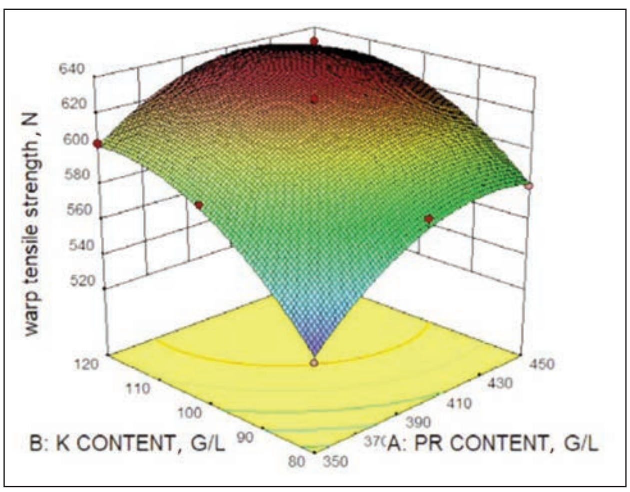

Fig. 5. Surface response curve related to warp tensile strength of treated samples

It could be suggested that, this loss of tensile strength of the fire-retardant treated cotton fabric may be mainly due to high temperature treatment. Beside the used chemicals can also affect to the mechanical strength of fabric, but it could be due to two opposite effects. First, the add-on on the treated fabric, linked to the fabric by covalent bonding, which could help to increase the tensile strength of the treated fabric. Secondly, the acidic effect of the used chemicals could reduce the mechanical strength of the fabric (both chemicals have low pH: pH of solution 100 g/l PR is 3.5÷6.0 and pH of K is 2.2÷3.5). When the second effect was stronger than the first one, the fabric strength began to decrease. Perhaps, when the concentration of chemical agents was too high, the acid effect could be stronger than other effects and the mechanical strength of the fabric began to decrease. The fitted model of the weft tensile strength in coded variables is presented in equation y4. The response surface curve of weft tensile strength of the samples is showed in figure 6.

$$\text{Weft TS} = 422.04 + 13.66A - 10.36B \quad (y4)$$

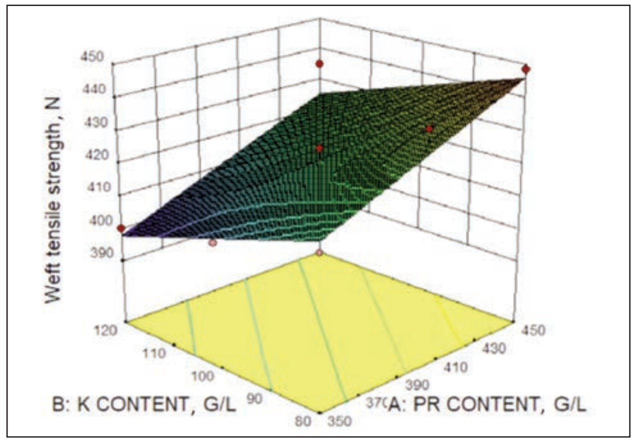

Fig. 6. Surface response curve related to weft tensile strength of samples

The equation y4 and figure 6 show that the response model of the weft tensile strength of the treated samples is based on two linear effects. One is the positive effect related to the PR concentration, the other is the inverse effect related to K concentration. That means, the higher the PR concentration is, the higher the weft tensile strength of treated fabric is. In contrast, the higher the concentration of K is, the lower the weft tensile strength of treated fabric becomes. Therefore, the highest weft tensile strength is related to the sample treated with 450 g/l of PR and 80 g/l of K. It is assumed that this phenomenon may also be related to the add-on on the treated samples and the acidity of the chemicals was used. In which, the increase in the tensile strength when increasing the PR content may be greater than the reduction due to the decrease in the pH of the finished solution. In contrast, the increase in the tensile strength when increasing the K content may be smaller than the reduction due to the decrease in the pH of the padding solution. This hypothesis can be accepted thanks to the following phenomena: Firstly, in equation y1, the coefficient of PR factor is higher than that of factor K. Secondly, the pH of K is lower than that of PR

Influence of chemical concentrations on formaldehyde-free content (FFC) of the treated fabric

Results of the hydrolyzed formaldehyde amounts of the treated samples are presented in table 2. The results of table 2 show that the formaldehyde-free content of un-treated sample is only 23 ppm. While it is from 205.76 to 292.35 ppm for all treated samples.

Knitex FFRC is a formaldehyde-free crosslinking agent. Therefore, the FFC of the treated samples could be mainly from Pyrovatex CP New [8]. Although the fitted model between FFC and 2 factors A and B has not been found, however, the formaldehyde-free content of all the treated samples is less than 300 ppm, it fulfills the criterion of OEKO-TEX® standard 100 for not direct skin apparel fabrics.

Optimizing content of Pyrovatex CP New and Knittex FFRC

The best PR and K concentrations focusing individual parameters are presented in the table 5. The errors calculated between the related experimental and the predicted values were relatively small indicating the adequacy of the models. The best processing conditions for each individual parameter are not the same. Therefore, it is necessary to find the optimal PR and K concentrations when combining all these characteristics, because there is no fitted model for afterflame time and formaldehyde-free content of the treated samples. The add-on is only an indirect parameter to predict the fire resistance of the fabric.

Therefore, the optimal concentrations of PR and K were determined when combining only 3 parameters of treated samples (LOI value, warp and weft tensile strength).

The optimal concentrations of PR and K were investigated from the numerical optimization approach with the assistance of software Design-Expert form. As the aim of this study was to obtain the fabric to have the highest flame resistance, maximum mechanical properties. Moreover, in this study, the LOI value of fabric was preferred over the tensile strength of the fabric. Therefore, the importance of the LOI, warp and weft tensile strength has been chosen as 5, 3 and 3 respectively. According to these criteria, Design-Expert software has given the optimal concentrations of PR and K and predicted the LOI values, tensile strength in the warp and weft direction of the cotton fabrics when they would be treated in this condition (table 6). From table 6, if the cotton fabric is treated at the optimal concentrations of PR and K, it will have a LOI value of 25.7%, the tensile strength of the fabric in the warp and weft directions will be 630.5 N and 431.7 N. It shows that if the cotton fabric is treated at this condition, it can be classified as flame retardant fabric with a LOI value higher than 25% [22]. The other properties of the fabrics (afterflame time, afterglow time, tensile strength) also can meet the requirements of fabrics for the protective clothing against heat and fire according to ISO 11612:2008 [23].

CONCLUSION

In this work, a response surface methodology with CCF experimental design was employed to study the effects of reagent concentrations on the finishing process and optimization of the parameters to attain the optimal formulation.

Four response models between reagent concentrations and the add-on amount, LOI value, warp and weft tensile strength of the treated fabric have been obtained. The R-squared values of these models were above 0.8 confirming that these models were significant. The experimental estimations at the best selected conditions (table 5) were comparably similar to the predicted values in the formulation. That indicates the adequacy of the models.

The optimum conditions selected for the combined parameters are 450 g/l PR and 107 g/l K. Cotton fabrics treated under these conditions can meet the criteria of flame-retardant fabrics for professional use. It also fulfils the criterion for formaldehyde-free content (<300 ppm) of OEKO-TEX® standard 100 for not direct skin apparel fabrics.

However, the high mechanical strength loss of fabric due to the flame-retardant treatment is still a limitation of this study. This may be due not only to the use of chemicals but also to cotton fabric heated at high temperatures for a long time (at 180°C for 120 seconds). Therefore, to minimize this limitation, it is necessary to determine the optimal curing conditions. This is the lowest possible curing condition to create a cross-linking between cellulose and PR. This content will be implemented in our further studies.

Table 5

THE BEST FORMULATIONS OF THE FINISHING SOLUTION FOR INDIVIDUAL PARAMETERS

Goal	PR con. (g/l)	K con. (g/l)	Predicted values	Actual values	Error (%)
Max Warp TS (N)	413.75	112.5	638.63	-	-
Max Weft TS (N)	450	80	446.056	448.48	–0.5
Max Add-on (%)	450	120	15.412	15.54	–0.82
Max LOI (%)	450	120	25.93	26.3	1.4

Table 6

OPTIMIZED FORMULATIONS OF THE FINISHING SOLUTION FOR COMBINED PARAMETERS

Number	PR content (g/l)	K content (g/l)	Warp tensile strength (N)	Weft tensile strength (N)	LOI	Desirability	Number
1	450.000	107.575	630.565	431.777	25.702	0.805	Selected

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Forecasting the conditional heteroscedasticity of stock returns using asymmetric models based on empirical evidence from Eastern European countries: Will there be an impact on other industries?

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ABSTRACT – REZUMAT

Forecasting the conditional heteroscedasticity of stock returns using asymmetric models based on empirical evidence from Eastern European countries: Will there be an impact on other industries?

This empirical study investigates the leverage effect in six Eastern European countries under normal and non-normal distribution densities for the sample period from January 2020 to August 2020. We find three countries, Bulgaria, Czech Republic and Russia which are subject to ARCH effect whereas Poland, Romania and Hungary do not exhibit ARCH effect in daily stock returns. Further, our study finds leverage effect, where past bad news affects is asymmetrical, past negative returns cause more volatility in current stock returns as compared to past positive returns, in three Eastern European countries. Based on the AIC and BIC model selection criteria we find that the non-normal student t-distribution and GED produce reliable estimates for Bulgaria, Czech Republic and Poland, respectively. The autocorrelation function Q1 statistic confirms the insignificance of autocorrelation in residuals of TGARCH model. The impact of stock market dynamics on other industries, such as pharmaceutical industry, textile and clothing industry, automotive industry is significant, especially in the conditions of COVID-19 pandemic.

Keywords*: stock market, Eastern European countries, TGARCH model, leverage effect, return*

Predicția heteroscedasticității condiționate a randamentelor acțiunilor utilizând modele asimetrice bazate pe cercetări empirice privind țările din Europa de Est: va exista oare un impact asupra altor industrii?

Acest studiu empiric investighează efectul de levier la nivelul a șase țări din Europa de Est în cazul distribuției normale, precum și a distribuției care nu este normală, pentru perioada de eșantionare din ianuarie 2020 până în august 2020. Rezultatele empirice identifică trei țări, și anume: Bulgaria, Cehia și Rusia care sunt supuse efectului ARCH în timp ce Polonia, România și Ungaria nu prezintă efect ARCH în cazul rentabilităților zilnice. Mai mult, studiul nostru constată existența unui efect de levier, în cazul în care impactul știrilor negative din trecut este asimetric, randamentele negative din trecut cauzează mai multă volatilitate a randamentelor actuale ale acțiunilor în comparație cu randamentele pozitive din trecut, în trei dintre țările din Europa de Est selectate. Pe baza criteriilor de selecție a modelelor AIC și BIC, constatăm că distributia t-Student care nu este normală și GED produc estimări fiabile pentru Bulgaria, Cehia și Polonia. Impactul dinamicii pieței bursiere asupra altor industrii, cum ar fi industria farmaceutică, industria textilă și a îmbrăcămintei, industria auto, este semnificativ, în special în condițiile pandemiei COVID-19.

