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Study of the flexural properties of polyurethane-foam-core composites reinforced with warp-knitted spacer fabric

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ABSTRACT – REZUMAT

Study of the flexural properties of polyurethane-foam-core composites reinforced with warp-knitted spacer fabric

In this paper, novel ternary composites consisting of polyurethane-foam-core, warp-knitted spacer fabrics and polyurethane resin were involved. The composites obtain unique three-dimensional structures, high strength and a variety of surface structures. The aim of this study was to investigate the flexural properties of the composites. First, the warp-knitted spacer fabrics with different structural parameters were laminated with polyurethane foam to produce the foam-core materials. Meanwhile, two types of microspheres were incorporated into the polyurethane foam. Then the prepared foam-core materials were combined with polyurethane resin to fabricate the polyurethane composites. A flexural test was conducted to investigate the effects of the surface structure of spacer fabrics, microspheres types and contents on the flexural properties of the polyurethane composites. The findings show that the composites had excellent flexural properties and the flexural performance can be significantly improved by varying the surface structure of the fabric and the type of microspheres to meet specific end-user requirements.

Keywords: *Polyurethane-foam-core, warp-knitted spacer fabric, polyurethane resin, microspheres, flexural properties*

Studiul proprietăților de încovoiere ale compozitelor cu miez din spumă poliuretanică armate cu tricot din urzeală ca distanțier

În această lucrare, a fost analizat un nou compozit ternar constând din miez de spumă poliuretanică, tricot din urzeală ca distanțier și rășină poliuretanică. Compozitele dețin o structură tridimensională unică, o rezistență ridicată și o varietate de structuri de suprafață. Scopul acestui studiu a fost de a investiga proprietățile de încovoiere ale compozitelor. În primul rând, tricoturile din urzeală distanțiere cu diferiți parametri structurali au fost laminate cu spumă poliuretanică pentru a produce materialele cu miez de spumă. Între timp, două tipuri de microsfere au fost încorporate în spuma poliuretanică. Apoi, materialele preparate din miez de spumă au fost combinate cu rășină poliuretanică pentru a fabrica compozitele poliuretanice. A fost efectuat un test de încovoiere pentru a investiga influenţă structurii suprafeței tricoturilor distanțiere, tipurile și conținutul microsferelor asupra proprietăților de încovoiere ale compozitelor poliuretanice. Rezultatele arată că materialele compozite au proprietăți de încovoiere excelente și performanța la încovoiere poate fi îmbunătățită semnificativ, prin modificarea structurii suprafeței tricotului și a tipului de microsfere pentru a îndeplini cerințele specifice utilizării finale.

Cuvinte-cheie: *miez din spumă poliuretanică, tricot din urzeală distanțier, rășină poliuretanică, microsfere, proprietăți de încovoiere*

INTRODUCTION

Textile composites have the advantages of high strength and specific modulus and low density, so they are gradually replacing traditional metallic materials in many fields. Warp-knitted spacer fabric, as one of the reinforcements used in textile composites, is compared with the traditional sandwich composites. It has obvious advantages in terms of delamination resistance, fracture toughness, and impact damage tolerance [1]. Textile composites as lightweight and high-strength composites, their main applications are in the form of various artificial stone panels for construction and plate materials such as ship hulls and automobile shells [2, 3]. For example, textile composites in the aerospace field are generally used in wing beams, tail structures, engine nacelles (especially jet engine nacelles), external culverts, seats and access panels [4]. In the construction field, it can be used in woven sound insulation panels, roof panels, etc. [5]. In the automotive field, it can be used for drive shafts, bodies, cantilever beams, etc. [6, 7]. It also can be used for hull bulkheads, interior walls, ship interior decoration materials, etc. [8, 9]. The form of application determines that the length of composite fabricated parts is generally much greater than their thickness [10]. Ma and Qin [11] prepared glass/unsaturated polyester resin composites and explored the tensile and flexural properties of the composites and found that Warp-knitted spacer fabric composites revealed good flexural mechanical properties. Chen et al. [12] prepared glass/unsaturated polyester resin composites and explored the tensile and flexural properties of the composites and found that Warp-knitted spacer fabric composites revealed good flexural mechanical properties. Therefore, the specific form of the parts determines that the flexural property is a very important mechanical property for composite materials, and the poor flexural property can seriously restrict the application field of composite materials and even produce safety hazards. Therefore, it is necessary and valuable to investigate the flexural properties of warp-knitted spacer fabric-reinforced composites [13, 14]. For these reasons, the flexural properties of warp-knitted spacer fabric-reinforced composites are systematically investigated in this chapter. First, three-point flexural tests were performed on composite samples, then the displacement-load images obtained were recorded and analysed, and finally, the effects of different spacer fabrics and microspheres parameters on the flexural properties of warp-knitted spacer fabric-reinforced composites were discussed in detail.

In this research, novel ternary composites consisting of polyurethane-foam-core, warp-knitted spacer fabrics and polyurethane resin were involved. And the flexural properties of the polyurethane composites were investigated. Furthermore, the effects of the surface structure of spacer fabrics, microspheres types and contents on the flexural properties of the polyurethane composites. In addition, the characteristics of polyurethane composites under flexural load were investigated by macroscopic observation and scanning electron microscopy (SEM).

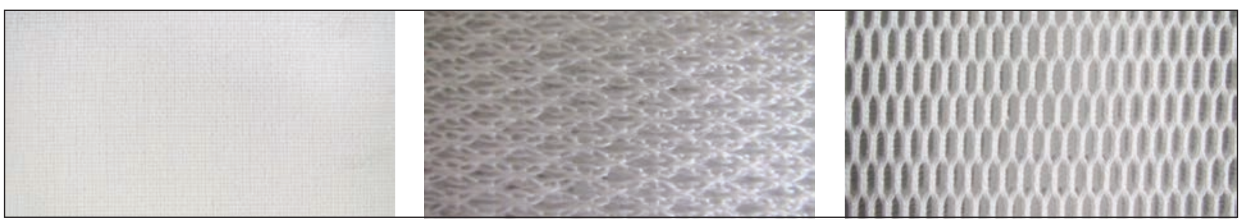
MATERIALS AND METHODS

Materials

Three warp-knitted spacer fabrics (purchased from Wuyang Co. Ltd., Jiangsu, China) with different outer structures were selected in this paper, as shown in figure 1. The surface structures of the spacer fabrics are Chain, Rhombic mesh and Hexagonal mesh, respectively. It can be seen that the size is continuously increasing. The types of yarns and the structural parameters of the spacer fabrics are shown in table 1. The PET multifilament yarn of 300D/96f was used for the surface layers, while the PET monofilament with 0.2 mm diameter was used for the spacer yarn. Despite the same warp and weft setting machine, the actual thickness of all three samples is near 7.4 mm, so it can be considered that the thickness of these fabrics is close to each other.

Fabrication of polyurethane composites

In this study, the spacer fabric is combined with polyurethane foam to produce the foam core materials firstly. The polyurethane foam is made of isocyanate and polyether polyol (BASF, Shanghai, China), and the foaming process was carried out at room temperature with a mass ratio of 43.9:100. Meanwhile, the weighted hollow glass microspheres were added to the polyurethane foam. The parameters of microspheres are shown in table 2. A mixer machine named FlackTek Speed Mixer (DAC 150.1



a *b* *c*

Fig. 1. The surface layer structures: *a* – chain; *b* – rhombic; *c* – hexagonal mesh

Table 1

STRUCTURE AND PARAMETERS OF WARP-KNITTED SPACER FABRIC

Surface layer structures	Materials		Thickness (mm)	Course-wise density (w/5 cm)	Wale-wise density (c/5 cm)	Density of surface (g/m^{-2})	Yarn count (Tex)	Lapping movement
	surface layer	spacer yarns						
Chain	A	B	7.72	7.07	5.57	8817	33.3	GB3: 1-0, 3-2/3-2, 1-0// GB4: 3-2, 1-0/1-0, 3-2//
Rhombic Mesh	A	B	7.66	7.24	5.57	772.0	33.3	GB3: 1-0, 3-2/3-2, 1-0// GB4: 3-2, 1-0/1-0, 3-2//
Hexagonal Mesh	A	B	7.64	7.07	5.79	756.8	33.3	GB3: 1-0, 3-2/3-2, 1-0// GB4: 3-2, 1-0/1-0, 3-2//

Note: A represents 300D/96f PET multifilament yarn, B represents 0.2 mm diameter PET monofilament.

FVZ, American) was carried out for the mixing process to ensure a slow and uniform speed so that the microspheres can be distributed evenly in the solution. The preparation of the foam core materials was carried out in a mould. All specimens are placed for 24 hours to reach full maturation and moulding. The prepared foam core materials are placed in a polyurethane resin with a 1:1 mass ratio of isocyanate to polyether polyol in a mould (BASF, Shanghai, China). The polyurethane composites were placed at a temperature of 25°C for 8 h to complete curing. The produced polyurethane composites are shown in figure 2, while the details of polyurethane composites are shown in table 3. In this study, two representative microbeads with different inner and outer diameter ratios and thus different mechanical properties, namely S15 and im16K, were selected as microbead fillers for the warp-knitted spacer fabric reinforced composites.

Table 2

PARAMETERS OF GLASS MICROSPHERES		
Types of micro microspheres	**Intensity (Mpa)**	**Average particle size (μm)**
S15	2.07	55
im16K	113.7	20

Flexural properties test

The three-point flexural test was conducted by using Hua long WDW-20 universal material testing machine with test standard ISO 14125:1998 (fibre reinforced plastic composites-determination of flexural properties). The size of the specimen was set to 160 mm × 15 mm × 8 mm, and the clamping distance was set to 120 mm. The loading speed was set to 2 mm/min and the test was stopped when the deflection of the centre point of the fabric-reinforced composite specimen reached 17 mm, and the load-displacement curves were plotted using the load and displacement values obtained from the test, and the flexural strength (MPa) and flexural modulus (MPa) of the samples were calculated using equations 1 and 2, respectively:

$$\sigma = \frac{3PL}{2wt^2} \quad (1)$$

$$E_f = \frac{L^3 k}{4wt^3} \quad (2)$$

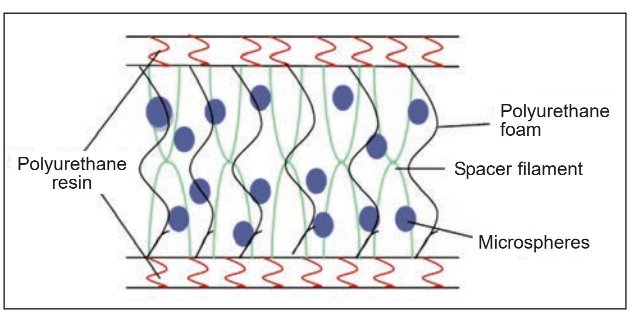
where P is the maximum value of the load, k – the slope value of the initial phase of the load-displacement curve.

The three-point flexural test was conducted at a temperature of 25°C and relative humidity of 60%, and each three-point flexural test sample was tested at least five times, and the average value was taken and the standard deviation was calculated. The

Table 3

THE DETAILS OF POLYURETHANE COMPOSITES			
Sample	**The surface layer structures**	**Types of micro microspheres**	**Content of microspheres (%)**
S1	None	None	None
S2	Chain	None	None
S3	Rhombic	None	None
S4	Hexagonal Mesh	None	None
S3-1-S15	Rhombic	S15	1
S3-1-im16K	Rhombic	im16K	1
S3-3-S15	Rhombic	S15	3
S3-3-im16K	Rhombic	im16K	3

Note: S1 represents pure resin without spacer fabrics and microspheres in the thickness of 7.4 mm.



a

b

Fig. 2. Schematic and real diagram of polyurethane matrix composite:
a – schematic of composites; *b* – real diagram of composites

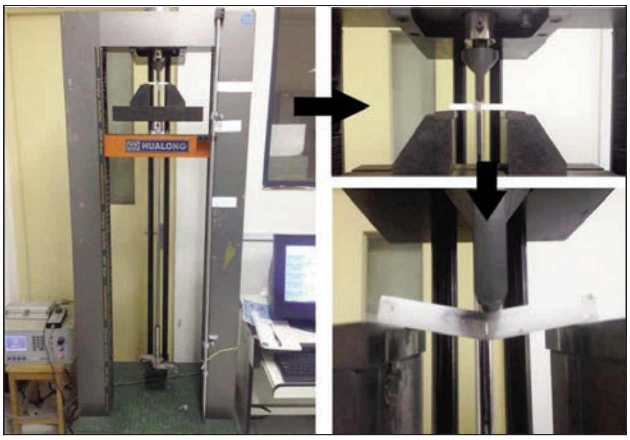


Fig. 3. Three-point flexural test machine and experimental process

experimental machine and test procedure are shown in figure 3.

RESULTS AND DISCUSSIONS

Effect of surface structure on flexural performance

Figure 4 shows the load-displacement curves of the flexural test for three composites (S2~S4) and the pure resin panel (S1). It can be seen from figure 4 that the load-displacement curves of all samples show a similar linear region in the initial stage. At the end of the linear region, i.e., the load reaches the peak, all curves show a slowly decreasing trend, among which the load value of S1 which is not reinforced by the warp spacer fabric is lower, which indicates that S1 has a poor flexural performance in the three-point flexural test. The flexural load of the other three composite samples with different fabric parameters did not drop to 0, which indicates that the composite still has a certain flexural resistance. At the same time, it can be found that the peak flexural load of the three samples with different fabric parameters is higher than that of the S1. The above mentions show that the flexural performance of the polyurethane composites with spacer fabric reinforcement is higher than that of the S1. Furthermore, the flexural performance of the polyurethane composites with hexagonal mesh surface structure was the best.

The flexural strength and flexural modulus for the specimens are shown in figures 5 and 6. From figures 5 and 6, it can be found that the flexural strength and flexural modulus increase as compared to S1. The flexural strength and flexural modulus of S4 increase the most, indicating that the flexural performance of the polyurethane composite with hexagonal mesh surface structure is the best. It can be also found that the shorter spacer yarn in S4 can withstand a larger critical force value and is less likely to be bent than the spacer yarn in S2 and S3, thus improving the flexural performance of the whole material. As the spacer fabric selected in this paper has the same spacer diameter, and the spacer and resin matrix in the warp-knitted spacer fabric reinforced

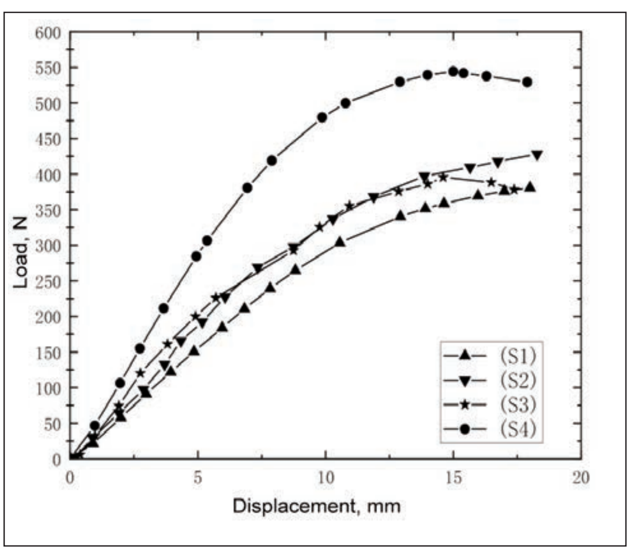


Fig. 4. Flexural load-displacement curves of spaced fabric composites

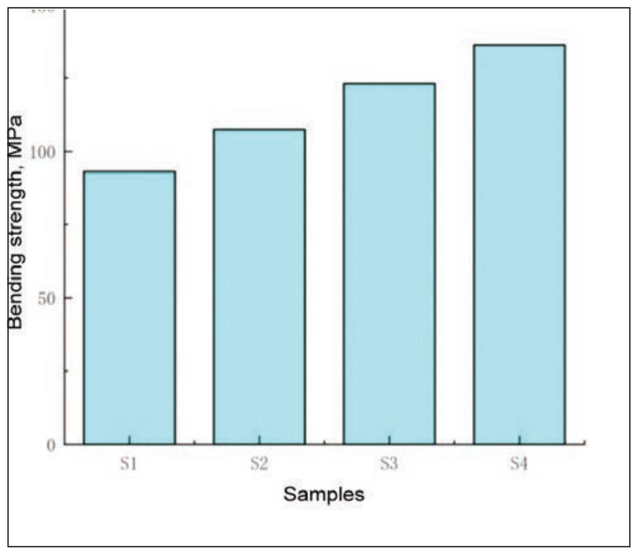


Fig. 5. Flexural strength of polyurethane composites

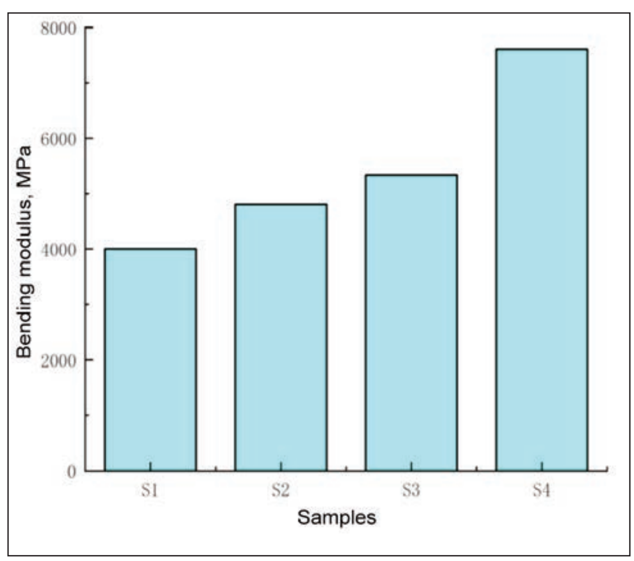


Fig. 6. Flexural modulus of polyurethane composites

composites are the main load bearers, and the spacer is subjected to bending load when its main form of damage is dislodged and deformed, and there is no case of pulling off damage. Therefore, the influence of the spacer filaments on the bending properties of the composite is excluded.

Effect of microspheres parameters on flexural performance

As an important reinforcement in the composites, the effect of volume fraction and type (inner and outer diameter ratio) of glass microspheres on the flexural properties of the composites is significant. It should be noted that the change in volume fraction and type of microspheres significantly affect the density of the composites.

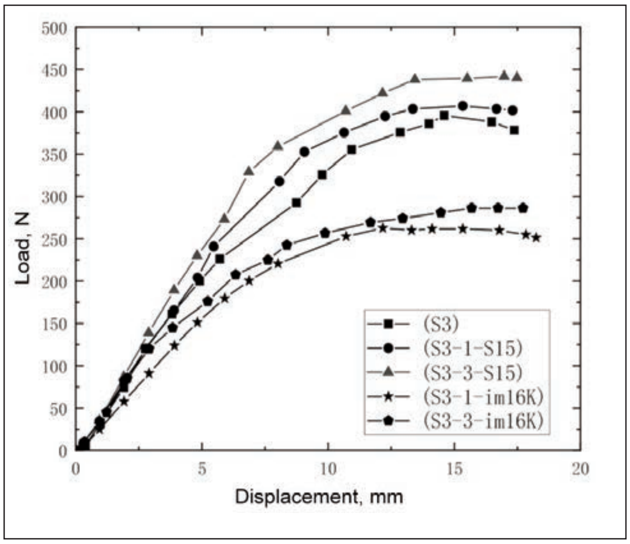


Fig. 7. Flexural load-displacement curves of composites

Figure 7 shows the load-displacement curves of flexural tests for S3-1-S15, S3-1-im16K, S3-3-S15, S3-3-im16K and S3. It can be seen from figure 7, the load-displacement curves of all samples show similar linear regions in the initial stage, and all curves show a slow decline when the load reaches its peak which is similar to S1 ~ S4. The load values of S3-3-S15 are higher than those of S3-3-im16K, which indicates the flexural performance of polyurethane composites reinforced by warp-knitted spacer fabric with S15 microspheres is higher than that of S3-3-im16K.

This means that the flexural properties of the polyurethane composites reinforced with warp-knitted spacer fabric and S15 microspheres are higher than those with im16K microspheres. Therefore, it can be basically concluded that the flexural performance of the warp-knitted spacer fabric reinforced composites increases with the increase of the inner and outer diameter ratio of the embedded microspheres.

S3-1-S15 and S3-3-S15 were embedded with the same type of diamond warp-knitted spacer fabric and S15 microspheres, but the volume fraction of the embedded microspheres was 1% and 3%, respectively. It reveals from the figure that the load value of the sample with a 1% microspheres volume fraction (S3-1-S15) is lower, which means that the S3-1-S15 sample exhibits poor flexural performance in the three-point flexural test. This phenomenon is due to reason that the addition of more low-density microspheres and the creation of more pores during the sample preparation process. The findings show that the flexural performance of the polyurethane composites reinforced can be improved by increasing the microspheres volume fraction.

The flexural strength and flexural modulus of these composites' samples are shown in figures 8 and 9, respectively. The flexural strength and flexural modulus of S3-1-S15 and S3-3-S15 are similar and higher than those of S3. Therefore, the addition of S15 microspheres improves the flexural performance of the composites. In addition, the specific flexural strength and specific flexural modulus of sample S3-3-S15 with the highest volume fraction of microspheres were higher than those of S3-1-S15 due to the addition of more low-density microspheres and

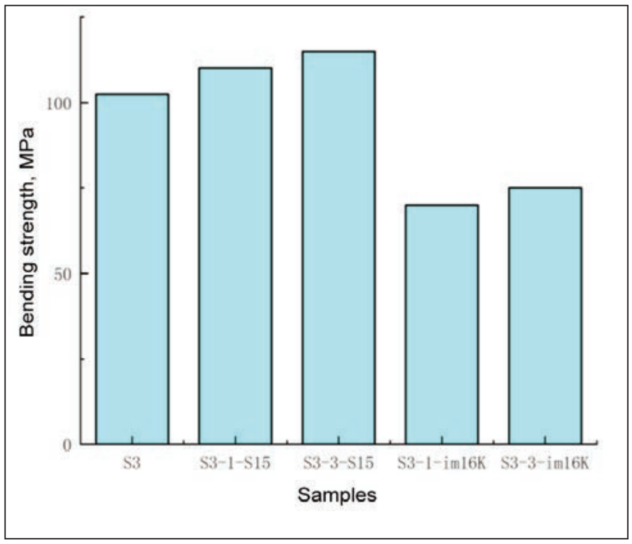


Fig. 8. Flexural strength of polyurethane composites

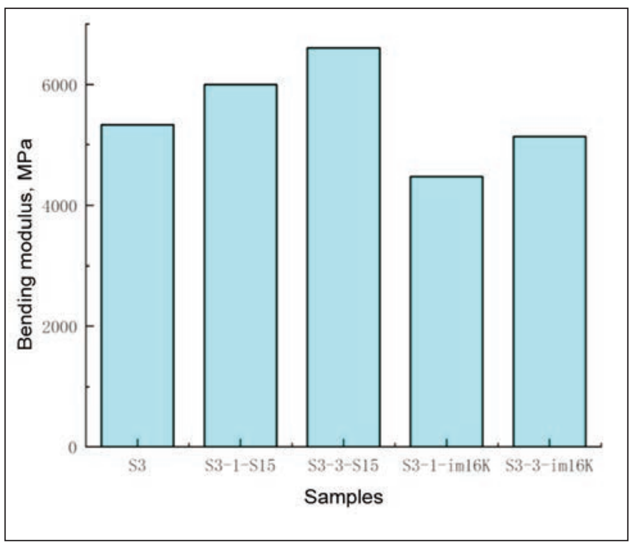


Fig. 9. Flexural modulus of polyurethane composites

more pores produced in the sample making process. In summary, when the volume fraction of S15 hollow microspheres was low, increasing the volume fraction of microspheres could improve the flexural properties of the composite more obviously.

Samples S3-3-S15 and S3-3-im16K were embedded with two different microspheres, S15 and im16K, respectively, while the volume fraction of warp-knitted spacer fabric and microspheres (3%) embedded in the three materials were identical. It can be seen that in the comparison of the above two indexes, S3-3-S15 with S15 microspheres embedded with the maximum inner and outer diameter ratio has the highest value, while S3-3-im16K with im16K microspheres embedded with the minimum inner and outer diameter ratio is lower than S3-3-S15 and S3. It may due to the incorporation of microspheres and the creation of more pores during the sample-making process, which reduces the overall force of the composites. Therefore, it is obvious that the flexural properties of the composites decreased with the decrease of the inner and outer diameter ratio of the embedded microspheres.

Macroscopic appearance of the experimental process of three-point flexural

Figure 10 shows the three-point flexural test procedure of the representative warp-knitted spacer fabric-reinforced composite S3-3-S15. It can be seen from the figure that S3-3-S15 did not show cracks throughout the experiment, indicating that the warp-knitted spacer fabric-reinforced polyurethane composite exhibited excellent flexural performance and toughness. According to the flexural theory of materials, in the three-point flexural test, the test sample is firstly subjected to compression load at the compression end, and then the load is propagated along with the thickness of the sample, and the sample is subjected to tensile load at the extension end, and the damage is firstly produced at the extension end. In summary, the three-point flexural test sample will be subject to vertical (compression and tension) and horizontal (shear) two directions of the load, therefore, based on the location of the material by the flexural load and the direction of crack propagation, you can determine the material in the three-point flexural test by which the main force of the load so that the macroscopic damage to the sample shape of the flexural performance analysis.

The morphology of the three-point flexural samples is presented by SEM images, and the SEM images of the three-point flexural test for samples S3-3-S15 are shown in figure 11. As can be seen in figure 11, the morphology of the glass microspheres in S3-3-S15 is well maintained, and no bead detachment occurs. It reveals that the microspheres of S15 were broken by the impact. In addition, the spacer filaments did not come out in S3-3-S15. In summary, the S15-type microspheres and the matrix resin were the main load carriers of S3-3-S15 in the three-point flexural test.

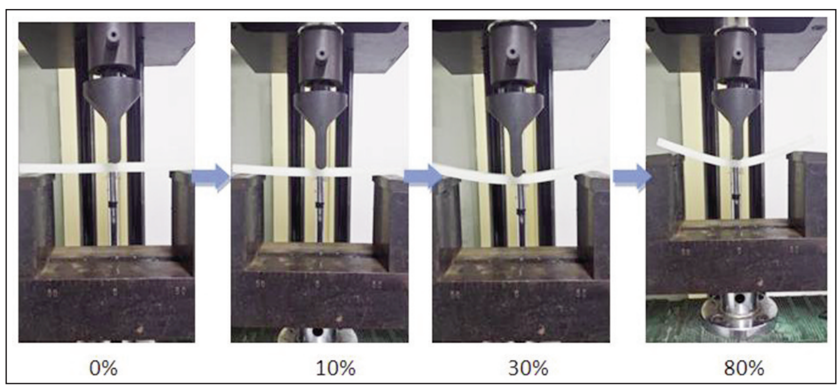
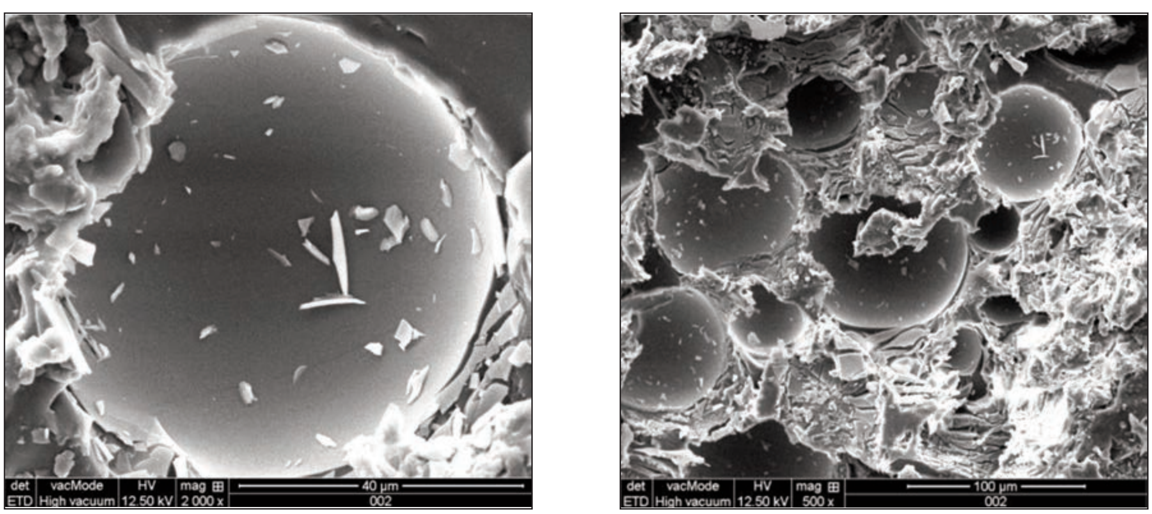


Fig. 10. The three-point flexural process of polyurethane composites



a *b*

Fig. 11. SEM images of polyurethane composites: *a* – the SEM image for S3-3-S15 (500x); *b* – the SEM image for S3-3-S15 (2000x)

This is because the strength of S15-type microspheres is low, and when the matrix resin is subjected to flexural load to produce force, the microspheres will share the force and absorb part of the force thus increasing the overall flexural performance. In warp-knitted spacer fabric reinforced composites, in addition to the matrix resin and foam, the spacer filaments are also one of the main load carriers, so the presence of spacer filaments can improve the flexural resistance of the material. While glass microspheres are still not the main bearer of the flexural load, their presence will share the force and absorb part of the force thus achieving the purpose of improving the flexural performance of the material. In summary, it is the different reinforcement methods of spacer fabric and glass microspheres that make the flexural performance of warp-knitted spacer fabric reinforced composites significantly better than that of traditional composites.

CONCLUSIONS

In this chapter, the flexural properties of warp-knitted spacer fabric reinforced polyurethane composites are investigated. With the help of three-point flexural test results, the effects of microspheres parameters and spacer fabric parameters on the flexural strength and flexural modulus of the composites are studied. The warp-knitted spacer fabric has significantly better load, flexural strength and flexural modulus, and thus better flexural properties and toughness. The structural parameters of the warp-knitted spacer fabric had a strong influence on the flexural properties of the material, with samples reinforced by spacer fabrics with a smaller number of spacer card back traverse stitches and a denser face structure showing better bending properties. Different volume fractions of microspheres and types of microspheres have a great influence on the flexural performance of the composites, and the flexural performance of the composites can be improved by appropriately increasing the volume fraction of microspheres and using higher strength microspheres. Additionally, this paper gives a theoretical explanation of damage conditions during the flexural process.

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Appropriate software model for evaluating the effect of untreated and treated sisal fibre with different gauge length and strain rates for geotextile applications

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ABSTRACT – REZUMAT

Appropriate software model for evaluating the effect of untreated and treated sisal fibre with different gauge length and strain rates for geotextile applications

Geotextiles are commonly used as reinforcement in building, engineering and road laying applications. The sisal fibre is one of the natural fibres which is used to reinforce soil and prevent damage. This sisal fibre is specifically helpful to fill gaps between roads to improve soil structure, and prevent soil erosion but allows the water to drain off. This paper is concerned with the study of the effect of gauge length on the strength and elongation of sisal fibres in untreated and treated states with sodium hydroxide at different concentrations and duration of treatment. The reason for applying sodium hydroxide treatment on sisal fibre is to remove the impurities from it and to improve the inter fibre adhesion with resin for producing a composite. The effective reinforcement of composites with plant fibres depends on the moisture content and the fibre matrix interfacial adhesion. Treatment with alkali improves the performance of fibres when they are used as composites. Also, the effect of strain rate on the strength and elongation of sisal in untreated and treated states has been investigated. The Weibull modelling software model has been used in many studies to quantify the degree of variability in the fibres. This paper deals with the application of an appropriate software model such as the Weibull distribution model for quantifying the variability in strength and elongation at different gauge lengths varied from 10 mm to 100 mm and also varied the strain rate from 10 mm/min to 500 mm/min. In addition to the Weibull distribution model, air plasma treatment and SEM (Scanning Electron Microscope) analysis on sisal fibre were also carried out in this paper. The result shows that the sisal fibre is more suitable for geotextile applications.

Keywords: *air plasma treatment, composite, gauge length, SEM analysis, sisal fibre, strain rate, Weibull distribution model*

Model de software adecvat pentru evaluarea influenței lungimii de referință și alungirii fibrei de sisal netratate și a celei tratate pentru aplicații geotextile

Geotextilele sunt utilizate în mod frecvent ca armare în domeniul construcțiilor, ingineriei și amenajării drumurilor. Fibra de sisal este una dintre fibrele naturale utilizate pentru a întări solul și pentru a preveni deteriorarea. Această fibră de sisal este utilă, în mod special, pentru a umple golurile dintre drumuri, pentru a îmbunătăți structura solului, pentru a preveni eroziunea solului, permițând apei să se scurgă. Această lucrare se referă la studiul influenței lungimii de referință asupra rezistenței și alungirii fibrelor de sisal în stare netratată și în cea tratată cu hidroxid de sodiu, la diferite concentrații și durate de tratament. Motivul aplicării tratamentului cu hidroxid de sodiu pe fibra de sisal este de a îndepărta impuritățile din aceasta și de a îmbunătăți aderența dintre fibre cu rășină, pentru producerea unui compozit. Armarea eficientă a compozitelor cu fibre vegetale depinde de conținutul de umiditate și de aderența la interfața matrice-fibră. Tratamentul cu alcalii îmbunătățește performanța fibrelor, atunci când sunt utilizate sub formă de compozite. De asemenea, a fost investigată influența vitezei de deformare asupra rezistenței și alungirii sisalului în stare netratată și în cea tratată. Modelul software de modelare Weibull a fost folosit în multe studii pentru a cuantifica gradul de variabilitate a fibrelor. Această lucrare tratează aplicarea unui model software adecvat, cum ar fi modelul de distribuție Weibull, pentru cuantificarea variabilității rezistenței și alungirii la diferite lungimi de referință variate de la 10 mm la 100 mm și, de asemenea, a variat viteza de deformare de la 10 mm/min la 500 mm/min.

Pe lângă modelul de distribuție Weibull, în această lucrare au fost efectuate și tratarea cu plasmă de aer și analiza SEM (microscop electronic cu scanare) pe fibra de sisal. Rezultatul arată că fibra de sisal este mai potrivită pentru aplicații geotextile.

Cuvinte-cheie*: tratament cu plasmă de aer, compozit, lungime de referință, analiză SEM, fibră de sisal, viteză de deformare, model de distribuție Weibull*

INTRODUCTION

Although the effect of gauge length on the tensile properties of sisal fibres by Mukherjee and Satyanarayana [1] and Silva et al. [2] has been investigated, the data were not modelled using Weibull distribution. Also, the gauge lengths used by them were limited (10 mm to 50 mm), and in this study, they ranged between 10 mm and 100 mm and also varied the strain rate from 10 mm/min to 500 mm/min. Tenacity and elongation values for untreated and treated sisal fibres at each gauge length and strain rate are discussed together with their values of

Weibull modulus and characteristic values. The overall trend of tenacity and elongation and their Weibull modulus values as a function of gauge length and strain rate are also commented on better understand side size effects. The relationship between ln (σ_f) and ln (ln (1/(1 – *Pf*))) was determined least-squares method.

RELATED WORK

Andrade Silva et al. [2] have reported on the tensile behaviour of sisal fibres. Weibull modulus decreased from 4.6 to 3 as the gauge length increased from 10 to 40 mm respectively. Young's modulus of sisal fibres was found to be around 18 GPa. It was found that the modulus was unaffected and the elongation decreased from 5.2 to 2.6% when the gauge length was increased from 10 to 40 mm. Abir et al. [3] studied the relationship between tensile behaviour and gauge length for sisal fibre composites. With the increase in gauge length, the tensile strength decreased. In general, the strength was found to be between 255 to 377 MPa and the Weibull modulus was around 2.5. Kulkarni et al. [4] used Weibull statistics to analyse the strength of coir fibres. This parameter Weibull treatment has been used for statistical analysis. The increase in Weibull parameters resulted in more uniform flow distribution. This was found in agreement with fibre strength histograms plotted for various fibre diameters of 150 µm to 350 µm. Andrade Silva et al. [5] presented an experimental analysis of the mechanical performance of sisal fibre. Young's modulus was determined using the tensile test. The increase in gauge length resulted in a decrease in Weibull modulus. At a stress level of 320 MPa, sisal fibres showed maximum fatigue. To investigate the failure mode of the fibres, SEM analysis has been used. Fernandes et al. [6] have studied the mechanical properties and tensile failure prediction concerning fibre treatment. Cork polymer composite materials were produced using sisal fibre with and without polyethylene-graft – maleic anhydride.

Improved tensile and flexural properties of the composite were achieved using alkali-treated sisal fibres and polyethylene-graft – maleic anhydride. The tensile strength failure of the hybrid materials was predicted using Weibull statistics. Inacio et al. [7] have studied Weibull analysis of sisal fibre tensile strength led to arrive at a correlation with the fibre diameter. SEM analysis was used to observe the ruptured fibres. The result showed that the tensile strength decreased with the diameter of the fibre.

Realff et al. [8] have conducted experiments to study the effect of test gauge length on the mechanical properties of yarns and fabrics. A Weibull distribution with shape and scale parameters was determined from yarn strength data. The yarn failure mechanism was attributed to changes in gauge length. SEM analysis was also provided. Fabrics were produced with plain and twill weave from the yarns produced at different spinning systems and these fabrics were also tested for tensile properties. The effects were found to be the same as that of yarn tenacity as a function of the gauge length. Tensile strength and modulus of elasticity were determined using a single fibre tensile strength tester and microscopic tests were used to study the fibre cross-sectional area. The high degree of linearity of R^2 = 0.942 was observed for coir fibre and the Weibull modulus was 3.650 giving good variability in tensile strength [9].

Zhang et al. [10] have developed a conventional Weibull weakest link model by incorporating the within fibre diameter variation. They claimed that this modified Weibull model could predict the effect of gauge length more accurately than the conventional model. This new model incorporated the diameter variation among the fibres. The fibre strength of wool has been found to fit in this model successfully. Sia et al. have found that Oil Palm Fibre (OPF) extracted from empty fruit bunches was good raw material for bio-composites [11]. The strength of these fibres was estimated at different gauge lengths and subjected to the Weibull weakest link distribution model. For exact prediction of the effect of gauge length the modified Weibull distribution was utilized. The failure strength of OPF was not affected by gauge length, unlike in the case of coir fibres [12–16]. The air plasma treatment [17] and SEM analysis [18] of sisal fibre are also discussed.

EXPERIMENTAL

The following tables 1 to 6 show the sample data for tensile properties of untreated and treated sisal fibres.

Weibull Distribution Model

The software model like Weibull modelling has been used in many studies to quantify the degree of variability in the fibres. Thus, the appropriate software

Table 1

UNTREATED SISAL FIBRE BREAKING LOAD (GF) AT DIFFERENT GAUGE LENGTHS (STRAIN RATE: 100 mm/min)

10 mm	20 mm	30 mm	40 mm	50 mm	60 mm	70 mm	80 mm	90 mm	100 mm
530.86	444.98	594.50	274.68	343.65	255.15	326.35	317.25	372.79	345.43
565.30	494.64	691.18	471.87	447.86	404.51	418.27	424.39	439.91	353.40
632.88	505.88	692.76	581.06	492.19	425.48	468.31	426.64	487.60	361.41
759.48	536.45	693.73	617.27	502.74	436.59	533.48	463.30	536.95	476.64
804.39	566.00	703.98	664.50	623.70	438.53	552.04	476.29	540.61	505.04

Table 2

UNTREATED SISAL FIBRE ELONGATION (%) AT DIFFERENT GAUGE LENGTHS (STRAIN RATE: 100 mm/min)									
10 mm	**20 mm**	**30 mm**	**40 mm**	**50 mm**	**60 mm**	**70 mm**	**80 mm**	**90 mm**	**100 mm**
11.61	6.05	2.18	6.57	4.71	2.27	3.46	3.60	2.20	2.25
12.00	7.00	5.96	6.86	5.43	6.06	5.53	4.34	4.18	3.88
12.01	8.80	6.62	8.01	6.47	6.39	6.05	4.79	4.35	3.95
12.07	9.20	8.72	8.13	7.45	7.12	6.30	5.30	4.69	3.97
12.07	9.59	8.91	8.25	8.34	7.30	6.43	5.90	5.30	4.37

Table 3

5% NAOH TREATED SISAL FIBRE BREAKING LOAD (GF) AT DIFFERENT GAUGE LENGTHS (STRAIN RATE:100 mm/min)									
10 mm	**20 mm**	**30 mm**	**40 mm**	**50 mm**	**60 mm**	**70 mm**	**80 mm**	**90 mm**	**100 mm**
230.8	349.2	277.7	204.0	207.3	221.9	218.7	184.0	204.2	200.5
261.0	360.1	280.7	223.1	265.0	247.3	275.3	216.8	253.5	220.7
270.6	389.0	308.9	243.9	272.5	264.0	291.5	280.9	268.9	223.0
289.2	394.4	364.5	249.0	274.4	279.6	296.3	283.3	273.4	225.1
305.6	396.3	394.5	277.9	279.3	281.0	300.7	285.9	292.0	225.2

Table 4

5% NAOH TREATED SISAL FIBRE ELONGATION(%) AT DIFFERENT GAUGE LENGTHS (STRAIN RATE: 100									
10 mm	**20 mm**	**30 mm**	**40 mm**	**50 mm**	**60 mm**	**70 mm**	**80 mm**	**90 mm**	**100 mm**
7.1	4.9	4.7	3.8	4.7	1.9	3.8	4.3	2.6	3.6
10.7	5.7	4.9	5.1	5.4	3.6	4.9	4.7	4.3	4.7
12.0	6.2	5.2	5.3	5.9	4.1	5.3	4.7	4.6	4.8
12.1	6.3	5.7	5.7	5.9	4.6	5.4	5.1	5.0	4.8
12.6	7.1	6.5	6.2	5.9	5.3	5.6	5.3	5.1	5.0

Table 5

10% NAOH TREATED SISAL FIBRE BREAKING LOAD (GF) AT DIFFERENT GAUGE LENGTHS (STRAIN RATE: 100 mm/min)									
10 mm	**20 mm**	**30 mm**	**40 mm**	**50 mm**	**60 mm**	**70 mm**	**80 mm**	**90 mm**	**100 mm**
265.8	257.7	237.7	297.3	232.1	241.3	237.5	160.8	235.3	208.8
323.1	288.2	288.7	347.9	277.2	291.7	323.5	277.4	246.6	222.5
347.7	293.1	317.2	350.5	294.6	303.2	325.4	280.6	277.5	228.6
408.7	368.8	321.1	360.4	314.3	304.3	327.6	305.9	299.7	233.6
424.7	380.2	331.8	361.2	322.1	332.5	331.6	306.8	314.4	240.6

Table 6

10% NAOH TREATED SISAL FIBRE ELONGATION(%) AT DIFFERENT GAUGE LENGTHS (STRAIN RATE: 100 mm/min)									
10 mm	**20 mm**	**30 mm**	**40 mm**	**50 mm**	**60 mm**	**70 mm**	**80 mm**	**90 mm**	**100 mm**
6.8	3.2	5.2	5.0	6.0	2.6	3.4	2.9	2.8	2.7
7.3	5.7	5.5	5.3	6.1	3.2	4.6	4.1	5.2	3.6
7.7	6.2	5.8	5.3	6.2	3.7	4.6	5.2	5.9	5.0
7.7	6.9	5.9	6.5	6.4	4.1	5.8	5.6	6.3	5.3
7.8	7.0	6.5	6.6	6.7	4.9	5.9	5.7	6.5	5.3

model such as the Weibull distribution model was used to quantify the strength and elongation data of both untreated and treated sisal fibres at different gauge lengths. Weibull parameters were determined by Microsoft Excel. The mean rank is obtained from the following equations: $\hat{F}(t_{(i)}) = (i - 0.5)/n$ (called the median rank estimator). The following procedures were used for Weibull modelling.

Part A: Plotting

1. Reorder the data from the smallest to the largest so that $t_{(1)} \leq t_{(2)} \leq \ldots \leq t_{(n)}$.
2. Compute $\hat{F}(t_{(i)})$ for $1 \leq i \leq n$.
3. Compute $y_i = \ln\{-\ln[1 - \hat{F}(t_{(i)})]\}$ for $1 \leq i \leq n$.
4. Compute $x_i = \ln(t_{(i)})$ for $1 \leq i \leq n$.
5. Plot y_i versus x_i for $1 \leq i \leq n$.

Part B: Estimation

6. Determine the best straight-line fit using regression or the least-squares method.
7. The slope of this line yields $\hat{\beta}$, the estimate of β which is the Weibull modulus.
8. Compute y_0, the y-intercept of the fitted line; $\hat{\alpha}$, the estimate of α, is given by $\hat{\alpha} = \exp(-y_0/\hat{\beta})$ which is the characteristic value.

Using the Weibull distribution, two parameters were estimated. These are the scale and shape. The shape parameter gives an idea of scattering of strength while the scale parameter gives the characteristic value which is an estimated one.

RESULTS AND DISCUSSION

Comparison of values of tenacity and elongation of sisal fibre with other workers

To know whether the values of tenacity and elongation of sisal fibre are correct, a comparison has been made with literature values and these are given in table 7. That the tenacity and elongation of sisal fibre compare favourably with values reported in the literature can be seen.

Table 7

COMPARISON OF VALUES OF THE TENACITY OF SISAL FIBRE WITH OTHER WORKERS

Tenacity (MPa)	Elongation (%)	References
600 – 700	3.0 – 5.0	Nam et al. [19]
568 – 640	2.0 – 3.0	Mahjoub et al. [20]
764	5.0	Mukherjee et al. [1]
363 – 700	2.0 – 7.0	Yan et al. [21]
511	7.63	Indu and Senthilkumar [22]
637 – 893	**7.0 – 16.0**	**Present work**

The effect of gauge length and alkali concentrations on tensile properties of sisal fibre

Table 8 presents data on tensile properties of untreated and alkali-treated sisal fibres at different gauge lengths. 25 readings are available for each gauge length with a constant strain rate of 100 mm/min, but only 5 sample details are given in tables 1, 3 and 5. It is apparent that with an increase in gauge length, there is a decrease in tenacity obviously due to a greater number of weak places. This is in agreement with the findings of Bharani and Mahendra Gowda [12]. Alkali-treated fibres generally show a drop in strength, but an interesting observation is that at 10% concentration and with a treatment time of 10 minutes the retention of strength is higher. This is due to the variation in cellulose content and the removal of lignin and waxes from the surface.

Effect of strain rate and alkali concentrations on tensile properties of sisal fibre

Table 9 presents data on tensile properties of untreated and alkali-treated sisal fibres at different strain rates. 25 readings are available for each strain rate with a constant gauge length of 50 mm, but only 5 sample details are given in tables 2, 4 and 6. It is noticed that the tenacity increases both for untreated

Table 8

TENACITY AND ELONGATION OF UNTREATED AND ALKALI-TREATED SISAL FIBRE AT DIFFERENT GAUGE LENGTHS (STRAIN RATE: 100 mm/minute) (EXPERIMENTAL VALUES)

Gauge length (mm)	Tenacity (MPa)						Elongation (%)					
	0% NaOH		5% NaOH		10% NaOH		0% NaOH		5% NaOH		10% NaOH	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
10	893.00	267.82	445.00	191.86	467.00	132.01	16.06	3.72	16.76	5.66	12.42	5.19
20	843.00	406.01	437.00	139.54	442.00	133.58	12.69	3.303	10.25	3.34	9.23	3.09
30	842.00	304.02	434.00	192.15	422.00	122.48	11.61	3.29	8.30	2.1	8.64	2.01
40	796.00	312.4	409.00	193.46	418.00	117.84	10.67	2.29	7.92	2.34	8.32	1.8
50	785.00	306.87	382.00	152.2	404.00	160.51	9.70	1.96	7.90	2.27	8.05	1.47
60	782.00	426.5	378.00	146.25	395.00	104.4	8.74	2.14	7.86	2.47	8.01	3.62
70	774.00	348.23	368.00	120.7	389.00	135.04	8.22	1.92	7.75	1.99	7.80	2.14
80	719.00	344.81	363.00	118.2	370.00	139.74	8.06	2.3	7.55	2.6	7.79	2.26
90	651.00	241.2	345.00	112.75	364.00	125.85	7.13	2.1	7.40	2.76	7.64	1.81
100	637.00	273.08	316.00	121.55	350.00	164.34	6.29	2.3	7.33	2.29	7.59	1.3

Table 9

TENACITY AND ELONGATION OF UNTREATED AND ALKALI-TREATED SISAL FIBRE AT DIFFERENT STRAIN RATES (GAUGE LENGTH: 50 mm) (EXPERIMENTAL VALUES)												
Strain rate (mm/min)	Tenacity (MPa)						Elongation (%)					
	0% NaOH		5% NaOH		10% NaOH		0% NaOH		5% NaOH		10% NaOH	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
10	303.00	158.43	338.00	101.44	392.00	121.97	5.75	2.59	8.86	2.57	8.87	2.61
50	309.00	170.23	369.00	123.36	409.00	139.76	6.14	2.49	8.45	2.5	8.69	3.21
150	327.00	147.72	411.00	124.48	419.00	113.18	6.77	1.91	8.39	1.73	8.28	2.62
250	338.00	140.16	457.00	143.9	428.00	154.9	6.95	2.31	8.63	1.83	7.85	2.45
500	504.00	283.59	510.00	162.32	559.00	176.59	5.92	2.22	10.75	3.75	11.86	2.67

and treated sisal fibres with the increase in strain rates. With theExcepted sisal fibre, elongation also increases following the same trend. As for treated fibres, elongation shows a higher value at 500 mm/min.