Cuvinte-cheie: *piață bursieră, țări din Europa de Est, model TGARCH, efect de levier, rentabilitate*

INTRODUCTION

The year 2020 was a major challenge for all countries in the world in the context of the COVID-19 pandemic. The selected European states are no exception. Most industrial sectors were affected, production was significantly reduced or even stopped, many employees lost their jobs, thus increasing the unemployment rate, global demand collapsed, consumption was severely limited, while global economy experienced significant disturbances. For example, the textile and clothing industry has been severely affected by the pandemic crisis. People were more interested in providing for essential necessities such as food, water, hygiene products, pharmaceuticals and medicines. Moreover, Europe's lockdown negatively influenced the sales volume as well as the production level. As a direct consequence, many companies have gone bankrupt. According to Tudor [1] textile and clothing industry is distinguished by its incremental changes but the current global business environment creates the premises of multiple organizational disruptive changes. On the other hand, cotton represents one of the most commonly used textile fibres in the world [2]. However, in the context of the COVID-19 pandemic, the textile industry refocused on the design of face masks or sanitary materials. In this extremely turbulent context, financial investments and stock market behaviour are essential in mitigating the effects of the pandemic on the economy.

In case of financial time series data, leptokurtosis and volatility clustering are commonly observed phenomenon that indicates the higher level of risk involved [3]. There is one more measure, leverage effect that has acquired great attention that inculcates the fluctuation in security prices are inversely correlated to the fluctuation in security's own volatility. Characteristically, a rising stock price is accompanied by the decline in volatility and vice versa. The term "leverage" refers to one possible economic interpretation of this phenomenon, developed by Black [4] and Christie [5]: as stock prices fall, companies become more leveraged because the relative value of their debt rises relative to that of their equity. As a result, it is common to believe that their stock have become riskier, hence more volatile. While this is only a hypothesis, but it is widely believed in financial literature that the term "leverage effect" refers to describe a statistical regularity in question. It has also been documented that the effect is generally asymmetric: other things equal, declines in stock prices are accompanied by larger increases in volatility than the decline in volatility that accompanies rising stock markets [6, 7]. To encounter these types of risks in financial time series data require to use wide variety of models that incapsulate varying variance to estimate current and predict future volatility.

Engle [8] has proposed Autoregressive Conditional Heteroskedasticity (ARCH) model that is based on conditional time varying variance which considers the lagged disturbance. (It models the change in variance over time in financial time series data).

Whereas the extension of ARCH model is proposed by Bollerslev [9], Generalized Autoregressive Conditional Heteroskedasticity (GARCH) model, that includes the higher order ARCH model to capture the dynamic behaviour of conditional variance. Although ARCH and GARCH models encounter leptokurtosis and volatility clustering due to symmetric distribution, however, fail to incapsulate leverage effect in financial time series data. To estimate the leverage effect, some non-linear extensions of GARCH model has been proposed, for instance, EGARCH [6], GJR [10] and asymmetric power ARCH (APARCH) [11].

Another drawback of GARH model is lack of embracing thick tail property of high frequency of financial time series. Bollerslev [12] and Baillie and Bollerslev [13] have provided the solution to this problem through using student's t-distribution. Furthermore, Liu and Brorsen [14] used asymmetric stable density to captures skewness. In order to model kurtosis and skewness Fernandez and Steel [15] supported skewed student's t-distribution that later on Lambert and Laurent [16, 17] incorporate this into GARCH framework. To make GARH and EGARCH model fit for stock markets, Harris et al. [18] use skewed generalized student's t-distribution to estimate skewness and leverage effect of daily stock returns.

Despite an extensive amount of research on symmetric and asymmetric GARCH models, less attention has been drawn to compare alternative density forecast model specially in the context of Eastern European stock markets after Drachal [19]. The financial time series data especially stock returns are mostly high-frequency data which means that stock returns are subject to fat-tailed distribution. It is well-known fact in finance literature that the stock returns mostly experience kurtosis higher than 3 [20, 21]. Kurtosis greater than 3 ascertains that stock returns are characterised by extreme returns than the normal distribution. Mittnik and Paolella [22] have argued that fat-tailed distribution density is important to model in the daily exchange rate of merging countries' currencies against dollar.

In this study we fill the gap by using normal distribution density (Gaussian) and non-normal distribution densities (Student's t-distribution and Generalized Error Distribution (GED)) to evaluate leverage effect in case of selected stock markets. In this discourse, we will explore whether change in distributional densities under ARCH, GARCH and TGARCH models leads to any substantial change in volatility and leverage effect. We will also explore the portfolio diversification opportunities in Eastern European countries and estimate the forecasts. We employ volatility model to test its ability to forecast and capture the volatility clustering, leptokurtosis and impact of negative vs positive stock returns (leverage effect) in financial time series data. We investigate the forecasting ability of ARCH, GARCH and TGARCH model with the use of normal and non-normal distributional densities.

DATA AND RESEARCH METHODOLOGY

This section discusses the data and methodology approach to estimate the leverage effect using TGARCH model and compares the three different densities under GARCH and TGARCH models.

Data

We selected six stock market indices daily data from Eastern European stock markets namely, Bulgaria (BSE SOFIX), Czech Republic (PX), Hungary (BUDAPEST SE as BUX index), Poland (WIG) Romania (BETI as BET index) and Russia (MOEX) from January 2020 to August 2020 by collecting data from websites, such as www.investing.com. We compute the returns of these six indices through following formula:

$$r_{it} = \ln\left(\frac{p_{it}}{p_{it-1}}\right)\cdot 100 \quad (1)$$

where r_{it} is the compounded returns of stock i at time t, p_{it} – current prices of stock i in t time and p_{it-1} – previous year prices of stock i in t time. Table 1 provides the descriptive statistics, test for normality and the presence of ARCH effect. It can be observed that all six countries exhibit negative mean returns. Trivedi et al. [23] pointed out that modelling the behaviour of European stock markets represents a current challenge of great interest. Hungary stock index is riskier followed by Poland and Russia as indicated by the unconditional standard deviation. The negative skewness estimates confirm that the distribution of all six countries is negatively skewed. The null hypothesis for skewness that conforms to a

Table 1

DESCRIPTIVE STATISTICS OF DAILY INDICES RETURNS						
Countries	**Bulgaria**	**Czech Republic**	**Hungary**	**Poland**	**Romania**	**Russia**
Mean	–0.1869	–0.1354	–0.1654	–0.0845	–0.0981	–0.0258
Median	–0.0787	–0.0406	–0.0389	0.0023	0.0814	0.1631
Standard Deviation	1.5075	1.9138	2.2391	2.1760	1.9271	1.9646
Max	3.9533	7.3691	5.6286	5.6337	5.9726	7.4349
Min	–10.8104	–8.1605	–12.2684	–13.5265	–10.0753	–8.6460
Skewness	–3.384	–0.8797	–1.3919	–1.7974	–1.2970	–0.7814
Kurtosis	23.869	7.9337	9.3687	12.7027	9.6812	8.9648
Jarque-Bera Test	0.000	0.000	0.000	0.000	0.000	0.000
ARCH (1), Chi2 > Prob	0.2436	0.3206	0.0111	0.0305	0.0063	0.2313
Observation	148	152	152	152	149	148

normal distribution with coefficients of zero has been rejected for all six indices. The returns for six indices also exhibit fat tail as seen in the significant kurtosis well above the normal value of 3. The higher value of Kurtosis, fat-tailed distribution density, indicates that Student's t-distribution or GED are more accurate distribution and produce better results than Gaussian distribution. Jarque-Bera test of normality shows the residuals are not normally distributed at 1 percent level of significance. Finally, Engle [8] LM test confirms the presence of ARCH effect in Bulgaria, Czech Republic and Russia whereas Hungary, Poland and Romania are not subject to ARCH effect. Hence, this supports the use of GARCH and TGARCH models for the countries where ARCH effect is significant.

Measuring the volatility through ARCH, GARCH and TGARCH model

Spulbar et al. [24] suggested that emerging stock markets reacts much more intense in case of positive or negative news impact compared to developed stock markets. It is also observed that large positive (negative) observations mostly appear in clusters in stock returns [25]. Thus, linear estimation techniques (OLS) are incapable of explaining the number of important features that are common the stock daily returns.

- *Leptokurtosis* – Stock daily returns experience fat-tailed distribution.
- *Volatility Clustering* – The tendency to stock returns volatility that appears in clusters in stock returns. For example – the large returns of stocks, either sign, are followed by large returns and small returns of stock, either sign, are expected to have small returns in the following period. One of the explanations to volatility clustering is that the arrival of information that creates volatility clustering in the stock returns.
- *Leverage effect* – the likelihood of volatility to increase more following the large dip in the prices, compared to the price rise of the magnitude.

The Autoregressive Conditional Heteroscedasticity model (ARCH)

Constant variance (homoscedasticity) is one of most important assumptions of classical regression model: $\text{var}(\mu_t) = \sigma^2(\mu_t)$, $\mu_t N(0, \sigma^2)$. A series with changing variance over time is characterized as heteroscedastic which is very likely in financial time series data. Such financial series require an estimator that does not assume that error term possesses constant variance and moreover, it should also ascertain that how error term variance evolves over time.

Another problem with time series financial data is volatility clustering, meaning that the period of high volatility is followed by higher volatility period and period of low volatility is characterized with period of lower volatility. Using ARCH model, the time series financial data with non-constant variance in error term can be parameterized. It is also necessary to define a conditional variance of error term μ_t in order to understand how ARCH model works. The conditional variance of μ_t is represented by σ^2 as follows:

$$\sigma_t^2 = \text{var}(\mu_t | \mu_{t-1}, \mu_{t-1} \ldots) = E \quad (2)$$

According to equation 2 a conditional variance of zero mean random variable μ_t that is normally distributed is equal to the conditional expected value of the square of μ_t. In such a situation ARCH model is as follows:

$$\sigma_t^2 = \alpha_0 + \alpha_1 + \mu_t^2 \quad (3)$$

Equation 5 is an ARCH (1) model which shows that conditional variance of error term σ_t^2 is influenced by its immediate previous square root value. However, it should be noted that equation 5 only ascertains the part of complete model because it does not have anything to say about conditional mean. The conditional mean equation, where dependent variable Y_t changes over time can take any form under ARCH model. The full ARCH model is as follows:

$$Y_t = \beta_1 + \beta_2 x_{2t} + \beta_3 x_{3t} + \beta_4 x_{4t} + \mu_t \quad (4)$$

$$\sigma_t^2 = \alpha_0 + \alpha_1 \mu_{t-1}^2 \quad (5)$$

where $\mu_t N(0, \sigma^2)$.