Effect of gauge length on tenacity and elongation

Table 10 presents data on Weibull modulus and characteristic value in respect of untreated and alkali-treated sisal fibres at different gauge lengths.

As far as the strength is concerned, values of the Weibull modulus do not show any specific trend. The difference in characteristic values of strength between 5% and 10% alkali is much less. Generally, the strength of treated sisal fibre is found to be lower than that of untreated. This is due to the removal of lignin, hemicelluloses and recrystallization. The same trend is noticed in elongation. The characteristic values of elongation of alkali-treated fibres are lower in comparison to untreated fibres except for 90 and 100mm gauge lengths. Gauge length has a significant effect on strength in that as the gauge length increases, there is a drop in strength. This is attributed to the weak places present in the fibre. These are in substantial agreement with the findings of Bharani and Mahendra Gowda [13]. Values of Weibull modulus in respect of elongation of treated fibres are found to be low in comparison to untreated fibre. Also, it should be clear that the values of Weibull modulus for elongation are found to be lower compared to strength.

Effect of strain rate on tenacity and elongation

Table 11 presents data on Weibull modulus and characteristic values at different strain rates for untreated and alkali-treated sisal fibres. It is apparent that with an increase in strain rate the tenacity shows an increase in all the cases. This is in substantial agreement with the finding of research workers Bharani and Mahendra Gowda [14].

As regards elongation, there is a drop which is attributed to the stiffening of the material. Values of Weibull modulus of strength show an increase with the increase in a strain rate. With regard to elongation, it is noticed that at a 500 mm/min strain rate, there is a drop in Weibull modulus for the material in untreated and 5% alkali-treated states. This shows that the scatter in elongation is quite high. While at 500 mm/min a significant increase in Weibull modulus

Table 10

VALUES OF WEIBULL MODULUS AND CHARACTERISTIC VALUE AT DIFFERENT GAUGE LENGTHS FOR UNTREATED AND ALKALI-TREATED SISAL FIBRES												
Gauge length (mm)	Tenacity (MPa)						Elongation (%)					
	Concentration of alkali						Concentration of alkali					
	0%	5%	10%	0%	5%	10%	0%	5%	10%	0%	5%	10%
	WM	WM	WM	CV	CV	CV	WM	WM	WM	CV	CV	CV
10	4.25	2.98	4.43	977	500	512	4.70	3.49	2.83	17.59	18.65	14.00
20	2.67	4.30	4.09	951	484	488	4.39	3.53	3.24	13.95	11.38	10.34
30	3.82	4.48	3.50	935	476	469	2.61	4.40	4.84	13.47	9.09	9.42
40	3.05	2.74	4.60	895	460	458	5.30	4.02	5.13	11.57	8.71	9.04
50	3.13	3.25	3.48	889	428	449	4.77	3.87	6.34	10.63	8.70	8.64
60	2.17	3.46	4.68	880	420	432	3.28	2.72	2.40	9.92	8.92	9.05
70	2.90	4.15	3.90	868	406	431	4.42	4.18	3.93	9.03	8.53	8.62
80	2.66	3.83	3.43	812	401	412	3.73	3.53	3.62	8.94	8.39	8.66
90	3.59	4.10	3.81	731	381	404	3.33	3.32	4.06	7.98	8.27	8.48
100	3.09	3.26	2.85	712	355	394	3.07	3.73	3.28	7.05	8.12	8.49

Table 11

VALUES OF WEIBULL MODULUS AND CHARACTERISTIC VALUE AT DIFFERENT STRAIN RATES FOR UNTREATED ANDALKALI-TREATED SISAL FIBRE

Gauge length (mm)	Tenacity (MPa)						Elongation (%)					
	Concentration of alkali (%)						Concentration of alkali (%)					
	0	5	10	0	5	10	0	5	10	0	5	10
	WM	WM	WM	CV	CV	CV	WM	WM	WM	CV	CV	CV
10	2.73	4.34	4.32	341	372	431	2.16	3.36	2.79	6.69	9.93	10.17
50	2.38	3.90	3.63	349	409	454	2.78	3.74	3.02	6.90	9.37	9.74
150	2.74	4.08	4.91	368	454	457	4.08	5.47	3.75	7.45	9.07	9.18
250	2.97	4.27	3.62	380	503	475	3.04	5.43	3.71	7.81	9.35	8.70
500	2.31	4.34	3.81	569	560	620	2.74	4.93	4.95	6.69	11.71	12.92

was noticed in respect of 10% alkali-treated sisal, in untreated and 5% alkali-treated samples the values are low. An increase in Weibull modulus in respect of elongation is observed in a few cases. A decrease in strength is noticed during sisal following treatment with caustic soda at 5% concentration. This is principally due to the removal of lignin and de-crystallization. Also, the same phenomenon is noticed at 10% concentration with a treatment time of 10 minutes. At 10 mm gauge length, alkali-treated sisal fibre exhibits a progressive increase in Weibull modulus and at other gauge lengths, treatment with 10% caustic soda is found to be better. Characteristic values of elongation are found to increase in alkali-treated samples as the treatments were applied in the slack state. This has been found to agree substantially with the findings of other research workers Mwaikambo and Ansell [15] and Anjali Karolia and Bhoj [16].

Weibull modelling

Tenacity and elongation values for untreated and treated sisal fibres at each gauge length and strain rate are discussed together with their values of Weibull modulus and characteristics values. The overall trend of tenacity and elongation and their Weibull modulus values as a function of gauge length and strain rate are also commented on to better understand the size effects. The figures for the Weibull distribution relationship between ln (σ_f) and ln (ln (1/(1 – *Pf*))) were determined by the least-squares method and were drawn in respect of untreated and alkali-treated sisal fibres tested at various gauge length such as 10 mm, 20 mm, 30 mm, 40 mm, 50 mm, 60mm, 70 mm, 80 mm, 90 mm and 100 mm respectively. Only the sample figures 1, *a–c* and 2, *a–c* display data on Weibull distribution in respect of untreated and alkali-treated sisal fibres tested at 10 mm is shown. Table 12 summarizes the data as noticed in the Weibull distribution plots.

Weibull parameters for untreated and treated sisal fibre tested at 10 mm gauge length with a strain rate of 100 mm/min.

Table 12 presents data on Weibull modulus and characteristic values. It may be noted that the characteristic values are more reliable than those of experimental values as they are estimated ones. It is noticed from table 8 that in respect of the Weibull modulus for tenacity, an improvement is noticed at a 10% concentration of alkali. Characteristic values, although in general, are lower in comparison to untreated fibre, the tenacity obtained at a 10% concentration of caustic soda with a duration of 10 min is slightly higher than that of 5% treated fibre.

Table 12

WEIBULL MODULUS AND CHARACTERISTIC VALUES – 10 mm GAUGE LENGTH

Details of sisal fibre samples	Weibull Modulus		Characteristic Value	
	Tenacity (MPa)	Elongation (%)	Tenacity (MPa)	Elongation (%)
Untreated	4.25	4.70	977	17.59
5% NaOH treated	2.98	3.49	500	18.65
10% NaOH treated	4.43	2.83	512	14.00

About elongation, there is a drop in Weibull modulus following treatment with caustic soda. The characteristic value for a 5% concentration of caustic soda is higher. Similarly, the Weibull plots for all gauge lengths from 20 mm to 100 mm were drawn.

Effect of treatments on sisal fibres tested at different gauge lengths keeping strain rate constant at 100 mm/min on the correlation coefficient

The correlation coefficient of untreated and alkali-treated sisal fibres obtained at various gauge lengths keeping strain rate constant at 100 mm/min were examined and are given in table 13. After the treatment with 10% for 10 minutes, values of correlation coefficient show an increase compared to untreated in 50% of the cases. Hence, it can be concluded that there is a very good relationship between the two parameters for which the linear regression analysis has been performed. The same trend is noticed in elongation also.

Weibull parameters for untreated and treated sisal fibre tested at a 10 mm/min strain rate with a gauge length of 50 mm

There is an all-around improvement in tenacity and elongation for both untreated and treated sisal fibres

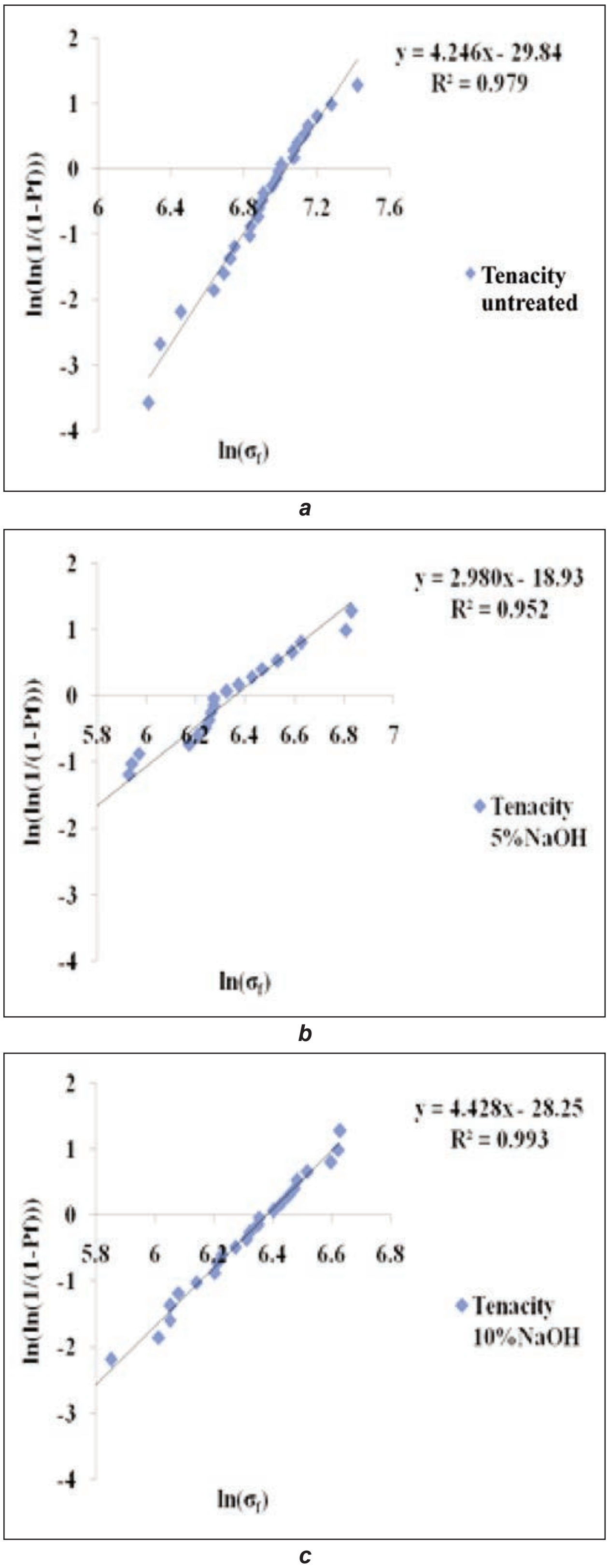


Fig. 1. Weibull plot for untreated and treated sisal fibre tenacity tested at 10 mm gauge length (Strain rate 100 mm/min): *a* – untreated; *b* – 5%NaOH treated; *c* – 10%NaOH treated

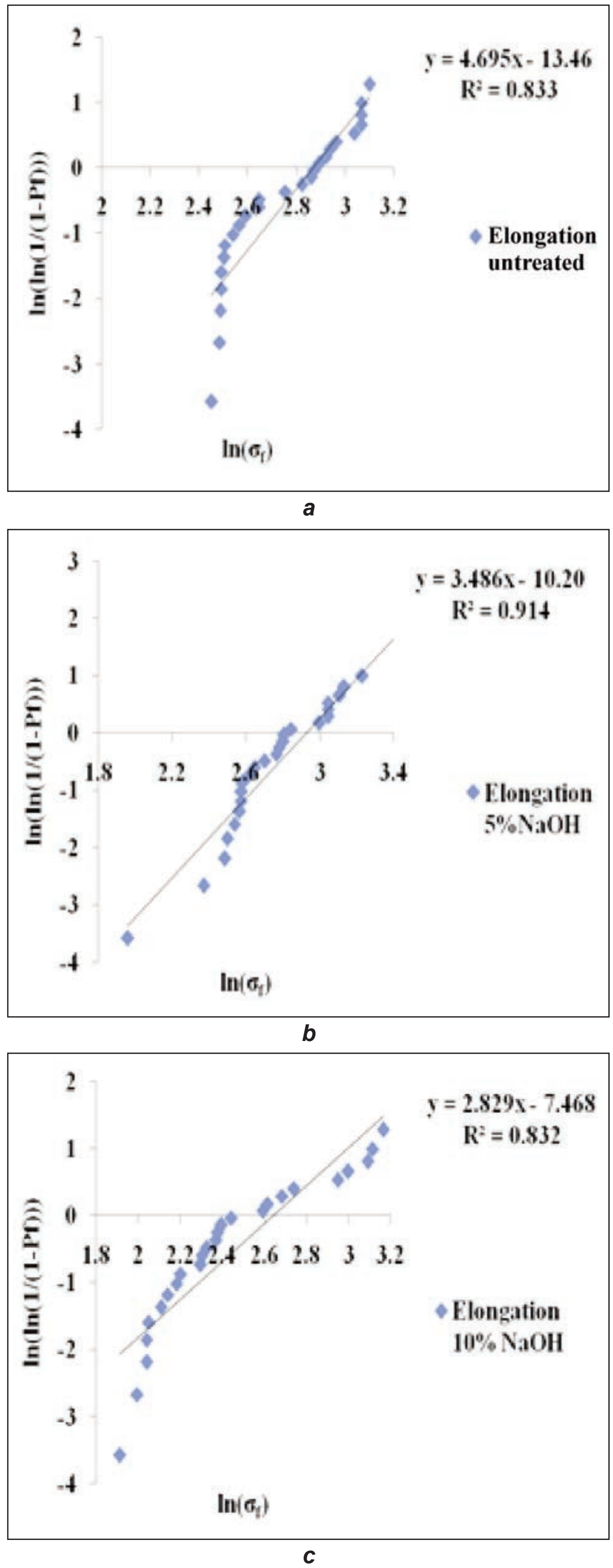


Fig. 2. Weibull plot for untreated and treated sisal fibre elongation tested at 10 mm gauge length (Strain rate 100 mm/min): *a* – untreated; *b* – 5%NaOH treated; *c* – 10%NaOH treated

tested at a 10 mm/min strain rate (table 14) and the Weibull plots are depicted in the figures 3, *a–c* and 4, *a–c*. Similarly, the Weibull plots for all strain rates 50 mm/min, 150 mm/min, 250 mm/mm and 500 mm/min were drawn.

Effect of alkali treatment and strain rates keeping gauge length constant at 50 mm of sisal fibre on the correlation coefficient

The correlations between the two parameters from which the two Weibull parameters have been

Table 13

CORRELATION COEFFICIENT FOR UNTREATED AND ALKALI-TREATED SISAL FIBRES TESTED AT DIFFERENT GAUGE LENGTHS KEEPING STRAIN RATE CONSTANT AT 100 mm/min						
Gauge length (mm)	**Tensile Strength**			**Elongation (%)**		
	0%	**5%**	**10%**	**0%**	**5%**	**10%**
10	0.98	0.95	0.99	0.83	0.91	0.83
20	0.92	0.80	0.98	0.95	0.97	0.92
30	0.82	0.98	0.95	0.85	0.97	0.97
40	0.97	0.95	0.91	0.96	0.95	0.97
50	0.98	0.94	0.93	0.93	0.84	0.91
60	0.94	0.94	0.98	0.84	0.97	0.97
70	0.98	0.94	0.89	0.94	0.97	0.99
80	0.93	0.98	0.95	0.99	0.89	0.98
90	0.95	0.96	0.92	0.96	0.97	0.87
100	0.94	0.89	0.89	0.94	0.94	0.98

Table 14

WEIBULL MODULUS AND CHARACTERISTIC VALUES – 10 mm/min STRAIN RATE				
Details of sisal fibre samples	**Weibull Modulus**		**Characteristic Value**	
	Tenacity (MPa)	**Elongation (%)**	**Tenacity (MPa)**	**Elongation (%)**
Untreated	2.73	2.16	341	6.69
5% NaOH treated	4.34	3.36	372	9.93
10% NaOH treated	4.32	2.79	431	10.17

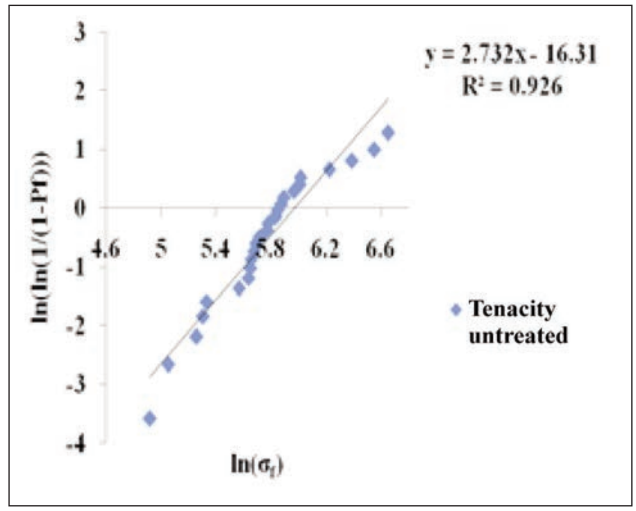
obtained by linear regression analysis are given in table 15. There is an improvement in the correlation following the treatment at the strain rates employed for the treated materials both in tenacity. Such a trend is not noticed in elongation.

Table 15

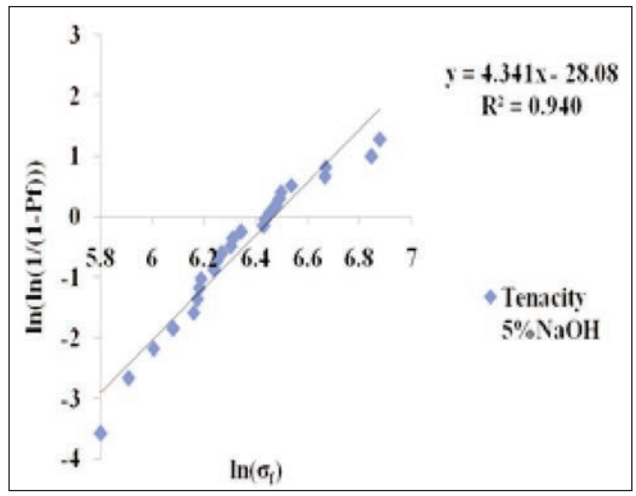
CORRELATION COEFFICIENTS FOR UNTREATED AND ALKALI-TREATED SISAL FIBRES TESTED AT DIFFERENT STRAIN RATES KEEPING GAUGE LENGTH CONSTANT AT 50 mm						
Strain rate (mm/min)	**Tenacity (MPa)**			**Elongation (%)**		
	0%	**5%**	**10%**	**0%**	**5%**	**10%**
10	0.93	0.94	0.94	0.97	0.96	0.88
50	0.92	0.95	0.95	0.96	0.95	0.96
150	0.97	0.99	0.92	0.96	0.98	0.89
250	0.98	0.96	0.97	0.99	0.94	0.92
500	0.91	0.94	0.99	0.98	0.94	0.96

Air plasma treatment on sisal fibre

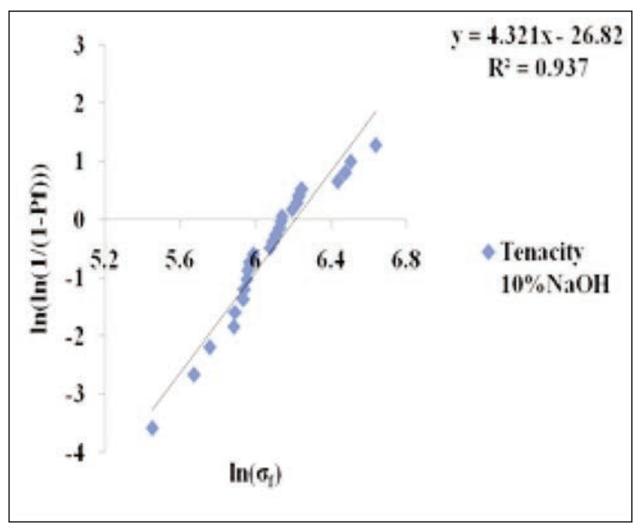
Air plasma treatment is used to modify the surface characteristics of sisal fibre [17]. The effects of air plasma treatment on interfacial bonding between untreated and treated sisal fibres are evaluated using



a



b



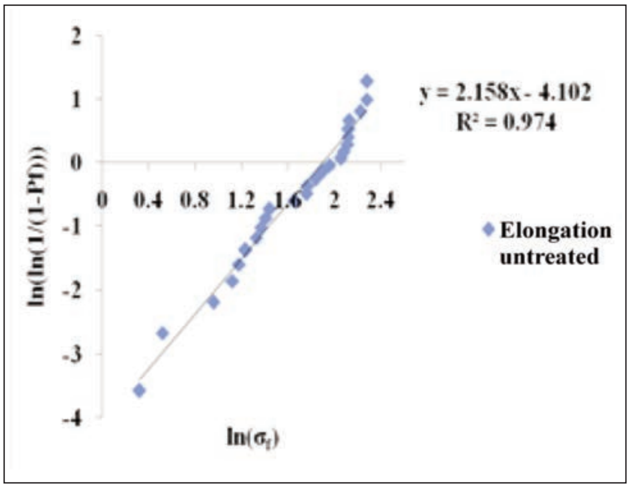
c

Fig. 3. Weibull plot for untreated and treated sisal fibre tenacity tested at 10 mm/min strain rate (Gauge length 50 mm): *a* – untreated; *b* – 5%NaOH treated; *c* – 10%NaOH treated

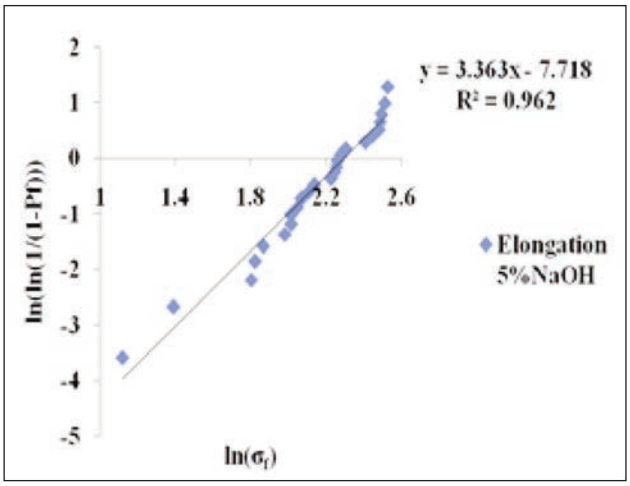
a single fibre pull-out test. In the present work, a single fibre pull-out test was used to measure the interfacial adhesion between an untreated and treated sisal fibre. All the pull-out tests were performed on the Instron testing machine using a special micro vise. The test results of untreated and air plasma-treated sisal fibres are given in table 16. The result shows that the tensile strength decreases almost proportionately with the increase in the treatment time. But elongation increases with the plasma treatment time.

SEM analysis of untreated and NaOH-treated sisal fibres

Figures 5, *a–c* show scanning electron micrographs of untreated and treated sisal fibres with sodium hydroxide with different concentrations and duration



a



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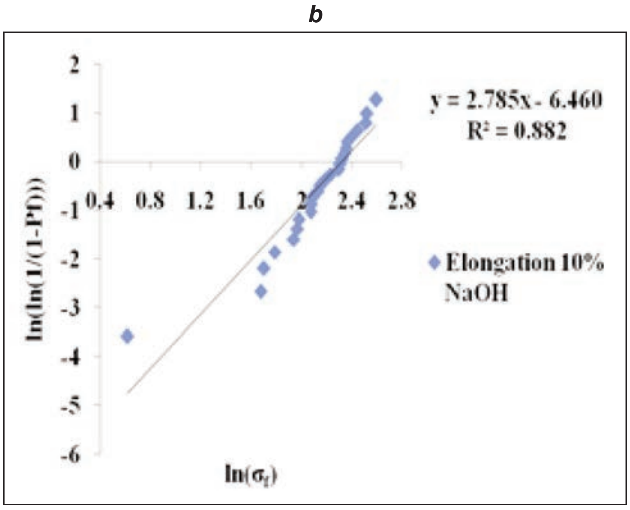
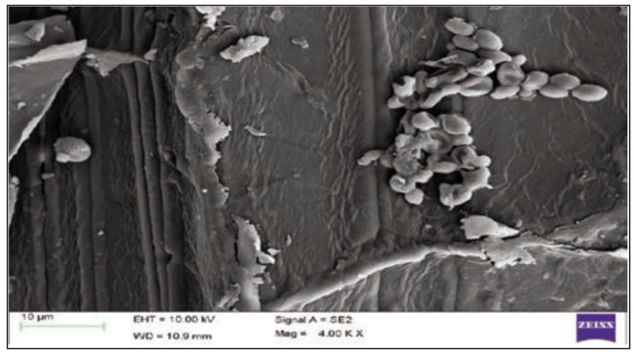
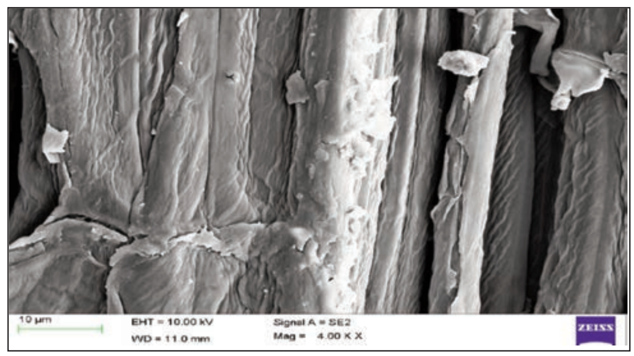


c

Fig. 4. Weibull plot for untreated and treated sisal fibre elongation tested at 10 mm/min strain rate (Gauge length 50 mm): *a* – untreated; *b* – 5%NaOH treated; *c* – 10%NaOH treated



a



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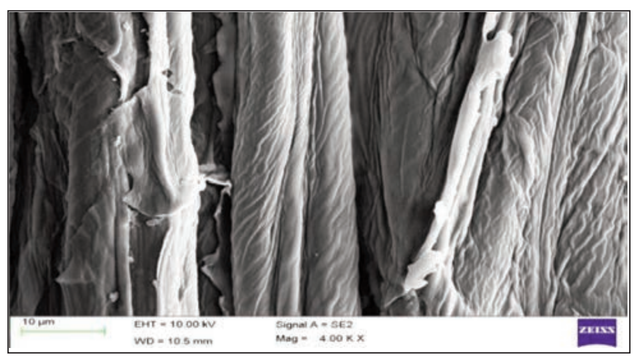

c

Fig. 5. SEM micrographs of untreated and treated sisal fibre at 4000 magnification (scale bar = 20 μm): *a* – Untreated sisal fibre; *b* – NaOH treated for 1 hour at room temperature; *c* – 10% NaOH treated for 10 min at room temperature

Table 16

Sample details	Testing conditions			Average fibre tensile strength (MPa)	Average fibre elongation (%)
	Time (s)	Power level (W)	Pressure (torr)		
Untreated sisal fibre	-	-	-	651	7.13
Plasma-treated sisal fibre	30	60	2	565	8.2
	60	60	2	512	9.7
	120	60	2	467	10.8

of treatment. In untreated sisal fibre, the presence of some impurities and waxes can be seen. The surfaces show a significant difference following alkali treatment.

CONCLUSION

With the appropriate Weibull distribution software model, the results show that gauge length affects the strength and elongation of untreated and alkali-treated sisal fibres in that with an increase in gauge length there is a decrease in strength and elongation. Strain rate significantly affects strength and elongation. While the former shows an increase, the latter shows a decrease. On basis of Weibull modulus values, treatment of fibre with 10% caustic soda at a treatment time of 10 minutes has provided better performance in comparison to treatment with 5% concentration for 1 hour. After the treatment with 10% for 10 minutes, values of correlation coefficient show an increase compared to untreated in 50% of the cases. Hence, it can be concluded that the treatment has improved the performance. The same trend is noticed in elongation also. Tensile strength shows an improvement following treatment with alkali. The correlation coefficients have improved showing a better relation compared to the gauge length effect, the strain rate for the treated materials shows an improvement. The scanning electron micrographs show the removal of impurities and the other substances following alkali treatment. The presence of fibrillar structure is noticed in alkali-treated sisal fibre. In addition to the Weibull distribution model, the air plasma treatment and SEM analysis also prove that the treated sisal fibre is more suitable for geotextile applications.

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Investigating the impact of COVID-19 pandemic on volatility patterns and its global implication for textile industry: An empirical case study for Shanghai Stock Exchange of China

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ABSTRACT – REZUMAT

Investigating the impact of COVID-19 pandemic on volatility patterns and its global implication for textile industry: An empirical case study for Shanghai Stock Exchange of China

This research paper aims to examine the impact of the COVID-19 pandemic on volatility patterns and its global implication for the textile industry in China. The COVID-19 pandemic has generated a global health crisis with profound economic, social and financial implications, but also has triggered a ruthless global recession. The global economic recovery as a result of the COVID-19 pandemic can also generate significant investment opportunities for the textile industry in China. In this paper, the application of empirical methods could explain historical prices, the movement dynamics of financial assets, and investigate various important characteristics of asset pricing that explore details of the Chinese stock market. The econometric framework includes the following: symmetric Generalize Autoregressive Conditional Heteroscedastic GARCH (1, 1) model, asymmetric GARCH models such as EGARCH and GJR models. The main aim is to identify the asymmetric volatility effect, and impact of news on the SSE Composite Index and investigate long memory properties in volatility using daily data for the sample period from 19th December 1990 to 31st December 2020. This empirical study contributes to the existing literature on the impact of the COVID-19 pandemic on international stock markets, by investigating symmetric and asymmetric volatility patterns in the case of the Shanghai Stock Exchange from China.

Keywords: *GARCH family models, symmetric volatility, asymmetric volatility, COVID-19 pandemic, apparel, textile industry, economic recession, leverage effect*

Analiza impactului pandemiei COVID-19 asupra modelelor de volatilitate și a implicațiilor sale globale pentru industria textilă: Un studiu de caz empiric pentru Shanghai Stock Exchange din China

Acest articol de cercetare își propune să examineze impactul pandemiei COVID-19 asupra modelelor de volatilitate și implicația sa globală pentru industria textilă din China. Pandemia COVID-19 a generat o criză globală de sănătate cu implicații economice, sociale și financiare profunde, dar a declanșat și o recesiune globală semnificativă. Redresarea economică globală ca urmare a pandemiei de COVID-19 poate genera, de asemenea, oportunități de investiții semnificative pentru industria textilă din China. În acest studiu de cercetare, aplicarea metodelor empirice ar putea să explice prețurile istorice, dinamica comportamentală a activelor financiare tranzactionate și să investigheze diferite caracteristici importante ale prețului activelor care explorează particularitățile pieței bursiere din China. Abordarea econometrică include următoarele: modelul simetric GARCH (1, 1), modelele GARCH asimetrice precum modelele EGARCH și GJR. Scopul principal este de a identifica efectul de volatilitate asimetrică și impactul știrilor asupra indicelui compozit SSE, precum și de a investiga proprietățile memoriei pe termen lung în volatilitate folosind date zilnice pentru perioada de eșantionare din 19 decembrie 1990 până la data de 31 decembrie 2020. Acest studiu empiric are contribuție în literatura de specialitate existentă privind impactul pandemiei COVID-19 pe piețele bursiere internaționale, prin investigarea modelelor de volatilitate simetrice și asimetrice în cazul Shanghai Stock Exchange din China.

Cuvinte cheie*: modele GARCH, volatilitate simetrică, volatilitate asimetrică, pandemie COVID-19, îmbrăcăminte, industria textilă, recesiune economică, efect de levier*

INTRODUCTION

COVID-19 pandemic has generated impressive losses but also attractive advantages for the global economy. The interaction between the financial market and the real economy can lead to sustainable economic growth, including based on the efficiency of the textile sector of China. World Bank indicates that the U.S. has been in the first position with financial market capitalization followed by an Asian emerging economy, China, in the second position. Historical statistics suggest that China was not even in the top five countries with high market capitalization till 2004. In the journey of the next 12 years, i.e., 2016, the Asian giant has secured the second position with financial market capitalization. Shanghai Stock Exchange has now had a market capitalization of over 6 trillion starting with a base index point of 100 in December 1990, which grew up to over 6000. There are several interesting market movement pattern that makes SSE China different from any other financial market. For instance, in the period 2004–2006, the time before the global financial crisis, when most of the world's financial markets are making new historical highs, the Chinese market (SSE) made its low, 1013 rim billion. Surprisingly, in the year 2007 and emerging weeks of 2008, when most of the financial markets were weak, and struggling to sustain the market, the SSE made its lifetime high trading levels global financial crisis was about to hit the world's financial markets. It is the exact time just before the global financial crisis impacted the reported high to 5903 rim billion.

Very recent, the effect of COVID-19 where most of the financial market performing weaker during December and January 2020, there was not any strong impact on SSE initially until more cases were reported, the major impact started from February 2020. Only a few major corrections appear in the movement pattern of SSE, which has wiped off billions of investors' investments, created panic out of investor's predictions and that panic escalated to the rest of the world's financial markets. The first case was identified on 4th January 2020, no changes were abstracted by SSE, and even a few more cases were reported up to 20th January 2020, still no change in SSE movement pattern until 23rd January, COVID-19 impact started with the first loss of over 200 rim billion. At the same time, the rest of the financial markets also abstracted on an average of more than 8% corrections due to novel pandemics. Volatility in the financial market changes the value of the investment. Castañeda-Navarrete et al. [1] suggested that the COVID-19 pandemic significantly affected international trade and global value chains, including the global apparel industry. The COVID-19 pandemic generated considerable losses in the global production system. Frederick and Daly [2] have conducted a grounded statistical research study and concluded that is still one of the most important apparel producers and exporters in the world. Moreover, the apparel industry in China has experienced favourable and competitive dynamics in recent decades because it has a great diversity of products and materials. Song et al. [3] investigated the effect of the COVID-19 pandemic on the manufacturing field in China and proposed an opportune alternative solution to creating a regional value chain in manufacturing managed by China, Japan and South Korea.

Volatility is one of the strongest fundamental parameters that create changes in asset prices. When asset price falls from the purchase price, it increases risk and stock returns. Volatility is the result of a combination of negative and positive shocks at the same time with different volumes of trades. Black [4] introduced the innovative concept that has explored details of the financial market and asset price – the concept of the leverage effect. The phenomenon introduced as the leverage effect indicates that negative shocks in previous volatility impact more negative shocks compared to positive shocks. This concept has captured worldwide attention. The financial market looked symmetric correlations until the introduction of the leverage effect. This asymmetric concept extended visibility and forecasting to asset price movement. The symmetric approach of volatility modelling focuses on volatility clustering that reflects in always positive autocorrelation of squared returns appearing movements to deterioration to zero.

This paper explores the Chinese Stock Market considering the Shanghai Stock Exchange index from the beginning of time i.e., 19th December 1990 to 31st December 2020 considering daily closing prices for 30 years. The paper focus to innovate 1) volatility estimation, 2) the presence of leverage effect, 3) impact of news and reaction of Chinese stock exchange index, and 4) index movement pattern and risk-return prospects. In December 2019, a novel coronavirus was identified that later spread in Wuhan, China. Inter-transmitted volatility details of the Shanghai Stock Exchange Composite Index were used to identify the probability distribution of asset price dynamics. Volatility change highlights important evidence in asset returns. Despite such invention, no impact appears anywhere during January 2020, until it was declared pandemic and uncertain fall started to appear from February 2020. We cover the impact of high volatility shocks during COVID-19 panic time which has created uncertain movements in the Shanghai Stock Exchange. A natural way to interpret financial series volatility estimation is to examine statistical relevance between investment and output at time *t*. Volatility is indicated by ups and down in index prices so as in asset prices. The most influential innovation by Robert Engle [5] represents the ARCH model that estimates volatility, further generalized by Bollerslev [6] that captures volatility clustering of asset prices so the model is symmetric along with one ARCH and one GARCH effect. Moreover, Birau et al. [7] conducted a research study and the empirical results suggested that GARCH (1, 1) model is not fitted for the sample stock markets of Spain and Hong Kong in the context of the COVID-19 pandemic. Brooks and Rew [8] argued that the GARCH model is the most representative and accurate for modelling volatility in financial time series data. We employ GARCH family models to estimate the volatility of the most representative stock index of SSE from China, which is the Shanghai Stock Exchange (SSE) Composite Index.

This research paper is structured as follows: the subsequent section presents a literature review. The third section covers the methodology used in the econometric approach to GARCH and GARCH Family models. The following section covers empirical analysis, presentation of the statistical property and detailed interpretation of the SSE Composite index movement. Conclusion marks and findings are presented in the fifth section.

LITERATURE REVIEW

There are two significant schools of thought on volatility. One school of thought (Lockwood and Linn, 1990) argues that the introduction of futures trading increases the volatility in the spot market and thereby the market gets destabilized. Another school of thought [9] argues that the introduction of futures actually reduces the volatility and thereby the market gets stabilized, while GARCH analysis confirmed no structural change after the introduction of futures trading on the National Stock Exchange (NSE) of India. Further, Kumar [10] opines that derivative trading helps in price discovery, improves the overall market depth, enhances market efficiency, augments market liquidity, reduces asymmetric information and hence the degree of volatility of the cash market decreases. Thenmozhi [11] says that the movements in future prices provide predictable information for the movements of the index. She also agrees that the volatility gets decreased due to the introduction of futures. Shenbagaraman [12] has studied the impact of the introduction of derivatives on the spot market volatility. The study explained that the increased volatility of the Indian stock market was due to the increase in the volatility of the US market. Nath [13] has found in his study that volatility decreases due to the introduction of derivatives. Vipul [14] examined the change in volatility in the Indian stock market especially after the introduction of derivatives. It was identified that there was a reduction in underlying shares after the introduction of derivatives.

World Health Organization (WHO) defines COVID-19 as an infectious disease determined by a new type of coronavirus named SARS-CoV-2. Moreover, WHO was first informed about this extremely contagious virus included in the family of coronaviruses, on 31 December 2019, due to an explosion of cases of "viral pneumonia" identified in Wuhan, which is the capital of Hubei province in central China. Moreover, China was the first country in the world which implemented the restrictive measure of lockdown to limit the spread of COVID-19 infection cases. On the other hand, Batool et al. [15] argued that it is well-known fact that pandemics determine economic distress so it is no surprise that the COVID-19 pandemic is similar. Government authorities in countries all around the world have been forced to impose harsh measures and lockdown restrictions to limit the spread and high infection rate of COVID-19 despite the tremendous economic cost associated with them. The global economy has been severely affected by the COVID-19 pandemic since its outbreak in China. Zulfiqar et al. [16] suggested that the governance quality should be strengthened that set the direction of change to achieve greater financial stability and growth. However, Spulbar et al. [17] suggested that sustainable development represents a great challenge for the global economy.

According to World Trade Organization also known as WTO [18], the COVID-19 pandemic which generated a global health crisis with profound economic, social and financial implications is "an unprecedented disruption to the global economy and world trade, as production and consumption are scaled back across the globe". Nicola et al. (2020) investigated the socio-economic impact of the COVID-19 pandemic and suggested that due to necessary measures such as social distancing, self-isolation and travel restrictions, it is expected to degenerate into severe economic crisis and recession.

The Organization for Economic Cooperation and Development also known as OECD investigated in March 2021 the impact of the COVID-19 pandemic on global financial markets and has identified significant shocks and turbulences compared to the turmoil and market risk aversion caused by the global financial crisis of 2007–2008 [19]. As an immediate consequence, stock markets have collapsed by more than 30% considering international stock market contagion, while the economic growth in China suddenly declined and the domino effect spread globally. Despite financial reforms, the severe economic recession has affected most countries all around the world.

Bahrini and Filfilan [20] examined the effect of the COVID-19 pandemic on stock returns in the case of Gulf Cooperation Council (GCC) countries for the sample period from April 1, 2020, to June 26, 2020. The empirical findings indicate that daily returns of the major stock market indices, in the GCC member states, such as ADSMI for Abu Dhabi of the United Arab Emirates, BHSEASI for Bahrain, MSM30 for Oman, SASEIDX for Saudi Arabia and DSM for Qatar, decreased as the number of confirmed deaths increased. Zhang et al. [21] have conducted an empirical study based on unsophisticated statistical analysis to determine the global implications of the COVID-19 pandemic, which is a global health crisis, on stock market risk in the case of financial markets all over the world. This empirical study included stock market databases collected for the top 10 most infected countries based on several confirmed cases of COVID-19 infection, together with Japan, South Korea and Singapore, while Iran is excluded due to unavailable data, up to March 27, 2020. The empirical findings revealed that the reaction of global financial market risks was characterized by a consistent increase due to the COVID-19 outbreak. Moreover, the impact of the COVID-19 pandemic generated high uncertainty and economic losses which determined that stock markets have become highly volatile and unpredictable.

Thus, there are two types of observations; one is that volatility increases if futures and options are introduced and the other is that the degree of volatility decreases or the stock market gets stabilized for the introduction of the futures segment. Dulababu [22] in his study reveals that the India VIX is not taken as a source of an opportunity to make returns. Further, the Indian traders treat the India VIX as a fear index.

They perceive it as a threat and a danger signal and hence they avoid trading when the market is falling. Unless the stock market becomes more and more sensitive to multiple external factors such as Govt policies in the country, wide and in-depth population exposure to the stock market after intensive awareness programs to encourage the public to have exposure in the equity market, global stock markets' movements, developed and dominating country economic policies etc, the India VIX and other instruments as mentioned above may not become a popular instrument to trade and invest in.

Chaudhary et al. [23] examined stock market volatility in the case of the most representative 10 countries in the world, using GDP databases, i.e.: the United States (S&P 500 index), China (Shanghai Composite index), Japan (Nikkei index), Germany (Dax index), India (BSE-Sensex index), the United Kingdom (FTSE100 index), France (CAC40 index), Italy (FTSE Italia All Share index), Brazil (IBX40 index) and Canada (S&P TSX Composite index). The econometric framework included the following: Descriptive Statistics, Unit Root Test, ARCH effect test and (GARCH) (1,1) model for the sample from the period from 1 January 2019 to 30 June 2020. The empirical findings revealed that GARCH (1,1) model exhibits the fact that the COVID-19 coefficient in the conditional variance equation has a substantial positive influence on conditional variance for all selected stock market indices, which indicates that the coronavirus pandemic has increased the volatility in the case of all these sample stock markets.

The volatility of the Shanghai stock index is found asymmetric by many researchers. To be specific, the negative information would engender more volatility than that caused by positive information. Numerous researchers like Sun and Yan [24], Gan [25] explored that the daily returns exist in the leverage effect of the two markets which indicates that the volatility caused by bad information shock is greater than that produced by the positive information with the same degree. This phenomenon resembles the feature of the mature stock market. Although the leverage effect confirmed the existence in the Shanghai and Shenzhen stock market, the results also show that the leverage effect in Shanghai Composite Index is stronger than Shenzhen Component Index. Similar findings were reported from other studies. Whereas, the results from research conducted by Liu and Zhang [26] and Huang [27] produced a very diverse set of events. Huang [27] suggested in his study came up that there is no significant leverage effect in the Shenzhen stock market. This researcher also pointed out that having no short-selling mechanism in the Chinese stock market might be the main reason. Although investors anticipate the stock price would fall further when the stock market is shocked by the negative information, only the investors who hold the shares would react to this. Though, the rest of the investors are not able to respond by selling stock so there is no remarkable leverage effect in a mature stock market. On the other hand, Liu and Zhang [26] explored that the Shenzhen stock market has a more significant leverage effect and volatility than the Shanghai stock market.

Fan et al. [28] investigated the volatility dynamics of Chinese stock markets, such as the Shanghai and Shenzhen stock markets from January 2005 to June 2015 based on GARCH family models. The empirical findings revealed that EGARCH (1,1) model is the most suitable and fits the sample databases in both cases, while also providing a higher prediction accuracy than the other selected GARCH models. In other words, the EGARCH model fits both Shanghai and Shenzhen exchanges well with consideration of the following two aspects. One is the model selection criteria AIC and SC, and the other is the forecast performance based on the forecast evaluation statistics. Moreover, the Shanghai stock market exhibits a much higher leverage effect compared with the Shenzhen stock market. However, some other researchers just take one aspect into analysing. For instance, Pei and Xu [30] just compare the fitting results by some criteria such as R square, AIC and SC and then make the conclusion, which is similar to Huang [27]. Though, being only in the view of the model selection criteria is not enough to choose the best-fitted model. It is essential to evaluate the forecast performance of each candidate model as a reliable reference by comparing the forecast evaluation statistics such as MAE, RMSE and MAPE. Also, it's noteworthy that the fundamentals of these two classification methods are different which might lead to distinct results. Alexander and Lazar [30] also comment that the one with the most accurate forecast performance is the most appropriate model to fit the stock market among the competing models. In other words, the latter aspect is more essential than the former one to some extent.

The research of Fan et al. [28] examined the volatility behaviour of Chinese stock markets by some variations of the heteroscedastic (or heteroskedastic) conditional volatility models. The results show that the EGARCH (1,1) outperform other traditional models in modelling and forecasting the volatility of the Chinese stock market. AIC, SC, RMSE, MAE and MAPE model selection criteria give proof of the above judgement. In detail, when the daily returns are shocked and then perform the abnormal volatility, the impacts would not eliminate in the short term. Hence, the overall risk of the Chinese stock market is high to some extent. More importantly, there exist significant leverage effects in the daily returns series of both indices. That is, the volatility in the diminishing market tends to be higher than in the booming market. It indicates that the investment consciousness of most Chinese investors is relatively weak so investment behaviour is easily affected by all kinds of information. This is also noteworthily that the leverage effect in Shanghai Compo-site Index is greater than that in the Shenzhen Component Index which indicates that the speculation in Shanghai stock market is greater than in the Shenzhen stock market. Provided that the investors could recognize these features of the volatility in the Chinese stock market, this may help them to avoid risk instead of noise trading, as well as provide a policy basis for decision-making departments of government to supervise the securities exchanges.

Moradi et al. [31] have conducted an empirical study on the effects of macroeconomic variables on stock price crash risk in the case of the Iranian market. The research results can be a red flag for political decision-makers in emerging markets struggling with financial issues to focus on the stock market in macroeconomic planning to avoid triggering a crisis and implicitly capital flight. The implementation of transaction policy has played an important role in the Chinese stock market in recent years. The phenomenon of sudden slump or rise in the prices of stocks has been brought down to a certain extent. Furthermore, the risk conduction mechanism is gradually developed. But there still exist many problems in the Chinese stock market. For instance, the stock market organization structure of Shanghai and Shenzhen could not effectively manage and deal with the occasional events, which caused strong impacts on the stock markets [32]. Regulators should take more stringent measures to reduce the number of vicious speculation and control the volatility. Understanding volatility in emerging capital markets is essential for determining the cost of capital and evaluating direct investment and asset allocation decisions. It would be of benefit for investors to identify risks and increase the awareness of risk investment.

DATA AND RESEARCH METHODOLOGY

From the above-reviewed literature, it is clear that researchers have explored various aspects of volatility in the stock market. The present study is an attempt to strengthen the existing literature. This paper focused to understand, analyse and explore volatility pattern and volatility clusters from the base index. Shanghai Stock Exchange (SSE) was introduced with a base index of 100 (99.98) on 19th December 1990 and a daily closing price considered for three decades. The daily closing price of the Shanghai Stock Exchange (SSE) Composite Index has been considered from 19th December 1990 to 31st December 2020 considering 7494 daily observations. The daily closing price of SSE is objected to provide historical evidence of the presence of volatility in today's price whether following the impact of yesterday's price, understanding price movement pattern, exploration of risk-return and impulse change in financial series movements.

The empirical study of the paper will provide support to understanding impulse magnitude, escalating risk-return and exploring the Shanghai Stock Exchange movement pattern. To meet with objected outcomes, we employ the application of several statistical tools that measure normality, movement of series pattern, explore volatility and leverage effect.

Statistical application set includes conversion to log, symmetric Generalize Autoregressive Conditional Heteroscedastic GARCH (1,1) model to estimate volatility, asymmetric GARCH model sets EGARCH and GJR to map leverage effect and predict the impact of the news. The financial series of SSE – China converted to log returns expressed in equation1. During the process of the equation, *rt* represents logarithmic daily returns of SSE China for time *t*, *Pt* indicates the closing price at time *t*, and similarly, *Pt*–1 indicates the corresponding price of time *t*–1. Unit root test is applied to SSE China series return that determines stationary in the case of selected observations. Application of ADF property indicates that if ADF statistics is less than its critical value along with p-value > 0.05, the null hypothesis is rejected, and the series return is ready for model application. This test employed to eliminate the normality of the distribution hypothesis, asymmetry distribution and kurtosis parameter (leptokurtic distribution) shown in equation 3.