Equations 4 and 5 can also be expressed in general form where variance of an error term is influenced by *k* lags of square errors. This type of model is called ARCH(*k*).

$$Y_t = \beta_1 + \beta_2 x_{2t} + \beta_3 x_{3t} + \beta_4 x_{4t} + \mu_t \qquad (6)$$

$$\sigma_t^2 = \alpha_0 + \alpha_1 \mu_{t-1}^2 + \alpha_2 \mu_{t-2}^2 + \dots + \alpha_k \mu_{t-k}^2 \qquad (7)$$

where $\mu_t N(0, \sigma^2)$. σ_t^2 is a conditional variance where it have positive value (a negative variance at any time is meaningless) which mean that the variance regression must produce positive coefficients, for instance $\alpha_i \geq 0$, $(\forall)\ i = 0, 1, 2, \dots, k$. GARCH is the extension of ARCH(*k*) model.

The Generalized Introgressive Conditional Heteroscedastic Model (GARCH)

The GARCH model, developed by Bollerslev [9] and Taylor [26] estimate conditional variance that is influenced by it only previous lagged values. Following equation is an example of conditional variance.

$$\sigma_t^2 = \alpha_0 + \alpha_1 \mu_{t-1}^2 + \beta \sigma_{t-1}^2 \qquad (8)$$

Equation 8 is a GARCH (1,1) model where $\alpha_1 \mu_{t-1}^2$ express the information of volatility pertaining to previous period and variance during that period $\beta \sigma_{t-1}^2$. GARCH (1/1) model can also be written in a GARCH (*k, p*) form where conditional variance is influenced by *k* lags of squared errors and *p* lags of conditional variances.

$$\sigma_t^2 = \alpha_0 + \alpha_1 \mu_{t-1}^2 + \alpha_2 \mu_{t-2}^2 + \dots + \alpha_k \mu_{t-k}^2 + $$
$$+ \beta_1 \sigma_{t-1}^2 + \beta_2 \sigma_{t-2}^2 + \dots + \beta_p \sigma_{t-p}^2 \qquad (9)$$

Equation 10 can be rearranged as:

$$\sigma_t^2 = \alpha_0 + \sum_{i=1}^{k} \alpha_i \mu_{t-i}^2 + \sum_{j=1}^{p} \beta_j \sigma_{t-j}^2 \qquad (10)$$

GARH (1,1) model is mostly estimated and sufficient to estimate the evolution of volatility as GARH (1,1) model is as good as ARCH (2) and GARCH (*k, p*) is as good as ARCH (*k+p*) model [25].

The Threshold Generalized Introgressive Conditional Heteroscedastic Model (TGARCH)

The Threshold GARCH (TGARCH) model was presented by Glosten et al. [27] which is also called GJR-GARCH (after its proponents). This model is similar to simple GARCH model but adds an additional ARCH term which is conditional upon the direction of the past information or innovation. It is specified as follows:

$$\sigma_t^2 = \alpha_0 + \beta_1 \sigma_{t-1}^2 + \alpha_1 \mu_{t-1}^2 + \lambda_1 \mu_{t-1}^2 d_{t-1} \qquad (11)$$

$$d_t = \begin{cases} 1\ \mu_t < 0\ (\textit{Bad News}) \\ 0\ \mu_t \leq 0\ (\textit{Good News}) \end{cases}$$

Equation 11, λ_1 estimates the leverage effect and d_t is the dummy variable which present 1 if μ_t is negative. If stock returns are characterized with leverage effect, the value of λ_1 should be negatively significant.

Density distributions

The GARCH model use Maximum Likelihood Estimation (MLE) which assumes that error distribution is Gaussian (normally distributed), nevertheless, financial literature is evident that error is subject to non-normal distribution densities [6]. It is an of utmost importance to select the most appropriate distribution for error term during volatility modelling because it reduces the problem posed by skewness and kurtosis due to residuals of conditional heteroscedasticity. Hence, our study employs all three form of distributions, Gaussian, Students' t-distribution and Generalised Error Distribution and compare the results.

Gaussian

The Gaussian distribution, which is also called normal distribution, is most widely used distribution when estimating GARCH models. For a stochastic process, it is important the log-likelihood function.

Student T-Distribution

The log likelihood function for non-normal distribution as follows:

$$L_{stu-t} = \ln\left(\Gamma\left[\frac{v+1}{2}\right]\right) - \ln\left(\Gamma\frac{v}{2}\right) - \frac{1}{2}\ln\left(\pi[v-2]\right) -$$
$$- \frac{1}{2}\sum_{t-1}^{T}\left(\ln \sigma_t^2 + [1+v]\ln\left[1 + \frac{z_t^2}{v-2}\right]\right) \qquad (12)$$

where degree of freedom is "v", $2 < v = \infty$, and $\Gamma(.)$ is the gamma function.

Generalised Error Distribution (GED)

Asset pricing, option pricing, portfolio selection, VAR, skewness and Kurtosis are very important in applied finance field. The GED distribution represents a generalised form of the Gaussian that has a parametric kurtosis that is unbounded above and has special cases that are identical to the normal and property which controls the skewness. The log likelihood function is as follows:

$$L_{GED} = \sum_{t-1}\left(\ln\left[\frac{v}{\lambda_v}\right] - 0.5\left|\frac{z_t}{\lambda_v}\right| - [1 + v^{-1}]\ln 2 -\right.$$
$$\left. - \ln\Gamma\left[\frac{1}{v}\right] 0.5 \ln[\sigma_t^2]\right) \qquad (13)$$

where $\lambda_v = \sqrt{\Gamma}$.

EMPIRICAL RESULTS AND DISCUSSION

This section interprets the empirical results and provides insight into the estimations using GARCH and TGARCH models under three different distribution densities.

Table 2 reports the statistics pertaining to the use of asymmetric TGARCH model using normal Gaussian, normal distribution density, Student's t-distribution and generalized error distribution (GED), abnormal distribution densities, for six indices, Bulgaria, Czech Republic, and Poland where Arch effect is present as shown in table 1. Table 2 also provides diagnostic test by estimating the values of AIC and BIC (Akaike's information criterion and Bayesian information criterion) to compare the results of TGARCH

Table 2

ESTIMATED STATISTICS-COMPARATIVE DISTRIBUTION DENSITY THRESHOLD-GARCH MODEL									
Country	**Bulgaria**			**Czech Republic**			**Poland**		
Parameter	Gaussian	Student's t-distribution	GED	Gaussian	Student's t-distribution	GED	Gaussian	Student's t-distribution	GED
	–0.0184	0.1355**	0.0429	–1.498**	–0.557	-0.998	0.3496	0.4396	0.3997
	0.509***	0.1267	03873	1.2903***	0.935***	1.1055***	0.4948***	0.4311***	0.4635**
	2.463***	1.912***	1.989***	0.2098**	0.3802**	0.2889*	1.0571***	1.032***	0.9331***
	–2.081***	–1.656***	–1.669***	–0.1473	–0.309*	–0.2109	–0.9959***	–0.9458***	–0.5313***
AIC	471.27	387.97	481.43	600.13	581.54	582.96	560.85	555.89	555.33
BIC	486.25	402.96	433.42	615.25	596.66	598.08	575.84	570.78	570.32
Q1	0.0041	0.0041	0.0041	2.2947	2.2947	2.2947	0.6771	0.6771	0.6771

Note: Table 2 shows the estimate of ARCH, GARCH and TGARCH model under normal (Gaussian)and non-normal distribution (Student t-distribution and GED) along with model selection criteria (AIC and BIC). Further table 2 shows autocorrelation in residuals on lag one pertaining to each distribution.

model under normal and non-normal distribution densities. The evidence shows that ARCH effect α_1 is significant at 1% level across in all six countries under normal and non-normal distribution density. This implies that past stock returns information can influence the current stock returns across all three countries. Analogously, the coefficient of GARCH effect β_1 is also significant at 1% for all three countries, except for Bulgaria under non-normal distributions, under normal and non-normal distribution densities. Positive significant β_1 states that past volatility of stock returns influences the present-day volatility of stock returns.

Moreover, the impact of news $\lambda_1 \neq 0$ is significant in Bulgaria and Poland that indicates the previous day negative stock returns (bad news) have greater impact of present-day stock returns volatility as compared to positive volatility (good news). On the other hand, $\lambda_1 = 0$ for Czech Republic under normal and abnormal distribution densities establishes the insignificance of leverage effect in Bulgaria and Poland. The leverage effect λ_1 is more profound in the case of Bulgaria than Poland. Under normal distribution densities are similar to Gaussian distribution. However, magnitude further falls when apply non-normal distribution. Thus, results indicate that in Bulgaria and Poland experience the leverage effect, where bad news does generate higher volatility than good news. The model selection criteria AIC and BIC suggest that non-normal distribution student t-distribution and GED produce more reliable results for Bulgaria and Poland, respectively.

CONCLUSIONS

The aim of the study is to evaluate and forecast the performance of asymmetric volatility (leverage effect) through TGARCH model under normal and non-normal distribution densities and then second, to explore the possible opportunities for portfolio diversification in African countries, South Africa, Nigeria and Egypt. Our study contributes to the existing literature as follows, first we select emerging stock market from Africa where such study has not been done yet. Second, we model asymmetric volatility of individual stock market as well as diversified portfolio and capture time series feature of kurtosis, skewness and volatility clustering. Third, we introduce the comparison among normal and non-normal distribution density of asymmetric model across all three countries.

Our results show that all six countries have leptokurtic (fat tail) and negative skewed distribution. TGARCH model for individual country shows that past stock returns (volatility) influence the current stock returns (volatility) across all countries under all distribution densities, whereas, leverage effect is only present in Bulgaria and Poland and negative returns do generate higher volatility as compare the positive returns. On the other hand, leverage effect is insignificant in Czech Republic. The diagnostic tests show AIC and BIC produce lowest estimates under student t-distribution for Bulgaria and GED for Poland. This infers that non-normal distribution produces better and reliable estimates for all countries.

The presence of ARCH effect suggests that investors in these markets should seek more information about volatility before allocating their funds for portfolio investment, fund managers and/or investors should go beyond the mean-variance analysis in regards to these markets and look into information about volatility, information asymmetry, correlation, but also skewness and kurtosis which measures the peakedness or flatness of

the distribution, i.e. leptokurtic distribution [28]. Cost of equity capital is expected to be high in these markets due to compensation for additional ARCH effect which places additional burden on indigenous in all six countries.

Finally, there are areas where further studies might be useful. We recommend that future research be directed at modelling and forecasting realised volatility from intra-day trading data. We will also consider the fact that COVID-19 pandemic has spread globally and affected economies around the world since January 2020 [29]. Furthermore, future research may also consider exploring a variety of models including other conditional variance models such as APARCH and long memory models such as FIEGARCH, FIAPARCH and CGARCH in order to allow a superior insight into the dynamics of these market series. Lastly the study should be replicated in other European countries in order to shed more light on the economic and structural variables that drive volatility in Eastern European stock markets.

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The effect of raw material combination, yarn count, fabric structure and loop length on the thermal properties of Eri silk bi-layer knitted fabrics

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ABSTRACT – REZUMAT

The effect of raw material combination, yarn count, fabric structure and loop length on the thermal properties of Eri silk bi-layer knitted fabrics

Eri silk is one of the wild silk varieties which are mainly available in the north-eastern areas of India. It exhibits good mechanical and thermal resistance properties. In this concern, the present study focused to develop a bi-layer knitted structure made from Eri silk yarn as one side(next to skin) and on another side bamboo yarn knitted fabric. Similarly, Tencel knitted fabric was used instead of bamboo. Twenty-four bi-layer knitted fabrics were developed and then analysed for its thermal comfort property. The air permeability, and wick-ability were found to be higher and the thermal resistance was found to be higher for bi-layer plated interlocked knitted fabric made out of Eri silk compared to bamboo and Tencel.

Keywords: *bamboo, Eri silk, Tencel, thermal resistance, thermal conductivity*

Influența combinației de materii prime, finețea firelor, structura tricotului și lungimea buclei asupra proprietăților termice ale tricoturilor dublu strat din mătase Eri

Mătasea Eri reprezintă unul dintre tipurile de mătase sălbatică disponibile în principal în zonele de nord-est ale Indiei. Aceasta prezintă proprietăți de rezistență mecanică și termică. În acest scop, studiul de față s-a concentrat asupra dezvoltării unei structuri tricotate dublu strat, realizată din fire din mătase Eri, pe o parte (în contact cu pielea) și pe cealaltă parte, din fire din bambus. În mod similar, a fost utilizat Tencel-ul în locul bambusului. Au fost dezvoltate 24 de tricoturi dublu strat și apoi analizate din punctul de vedere al proprietăților de confort termic. S-a constatat că permeabilitatea la aer, capacitatea de absorbție și rezistența termică sunt mai ridicate pentru tricoturile interlock dublu strat din mătase Eri, comparativ cu bambusul și Tencel-ul.

Cuvinte-cheie*: bambus, mătase Eri, Tencel, rezistență termică, conductivitate termică*

INTRODUCTION

The main purpose of clothing is to maintain normal body temperature and to protect the body against varying external conditions. Thermal insulation is defined as the effectiveness of a fabric in maintaining a normal temperature of a human body under equilibrium conditions. Thermal insulation of fabrics depends largely on the thickness of the fabric and it is independent of the fibre material [1]. The capillary structure and surface properties of yarns are linked to heat transfer [2].The thermal conductivity decreases with increasing material density [1, 3]. The entire three thermal resistant properties transfer the heat from the human body to an environment [4]. The performance of layered fabric in thermo-physiological regulation is better than for a single layer structure [5–9].

Hydrophilic fibres like viscose can absorb liquids into the fibre structure thus preventing the spread of liquids, including sweat, along the fabrics [10]. The thermal resistance of multi-layered fabrics increases with increase of mass per unit area [11]. The moisture content of one layer is not only dependent on its material properties but also on the comfort properties of neighbouring layer [10]. Blending wool with polyester or wool with bamboo has improved comfort properties of the fabrics in comparison to 100% wool and 100% bamboo fabrics [12]. The double layer knitted structures were developed where the inner (contact) layer is made of polypropylene yarns and the outer layer is made of cotton or viscose yarns [13]. Due to various micro-gaps and micro-holes in cross-section of bamboo fibre, it has better wicking ability than modal yarn [14]. Eri silk has better softness compared to other silk materials. It also possesses better thermal insulating properties than wool and higher comfort than cotton and mulberry silk [15–17]. Utilization of knitted fabrics for functional garments is emerging, as it provides better comfort, good extensibility, shape retention to the body and soft feel, as well as being of lightweight, with wrinkle resistance and ease of care. Knitted structures provide good thermal and moisture management properties for active applications [18].

Eri silk has unique thermal, physical and moisture management characteristics when compared to other commercial silk varieties [19–21]. Eri silk knitted structures with coarser yarn and tighter stitch length gives higher thermal absorption, thereby providing cool feeling on initial skin contact. Eri silk knitted fabric has good comfort properties, which confirms its suitability for light winter active applications. It is expected that knitted fabric produced from these yarns has good demand in the international market because Eri silk fabric is produced by non-violent methods (without killing silk worm) and has better dimensional, thermal and wicking properties [15]. Eri fibre possesses unique dual nature with excellent strength and softness properties of silk fibre coupled with warmth properties similar to wool fibres [22]. Eri silk is known for its excellent strength, soft-smooth feel, comfort and lustre besides having good thermal behaviour [23]. The Eri fabric is an excellent material for shirting, suiting, bed spreads, curtains and other furnishings and it possesses excellent dimensional and thermo-physiological comfort properties [24]. The thermal conductivity of knitted fabrics reduces as the proportion of bamboo fibre increases in the thermal radioactive properties of penguin down and yarn [25]. The bamboo and cotton double knitted fabrics have the least water vapour and thermal resistance values when compared to other bi-layer fabrics [26].

MATERIALS AND METHODS

Yarn selection

Eri silk yarn was procured from Eco Tasar silk Pvt Ltd, New Delhi, India. Bamboo, Tencel and micro denier polyester were procured from Ganapathi Chettiar yarn agency, Tirupur, Tamilnadu, India. The physical parameters of Eri silk yarn, bamboo, Tencel samples yarn count was measured according to American Society for Testing and Materials D1907-01 standard and single yarn strength was evaluated by using Instron strength tester as per American Society for Testing and Materials D2256 standard. The evenness parameters were measured as per American Society for Testing and Materials D1425 M: 14 method by using USTER evenness tester UT 5. Table 1 shows the various yarn characteristics.

Fabric production

In this research an idea has been made to analyse thermal properties of Eri silk bi-layer knitted fabrics blended with bamboo and Tencel yarns. Eri silk yarns and bamboo yarns were selected on either side for constructing bi-layer knitted fabrics and bamboo was replaced by Tencel yarn for conducting the investigation:

- Eri silk and bamboo yarns were used to make plated interlock, mini flat rib and flat back rib knitted fabric.
- Eri silk and Tencel yarns were used to make plated interlock, mini flat rib and flat back rib knitted fabric.

The bi-layer knitted structures were prepared using 16.7 Tex and 14.3 Tex for Eri silk, 19.7 Tex and 14.8 Tex for bamboo and Tencel. All samples were produced in circular multi-track weft knitting machine (Keumyong knitting machine) with 34 inches diameter, 82 feeders, 18 gauge and 3840 needles. In this experimental work, the bi-layer fabric was developed in which the outer layer is made of bamboo and Tencel that is regenerated cellulosic fibres. The inner (next to skin) layer is made up of Eri silk fibre. The yarn which has to form an outer layer is fed into the dial needle and as an inner layer is fed into the cylinder needle. Plated interlock, mini flat rib and flat back rib knitted fabrics were produced using two different yarn counts and two different loop lengths. The visual appearances of the stitch diagrams are mentioned in figure 1.

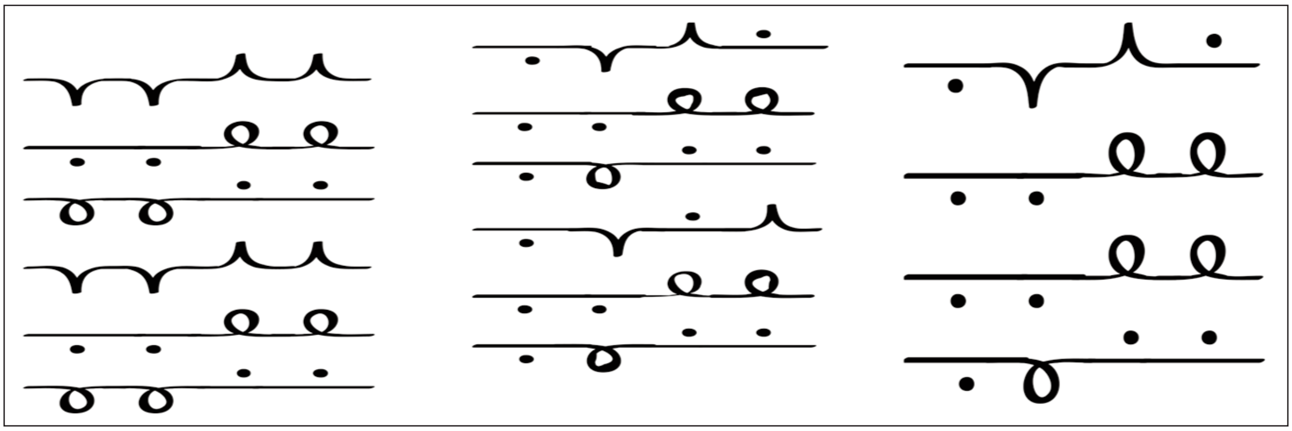
TEST RESULTS AND DISCUSSION

The fabric produced with different count of yarns, structures and loop length combinations were inves-

Table 1

YARN CHARACTERISTICS

Test particulars	Eri silk-16.7 Tex	Eri silk-14.3 Tex	Micro denier polyester-155 denier (binding yarn)	Bamboo-14.8 Tex	Bamboo-19.7 Tex	Tencel-14.8 Tex	Tencel-19.7 Tex
Average count in Tex	18.00	14.99	17.33	15.27	19.67	14.00	19.61
Count CV%	5.37	4.11	0.42	1.07	0.7	1.83	0.79
Strength	66.7	116.1	170	60.6	88.8	80.3	128.2
Strength CV%	9.93	3.54	2.56	2.57	8.9	6.67	3.41
CSP – Count Strength Product	2186	4568	5786	2340	2662	3384	3857
Unevenness U%	18.86	9.79	1.34	10.04	9.25	10.62	9.63
Thin/1000 m (–50%)	493	0	0.5	0.5	0	12	1
Thick/1000 m (+50%)	1751	61	3	14	6	24.5	16
Neps/1000 m (+200 %)	2038	32	5	11.5	10.5	35.5	22.5
IPI – Total Imperfections	4282	93	9	26	17	72	40
Hairiness	4.39	4.84	7.3	11.5	6.06	5.69	8.02
TPI – Twist per inch	22.50	23.40	33.10	21.30	18.80	22.50	17.60



a b c

Fig. 1. Plated interlock, mini flat back rib and flat back rib structures stitch diagrams: *a* – plated interlock, technical graph (connecting with more tuck points); *b* – mini flat back rib – Technical graph (connecting with partial tuck points); *c* – flat back rib – Technical graph (no connecting)

tigated for aerial density, thickness, air permeability, thermal conductivity, thermal resistance and wicking ability using standard testing methods.

Physical properties of Eri silk bi-layer knitted fabrics

Shirley thickness gauge machine is used to measure the fabric thickness in mm at different place of fabric, and areal density in g/m^2 and air permeability in cm^3/s/cm^2 of the samples. The areal density of a two-dimensional object is calculated as the mass per unit area and is expressed in Grams per Square Meter (GSM). The air permeability is measured by utilizing American Society for Testing and Materials D737 standard [27]. Physical characteristics are determined and mentioned in the tables 2 and 3.