Log conversion:

$$r_t = \ln\left(\frac{p_t}{p_{t-1}}\right) = \ln(p_t) - \ln(p_{t-1}) \quad (1)$$

Symmetric GARCH (1, 1) model:

$$h_t = \omega + \alpha_1 u_{t-1}^2 + \beta_1 h_{t-1} \quad (2)$$

The variance equation assumption process assures that value of the constant is higher than 0. GARCH (1, 1) represents the symmetric model that is extensively used to estimate volatility in time-series returns. One limitation of the symmetric model is that it does not capture the leverage effect which is required to have additional lags and exponential process, thus asymmetric GARCH type models i.e., EGARCH also called Exponential GARCH and GJR. Negative news creates a more pronounced effect on the financial market and probable impact measurement can be interesting in a manner to get an idea about the elasticity of market movement during a negative news reaction.

EGARCH by Nelson [33] captures asymmetric responses of time-vary variances to volatility shocks and also ensures that variance is always positive.

$$\log(\sigma_t^2) = \omega + \sum_{j-i}^{p} \beta i \log(\sigma_{t-i}^2) + \\ + \sum_{j-1}^{q} \alpha i \left\langle \frac{si-t}{\sigma i-t} \left| \frac{-\sqrt{2}}{n} \right| - \text{yi}\, \frac{si-t}{\sigma i-t} \right\rangle \quad (3)$$

Another asymmetric model GJR is a variant of Threshold GARCH and developed by Glosten, Jagannathan and Runkle [34] also measures stylized facts such as the leverage effect and effect of the news on stock markets. In this model there is only regression in the mean equation which is constant:

$$ht = \delta + \alpha_1 e_{i-1}^2 + \gamma d_{i-1} e_{t-1}^2 + \beta_i h_{i-1} \quad (4)$$

$$\sigma_t^{\delta} = \omega + \alpha$$

where *dt* represents two cases in case of 1 and 0, where *et* < 0, creates bad news and 0, *et* > 0 indicates good news. Further the value of alpha, Gamma and Beta are non-negative parameters satisfying condition similar to the EGARCH model in an otherwise manner. In 1993 Ding, Granger and Engle introduced the Asymmetric Power ARCH Model known as APARCH which is an asymmetric model and perfectly expresses details of Fat tails, presence of leverage effect and leptokurtic effect. APARCH model expands as follows; APARCH model includes ARCH and GARCH model and by changing parameters, the result can also be abstracted for ARCH, GARCH, GJR, TARCH, NARCH and Log-ARCH models.

INTERPRETATION, EMPIRICAL RESULTS AND DISCUSSIONS

Shanghai Stock Exchange Composite Index was introduced in December 1990 with a base index of 100 points over 30 years it has never traded below the base level. The paper includes data ranging from 19^{th} December 1990 to 31^{st} December 2020 considering 7494 daily closing observations. We parted data for the year 2020, i.e., January to June and July to December to compare high magnitude negative and positive changes. It provides interesting and lucrative outputs such as 100 low and 6092 lifetime high and low index trading levels. SSE Composite index movement shows constant upward trend between 2006 and 2007 escalating trading level from 1000 to 6000 which denoted as rapid and aggressive transmitting index movement pattern as high positive and negative shocks reported. Before the global financial crisis movement pattern. It is insightful to note the most aggressive series transmitting pattern for the Chinese stock exchange. Two strongest positive high magnitude shocks appear followed by negative continuous shocks correcting excess gambling trading. SSE Composite Index series movement rejects the hypothesis of financial theory for normal distribution as the series jumps from base 100 to above 6000 with the continuous escalation of a central point. By looking at the series movement, it appears attention to 2006, 2007, 2008, 2013, and 2014 which indicate the largest market growth and fall. Using log conversion and considering the first log-difference, the SSE China series is converted into stationary and reflects volatility clustering. Thus, it reviews earlier assumption that appears on actual series movement for higher magnitude shocks. Figure 2 provides information that high shocks follow several low shocks. Further, negative shocks with high magnitude follow several positive high shocks with low magnitude continuously for a prolonged period. It indicates volatility is clustering and makes a constant mean. This phenomenon attracts more loss and complex trading during the intra-day session.

The property of descriptive statistics is summarized in table 1. The mean value is non-negative indicating a positive return and an increase in asset value over time. From table 1 it is inferred that asset return is positively skewed with an exceptionally high degree of positive kurtosis. It creates a leptokurtic effect, makes a distinct peak near the mean and contains a probability of rapid decline (graphical presentation appears in figure 3). The statistical hypothesis of the normal distribution is three. In the present study, excess kurtosis indicates over 160 suggesting stock increases the probability of extreme events. This indicates that Shanghai Stock Exchange pertain probability for large numbers of unexpected and extreme events rises in the aspect of stock returns. It creates thicker tails and higher peaks. This read as highly speculation in asset prices during intra-day sessions.

Table 1

DESCRIPTIVE STATICS OF SSE COMPOSITE DAILY RETURNS FOR THE SAMPLE PERIOD DECEMBER 1990 – DECEMBER 2020

Mean	Median	Minimum	Maximum
0.000438	0.0004	–0.17905	0.7191
Std. Dev.	**Skewness**	**Ex. kurtosis**	**N**
0.022	5.39	163.52	7490

Table 2

DESCRIPTIVE STATICS OF SSE COMPOSITE DAILY RETURNS FOR THE SAMPLE PERIOD JANUARY 2020 – DECEMBER 2020

Mean	Median	Minimum	Maximum
0.000479	0.00071	–0.080	0.0555
Std. Dev.	**Skewness**	**Ex. kurtosis**	**N**
0.013	–0.98	6.99	241

The descriptive property indicates a strong positive skewed return indicating higher peaks at left-to-right. It implies extreme value on the left side of the mean are more likely than corresponding extreme value to the right side of the mean. Intra-day activity or movement of the index during exchange hours allows a high probability for extreme events with more positive side than negative. In an abridged way, stocks over and over yield high positive amounts and often charge negative shocks. The property of table 1 which provides a summary of statistics for 30 years indicates positively skewed returns with extremely high leptokurtic impact and a greater degree of standard deviations. The index has delivered over 60 times returns if considered the SSE index. However, the descriptive statically property of table 2 provides details only for the COVID-19 time frame and absorbs volatile changes for a period of 1 year, i.e. January 2020 to December 2020. It provides unexpected negative and positive shocks with negatively skewed returns and abnormal kurtosis.

The comparative pattern of SSE China for 30 years and pandemic time appears in figure 2, provides evidence of strong negative magnitude, creating sudden

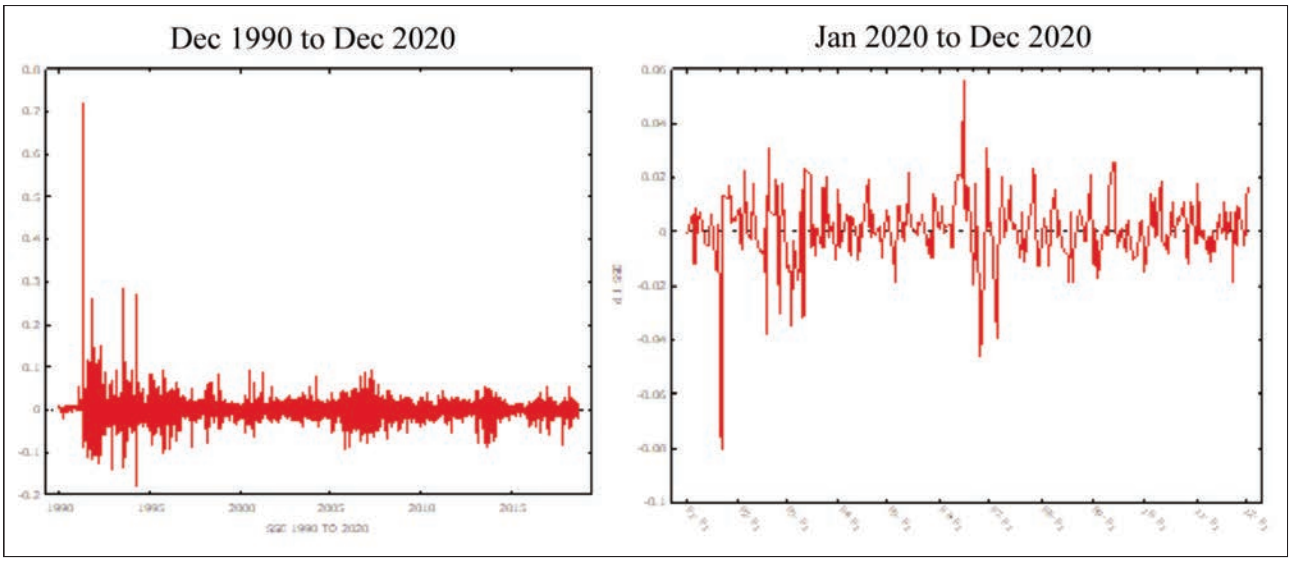

Fig. 1. Volatility shocks (stationary pattern) SSE China

fall and its recovery. The emerging period for SSE China financial markets i.e., 1990 to 1992 provided exceptional returns to early investors, and a few other major negative and positive shocks were observed in the first frame. The second frame provides two significant and contrasting movement pattern of the SSE index.

Table 3

RESULT OF ADF TEST (UNIT ROOT TEST) FOR RESIDUALS	
Value	**A D F**
t – statistics	–38.7308
Probability	0.000
A I C	–34299.5
B I C	–34258.2
H Q C	–34285.3

Baseline result of table 3 shows the presence of unit root in the series tested using the Augmented Dickey-Fuller test [35]. The probability value <0.05 ensures the time series for the entire study is stationary. ADF result property inferred volatility clustering in series returns of Shanghai Stock Exchange Composite Index. The study now focuses on the application of GARCH family models to find the best fit using student's t distribution and skewed t distributions. Property of table 4 indicates the result of GARCH (1, 1), EGARCH (1, 1) GJR GARCH and APARCH reveals parameter significant at 1% in case student's t distribution for entire series return (mean and variance equations both). Whereas the property of the mean equation is significant at 5% using skewed t distribution, the rest property of the variance equation is significant at the level of 1%.

Considering high and floating volatility in the Shanghai Stock market based on selected time variables, the statistical property of asymmetry GARCH models confirms the presence of leverage effect (asymmetry) at a significant level of 1% indicating stock over-reacts during negative movement than positive movement. Further, it indicates that mean returns are merely zero and a high degree of standard deviations that make the market difficult to predict even during intra-day trade activity. Summary of statistics indicates that there is a high probability of loss transaction during day trading activity.

Application of GARCH and GARCH type model based on Student's *t* distribution and Skewed t distribution where the application of GARCH and GARCH type model fitted better in comparison to skewed distributions. Across all GARCH class models, APARCH with student's t distribution estimates the highest value for β, and best fit, while compared to BIC value criterion, followed by APARCH, skewed t distributions.

COVID-19 pandemic shock to the world economy impacted the SSE Composite index which appears to start from January 2020, the pandemic created unexpected and extended magnitude changes in asset returns. The novel outbreak has been declared a global pandemic by WHO and to prevent its spread, most of the economic activities have been significantly limited across the world. Detailed observation of the following charts indicates volatility reaction in Shanghai Stock Exchange, which reacted abnormally during the pandemic period i.e., March 2020 to June 2020. Despite news that started to appear in December 2019, there is no evidence on the SSE market until after a couple of sessions from January 2020. The first sudden reaction made SSE slip from the level of above 3100 to trade below 2700. Nevertheless, the second major negative movements appeared not until the index mostly recovered from the previous fall i.e. (January first negative movements). The second negative movements have made SSE China new low and escalated fears amongst the investors. Interestingly and very aggressively the

Table 4

PROPERTY OF GARCH FAMILY MODELS					
GARCH (1, 1)					
Student's t distribution			Skewed t distribution		
Variable	Coefficient	z Statistic	Variable	Coefficient	z Statistic
Mean	0.0006	4.338 (1%)	Mean	0.00038	2.328 (5%)
Ω	4.99471e-06	3.579 (1%)	Ω	5.2256e-06	3.637 (1%)
α	0.152	5.998 (1%)	α	0.153668	6.099 (1%)
β BIC:	0.88 –42192.74	40.75 (1%)	B BIC:	0.877 –42190.24	45.57 (1%)
EGARCH (1, 1)					
Student's t distribution			Skewed t distribution		
Variable	Coefficient	z Statistic	Variable	Coefficient	z Statistic
Mean	0.0006	2.932 (1%)	Mean	0.00037	2.11 (5%)
Ω	–0.3150	–6.543 (1%)	Ω	–0.3213	–6.690 (1%)
α	0.2389	9.713 (1%)	α	0.259810	9.912 (1%)
β	0.9820	211.2 (1%)	β	0.9815	211.3 (1%)
γ BIC:	–0.0413798 –42271.04	–4.486 (1%)	γ BIC:	–0.403788 –42267.98	–4.379 (1%)
GJR					
Student's t distribution			Skewed t distribution		
Variable	Coefficient	z Statistic	Variable	Coefficient	z Statistic
Mean	0.0006	4.030 (1%)	Mean	0.00036	2.214 (5%)
Ω	5.27697e-06	3.744 (1%)	Ω	5.43186e-06	3.812 (1%)
α	0.153111	6.322 (1%)	α	0.155646	6.415 (1%)
β	0.874500	41.49 (1%)	β	0.872296	41.52 (1%)
γ BIC:	0.112353 –42198.40	4.343 (1%)	γ BIC:	0.107221 –42194.72	4.131 (1%)
APARCH					
Student's t distribution			Skewed t distribution		
Variable	Coefficient	z Statistic	Variable	Coefficient	z Statistic
Mean	0.0006	3.728 (1%)	Mean	0.00041	2.406 (5%)
Ω	6.03562e-06	3.857 (1%)	Ω	6.22662e-06	3.894 (1%)
α	0.1319	8.165 (1%)	α	0.1336	8.148 (1%)
β	0.8960	59.96 (1%)	β	0.8944	58.98 (1%)
γ	0.1339	4.524 (1%)	γ	0.1281	4.311 (1%)
δ BIC:	0.9858 –42275.85	11.75 (1%)	δ BIC:	0.9935 –42272.37	11.80 (1%)

SSE financial market movement appears strongly positive soon starting in July 2020. Further, the index remained traded between 3200 to 3500. In October 2008, the Shanghai Stock Exchange (Composite Index) faced a major impact on GFC, resulting in index trading almost greatest loss from its earlier trading level.

Two different frames appear in figure 3 providing observation for movement pattern during the pandemic period, in case assumed probably for January 2020 to June and July 2020 to December 2020, index movement observation indicates normal pattern even in January 2020 despite popularity news already appeared. The sudden negative fall appears on the first trading day of February 2020, the market opened over 10% below than previous day opening approaching the index 321 points down and at the level of 2716 compared to the last trading day of January 2020 where the index opened at 3037. On the next trading day i.e., 4th February 2020, the index traded at 2685 and that remained the lowest trading level throughout the pandemic time. In the following 13 trading days, the SSE Composite index approached the index level of 3000 points. And regained previous loss. For the following trading days of March, April, May and June the index did not create a new low trading level either new high level i.e., above 3100 as closing or opening. The fall slop that appears during the months of February 2020 and Mar 2020 impacted a loss of over 400 index points

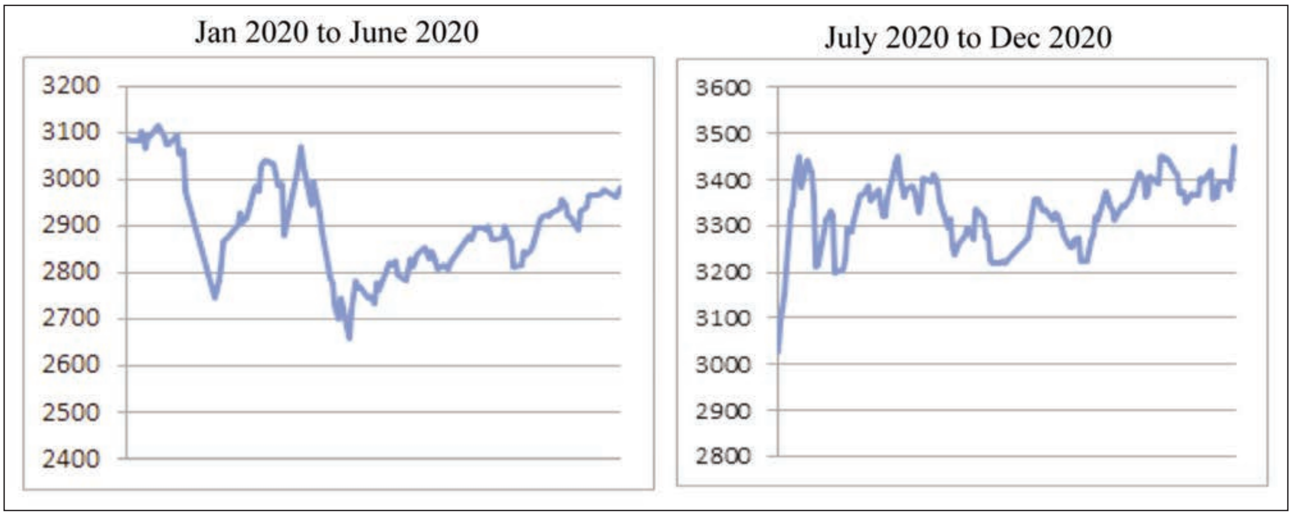

Fig. 2. SSE China – the pre and post-impact of COVID-19 pandemic

accounting for over 10% in just a few days. Further, the index recovered over 300 points which is again over 11% from the trading level of 2700, and breached the level of 3050, until retail investors restart investing. Surprisingly the index created a minor fall i.e., about 140 points and sustained a level of 3060 before the second sharp fall. This incident has impacted huge losses for the retail investors as the moments were entirely unpredictable. Steady and slow recovery of loss appears from the first week of April 2020. We evident the aggressive movement of the financial market starting with July 2020, also found the same aggressiveness to recover financial losses at the time of the Global Financial Crises of 2008.

The global financial crisis impacted entire economies of the world (including SSE – China) and has dramatically collapsed all economic stability across the countries. However, considering the collapse of the Chinese stock market (figure 1) provides evidence that Shanghai Stock Exchange is aggressively capable to recover from financial losses that occurred during the last GFS. Further considering the present pandemic situation, the Chinese Stock Exchange (SSE), has recovered and re-established financial stability as an immediate start with the month of July 2020. It is not only about the financial markets, many researchers and scholars have captioned those financial markets at some point in economic activities and growth. However, it may not be absolute applicable to all economies. At present, China supplements equipment in various sectors across the world. Compared to the recovery process from the financial crisis, the first which appears in figure 3, at the time of 2005 (June and July) and in the second graph appears in figure 3, the movement of recovery of the financial market after the global financial crisis. The movement indicates the aggressiveness of recovery from 3000 index points to exceeding over 6000 within the period of one year. It indicates that the SSE – China reacts strongly to recover from the news-based financial impact.

Since the panic of lockdown and major economic damage across the world, China remained one of the

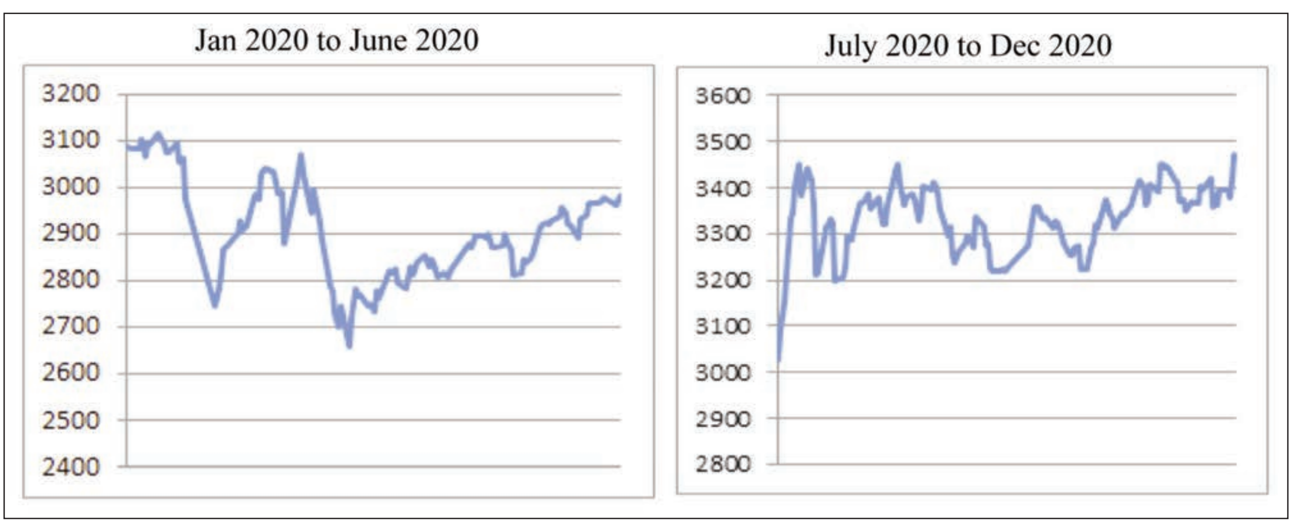

Fig. 3. SSE China January to December 2005 and January 2007 to January 2008 movement patterns

suppliers of medic and medic-related goods. The above graph indicates an abnormal rise for the SSE Composite index particularly starting in July and August. The index traded above 500 points more than the previous low of 2685 and created a new high instead of any negative movement. An interesting recovery that boosted up with strong positive shocks, which even higher degree of magnitude than the earlier negative shock (see figure 1). The SSE index trading at the level of 3000 points at beginning of July 2020, escalated to 3400, making over 10% movement in sudden and aggressive scale, approaching making new high even before pandemic levels. The pandemic of COVID-19 impacted the sample Chinese market SSE Composite index possibly for only the two highest magnitude shocks that were observed in the month of February and repeated negative and more frequent positive shocks in the month of April, May and June.

CONCLUSIONS

An empirical study on Shanghai Stock Exchange applying symmetric and asymmetric GARCH and GARCH type models explored volatility and volatility clusters in series returns. The study finds a high to extremely high presence of volatility particularly from January 2020 to December 2020 and reported the presence of leverage effect, highly unpredictable market movement during day trading, over exceeding kurtosis (160) and risky returns as over twice movement between a high and low range of the trading index. Shanghai Stock Exchange indicates a high volume of gambling transactions that escalates volatility to an additional level and makes the stock market even more difficult to predict for artificial intelligence software.

The movement pattern of the Shanghai Stock Exchange found high volatility during prolonged periods with unpredictable high and low magnitude shocks. It probably provides a shocking experience during intra-day trading. Volatility sketches indicate that high magnitude shocks do not create continuous following impact. However, negative shocks with high magnitude attract further negative shocks in continuation with comparative low magnitude. Statistical property of summary of statistics provided mean return merely to zero indicating investor's asset valuation either with least profit or lower than the purchase value. Findings of this study prove that bad news has a greater impact on financial markets compared to any good news as Sun and Yan [24], and Gan [25] found and indicated that daily returns exist in leverage effect and negative information shock remains greater.

The degree of standard deviation found (0.22) for the entire study period and (0.13) for the pandemic period, along with positively skewed over (5.39) for the entire study period and negatively skewed return for January 2020 to December 2020. This indicates market reacts to unpredictable positive shocks particularly when it is not expected. It impacts not allowing investors to reserve their profits. Further, it also creates a strong positive skewed pattern moving from left to right with some high positive shocks that creates a market more lucrative to investors. Symmetric GARCH (1,1) provides high volatility and persistence in volatility. Asymmetric GARCH models (EGARCH, GJR, APARCH) indicate the presence of leverage effect (asymmetry) in series returns of the Shanghai Stock Exchange. Statistical property of GARCH and GARCH type models significant at the level of 1% except for mean return by (skewed *t*) distribution significant at the level of 5%. APARCH model with student's t distributions was found to be the best model to estimate the volatility of pandemic time-varying volatility.

The dynamics of stock markets are important in the context of financial opportunities based on the international diversification of the portfolio. For instance, attracting foreign investors in China represents a possibility to improve the negative effects of the recent health crisis. Improving the innovation capability of China also plays a key role in recovering from losses caused by the COVID-19 pandemic.

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Study on the influence of external wind field on the terminal trajectory of projectile-parachute system

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ABSTRACT – REZUMAT

Study on the influence of external wind field on the terminal trajectory of projectile-parachute system

Parachutes are used for aerial projectile deceleration and trajectory control in the military field. Although the existing multi-degree-of-freedom and multi-body dynamics model has a small amount of calculation, the external wind field in this model is simplified, and the influence laws of which on the terminal trajectory are not clear. Therefore, a projectile-parachute system is regarded as the research object in this work. A Fluid-Structure Interaction (FSI) model was used to analyse this system's terminal trajectory. The cases with different wind velocity, wind directions, and initial trajectory angles were calculated. As a result, the external wind field has a great influence on the terminal trajectory of this projectile-parachute system. The difference in impact points in cases is positively correlated with the external wind velocity. At the same wind velocity, the trajectory in the upwind condition is easier to change than that in the downwind condition, and the difference in impact points is negatively correlated with the initial trajectory angle. While the external wind field has little influence on the projectile-parachute system's deceleration, the swing angle, and the trajectory angle of the canopy. This system's deceleration effect in the initial dropping process is more obvious under the upwind condition, and the deceleration effect will tend to be the same with the trajectory angle close to 90 degrees. Therefore, the influence of the external wind field on the terminal trajectory can be effectively reduced by increasing the initial trajectory angle, and the changes in canopy swing angle and trajectory angle will tend to be more stable in this situation.

Keywords: *terminal trajectory, engineered fabrics, parachute, Fluid-Structure Interaction*

Studiul influenței câmpului eolian extern asupra traiectoriei terminale a sistemului proiectil-parașută

Parașutele sunt folosite pentru decelerarea proiectilelor aeriene și controlul traiectoriei în domeniul militar. Deși modelul existent cu mai multe grade de libertate și dinamică multicorp are un volum redus de calcul, câmpul eolian extern din acest model este simplificat, iar legile de influență pe traiectoria terminală nu sunt clare. Prin urmare, un sistem proiectil-parașuta este considerat obiectul de cercetare în această lucrare. Un model de interacțiune fluid-structură (FSI) a fost utilizat pentru a analiza traiectoria terminală a acestui sistem. Au fost calculate cazurile cu diferite viteze ale vântului, direcțiile vântului și unghiurile de traiectorie inițiale. Prin urmare, câmpul eolian extern are o mare influență asupra traiectoriei terminale a acestui sistem proiectil-parașută. Diferența punctelor de impact în aceste cazuri este corelată pozitiv cu viteza vântului extern. La aceeași viteză a vântului, traiectoria contra vântului este mai ușor de schimbat decât cea în direcția vântului, iar diferența de puncte de impact este corelată negativ cu unghiul traiectoriei inițiale. Câmpul eolian extern are o influență redusă asupra decelerării sistemului proiectil-parașută, a unghiului de balansare și a unghiului traiectoriei cupolei. Efectul de decelerare al acestui sistem în procesul inițial de cădere este mai evident în condiții de contravânt, iar efectul de decelerare va tinde să fie același cu unghiul de traiectorie închis la 90 de grade. Prin urmare, influența câmpului eolian extern asupra traiectoriei terminale poate fi redusă eficient prin creșterea unghiului traiectoriei inițiale, iar modificările unghiului de balansare al cupolei și unghiului traiectoriei vor tinde să fie mai stabile în această situație.

Cuvinte-cheie: *traiectorie terminală, țesături tehnice, paraşuta, interacțiunea fluid-structură*

INTRODUCTION

The parachute has been widely used in the military field because of its small size, low cost and reliable deceleration performance. Early in World War II, the parachute replaced the tail fin of conventional projectiles. This replacement shorts the length of the projectile body and increases the number of projectiles carried by aircraft. The parachute also provides projectiles with an impact angle of more than 60°, which means a broad killing range for projectiles. In addition, parachutes can prevent aerial torpedoes and mines from being damaged or bouncing off the water. Flares with parachutes can prolong the illumination time of battlefields. With the improvement of ammunition intelligence, the parachute is also used in the air delivery of terminal sensitive projectiles, blockade and control projectiles and other projectiles for precision strikes. At present, there are two main functions of parachutes in aerial projectiles. On the one hand, parachutes are used to decelerate the projectile. The deceleration of the projectile ensures that the aircraft can drop the projectile at a low altitude with high hit precision, and provides the aircraft with enough time to escape from its projectile's killing range. On the other hand, parachutes play a role in trajectory control.

With the increasing demand for precision strikes in various countries, the requirements for trajectory control in the military field are also increasing. Consequently, the trajectory analysis of the projectile-parachute system has become the focus of intelligent ammunition design. Guglieri used the six DOF and multi-body dynamics model to simulate the trajectory of the parachute-payload system [1]. The same model was also used to obtain the trajectory characteristics of air-dropped torpedoes [2], terminal-sensitive projectiles [3], blockade and control projectiles [4]. Furthermore, this model was modified by Cao in his work, the influence of random factors on the projectile trajectory and the impact point was considered [5]. At present, the six DOF and multi-body model is commonly used in the terminal trajectory analysis of the projectile-parachute system. Although low computational cost is required, the model is greatly simplified. The projectile-parachute system is regarded as a rigid body system without the asymmetric changes of the canopy in the parachute descent stage. And the influence laws on the trajectory angle and parachute opening process cannot be obtained because the external wind field is especially simplified in this model. With the development of computer hardware and the maturity of algorithms, more and more FSI models are used in parachute analysis. The application of FSI models could obtain rich information on the structure domain and flow field, and overcome shortcomings of the existing multi-DOF and multi-body dynamics model.

However, the FSI models are commonly used in the analysis of parachute inflation because of the high computational cost. The analysis of projectile trajectory is rarely published based on these models.

This work aims at obtaining the influence laws of the external wind field on the terminal trajectory of projectile-parachute system and reducing the consumption of computing resources. In this work, an aerial projectile-parachute system is regarded as the research object, the local coordinate system is applied to control the finite flow field movement, and the terminal trajectory of this system is calculated under different conditions. The influence laws of different wind velocity and direction on the terminal trajectory under different initial trajectory angles are obtained.

MATHEMATICAL MODEL

It is difficult to build the body-fitted mesh models because the gaps between the initial folded parachute structures are too small. Besides, in the parachute inflation process, large deformations and displacements occur on the canopy in a very short time, and irregular folds also occur in the meantime. The reconstruction of body-fitted mesh will further increase the difficulty and consumption of calculation. Therefore, the structure domain and flow field domain in this work are discretized by the finite element approach. The two domains above are assembled by the intercrossing approach, and calculated based on the Arbitrary Lagrange-Euler (ALE) method. This method naturally satisfies the mass conservation. Since the heat transfer is ignored, the momentum conservation equations 1 and 2 are only solved in this work. The equation 1 and 2 are coupled with each other by the contact algorithm [6]:

$$\rho v_{i,t} + \rho v_{i,j} c_j = \sigma_{ji,j} \rho b_i \quad (1)$$

$$\rho \dot{v}_i = \sigma_{ji,j} \rho b_i \quad (2)$$

where ρ is the density, v – the velocity, σ – the stress, b – the body force, and c – the fluid convection velocity with reference to the flow field domain.

In order to achieve the finite flow, the field surrounds the projectile-parachute system and moves with the system at all times (figure 1). The local coordinate system is defined and applied according to three non-collinear nodes A, B and C selected on the structural domain, which axis vectors are respectively:

$$\begin{aligned} \boldsymbol{x}' &= (\boldsymbol{x}_B - \boldsymbol{x}_A)/|\boldsymbol{x}_B - \boldsymbol{x}_A| \\ \boldsymbol{z}' &= \boldsymbol{x}' \times (\boldsymbol{x}_C - \boldsymbol{x}_A)/|\boldsymbol{x}' \times (\boldsymbol{x}_C - \boldsymbol{x}_A)| \\ \boldsymbol{y}' &= \boldsymbol{z}' \times \boldsymbol{x}' \end{aligned} \quad (3)$$

where $\boldsymbol{x}_A$, $\boldsymbol{x}_B$ and $\boldsymbol{x}_C$ represent global coordinates of three nodes respectively.

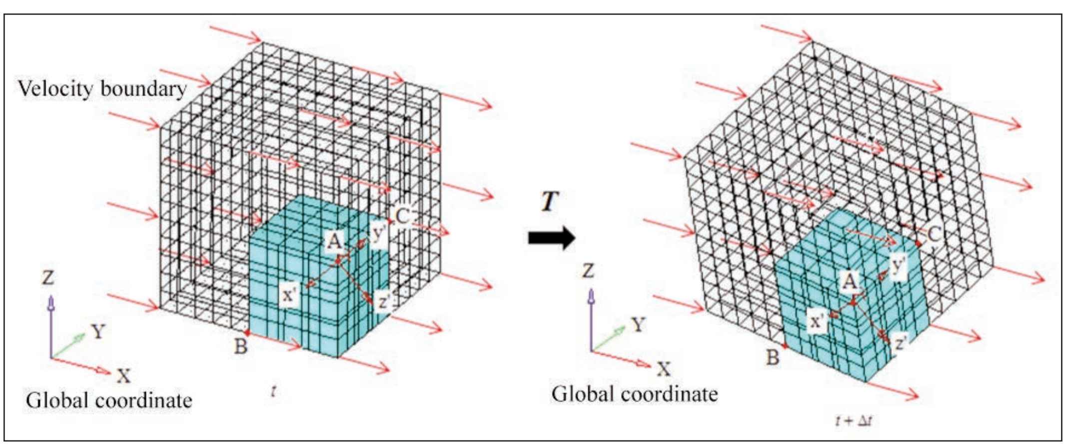


Fig. 1. Control of flow field motion

The transformation matrix $\boldsymbol{T}$ can be obtained when the local coordinate system fixed with the structure domain is displaced [6]. And the flow field's information is updated by the following equations:

$$\boldsymbol{x}_{t_0+\Delta t} = \boldsymbol{x}_{t_0} \cdot \boldsymbol{T}$$
$$\hat{\boldsymbol{v}} = (\boldsymbol{x}_{t_0+\Delta t} - \boldsymbol{x}_{t_0}) / \Delta t \quad (4)$$
$$\boldsymbol{c} = \boldsymbol{v} - \hat{\boldsymbol{v}}$$

where $\boldsymbol{x}$ is the node coordinates in the flow field, $\hat{\boldsymbol{v}}$ – the flow field's velocity, $\boldsymbol{c}$ – the convection velocity required by equation 1.

While the flow field is moved in the global coordinate system, the fluid material in the flow field cannot bear the shear stress, resulting in serious element distortion. Therefore, it is necessary to reconstruct the flow field grid and update the flow field information [7].

CASE STUDY

An aerial projectile-parachute system is regarded as the research object in this paper. The parachute arm length in this system is 1.8 m, and the width is 0.4 m, and the total area is 1.28 m^2, the fabric elastic modulus is 0.42 GPa, the thickness is 4 E-4 m and the fabric porosity is 0.327 m/s under 49 Pa pressure difference (in Russian standard). Moreover, the canopy in this parachute is restrained by 12 lines with a length of 1.2 m, and reinforced by crisscross reinforcements. Then the grid model shown in figure 2 is established according to the geometric characteristics of this parachute. In this model, 8,156 triangular elements are used to discretize the canopy, while 681,060 hexahedrons are used to discretize the flow field. The canopy is assembled with the flow field by the intercrossing approach.

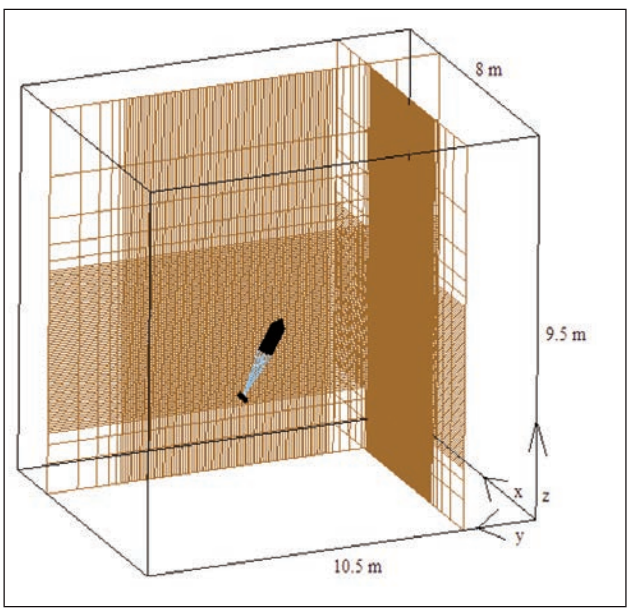


Fig. 2. The grid model

With the purpose of studying the influence laws of different wind velocity and direction on the terminal trajectory of projectile-parachute system, the different conditions shown in table 1 are calculated. The payload in all cases is 7.5 kg, the initial velocity is 300 m/s and the flight time of the projectile is 3.5 s. At the initial angle of 90°, the calculation results are the same no matter the wind field direction along with the positive or the negative X/Y axis. Therefore, the cases with the initial angle of 90° are calculated only on the condition that the wind field direction is along the positive Y axis.

Table 1

CONDITION IN CASES

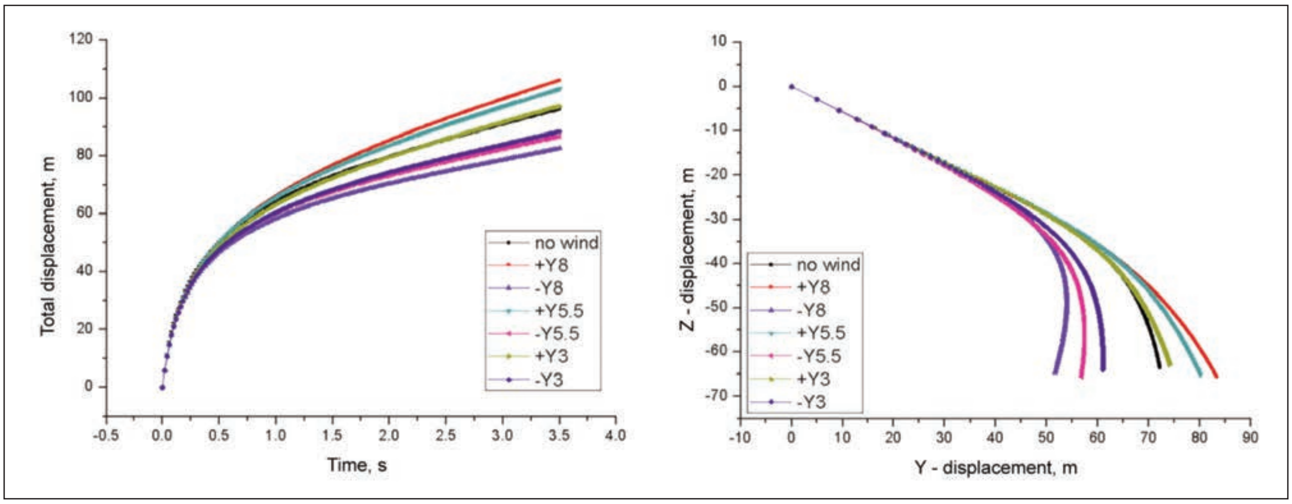
Group	Case	Initial trajectory angle (degree)	Wind direction*	Wind velocity (m/s)
Group 1	Case 11	30	—	—
	Case 12		+Y	8
	Case 13		–Y	8
	Case 14		+Y	5.5
	Case 15		–Y	5.5
	Case 16		+Y	3
	Case 17		–Y	3
Group 2	Case 21	60	—	—
	Case 22		+Y	8
	Case 23		–Y	8
	Case 24		+Y	5.5
	Case 25		–Y	5.5
	Case 26		+Y	3
	Case 27		–Y	3
Group 3	Case 31	90	—	—
	Case 32		+Y	8
	Case 33		+Y	5.5
	Case 34		+Y	3

Note: +Y represents the downwind condition, –Y represents the upwind condition.

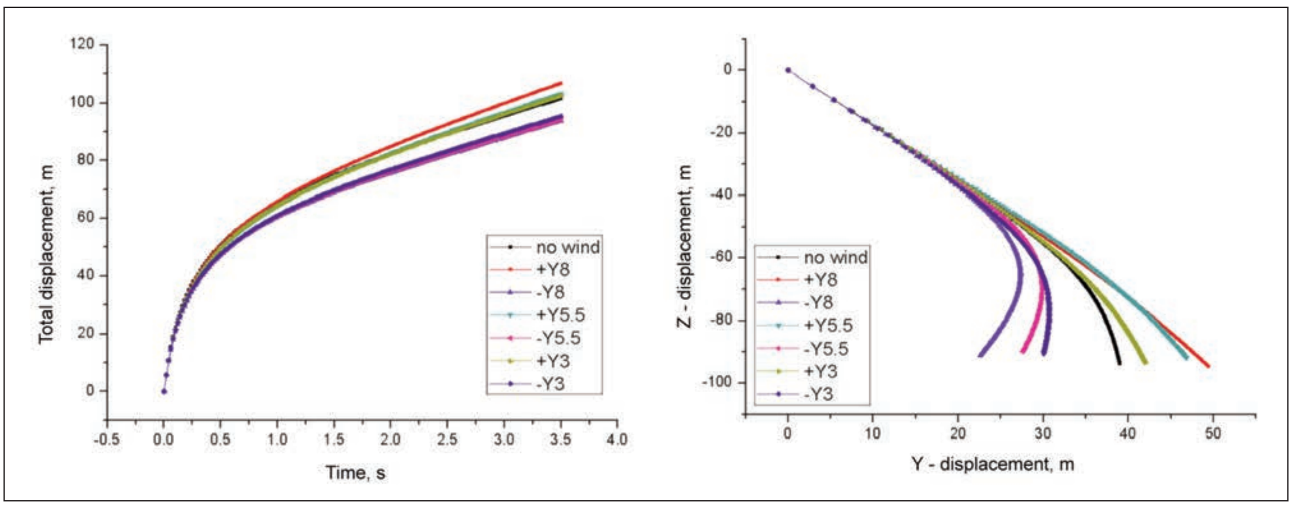
RESULTS AND DISCUSSIONS

Figure 3 shows the comparison of the total displacements and the trajectories of the projectile-parachute system in different conditions. From the comparison of total displacements, the difference between total displacements is small at the initial stage, but the difference is gradually obvious as time advance. However, the impact of external wind velocity and direction on total displacement can be enlarged by a small initial trajectory angle. When the initial trajectory angle is 30°, the maximum difference of total displacements can reach 23.3 m at 3.5 s (Case 12 and Case 13). When the initial trajectory angle is 60°, the maximum difference is 12.9 m (Case 22 and Case 23). When the initial trajectory angle is 90°, the maximum difference becomes no more than 2 m (Case 31 and Case 32). In addition, the projectile-parachute system in the upwind condition is equivalent to an additional lift applied, which causes a total displacement reduction. The reduction is increased as the initial trajectory angle increases. While the results in downwind condition are just opposite to that in upwind.

From the comparison of different trajectories, it can be found that the initial trajectory angle, wind velocity and direction have more obvious effects on the terminal trajectory. When the initial trajectory angle is 30°, and the wind velocity is 8 m/s, the maximum horizontal difference of trajectories under the downwind condition and the upwind condition is 31.7 m (Case 12 and Case 13). While the wind velocity is decreased to 5.5 m/s or 3 m/s, the maximum horizontal difference is 23.24 m (Case 14 and Case 15) and 13.06 m (Case 16 and Case 17). At the same wind velocity, the horizontal displacement difference



a



b

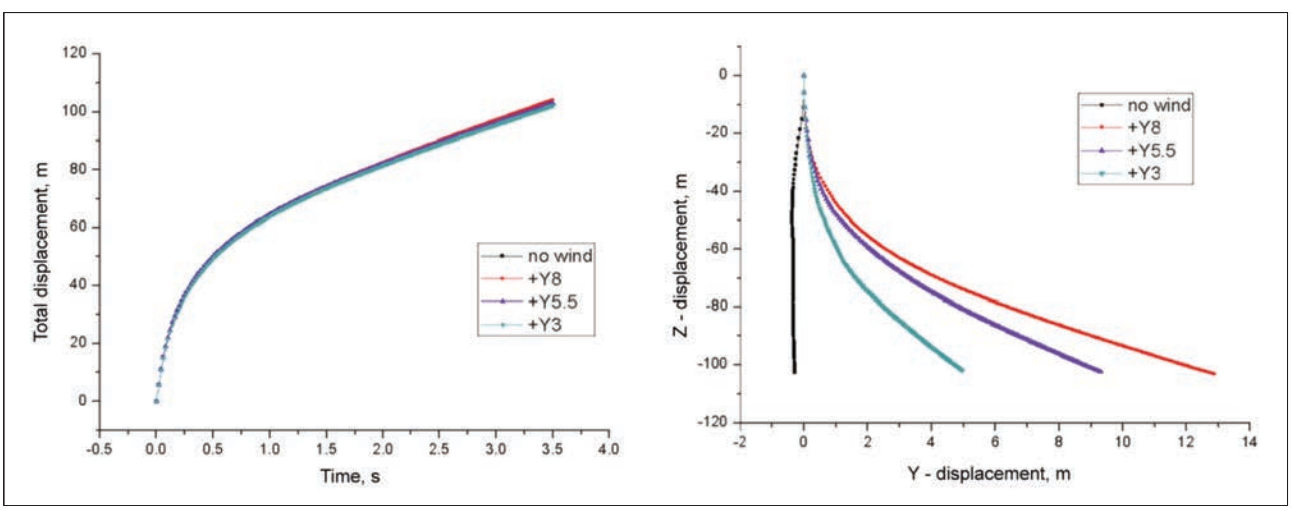


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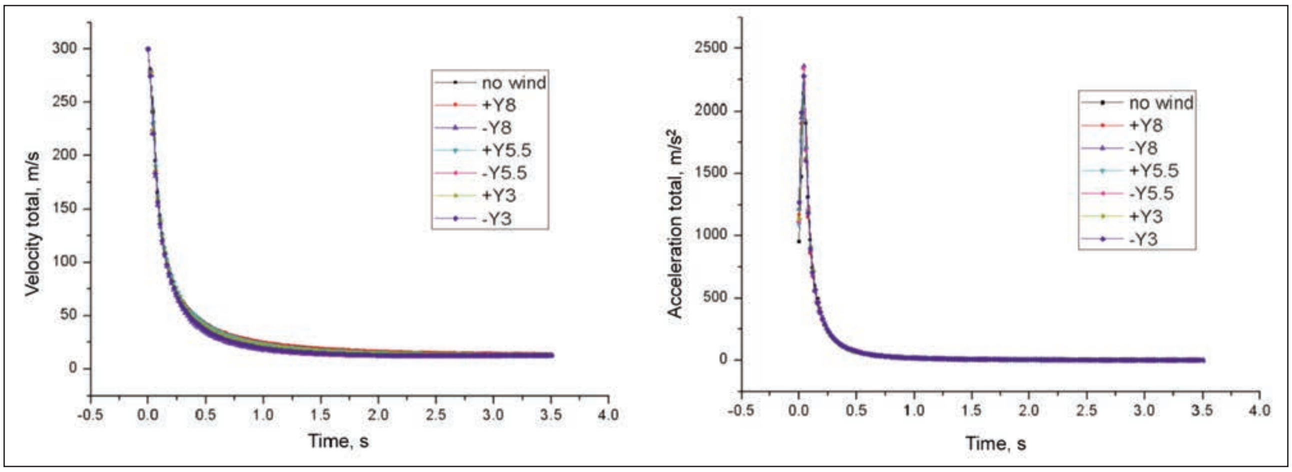
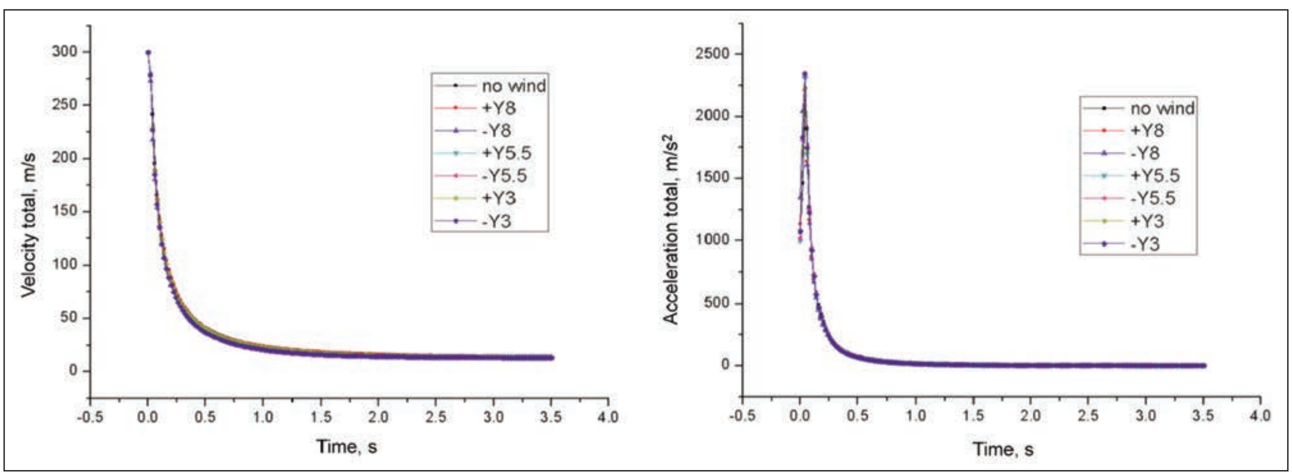
Fig. 3. Comparison of total displacements and trajectories: *a* – Group 1; *b* – Group 2; *c* – Group 3

is incessantly decreased with the increase of the initial trajectory angle and the decrease of the wind velocity. In addition, the trajectory of the projectile-parachute system in the upwind condition is easier to change than that in the downwind. In conclusion, the horizontal difference is negatively correlated with the initial trajectory angle and positively correlated with wind velocity.