Areal density

The results show that the areal density of the sample S1EB is found to be high among all the samples. It's confirmed that the areal density of the fabric is influenced by the structure and loop length of fabric.

A study between the yarn count and fabric areal density displays that the fabric areal density of 30 s yarn count is higher than 40 s. This highlights that the fabric areal density of 0.3 cm loop length is better than the 0.4 cm loop length. When the raw material combination and fabric areal density were studied, Eri silk with bamboo and Eri silk with Tencel showed only slight variation in the fabric areal density. The fabric areal density was found to be superior for the plated interlock structure when compared to the mini flat back rib and flat back rib structures.

Thickness

The thickness results of all 24 samples showed slight variation and this was due to the fabric production using two different counts and two different loop lengths.

A comparison between the yarn count and thickness indicates that 30 s yarn count is better than 40 s yarn count. Very slight variations were found among 0.3 cm and 0.4 cm loop lengths when the loop length and thickness were studied. As the raw material combination and thickness are taken up for study, Eri silk with bamboo and Eri silk with Tencel were more or less the same. In very few cases Eri silk with Tencel was superior and in the rest Eri silk with bamboo was good. A study on the fabric structure and thickness revealed that the plated interlock structure possessed higher thickness followed by flat back rib structure. The mini flat back rib had the least thickness

Air permeability

The results of air permeability of fabric samples show that the samples S18ET, S24ET and S22ET have more air permeability when compared to all other 21 samples. Based on the result it is considered that the tightness factor and fabric structure had an influence on air permeability of the fabric samples.

A comparison between the yarn count and air permeability showed that the 40 s count had a higher air permeability than the 30 s count. The air permeability for 0.3 cm loop length was higher than that of 0.4 cm loop length. Results showed that Eri silk with Tencel exhibited higher air permeability than Eri silk with bamboo. A study between the fabric structure and air permeability insisted that the flat back rib structure and mini flat back rib structure had at times the same air permeability and at times the flat back rib had higher air permeability. The plated interlock had the least air permeability because of more tuck points in plated interlock structure.

Thermal comfort properties of Eri bi-layer knitted fabrics

NETZSCH HFM 436 testing instrument was used to measure the thermal properties of the fabrics, such as thermal conductivity and thermal resistance. The thermal resistance of clothing as a set of textile materials depends on the thickness and porosity of particular layer of the fabrics. The sample is kept between two plates (one is hot and another is cold) provided in the instrument, according to ISO 8301-1991/1: 2010 standards.

Table 2

SAMPLE CODE, YARN COUNT, FABRIC STRUCTURE, LOOP LENGTH AND STITCH DENSITY OF SAMPLES					
Sample no.	**Sample code**	**Yarn count**	**Fabric structure**	**Loop length (cm)**	**Stitch density (loops/cm^2)**
1	S1EB	Eri silk – 16.7 Tex Bamboo – 19.7 Tex	Plated interlock	Inner – 0.31 Outer – 0.31	Inner – 1053 Outer –1053
2	S2ET	Eri silk – 16.7 Tex Tencel – 19.7 Tex	Plated interlock	Inner – 0.3 Outer – 0.31	Inner – 1000 Outer – 1000
3	S3EB	Eri silk – 16.7 Tex Bamboo – 19.7 Tex	Plated interlock	Inner – 0.34 Outer – 0.34	Inner – 864 Outer – 864
4	S4ET	Eri silk – 16.7 Tex Tencel –19.7 Tex	Plated interlock	Inner – 0.32 Outer – 0.33	Inner – 875 Outer – 875
5	S5EB	Eri silk – 16.7 Tex Bamboo – 19.7 Tex	Mini flat back rib	Inner – 0.31 Outer – 0.4	Inner – 988 Outer – 532
6	S6ET	Eri silk – 16.7 Tex Tencel – 19.7 Tex	Mini flat back rib	Inner – 0.31 Outer – 0.39	Inner – 1036 Outer – 518
7	S7EB	Eri silk – 16.7 Tex Bamboo – 19.7 Tex	Mini flat back rib	Inner – 0.30 Outer – 0.40	Inner – 1118 Outer – 559
8	S8ET	Eri silk – 16.7 Tex Tencel – 19.7 Tex	Mini flat back rib	Inner – 0.30 Outer – 0.36	Inner – 1134 Outer – 588
9	S9EB	Eri silk – 16.7 Tex Bamboo – 19.7 Tex	Flat back rib	Inner – 0.30 Outer – 0.38	Inner – 1456 Outer – 354
10	S10ET	Eri silk – 16.7 Tex Tencel –19.7 Tex	Flat back rib	Inner – 0.29 Outer – 0.43	Inner – 1377 Outer – 350
11	S11EB	Eri silk – 16.7 Tex Bamboo – 19.7 Tex	Flat back rib	Inner – 0.32 Outer – 0.40	Inner – 1300 Outer – 312
12	S12ET	Eri silk – 16.7 Tex Tencel –19.7 Tex	Flat back rib	Inner – 0.31 Outer – 0.45	Inner – 1225 Outer – 299
13	S13EB	Eri silk – 14.3 Tex Bamboo – 14.8 Tex	Plated interlock	Inner – 0.31 Outer – 0.31	Inner – 1040 Outer – 1040
14	S14ET	Eri silk – 14.3 Tex Tencel – 14.8 Tex	Plated interlock	Inner – 0.33 Outer – 0.33	Inner – 884 Outer – 884
15	S15EB	Eri silk – 14.3 Tex Bamboo – 14.8 Tex	Plated interlock	Inner – 0.33 Outer – 0.33	Inner – 840 Outer – 840
16	S16ET	Eri silk – 14.3 Tex Tencel – 14.8 Tex	Plated interlock	Inner – 0.34 Outer – 0.34	Inner – 816 Outer – 816
17	S17EB	Eri silk – 14.3 Tex Bamboo – 14.8 Tex	Mini flat back rib	Inner – 0.31 Outer – 0.42	Inner – 980 Outer – 490
18	S18ET	Eri silk – 14.3 Tex Tencel – 14.8 Tex	Mini flat back rib	Inner – 0.3 Outer – 0.4	Inner – 980 Outer – 490
19	S19EB	Eri silk – 14.3 Tex Bamboo – 14.8 Tex	Mini flat back rib	Inner – 0.29 Outer – 0.37	Inner – 1120 Outer – 560
20	S20ET	Eri silk – 14.3 Tex Tencel – 14.8 Tex	Mini flat back rib	Inner – 0.3 Outer – 0.40	Inner – 1320 Outer – 660
21	S21EB	Eri silk – 14.3 Tex Bamboo – 14.8 Tex	Flat back rib	Inner – 0.27 Outer – 0.47	Inner – 1410 Outer – 360
22	S22ET	Eri silk – 14.3 Tex Tencel – 14.8 Tex	Flat back rib	Inner – 0.30 Outer – 0.48	Inner – 1400 Outer – 350
23	S23EB	Eri silk – 14.3 Tex Bamboo – 14.8 Tex	Flat back rib	Inner – 0.29 Outer – 0.49	Inner – 1260 Outer – 308
24	S24ET	Eri silk – 14.3 Tex Tencel – 14.8 Tex	Flat back rib	Inner – 0.32 Outer – 0.49	Inner – 1248 Outer – 286

Thermal conductivity is a property of fabrics that expresses the heat flux that will flow through the fabric if a certain temperature gradient exists over the material [28]. The thermal conductivity and thermal resistances of the fabric samples are mentioned in table 3.

Thermal conductivity

Based on the results it is understood that there are significant variations in the fabric thermal conductivity and it depends on the fabric structure, count of yarn, loop length and density of the fabric. The sample S1EB has more thermal conductivity compared to all other 23 samples.

Table 3

FABRIC AREAL DENSITY, THICKNESS, AIR PERMEABILITY, THERMAL CONDUCTIVITY AND THERMAL RESISTANCES OF THE FABRIC SAMPLES						
Sample no.	**Sample code**	**Fabric areal density (G/M^2)**	**Thickness (mm)**	**Air permeability ($cm^3/s/cm^2$)**	**Thermal conductivity ($W/M\text{-}k*10^{-3}$)**	**Thermal resistance ($M^2*k/w*10^{-3}$)**
1	S1EB	334	1.19	35.9	15.87	57.35
2	S2ET	332	1.26	42.4	11.55	80.01
3	S3EB	310	1.28	55.6	14.52	52.47
4	S4ET	293	1.22	54.4	10.56	73.20
5	S5EB	231	1.07	67.4	13.15	55.80
6	S6ET	228	1.11	108.0	12.92	55.74
7	S7EB	250	1.05	84.8	11.83	50.22
8	S8ET	237	1.01	98.6	11.62	50.16
9	S9EB	239	1.18	97.5	13.19	59.90
10	S10ET	233	1.22	108.0	13.00	59.21
11	S11EB	245	1.19	99.5	11.87	53.91
12	S12ET	238	1.21	107.0	11.70	53.28
13	S13EB	254	0.98	47.6	13.07	55.12
14	S14ET	237	1.05	59.8	12.40	54.62
15	S15EB	215	0.98	71.8	11.56	48.78
16	S16ET	229	1.07	98.9	10.97	48.33
17	S17EB	190	1.08	122.0	12.13	55.23
18	S18ET	163	0.98	166.0	10.35	55.06
19	S19EB	179	1.01	134.0	10.79	49.15
20	S20ET	205	1.07	108.0	9.21	49.00
21	S21EB	180	1.04	128.0	10.28	55.46
22	S22ET	158	0.96	167.0	9.45	55.01
23	S23EB	190	1.05	134.0	9.09	49.08
24	S24ET	162	0.98	160.0	8.36	48.68

Note: E – Eri silk yarn, B – Bamboo yarn, T – Tencel yarn.

The comparison between yarn count and thermal conductivity displayed that 30 s yarn count had superior thermal conductivity than the 40 s count. The thermal conductivity of 0.3 cm loop length was higher than the 0.4 cm loop length. Eri silk with bamboo possessed higher thermal conductivity when compared with that of Eri silk with Tencel. The thermal conductivity of the plated interlock structure is higher when compared to mini flat back rib structure and flat back rib structure.

Thermal resistance

The thermal resistance of the sample S2ET was very high when compared to all other samples. The combination of Eri silk and Tencel yarn with different structures have an influence on thermal resistance.

A study on the yarn count and thermal resistance indicated that the 30 s yarn count had higher thermal resistance than the 40 s yarn count. It was observed that the thermal resistance of 0.3 cm loop length was better than 0.4 cm loop length. A study on the raw material combination and thermal resistance showed that Eri silk with Tencel had higher resistance for some samples and in the rest of the samples the thermal resistance was the same for both the combinations. Studies on the fabric structure and thermal resistance showed that the plated interlock structure had higher thermal resistance in few cases and the same thermal resistance in most of the cases.

Wicking behaviour of Eri bi-layer knitted fabrics

The moisture and thermal properties were affected by the fabrics wetting and wicking characteristics as in table 4 [29–32]. The specimens were cut along the wale-wise and course-wise directions (250 mm × 30 mm), which suspended vertically with its bottom edge of 5 mm immersed in a reservoir of distilled water. The wicking heights were measured and recorded at regular intervals for 10 minutes to evaluate the wicking ability.

Wicking behaviour (Course wise)

The results show that the fabric sample S18ET has highest level of 16 cm wicking ability course wise for 10 minutes of time interval.

A comparison between the yarn count and course wise vertical wicking showed that the vertical wicking was maximum for 40 s count-10 minutes. A study between the loop length and course wise vertical

Table 4

WICKING BBEHAVIOUR OF FABRIC SAMPLES									
Sample no.	Sample code	Course wise (cm)				Wales wise (cm)			
		1 min	3 min	5 min	10 min	1 min	3 min	5 min	10 min
1	S1EB	4.7	7.0	8.5	10.1	6.1	8.2	9.9	12.0
2	S2ET	4.6	6.5	7.8	9.8	6.0	7.2	9.0	10.9
3	S3EB	4.7	7.0	8.4	10.2	5.7	8.5	10.4	12.4
4	S4ET	3.2	4.5	6.6	8.2	5.0	6.7	8.9	10.4
5	S5EB	5.8	8.3	10.1	11.6	5.2	7.0	8.9	10.1
6	S6ET	4.2	6.4	7.6	9.2	4.2	6.4	7.5	8.8
7	S7EB	7.0	9.2	10.3	12.7	7.2	9.5	10.5	12.4
8	S8ET	6.8	9.0	10.3	12.5	6.5	8.8	9.8	12.0
9	S9EB	4.9	7.0	8.8	10.8	5.4	7.2	9.2	11.0
10	S10ET	5.9	7.0	8.2	9.7	6.9	7.8	10.0	12.8
11	S11EB	5.8	7.8	9.3	11.9	6.3	8.0	9.8	12.4
12	S12ET	6.4	7.9	9.2	11.1	7.1	9.1	10.5	12.8
13	S13EB	5.3	7.7	9.5	12.8	6.1	8.6	10.8	13.9
14	S14ET	7.2	10.0	12.1	14.4	6.8	9.2	11.0	13.6
15	S15EB	5.4	7.7	10.6	12.8	5.6	7.3	10.2	12.3
16	S16ET	4.0	6.4	8.4	11.8	4.4	6.5	8.8	12.2
17	S17EB	7.0	9.7	11.2	13.8	5.7	8.4	10.1	12.2
18	S18ET	7.2	9.8	13.0	16.1	5.4	8.6	12.2	15.3
19	S19EB	6.1	10.0	12.2	14.6	5.0	8.0	10.5	13.0
20	S20ET	6.4	8.4	10.2	12.5	5.8	7.9	9.0	11.4
21	S21EB	5.5	8.9	10.7	13.2	6.0	9.4	11.1	13.6
22	S22ET	6.7	9.0	11.5	14.5	6.0	8.5	10.9	13.7
23	S23EB	5.8	7.7	9.5	11.1	5.3	7.3	9.9	11.4
24	S24ET	6.8	9.4	11.5	14.0	6.0	9.0	10.7	13.2

Note: E – Eri silk yarn, B – Bamboo yarn, T – Tencel yarn.

wicking showed that the vertical wicking was at maximum for 0.3 cm loop length-10 minutes and then it was noticed high in 0.4 cm loop length-10 minutes. The raw material combination and course wise vertical wicking clearly showed that Eri silk with Tencel combination 10 minutes possessed higher vertical wicking in few samples and in the rest of the samples Eri silk with bamboo combination-10 minutes had the highest vertical wicking. The course wise vertical wicking was the highest in the mini flat back rib-10 minutes.

Wicking behaviour (Wales wise)

The results show that the fabric sample S18ET has highest level of 15 cm wicking ability wales wise for 10 minutes of time interval.

The vertical wicking wales wise was observed to be highest for 40 s count-10 minutes. A study between the loop length and vertical wicking emphasized that the vertical wicking was highest in 0.3 cm loop length-10 minutes and then it was better in 0.4 cm loop length-10 minutes. The raw material combination and wales wise vertical wicking study showed that the Eri silk with Tencel combination-10 minutes had highest vertical wicking. Eri silk with bamboo combination-10 minutes had the highest vertical wicking. A study between the fabric structure and wales wise vertical wicking showed that the vertical wicking was highest in mini flat back rib-10 minutes and then in flat back rib-10 minutes.

Effect of raw material combination

The effect of different raw material on fabric areal density, air permeability thermal conductivity and thermal resistance has been studied and recorded. The areal density of fabric which is manufactured by Eri silk and bamboo yarn gains more areal density as the combination of Eri silk and Tencel gained less. The air permeability of the fabric made using Eri silk and Tencel is more as compared to the fabric made using Eri silk and bamboo.

Effect of yarn count combination

The effect of two different yarn counts of Eri silk, bamboo and Tencel on fabric areal density, air permeability thermal conductivity and thermal resistance has been studied and recorded. The fabric made with Eri silk-16.7 Tex, bamboo/Tencel-19.7 Tex yarns have good areal density when compared to the fabrics made with Eri silk-14.3 Tex, bamboo/Tencel-14.8 Tex yarns. The air permeability of the fabric produced using Eri silk-14.3 Tex, bamboo/Tencel-14.8 Tex yarns have better results than the fabrics made of Eri silk-14.3 Tex, bamboo/Tencel-14.8 Tex yarn. Thermal conductivity of fabric manufactured using Eri silk-16.7 Tex, bamboo/Tencel-19.7 Tex yarns are greater than the other fabrics made with Eri silk-14.3 Tex, bamboo/Tencel-14.8 Tex yarn. The resistance of the fabrics made with Eri silk-14.3 Tex, bamboo/Tencel-14.8 Tex yarn are less as compared to the fabrics made with Eri silk-16.7 Tex, bamboo/Tencel-19.7 Tex yarns.

Effect of fabric structure combination

The effect of fabric structures such as plated interlock, mini flat back rib and flat back rib on the fabric areal density, air permeability, thermal conductivity and thermal resistance has been studied and recorded. Based on the results the fabric areal density, thermal conductivity thermal resistance of the fabric knitted using plated interlock structure were more when compared to mini flat back rib and flat back rib structured fabrics. The air permeability of plated interlock structure fabric was less when compared to mini flat back rib and flat back rib structured fabrics.

Effect of loop length combination

The effect of two different loop lengths such as 0.3 cm and 0.4 cm on the fabric areal density, air permeability, thermal conductivity and thermal resistance has been studied and recorded. The results show that the areal density and thermal conductivity of fabrics produced using the loop length of 0.3 cm are more when compared to the fabrics produced using the loop length of 0.4 cm. The air permeability and thermal resistance of the fabric made using 0.4 cm are higher than that of the fabrics made using 0.3 cm loop length.

REGRESSION ANALYSIS

A relationship between the fabric areal density and air permeability was studied. The trend of the linear line clearly indicates the change in air permeability. The R^2 value (0.8001) shows that the change is great for the fit. The change in the fabric areal density is responsible for the variations in the air permeability. The 80% change in the air permeability is due to changes in the fabric areal density (table 5).

The relationship between fabric areal density and thermal conductivity of Eri silk bilayer knitted fabrics were plotted for regression. The R^2 value (0.4744) indicates that the fit is slightly less. The 47% change in the thermal conductivity is due to changes in the fabric areal density.

A relationship between fabric areal density and thermal resistance of Eri silk bilayer knitted fabrics was studied. It was observed from the graph that the R^2 value (0.3178) exhibited a very low fit. Hence the thermal resistance with respect to the fabric areal density is low. The 31% change in the thermal resistance is due to changes in the fabric areal density.

Table 5

REGRESSION RELATIONSHIP		
Sample no.	**Regression relationship**	**R^2 value**
1	Relationship between fabric areal density and air permeability	0.8001
2	Relationship between fabric areal density and thermal conductivity	0.4744
3	Relationship between fabric areal density and thermal resistance	0.3178
4	Relationship between thickness and air permeability	0.2626
5	Relationship between thickness and thermal conductivity	0.2599
6	Relationship between thickness and thermal resistance	0.3339
7	Relationship between stitch density and air permeability	0.2604
8	Relationship between stitch density and thermal conductivity	0.0869
9	Relationship between stitch density and thermal resistance	0.0118

The thickness and air permeability of Eri silk bilayer knitted fabrics was observed and the fit for regression was plotted on the graph. On observing the R^2 value (0.2626) it is concluded that air permeability with respect to fabric areal density is very low. The 26% change in the air permeability is due to changes in the fabric thickness.

A relationship between thickness and thermal conductivity of Eri silk bilayer knitted fabrics was interpreted. The R^2 value (0.2599) gave a clear picture indicating that the fit between both is very less. The thickness is responsible for the same. The 25% change in the thermal conductivity is due to changes in the fabric thickness.

The thermal resistance for Eri silk bilayer knitted fabrics with respect to thickness was studied. The regression fit plotted for the graph showed that the R^2 value (0.3339) is slightly less. Hence the thermal resistance is affected due to its thickness. The 33% change in the thermal resistance is due to changes in the fabric thickness.

The relationship between the stitch density and air permeability of Eri silk bi layer knitted fabrics was interpreted. The results were plotted for the regression fit on the graph. The interpreted R^2 value (0.2604) mentioned that the fit possessed a very less regression value. The 26% change in the air permeability is due to changes in the fabric stitch density.

A study between the stitch density and thermal conductivity was taken up and the results were fitted for regression. The obtained R^2 value (0.0869) showed that regressive fit is very low. Hence the thermal conductivity is influenced by stitch density. The 8% change in the thermal conductivity is due to changes in the fabric stitch density.

The relationship between the thermal resistance and stitch density was studied and the regressive fit was done. The acquired R^2 value (0.0118) proved the regressive fit to be very less. Thus thermal resistance is found to be influenced by stitch density. The 1% change in the thermal resistance is due to changes in the fabric stitch density.

CONCLUSION

Loop length and fabric structure has significant influence on the fabric physical properties such as fabric areal density, thickness and air permeability. Fabric samples of S18ET, S24ET and S22ET has higher air transmission rate, due to openness created by fabric structures. The air permeability of the bi-layer fabric increases when the thickness of fabric decreases with more openness in the fabric. The Eri silk-bamboo bi-layered fabrics has better thermal resistance than equivalent Eri-Tencel fabrics, due to high areal density as well as thermal insulation properties of materials. The wicking characteristics of the bi-layer fabrics were highly influenced by thickness. It is concluded from the study that the bi-layer Eri silk with bamboo has good thermal comfort property than Tencel layered fabrics, besides layered fabrics with more tuck-points provides better thermal comfort properties.