Figure 4 shows the comparison of velocities and accelerations of the projectile. Because the parachute parameters have not changed, the characteristics of the velocity and acceleration under different conditions are almost the same. Similarly, the parachute inflation time is less affected by different conditions. The canopy in almost all cases is fully inflated within 0.04 s, and the overloads reach their maximum with a small difference in the meantime. Furthermore, the upwind condition is equivalent to an additional lift applied for the projectile-parachute system, which makes the system's deceleration effect noticeable. Therefore, the velocity of the projectile in the upwind condition is smaller than that in other



a



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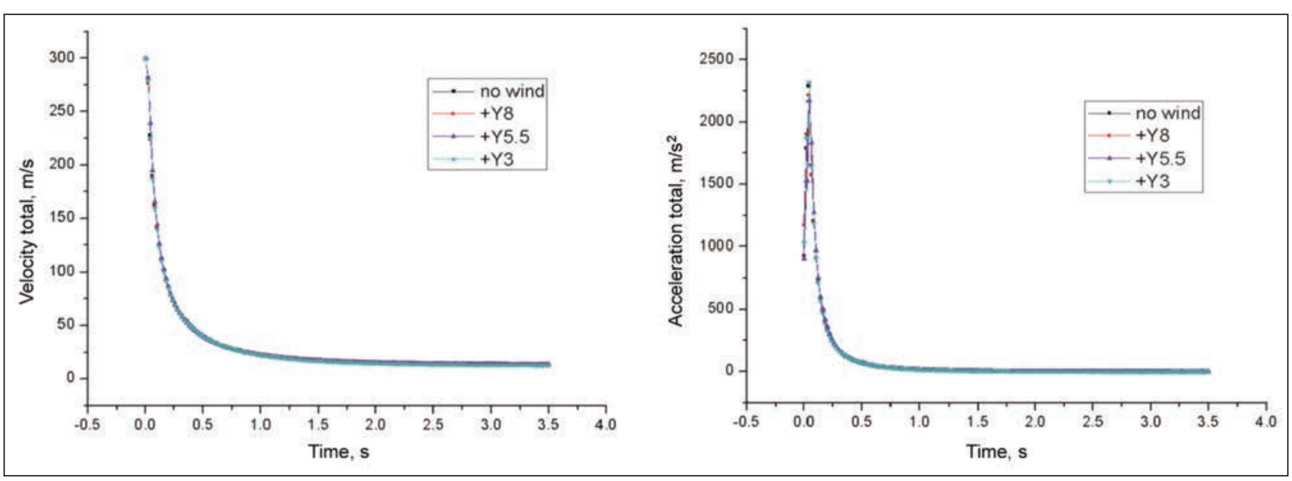

c

Fig. 4. Comparison of velocities and accelerations: *a* – Group 1; *b* – Group 2; *c* – Group 3

conditions at the same time. And the velocity difference caused by different conditions is decreased with the increase of the initial trajectory angle and the decrease of wind velocity. While the change of velocity difference in downwind conditions is just the reverse. The velocity difference in downwind conditions decreased with time, decreasing to 12.58–14.01 m/s at last.

Figure 5 shows the comparison of trajectory angles and swing angles of the canopy under different conditions. It can be found that the trajectory angle changes dramatically in the initial dropping stage, but as the deceleration effect becomes obvious, the change of the trajectory angle is weakened, and the trajectory angle gradually approaches 90°. The swing angle changes in a similar way. It also changes dramatically in the initial dropping stage. But the change of swing angle's frequency is decreased with the stability of the projectile-parachute system improved, and the swing amplitude is controlled within 3° (figure 5, *b* and *c*). However, there is one particular case in Group 1. The amplitude of swing angle, in this

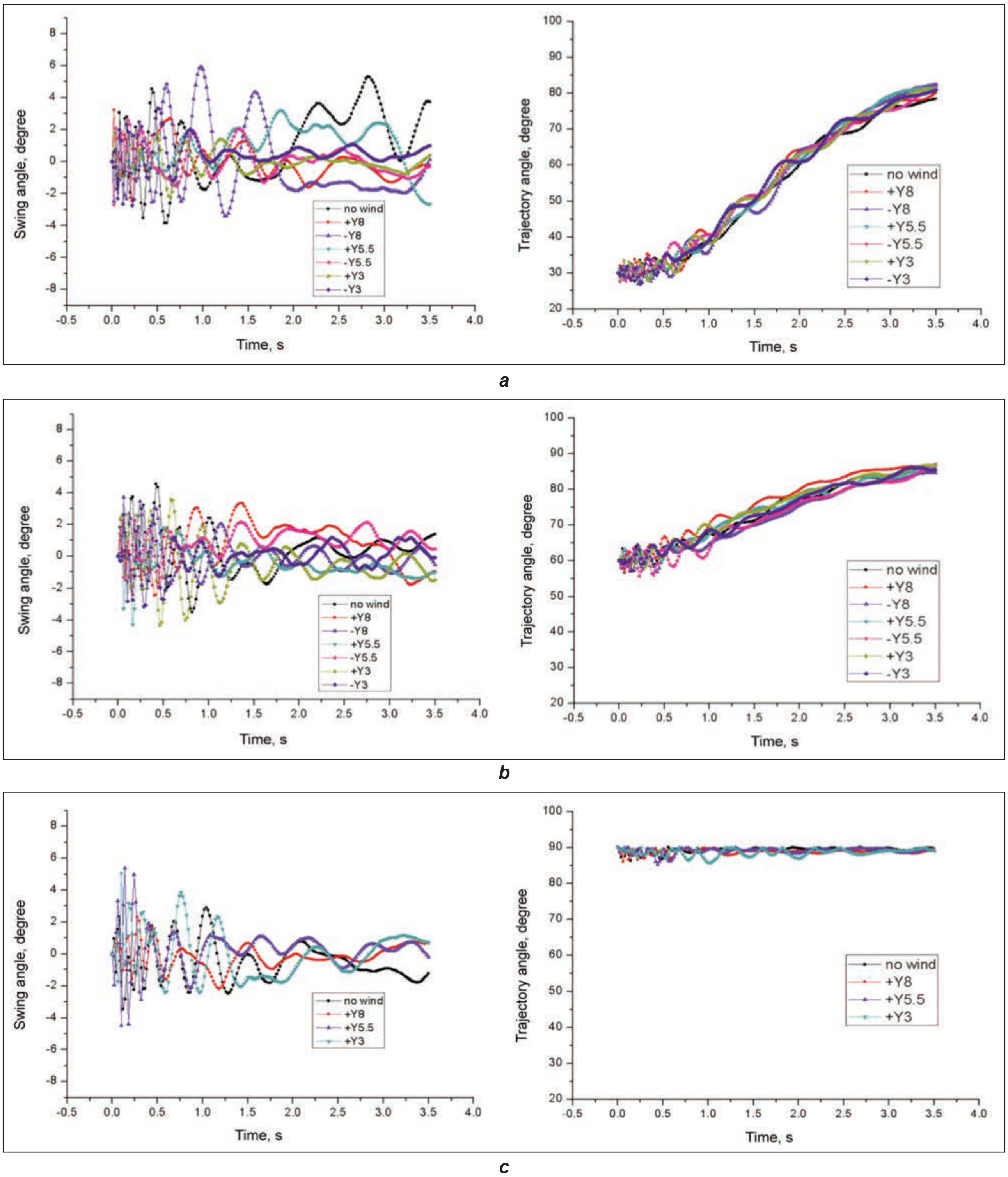

Fig. 5. Comparison of swing angles and trajectory angles: *a* – Group 1; *b* – Group 2; *c* – Group 3

case, is controlled within 5° at the parachute terminal descent stage. Although the parachute descent velocity is nearly constant in this particular case, the trajectory angle can't be completely stable within 3.5 s because of the small initial trajectory angle, causing larger swing angle amplitude than in other cases. In general, the swing angle and the trajectory angle of the parachute are less affected by the external wind velocity and direction. But a small initial trajectory angle can prolong the time that the swing angle and trajectory angle to be stable.

CONCLUSIONS

In order to study the influence laws of different wind fields on the projectile-parachute system's terminal trajectory, the FSI methods are used to study the influence laws of projectile-parachute system under different wind velocity, wind direction and initial trajectory angle. The following conclusions are obtained:

- The external wind field has a great influence on the terminal trajectory of the projectile-parachute system, and the impact point difference (horizontal displacement difference) is positively correlated with wind velocity. At the same wind velocity, the trajectory of the projectile-parachute system in the upwind condition is easier to change than that in the downwind condition.
- The impact point difference is negatively correlated with the initial trajectory angle. Therefore, the influence of the external wind field on terminal trajectory can be decreased by increasing the initial trajectory angle.
- The deceleration of the projectile-parachute system is less affected by the external wind field. But the upwind condition for the projectile-parachute system is equivalent to an additional lift, which enlarges the deceleration effect at the initial dropping stage. While the deceleration effect tends to be the same with the trajectory angle closed to 90°.
- The changes in swing angle and trajectory angle are also less affected by the external wind field. But a small initial trajectory angle can prolong the time of swing angle and trajectory angle to be stable.

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An empirical study regarding the environmental sustainability practices in the textile industry

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ABSTRACT – REZUMAT

An empirical study regarding the environmental sustainability practices in the textile industry

The textile industry causes various types of pollution due to extensive utilization of resources, resulting in harmful impacts on the natural environment and people's health. As a result, many environmental organizations and countries are implementing various environmental safety policies. The developing countries are making less effort in the protection of the global environment. Hence, it is very important to analyse the environmental sustainability situation of the developing production markets and subsequently provide suggestions for improvement. Pakistan is a developing textile market, providing a range of textile products around the world. This paper presents the results of a survey regarding the environmental sustainability in the textile industry of Pakistan related to energy sustainability, water sustainability, air sustainability, materials sustainability, transportation sustainability, safety & health and consumer use sustainability. For the data collection, this research uses a structured questionnaire, interviews, and personal visits to 122 textile mills. Data collected through a questionnaire related to the above areas of sustainability was analysed by calculating the frequency distribution, mean, and median in the statistical software SPSS. The results of the data analysis exhibited that the Pakistani textile companies are gradually improving many environmental sustainability areas. The paper identifies some weak sustainability areas which need more attention to accelerate the implementation process. In addition, the textile companies that are involved in international trade tend the implementation of environmental sustainability. In addition, this study integrates the insights for policymakers and practitioners to improve the environmental sustainability in the textile industry of the developing markets.

Keywords: *textile sustainability, energy sustainability, materials sustainability, water sustainability, sustainable development, survey methods*

Un studiu empiric privind practicile de sustenabilitate a mediului în industria textilă

Industria textilă creează diverse tipuri de poluare din cauza utilizării pe scară largă a resurselor, având ca rezultat efecte nocive asupra mediului natural și sănătății oamenilor. Prin urmare, multe organizații de mediu și țări pun în aplicare diverse politici de siguranță a mediului. Țările în curs de dezvoltare depun eforturi mai reduse în protecția mediului global. De aceea, este foarte important să analizăm situația de sustenabilitate a mediului pe piețele de producție în curs de dezvoltare și, ulterior, să oferim sugestii de îmbunătățire. Pakistanul este o piață textilă în curs de dezvoltare, care furnizează o gamă largă de produse textile în întreaga lume. Această lucrare prezintă rezultatele unui sondaj privind sustenabilitatea mediului în industria textilă din Pakistan, legată de sustenabilitatea energetică, sustenabilitatea apei, sustenabilitatea aerului, sustenabilitatea materialelor, sustenabilitatea transportului, siguranța și sănătatea și sustenabilitatea utilizării de către consumatori. Pentru colectarea datelor, această cercetare utilizează un chestionar structurat, interviuri și vizite personale în 122 de companii textile. Datele colectate prin chestionar legate de domeniile de sustenabilitate de mai sus au fost analizate prin calcularea distribuției frecvenței, mediei și medianei în software-ul statistic SPSS. Rezultatele analizei datelor au arătat că, companiile textile pakistaneze îmbunătățesc treptat multe domenii de sustenabilitate a mediului. Lucrarea identifică unele zone cu interes scăzut pentru sustenabilitate, care necesită mai multă atenție pentru a accelera procesul de implementare. În plus, companiile textile care sunt implicate în comerțul internațional prezintă o tendință către implementarea sustenabilității mediului. În plus, acest studiu integrează perspectivele pentru factorii de decizie și practicieni, pentru a îmbunătăți sustenabilitatea mediului în industria textilă pe piețele în curs de dezvoltare.

Cuvinte-cheie: *sustenabilitate textilă, sustenabilitate energetică, sustenabilitatea materialelor, sustenabilitatea apei, dezvoltare durabilă, metode de sondaj*

INTRODUCTION

Environmental sustainability can be defined as the protection of the internal and external environment of an organization from the effects of harmful practices such as energy wastage, water pollution, air pollution, excessive solid waste, transportation emissions, and severe safety and health issues. The effects of these harmful practices are noticeable in the textile industry due to their unsustainable nature. For instance, the many environmental sustainability issues are associated with the textile industry such as considerable water usage, discharging excessive waste into the land, intensive chemicals use, unsafe raw material processing, globalization of the industry, dangerous pollutants, use of considerable electricity, emission of harmful gases, greater transportation distances, unsustainable practices in the industry, and disposing the textile products into the municipal solid waste after end use [1–8]. Companies in the developed markets prefer the manufacturing of their products in the developing markets for cost-saving [9]. However, developing countries are facing serious challenges to deal with environmental issues.

For instance, the textile processing industry in Bangladesh discharges a considerable quantity of polluted and toxic wastewater into sewers and drains without any kind of treatment. In addition, an excessive quantity of effluents, solid waste, and sewage sludge are discharged into the environment [3]. Nowadays, an increased focus of customers and retailers on environmental issues has caused the companies in the developed markets to source only from environmentally friendly suppliers [7, 10]. In future, global companies will always prefer the textile markets that have implemented environmental sustainability practices. In addition, there is an increased awareness among consumers regardless of any specific market in the world. Therefore, only environmentally-conscious companies will survive in future.

Pakistan is a developing textile manufacturing market and is involved in the production and export of all kinds of textile products from fibre production to garment manufacturing. Pakistan has a large number of small and medium-sized textile companies. All Pakistan Textile Mills Association (APTMA) is a leading association of textile companies which represents 396 textile mills [11]. Another association "All Pakistan Textile Processing Mills Association (APTPMA)" represents 386 textile processing mills in Pakistan. In addition, there are many textile companies which are not registered under these associations. The number of textile mills in Pakistan increased from 3 to 600 between 1947 and 2000 [12]. Consequently, the actual number of textile companies in Pakistan is more than 600. In addition, there are some multinational textile chemical suppliers in Pakistan. The contribution of the textile industry is 46% of the total manufacturing in Pakistan. The share of textile exports is 68%. The textile industry makes 8.5% of the gross domestic product (GDP) and 38% of the total employment [13, 14]. The textile industry in Pakistan is facing many challenges such as more cost, waste of resources, gas and electricity shortage, and use of unsustainable sources of energy [15].

There is a lack of literature about the environmental sustainability situation of the textile industry in developing production markets such as Pakistan. The key objective of this research is to measure the environmental sustainability in the textile industry of Pakistan. In this study, the data collection was performed using the following three methods: (a) a structured questionnaire was developed based on the literature review and discussion with textile experts, (b) interviews with management in the textile companies, and (c) personal visits in the textile industry. The results provide various insights to improve the environmental sustainability in the textile industry of developing markets.

METHODOLOGY

This paper uses three methods for data collection. These methods include a structured questionnaire, interviews, and personal visits (figure 1).

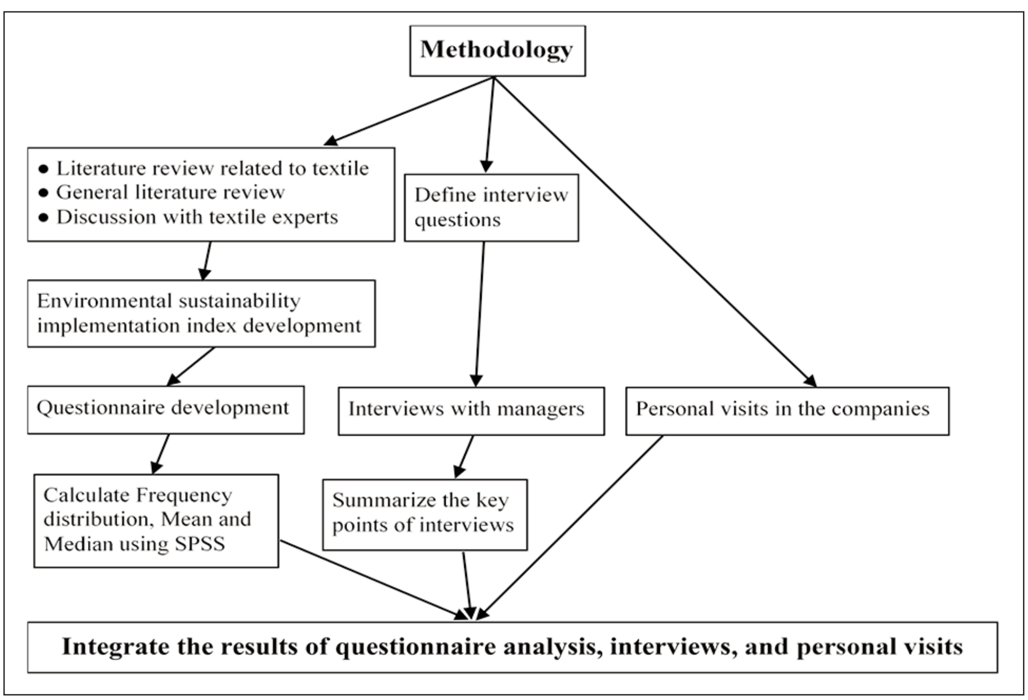

Fig. 1. Methodology

For the questionnaire development, thorough literature was reviewed. For the questionnaire development, several factors were identified from the existing literature related to environmental sustainability in the textile industry. Second, general literature about environmental sustainability was reviewed to enhance the inclusiveness of the index. Based on these two steps and discussions with experts in the textile industry, an environmental sustainability implementation index was developed for the measurement of environmental sustainability in the textile industry. This index was divided into seven major factors which include energy sustainability, water sustainability, air sustainability, materials sustainability, transportation sustainability, safety and health, and consumer use sustainability (table 1).

Table 1

ENVIRONMENTAL SUSTAINABILITY IMPLEMENTATION INDEX FOR THE TEXTILE INDUSTRY			
Factors	**Symbol**	**Environmental sustainability variables**	**References**
Energy sustainability	ES1	Take practical steps to save energy, and initiate energy efficiency programs to minimize energy use.	[1,7,16]
	ES2	Prefer energy-efficient products and processes for efficiency in electric heating, electric motor, lighting, fuel use, and steam use.	[17]
	ES3	Use renewable energy sources such as sunlight, wind energy, and water.	[18,19]
	ES4	Involve everybody to improve awareness and knowledge about energy consumption and savings.	[18]
	ES5	Seek environmentally friendly materials/production methods that require the least natural resources.	[21]
	ES6	Use waste to produce energy such as heat, electricity, and fuel.	[22]
	ES7	Implement practices of efficient maintenance of machinery.	[23]
Water sustainability	WS1	Take practical steps to reduce the volume of freshwater used in production and introduce guidelines for saving water in all departments.	[1,7,16,17,24]
	WS2	Identify water sources and estimate water used in the production process.	[16]
	WS3	Use waterless or reduced water techniques (e.g. foam coating).	[17,20,21]
	WS4	Have a good system for water recycling, reuse, and discharge of polluted wastewater.	[1,7,21]
	WS5	Wastewater should not be discharged without treatment.	[1,7,25]
Air sustainability	AS1	Develop air emissions reduction strategies.	[18,26]
	AS2	Have availability of a good system to measure the level of direct and indirect greenhouse gas emissions.	[16]
	AS3	Have a system to trap and store hazardous gases such as carbon dioxide emitting from the production process (e.g., Carbone Capture and Storage).	[7]
	AS4	Encourage environment-friendly activities such as planting trees.	[18]
Materials sustainability	MS1	Encourage materials savings at every stage.	[1,17,21]
	MS2	Make strategies for efficient material utilization at every stage.	[1,17,20]
	MS3	Encourage using recycled input materials at every stage.	[16,27]
	MS4	The material should be selected based on the least toxicity when possible. Avoid the use of environmentally damaging auxiliaries and dyestuffs.	[1,20,24,26]
	MS5	Carefully estimate and purchase materials, and perform careful inventory control.	[1]
	MS6	Prefer environmental sustainability on price in purchasing and production (e.g., durable, reliable, reusable, re-manufacturable, repairable, recycled easily, energy recovery).	[7,16,17,21]
	MS7	Implement waste reduction strategies such as reducing weight, volume, toxicity, extending the life of materials, and energy use in the production process.	[1,7,16,28]
	MS8	Materials and products should have ecolabels with instructions to recycle and reuse, biodegradable, etc.	[7,16,21,24]
	MS9	Prefer electronic methods of communication instead of paperwork so that paper is not wasted.	[7,17]
	MS10	Reduce waste from product defects and overproduction.	[1,17]

Table 1 (*continuation*)

ENVIRONMENTAL SUSTAINABILITY IMPLEMENTATION INDEX FOR THE TEXTILE INDUSTRY			
Factors	**Symbol**	**Environmental sustainability variables**	**References**
Transportation sustainability	TS1	The company should be located close to the suppliers for sourcing materials. Prefer on buying local materials/products.	[1,7,21]
	TS2	Implement environmentally friendly methods of transporting such as transport network optimization, fuel-saving driving, use of the full capacity of transportation, and route optimization.	[1,7,26]
	TS3	Measure the environmental impacts associated with the transportation of materials and products.	[1,7,16]
Safety and health	SS1	Have clear guidelines for the health and safety of employees.	[7,17,28,29]
	SS2	Machinery should be well maintained to reduce the level of noise. Workers should be provided with earplugs.	[1]
	SS3	There should be proper ventilation and lighting as required for the specific work.	[28]
	SS4	Proper dust control equipment should be set up and maintained to reduce the exposure of workers to dust. Workers should be provided with masks.	[28]
	SS5	Trained medical personnel and first aid facilities should be available. Medical examinations of workers should be conducted regularly. If health problems are observed, take appropriate measures.	[17]
	SS6	Safety equipment such as fire extinguishers and fire alarms should be available.	[28]
	SS7	In units where there is heavy exposure to dangerous chemicals, workers should be provided with safety gloves.	[1]
	SS8	Avoid Restricted Substance List (RSL) that considers health impacts on workers and other people.	[7]
	SS9	Encourage practices to determine whether or not the chemicals, materials, products, and processes are linked with harmful health effects.	[1,7]
	SS10	The company should be certified with any reputable environmental testing and certification system (e.g., ISO 14001, eco-labelling, etc.)	[7,16]
	SS11	Have waste treatment technologies for disposal of hazardous waste. Before disposal, waste should be transformed into less hazardous substances using techniques such as oxidation/ reduction, precipitation, and PH neutralization.	[1,7]
Consumer use sustainability	CS1	Produce multi-functional, durable products designed with fewer materials and made to last more than one season.	[17,21]
	CS2	Seek technical coatings to reduce laundering at the consumer use phase.	[17,21]
	CS3	Ensure colour resistance to washing, rubbing, perspiration, and light exposure.	[28]
	CS4	A company's products should be capable of being returned safely to the environment at the end of their useful life.	[17,29]
	CS5	The company's products should be capable of being washed at low temperatures using environmentally friendly laundering agents.	[29]

In table 1, some of the research papers have been referred to present the important factors related to the implementation of environmental sustainability in the textile industry.