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Textile fibres in product design

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ABSTRACT – REZUMAT

Textile fibres in product design

High-performance fibres, especially carbon and glass fibres are used typically in many industries due of their performance. In addition to being widely used in industry, these fibres have attracted the attention of designers in recent years. In this research, a selection of innovative products that have received awards in international design competitions such as RedDot and IF and the use of carbon and glass fibres have been examined.

Research topics and objectives in the textile engineering literature include fibre production and performance analyses, but there are limited studies on their use and their impact in daily life. In this research, the use of high-performance fibres designed in innovative consumer products will be demonstrated to provide information on how these fibres meet everyday people as consumers to improve their lives. This research also aims to create common studying areas for two different disciplines.

***Keywords:** glass fibre, carbon fibre, industrial product design, material selection, interdisciplinary*

Fibrele textile în proiectarea produselor

Fibrele de înaltă performanță, în special fibrele de carbon și sticlă, sunt utilizate în multe industrii datorită performanței lor. Pe lângă faptul că sunt utilizate pe scară largă în industrie, aceste fibre au atras atenția designerilor în ultimii ani. În cadrul acestei cercetări, a fost analizată o selecție de produse inovatoare, care au primit premii la concursuri internaționale de design precum RedDot și IF, ce includ fibre de carbon și sticlă.

Subiectele și obiectivele de cercetare din literatura de inginerie textilă includ producția de fibre și analize de performanță, dar există studii limitate privind utilizarea și impactul acestora în viața de zi cu zi. În cadrul acestei cercetări, va fi analizată utilizarea fibrelor de înaltă performanță în produse inovatoare de consum, pentru a oferi informații despre modul în care aceste fibre au impact asupra consumatorilor, în creșterea calității vieții. Această cercetare vizează, de asemenea, crearea unor zone comune de studiu pentru două discipline diferite.

***Cuvinte-cheie**: fibră de sticlă, fibră de carbon, proiectarea produselor industriale, selecția materialelor, interdisciplinar*

INTRODUCTION

In recent years, there are many products in the market with the same specifications. Because of these designers want to create differences in the product's view. Products increasingly personalized and desired has been one of the decisive characteristics in the industrial product design. Individuals associate their identities with the product to represent their uniqueness. Material selection is one of the basic parameters to make difference in the products. Design is not an only visualization process. As well, designers create working with engineers and researchers [1].

Today products are personalized day by day and users start to accommodate products with their identity. Material is one of the main parameters of product design. Different materials differentiate the aesthetic and symbolic value of the product [2].

Material identification and material selection are important stages of product design. Materials are not a tool for product design. Also, they are used for determining the performance of products. Composite materials, which started to be used in product design in the 1940s, are increasingly preferred day by day. Carbon and glass fibres are one of them.

Nowadays, textiles have gone beyond their traditional usage as fabric. As a result of interdisciplinary research in textiles intersecting with composite material science, polymer science, and electronics science, high-performance fibres were developed after being widely used in construction, aircraft and automobile sectors.

The general function of textile structures is to wrap the body and protect it from external factors. Advances in textile research and development have extended the function of this material to the use of artificial vessels made of fibre. This material, which is called technical textile, is waterproof, breathable and has high-performance properties such as being antibacterial, as well as protecting against chemicals and biological organisms, ten times more durable than concrete in an earthquake [3].

The benefits of technical textiles go beyond heavy industries such as aircraft and automobile manufacturers. The use of these materials should not be limited to automotive or any other major industry. Although these materials are not widely used, they have also been incorporated in consumer products. Design products with different innovative features include fibre-reinforced composites. The use of composites reinforced with textile fibres completes the target of the market competition of the manufacturers and meets the needs of the user with many positive features provided to the product. These products range from chairs to coffee bottles. Their importance is to be an interface that the engineering fibre encounters and serves the public good with its high performances. Therefore, this research was necessary to demonstrate the effect of textile engineering on product design with fibre-reinforced composites. The importance of composite materials reinforced fibres in the product is to realize new materials and material features for new products.

EXPERIMENTAL WORK

Structure and properties of carbon fibres

Carbon, the main components of coal and other organic compounds is non-metallic. It was introduced to the world in 1963 by the Great Britain, with its high strength and superior rigidity properties. Production started in 1968. The density of the carbon fibre varies between 1.6 and 2.2 g/cm^3 depending on the raw materials used and treatment temperature. The density of raw material used to produce carbon fibre is between 1.14 and 1.19 g/cm^3. The modulus fibres increase with the temperature of graphitization [4]. Composite materials made from carbon fibres are five times more resistant to steel constructions and their weights are 1/5 of it. Likewise, they are 7 times more durable of “6061 Aluminum” used in aeronautic sector and 2 times harder and 20% lighter. Fatigue of carbon fibre is better than all known metals if the composite material is covered with a suitable resin, thus obtaining good corrosion resistance. The electrical conductivity of far-based carbon fibres is three times more than copper [5].

Carbon fibres are used in the automotive industry mostly. This is determined by the global fibre producers. A lot of leading firms in the automotive sector such as BMW, Lamborghini, and Mercedes Benz use carbon fibre composites in their designs increasingly. The main reason for this is to reduce vehicle weight. Carbon fibre is used in the construction of car body and gear. Being lightweight and stainless increase the applicability of this fibre in industrial products [5]. Furthermore, exhaust filters are combined with carbon fibre which has capable of absorbing the stench. When automobile moves, gas emissions are captured and sent back to the fuel tank [6].

Structure and properties glass fibres

Glass can be produced in many forms from the quartz crystal to fog mosque. Glass which has an amorphous structure shows the polymeric structure. Silicon atom indicates a three-dimensional structure with turning by 4 oxygen atoms. Silicon is a lightweight and non-metallic material. Silicon located in nature in the form of silica with oxygen. For obtaining glass, silica sand is heated around 1500 °C with additives, while they dry. After that, it is allowed to cool and a rigid structure is obtained.

Glass fibres have many features: high tensile strength, weight per unit higher than steel, low thermal resistance. They do not burn but they macerate at high temperature. Also, they are resistant to chemicals. They do not conduct electricity. So they are used in case of needed electrical insulation [7].

Transition of composites to product design

Since the 1940s, designers and industry have quickly become aware of fibre-reinforced composites [8]. Charles Eames first recognized the properties of composites and became the first designer to use it. In fact, plywood is also a composite, but Eeames and Eero Saainen used this material in the chair they designed for a furniture competition in 1944, and they saw with this design that the limitations in plywood led to searching for different materials. Eames, who was searching for chair material, discovered glass fibre. The glass fibre provided the designer with lightness, durability and freedom in design. In addition, another feature of this material that affects the designer is its low price because this means that designs reach larger markets [9].

In the past few years, designers have witnessed the technical success of carbon fibre and started to experience it in the same way. Sylvain Dubisson’s table composite and Alberto Medo’s Light Chair (both products belong to 1987) are a turning point in this technology, and only one blocker was the high production cost. When this situation is prevented, both designs will have a commercial success [8].

METHODOLOGY

For this research, it is used qualitative research and has three stages.

Literature review

Some keywords are used such as Product design, Textile fibres, composite materials, carbon fibre, glass fibre, design-material relationship, new product development.

Sampling

To evaluate the relationship between fibres and product design some award-winning products with carbon and glass fibre reinforced were selected from RedDot and IF international design competition (table 1).

To select these products the databases of the competitions have been scanned with the key word “Carbon fibre and glass fibre” between 21th and 25th of January, 2014 [10, 11]. After this selection, a table was created which includes information about products. This information is found from the website of RedDot and IF features which are related to carbon and glass fibre are signed. Table 2 presents only an example of the developed table.

Table 1

INTERNATIONAL DESIGN COMPETITIONS	
Logo	**Detailed presentation**
reddot design award	The Red Dot Design Award is an international product design prize awarded by the Design Zentrum Nordrhein Westfalen in Essen, Germany. There are prize categories for product design agencies and design concepts. The oldest of the three awards, the Red Dot Award: Product Design had been known as Design Innovation until 2000. The competition is open to several fields of manufacturing, including but not limited to furniture, home appliances, machines, cars and tools [10].
iF	IF Product Design award started in 1954 and are organized annually by the IF International Design Forum. More than 2000 products from 32 different nationalities enter the competition every year. These products are evaluated by experts and are entitled to receive the IF seal according to the superior design quality. Named as the best of the best, IF Gold awards are also known as design Oscars. Starting from 2015, IF Design award will be divided into 5 different disciplines. These are product, communication, packaging, interior design and professional concepts [11].

Table 2

FEATURES OF PRODUCTS RELATED WITH CARBON OR GLASS		
Year	**Products**	**Properties**
2008	 1E58 Axtion® DP Prosthetic Foot	The 1E58 Axtion® DP prosthetic foot combines materials and form in an appealing design with a three-dimensional surface. It is functional, efficient and suitable for sports activities. Supported by the dynamic heel element, the hybrid construction of carbon and polyurethane absorbs the shock from heel strike to foot flat, thus providing more comfort while on the move. The dynamic carbon-fibre plate extends to the toe area and ensures a good energy return at the forefoot during use.
2010	 Swix Triac® Ski Pole	The innovative advancement of the Swix Triac® Nordic ski poles presents a range of technical improvements. The new hand-strap grip system ensures power transfer without loss of energy. Moreover, a new retention system allows for optimized adjustment to various hand sizes. With its triangularly shaped carbon-composite construction, the shaft is very light, and the carefully considered material selection results in optimal rigidity and strength. Also, the Swix Triac® is conceived to accommodate a change of baskets to adapt to varying snow conditions.
2011	 Element Collar	The element Collar necklace is made of small diamond pieces and carbon fibre. The concave inner surface is ergonomic, conforms to the user’s neck.
2012	 The Concept Speedmax	Speedmax is pushing the boundaries of carbon fibre material by optimizing aerodynamic properties. The use of high quality carbon fibre has reduced the weight of the product to a minimum.
2013	 SR3 Pro Carbon	The SR3 Pro Carbon provides high comfort with its thin, carbon, high-positioned seat and filler under the sit-bones.
2014	 ThinkPad Ultralight Backpack	The interior is reinforced with carbon fibre rods to ensure that it has the shape of the back.

Descriptive analysis

Descriptive analysis is a qualitative research method. The descriptive analysis consists of four stages.

- establishing a framework for analysis;
- placing the data generated frame;
- data are defined and supported with quotations if deemed necessary;
- interpretation of data obtained.

In this study, tables are created and the information obtained from tables was divided into various categories and all data obtained were evaluated by examining separately. These categories are years and product groups.

RESULTS

Determination of the rise and fall according to the year of production

The first grouping is according to years. When this grouping is done, years started giving the award in the competition were accepted as the beginning in RedDot using composite material reinforced via carbon fibre started in 2007. From 2007 to 2008 there was a rising and after that a decline in 2009. But using carbon fibre in products increased rapidly to 2013 (figure 1, *a*).

In IF using composite materials reinforced via carbon fibre started in 2004. The use of materials increased and decreased in 4 years, and increased again from 2008 to 2013. While passing from 2013 to 2014, there was a decrease (figure 1, *b*).

The reason is increasingly recognized materials. Designers want to make a difference in their products and start trying new materials for their products. When 2014 was examined, it was clearly observed that there is a rapid fall, from 7 products to 3 products in RedDot. The cause of this fall is closely related to the concept of sustainability. In 2004, there is a new product Creative Aurvana Live! 2 (figure 2, *a*). This product was produced using bio-cellulose and this material provided high-performance features. This is an important step for a sustainable world.

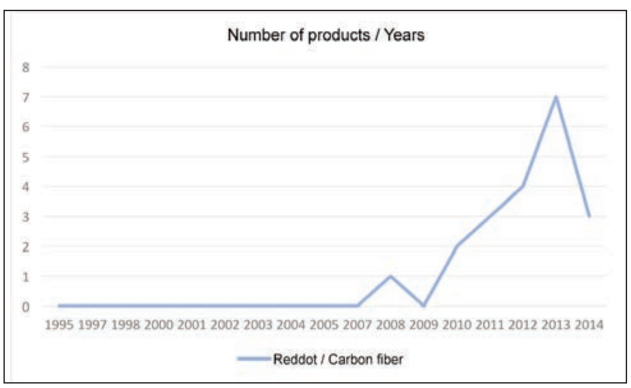
It is possible to attribute the reason for this decline to the realization of composite materials reinforced with natural fibre in IF, just like in the Red Dot competition. The product named The Pencil (figure 2, *b*) launched in 2014, confirms this hypothesis. This product uses a material called Wopex. This material is a natural fibre reinforced composite material with 60% cellulose.

In RedDot using composite materials reinforced via glass fibres started in 2004. The graph in figure 3, *a* has an unstable trend. Because this material has not high-performance features and there is a lot of material instead of composite material reinforced with glass fibres.

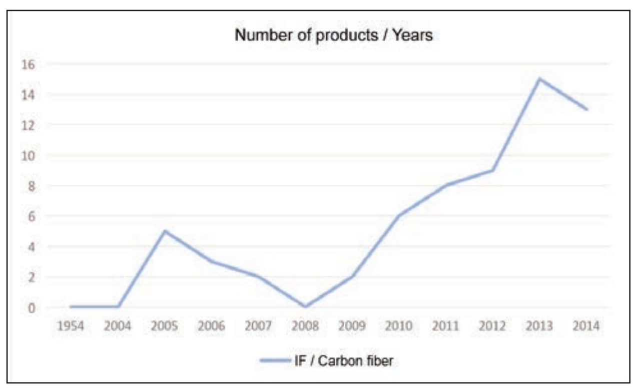
In IF using composite materials reinforced via glass fibre started in 2004. This material, which is constantly increasing and decreasing, shows an unstable trend (figure 3, *b*). The reason is that the material do not show high performance features just like the Red Dot competition.

Determination of usage by product group

The composite material reinforced via carbon fibre is widely used in sports equipment according to RedDot. This material has high-performance features and this product group requires the strength of resistance and durability (figure 4, *a*).



a



b

Fig. 1. Using composite materials which are reinforced with carbon fibre in: a – RedDot; b – IF according to years

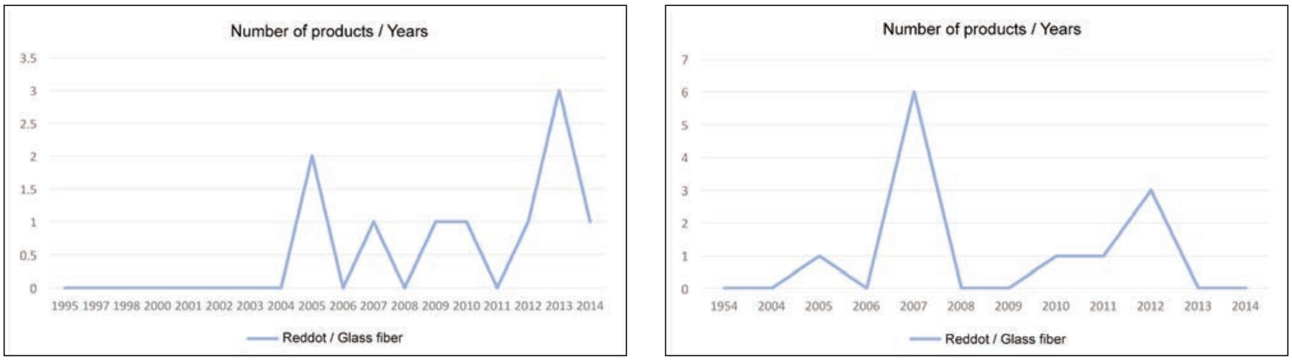
a

b

Fig. 2. *a* – Creative Aurvana Live! 2 [10]; *b* – The Pencil [11]

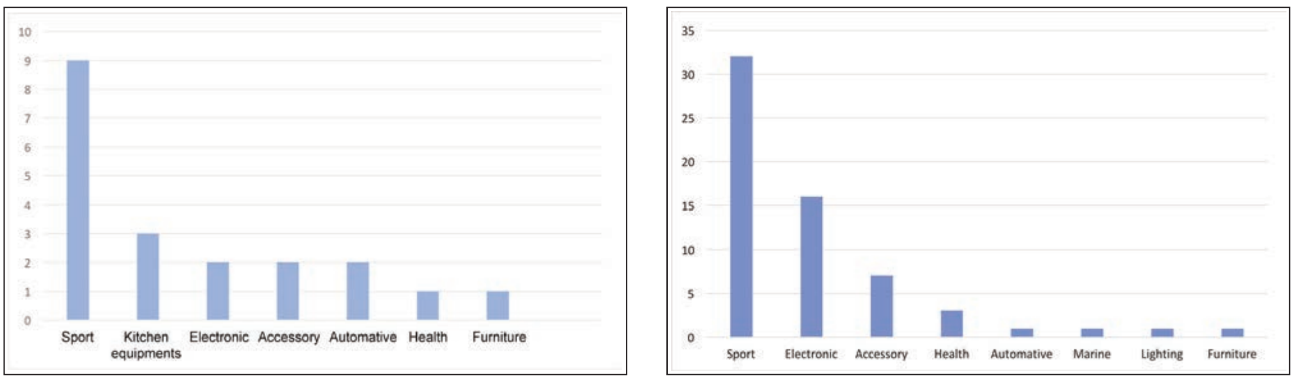
The composite material reinforced via carbon fibre is used in sports equipment widely according to IF because of lightness. The surprising point here is that when the literature research is done, the sector that was encountered the most in the use of composite materials reinforced with carbon fibre has fallen to the last places in shipping and automotive (figure 4, *b*).

The composite material reinforced via glass fibres is widely used in the furniture sector according to



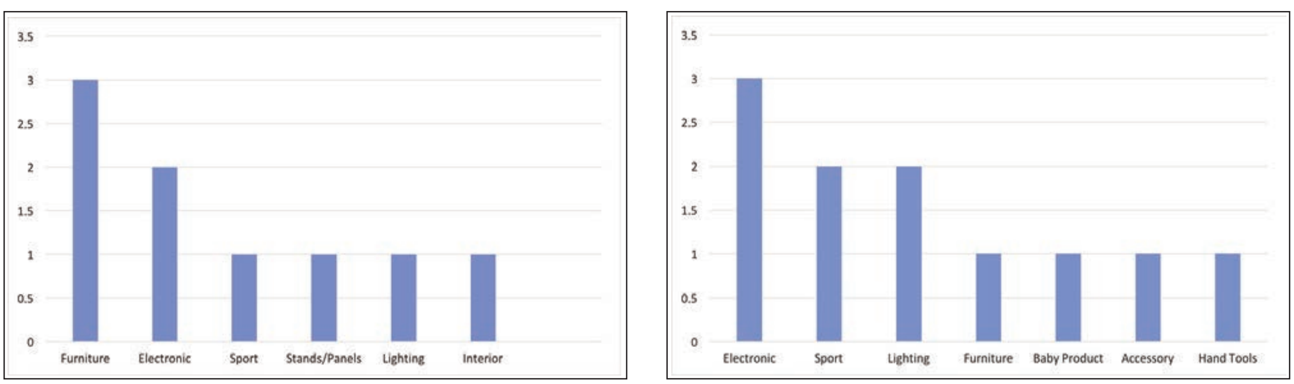
a *b*

Fig. 3. Usage of composite materials reinforced with glass fibre in: *a* – RedDot; *b* – IF according to years



a *b*

Fig. 4. Usage of composite materials reinforced with carbon fibre in: *a* – RedDot; *b* – IF according to product groups



a *b*

Fig. 5. Usage of composite materials reinforced with glass fiber in: *a* – RedDot; *b* – IF according to product groups

Reddot (figure 5, *a*), because this material gives lightness features to products. The lightness is one of the basic parameters for furniture design. The composite material reinforced via glass fibres is used in the electronics sector instead of Alluminium according to IF (figure 5, *b*).

DISCUSSIONS

Design is not a linear process. This study is interdisciplinary coordination between textile and product design. Other coordination is suggested for example between materials science and product design based on this work. This study has been focused on the material, mostly new and technological materials. Therefore, the high design education with predictable performance characteristics should be involved in promoting better awareness and use of these materials. Today, the search for new materials continues with the same excitement. Even today, it seems impossible for a completely plastic aircraft to be possible. However, while 40 percent of composite-used aircraft have emerged today, they will all be reinforced with carbon or various fibres in the future and will be reinforced with ceramic engines and spread over a large area [9].

CONCLUSION

According to Mike Ashby, a designer who is aware of market needs and the best way of combining this awareness with the products is a good designer [12]. Designers are required to constantly renew and develop themselves. Therefore, designers must be aware of new technologies and follow scientific researches. Material selection is one of the important stages of product design. Making a difference in products is possible with using material selection. Today new technological materials are discovered instead of traditional materials. This study has come up from this point. Composite material reinforced with textile fibre had been firstly used in 1944 but they didn't spread because of both cost and lack of information. According to literature reviews, these composite materials are frequently used in automotive or aviation sectors which required high cost. But in daily-life products, traditional materials are preferred. In this study, a famous competition is selected and examined materials that contain carbon and glass fibres. It was clearly observed that carbon fibre has entered in our lives late but quickly. It has increased in graphs annually. Designers have had to become more aware of this material every day. This material has emerged for products that require much higher performance. For example, sports types of equipment.

But for a sustainable world, it has a decline in 2014 but it is not possible to be abandoned completely. When the glass and carbon fibre were compared, glass fibre is recognized mostly. Designers preferred this material when needed for their high-performance features.

Besides all of these, this study is very useful to see interdisciplinary coordination. According to textile disciplinary, research topics and objectives include fibre production and analysis and have limited knowledge of the use of these materials in product design. Engineers and researchers who belong to textile disciplinary will find some information about transferring some features of materials that they produce to the products. According to product design disciplinary, designers can recognize and learn new technological materials and use them in their products.

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