In table 1, each environmental sustainability variable has been defined with a symbol. These symbols were supposed for a good presentation of the results. The environmental sustainability implementation index in table 1 was adopted as the environmental sustainability questionnaire using a 5-point Likert scale (5 indicates the strong support for a statement, and 1 indicates the least support for a statement). "All the statements in table 1 were modified in such a way that each statement showed the extent of the implementation in a company. For instance, the first statement in table 1 is "take practical steps to save energy, and initiate energy efficiency programs to minimize energy use." In the actual questionnaire, this statement was adapted as "Your company takes practical steps to save energy, and initiates energy efficiency programs to minimize energy use". The 5-point Likert scale has several advantages such as ease for participants and the more reliability of results [30–32].

The questionnaire was sent to the management of 298 textile companies around Pakistan. Out of these 298 companies, 122 companies responded positively. Some of these companies sent more than one reply. 140 filled replies were included in the statistical analysis (47 per cent response rate). The companies comprised one or more of the following textile divisions:

- Yarn manufacturing division (24 responses, 24 companies);
- Fabric manufacturing division (14 responses, 14 companies);
- Wet processing division (44 responses, 38 companies);
- End-product/garment manufacturing division (18 responses, 12 companies);
- Composite divisions comprising more than one division (40 responses, 34 companies).

The incomplete responses were excluded from the analysis. The confusion in the questionnaire data was clarified with the management of the related companies. Many companies did not respond to the first request. Therefore, the reminders were sent to these companies. In some cases, the respondents did not respond despite several reminders. In these cases, the authors visited those companies and filled out the questionnaire by discussing it with managers. Most of the textile companies in Pakistan are small and medium-size companies with one or more divisions of the textile manufacturing processes. This was evident from the production and exports of these companies. Hence, the responses from the large companies were fewer. Most medium-size companies are involved in global trade. Some multinational companies are involved in the textile business in Pakistan. Hence, there were a few responses from the multinational companies. All the respondents were in senior management positions in their organizations. In addition to the questionnaire, the interviews were arranged with managers of the different textile companies to collect their views on the different questions about the implementation of environmental sustainability. The following were the key questions that were asked:

- Which practices are used by the company to improve environmental sustainability?
- In your opinion, what is the best way to implement environmental sustainability measures in the company?
- What are the difficulties in the implementation of environmental sustainability measures in the company?
- Has the company any ecolabel or environmental certification? If not, what are the reasons?
- What are the further remarks about the environmental sustainability in the textile industry?

Moreover, personal visits to the different textile companies were arranged to examine the situation of the textile companies from an environmental sustainability perspective. Data collected through a questionnaire were analysed using the Statistical software SPSS. SPSS has several advantages such as a user-friendly interface, wide availability, suitable for questionnaire data analysis, and less time consumption [33–35]. The frequency distribution, mean, and median were performed in SPSS. Frequency distribution represents "what number or percentage of companies believes a specific point". In statistics, mean and median are the measures of central tendency. Mean represents "the average value for the responses of companies about a specific point". The median separates the upper half of a data set from the lower half. In the case of an odd number of observations, the median is the middle value. In the case of an even number of observations, the median is the mean of two middle values. Questionnaire data analysis along with interviews and personal visits increased the credibility of the results. The questionnaire was available as both the paper-based and the online google survey form. The online survey responses were accumulated into an excel sheet. On the same excel sheet, the paper-based responses were added by the authors as soon as the individual responses were received. The data based on interviews and personal visits were analysed, discussed, and updated regularly by the authors.

RESULTS AND DISCUSSION

This section summarizes the results of the study based on the questionnaire analysis, interviews, and personal visits. It has been revealed that most industrialists are serious and willing to implement environmental sustainability because the retailers are encouraging them. Managers believe that it is a war of survival and a need to sustain the market. New multinational textile brands are focusing on environmental sustainability. They prefer to be partners in sustainable industries. Therefore, the companies have to work on environmental sustainability on a priority basis.

Many textile companies in Pakistan are implementing environmental sustainability due to the increased pressures from local and international factors. Multinational companies and companies with global trade exposure are aware of environmental sustainability issues. For instance, a renowned textile company in Pakistan responded that they tend the full implementation of environmental sustainability measures. They have implemented the maximum certifications that exist in Pakistan. Another textile company with all the textile divisions responded that it has implemented several possible measures such as wastewater recycling, treated water for crops, complete health and safety measures for workers, and a successful reduction in energy consumption. A multinational textile company (i.e., a processing lab) in Pakistan responded that they have implemented many environmental sustainability measures.

However, they do not have a system to trap and store hazardous gases such as carbon dioxide emitting from the production process. They responded that "our company is equipped with state-of-the-art facilities to improve sustainability. We have all products with ecolabels. We do not waste even a single drop of water in the production process. We use wastewater for irrigation of plants and crops." For this company, it was observed during the personal visit that they follow all the health and safety rules. They take steps for sustainable products. They encourage their employees to follow the sustainability rules in transportation. The above evidence shows a tendency of the textile companies toward environmental protection. However, most companies lack the proper implementation of eco-friendly practices. This section examines the environmental sustainability practices in the textile industry of Pakistan. In this section, the figures with frequency distribution present the results in a different way than the figures with mean and median. A figure with frequency distribution shows the sorting of the number of companies regarding the extent of implementation of a sustainability measure. In contrast, a figure with mean and median shows the overall implementation of a measure in all the companies. The mean and median values range between 1 and 5 because they have been calculated from the results of the Likert scale for each company.

Energy sustainability

Figure 2, *a* shows the frequency distribution for energy sustainability. ES1 to ES7 are the symbols of the seven variables under energy sustainability (table 1). For frequency distribution, 5 is a strong agreement of specific companies about a variable, and one is a strong disagreement about a variable. The numbers 2, 3, and 4 are intermediate values of the 5-point Likert scale. Figure 2, *a* shows that the % companies do not use renewable energy sources. Similarly, most companies do not produce energy from waste (98.6%). In Pakistan, the energy crisis has pressurized the textile industry to produce energy from harmful fuels and cut forests. These practices are disturbing the balance of the natural environment, resulting in severe health issues for people. Government should overcome the energy crisis on a priority basis and discourage such practices. For instance, the waste produced from the cotton ginning can be used as an alternative energy source because cotton fibres are the major parts of textile fabrics. Besides, there is an increased tendency of many companies towards the adoption of energy-saving practices (companies take practical steps (64%), prefer energy efficiency (71%), involve everybody (60%), seek eco-friendly materials/methods (55%), and ensure efficient maintenance of machinery (75%)). Figure 2, *b* presents the mean and median for each variable in energy sustainability. The use of renewable energy sources and the production of energy from waste has the least mean and median. These findings are consistent with the results of frequency distribution.

Water sustainability

Due to the rapid increase in the population of Pakistan, the residential areas are coming close to the industrial areas. This is causing the release of industrial wastes and water into the surroundings, resulting in serious health issues for communities. Only some dedicated companies have invested in the water treatment plants, but the other companies lack a complete understanding of the benefits. Hence, the situation of water sustainability is not good in the textile industry of Pakistan. Near an industrial area, it was observed that the wastewater from the many textile companies was entering the main drain provided by the government. However, most companies discharge wastewater into the drain without any treatment. A similar situation was observed near another industrial area. Near these industrial areas, a few well-known textile companies responded that they have the latest water treatment technology to treat wastewater before discharge. However, they criticized that there is no benefit of water treatment because the other companies near them drain the water without any treatment. In a home textile company (spinning to stitching), it was observed that they have a proper drainage system, and the water pools were covered. They have Oeko-Tex Standard 100 testing and certification system. However, they lacked the focus on some other sustainability measures like safety and plantation. Another textile company responded that they have a water drainage problem, and they have no environmental certification. It was observed that this company has a very poor implementation of sustainability except for some health and safety rules inside the organization. There were leaked pipes and holes of water in the drainage system. Another textile company specialized in spinning responded that they have not taken any satisfactory steps for sustainability. They are not involved in international trade. They have poor water sources and drainage systems. During the visit, it was observed that the wastewater was stored in a pool inside the company. They were facing several issues such as the absence of any environmental certification, no health and safety measures, and no plantation. The management suggested that the major reason for the least environmental sustainability is the lack of government support. Some companies said that the wastewater treatment plant cost is very high and they are not able to afford its installation. After the awareness, most of the managers suggested that the second most effective strategy for implementing environmental sustainability could be "government support". Many textile companies complained about the lack of resources for environmental sustainability. Companies described that they have a lack of capital for the implementation of sustainability, and the key difficulty is to bring funds and support for sustainability. Government, industry, and institutions should join hands to work on weak areas such as renewable energy, water and energy-saving techniques, air emissions control, relocation of the industry etc. Managers suggested that the textile companies can protect the global environment by saving resources like water, energy and materials. For instance, the recycling of water can contribute to the efficient utilization of water. It can be said that only the multinationals and the companies involved in international trade are willing to water saving, recycling, and treatment.

Quantitative analysis shows that 71% of textile companies lack the implementation of waterless or reduced water techniques (figure 2, *c*). There is a tendency of the textile companies towards the adoption of other measures (54% of companies reduce freshwater use, 50% monitor used water and its sources, 49% have a system to control wastewater, and 46% discharge water after treatment). However, the overall situation is unfavourable and requires special attention from the Pakistani government to join hands with the textile companies to protect the environment. Government should closely monitor the performance of the whole textile industry. Also, the government should appreciate the performance of the textile companies which have taken the initiatives to improve water sustainability. Figure 2, *d* presents the mean and median for each variable in water sustainability.

Air sustainability

From the quantitative data analysis (figure 2, *e*), it is obvious that 40% of textile companies have some tendency toward the development of strategies to reduce air emissions. Also, 69% of companies are encouraging the planting of trees. However, all the companies lack a system to trap and store hazardous gases. Also, 9% of companies have a good system to measure the level of direct and indirect greenhouse gas emissions. Figure 2, *f* presents the mean and median for each variable in air sustainability.

Management in a well-known textile processing company responded that they have implemented all the environmental sustainability measures except the use of wastes to produce energy and a system to trap and store hazardous gases. The company has been constantly investing in environmental sustainability. Another similar textile processing company responded that they have implemented all the environmental sustainability measures except a system to trap and store hazardous gases. These two companies have a good system to measure the level of direct and indirect greenhouse gas emissions. Hence, some companies are willing to take practical steps to increase air sustainability. However, it is not enough because most companies are ignoring the effects of harmful emissions.

Materials sustainability

From the quantitative analysis (figure 2, *g*), it can be said that textile companies tend to materials saving (74% of companies encourage material saving, 71% make strategies to save materials, 73% perform careful material planning and control, and 71% reduce waste from poor quality and excess production). However, many companies lack some measures (48% of companies prefer the environment on price, 53% select materials based on least toxicity, 50% prefer electronic methods of communication instead of paperwork, 51% have ecolabels, 44% implement waste reduction strategies, and 41% use recycled input materials. Figure 2, *h* presents the mean and median for each variable in the sustainability of the materials. Management in a textile company responded that the products should be selected based on their toxicity and hazard. Materials should be biodegradable and produced with renewable energy sources. However, they agreed that they lack the actual practice for materials sustainability. Another textile company responded that "they did not take a proper step towards the sustainability of the materials. However, they are focusing on the reduction of paper wastes." Managers in several textile companies responded that the key target given to them is to reduce expenses. The focus is not the environmental protection. Hence, there is a lack of material sustainability in many textile companies.

Many companies complained that the customer demand is fluctuating and there is no proper planning for production management. Therefore, their whole focus is on fulfilling the customer's order. In this situation, they cannot focus on environmental issues. Hence, proper production planning and control could help these Pakistani companies to address this issue. A few companies said that the product cost is high. They use cheap materials which are harmful to the environment. Some companies revealed that they use nontoxic chemicals, recycled fibres, remanufacture materials, implement a lean manufacturing system, study material safety data sheet (MSDS) of the dyes and chemicals before selection, follow the manufacturing restricted substances list of ZDHC (Zero Discharge of Hazardous Chemicals), and prefer the local production of materials.

Transportation sustainability

In a few textile companies, it was observed that they have implemented transportation sustainability measures. In a multinational textile company (i.e., processing lab), it was observed that the management encourages the employees to follow the sustainability rules in transportation. From the quantitative analysis, it is obvious that 44% of companies are located close to the material suppliers (figure 3, *a*). However, most companies select the nearest suppliers for cost-saving instead of the emissions reductions related to the transportation of the materials. 46% of textile companies implement environmentally friendly methods of transportation and 37% of companies measure the environmental impacts associated with transportation. Figure 3, *b* presents the mean and median for each variable in transportation sustainability. For a textile company, a good transportation system was observed. However, it lacked the implementation of the other sustainability measures. Hence, a good transportation system does not guarantee the implementation of transportation sustainability. For this purpose, textile companies should intentionally integrate transportation sustainability into their supply chains. Several companies admitted that the lack of awareness is a major difficulty in implementation of the environmental sustainability.

Most textile companies suggested that the best way to implement environmental sustainability is to promote awareness among people about advantages of the environmental sustainability. Employees should take the implementation of environmental sustainability as a social responsibility. Companies should

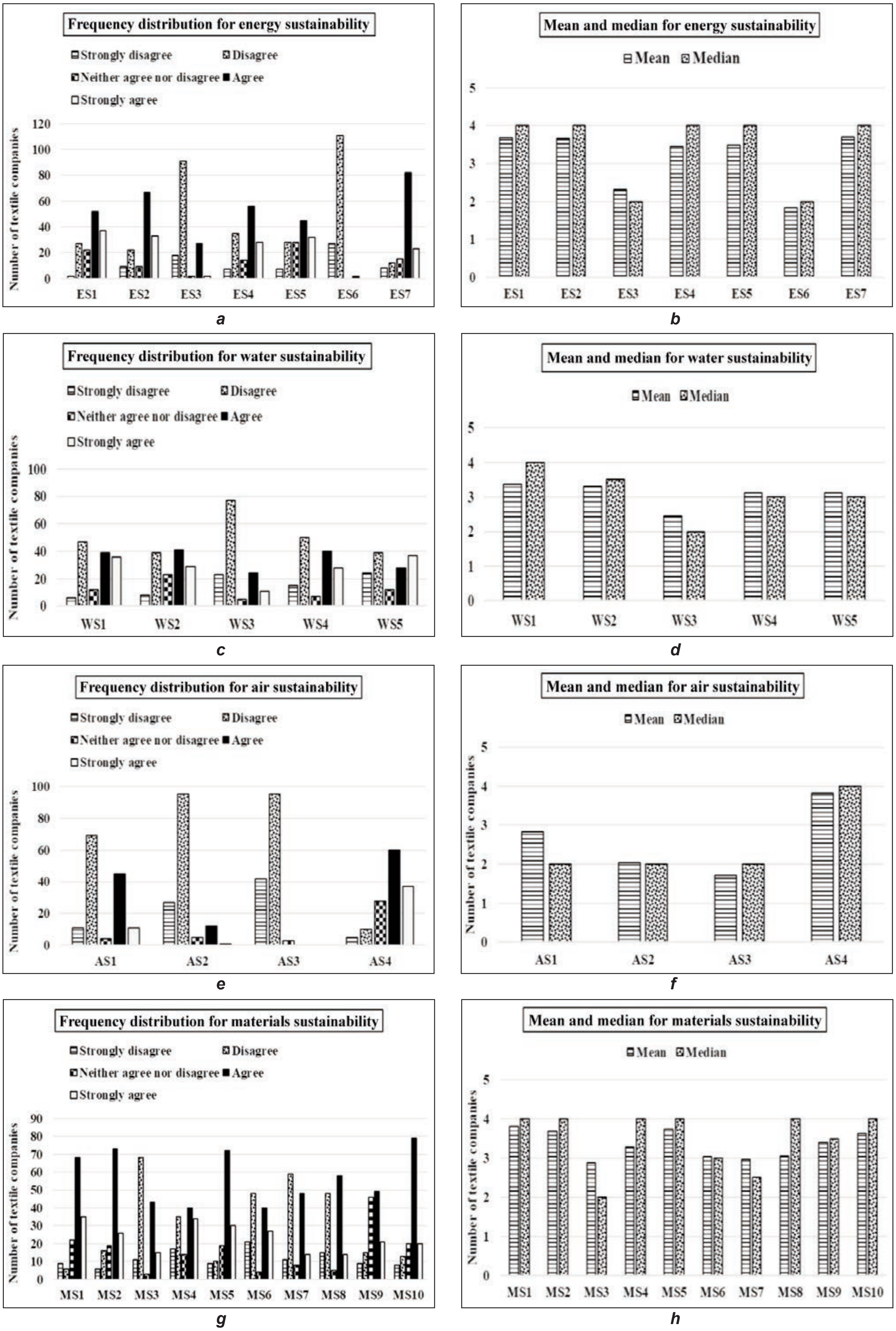

Fig. 2. Frequency distribution, mean, and median for energy, water, air, and materials

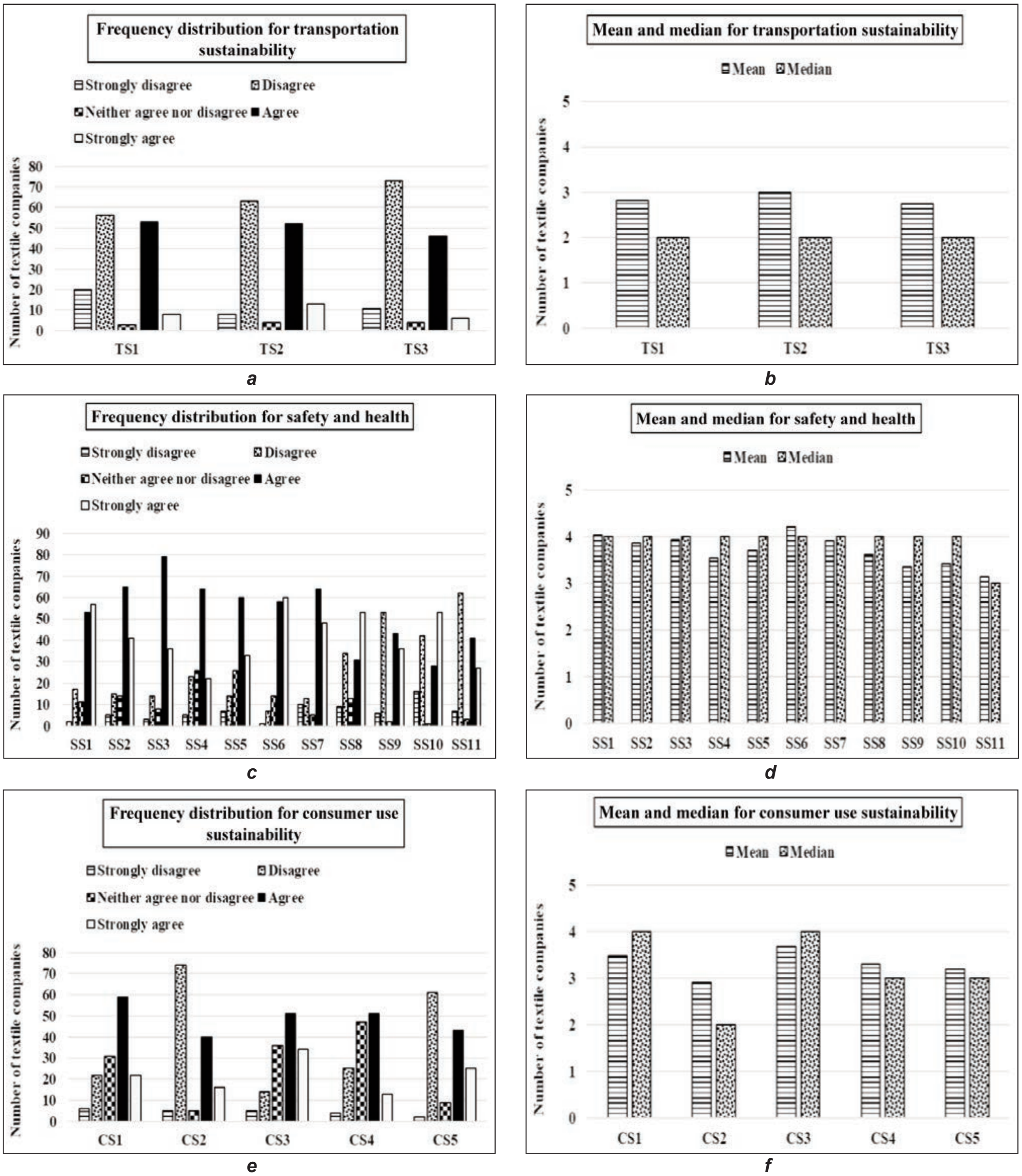

Fig. 3. Frequency distribution, mean, and median for transportation, safety and health, and consumer-use sustainability

discuss the environmental issues in their meetings at all levels. The top management should know the importance of environmental sustainability. The involvement of the top management can encourage the employees the better implementation of sustainability. Many companies said that the mindset of the industry is a major difficulty. Employees should take ownership. Companies should change their mindset at a basic level. Employees should be motivated to follow the rules related to the environment. Everybody should participate unconditionally in the protection of the environment.

Some companies said that the importance of environmental sustainability can be discussed with employees by organizing training and session presentations. Some companies suggested that environment, health, and safety teams should be formed. A few companies argued that people do not think about the future of the next generations. It is necessary to make this world a place where the next generations can survive, and the improvement in the environmental sustainability of the textile industry can play an important role.

Safety and health

Most textile companies tend the implementation of safety and health measures for their employees (figure 3, *c*). It is noticeable that 79% of companies have clear guidelines for health and safety, 76% manage noise pollution, 82% have proper ventilation and lighting, 84% have safety equipment such as fire extinguishers and fire alarms, and 80% have safety gloves in the dangerous areas. However, many textile companies lack the full implementation of safety and health rules. It is evident that 61% of companies adopt dust control measures, 66% have medical adequacy, 60% avoid restricted substance list, 56% check the materials harmfulness, 58 % are certified with a reputable certification system, and 49% have the waste disposal technologies for the hazardous waste. From the above statistics, it can be said that the textile companies in Pakistan are making a considerable effort toward the health and safety of their employees. Besides, several weak areas can be observed. Figure 3, *d* presents the mean and median for each variable in safety and health.

Several key facts were captured during the interviews and personal visits. For instance, a textile company responded that they have implemented small measures for environmental safety such as filters for dust collection, safety masks, planting trees, and a tendency to improve environmental sustainability. They have no certification, but they are hopeful to get the environmental certification shortly. They have a separate health and safety department. Another textile company responded that they are certified with ISO 14001 and OSHA 1800 systems. Many companies revealed that they lack the acquisition of reputable certifications. They said that the existing certifications need to be strict to get real benefits. Some companies revealed that the local laws are very flexible regarding environmental issues and the textile companies are taking full advantage of it. There are very low fines and least monitoring of the environmental issues inside and outside the textile companies. Therefore, the local laws should contain strict criteria for environmental sustainability, and the progress should be monitored. The companies should perform the proper monitoring of their environmental issues, such as monitoring wastewater, solid wastes, and sources of energy. The government must devise guidelines and laws that must be followed. Then, these laws and guidelines should be implemented strictly. Many companies said that improper monitoring and the flexibility in the international certifications are two important reasons for the improper implementation of environmental sustainability in the textile industry of Pakistan. The customer is demanding environmental certifications. The international certifications should implement strict criteria for certifications. Some companies said that they have installed machines that create much noise pollution. Similarly, a good implementation of some measures such as the proper air ventilation system and the proper training was observed in some companies. The textile industry in Pakistan should increase efforts in the weak areas to ensure the health and safety of their employees.

Consumer-use sustainability

Many textile companies agreed that they are producing durable (58%) and colour-resistant products (61%). 56% of companies lack products with technical coatings. 49% of companies agreed that their products allow environmentally friendly washing. 46% of companies said that their products are recyclable. From the quantitative data, it can be observed that many companies prefer the option "neither agree nor disagree" for durability, colour resistance and recyclability (figure 3, *e*). It may be because these companies are not sure about the environmental performance of their products at the consumer use phase. Figure 3, *f* presents the mean and median for each variable in consumer-use sustainability.

The textile industry affects the natural environment from the production of raw materials to the end-use of textile products [29, 36]. For example, textile and clothing products are at least 4% of municipal solid waste in the United States [29]. To reduce the harmful effects of products, textile companies and customers should consider consumer-use sustainability for producing a product. Nowadays, customers and retailers know that consumers are aware of the consequences of non-sustainable products. Therefore, sustainability at the consumer-use phase is demanded by environmentally conscious customers.

Durability, colour resistance, technical coatings, recyclability, and eco-friendly washing are the key characteristics that can improve sustainability at the consumer-use phase.

Weak sustainability areas

Figure 4 prioritizes the weak sustainability areas identified based on the least mean and median. The variables which indicated the means and medians nearly 4 or more than 4 may be considered as the strong areas of the textile industry of Pakistan. Strong areas include the availability of safety equipment

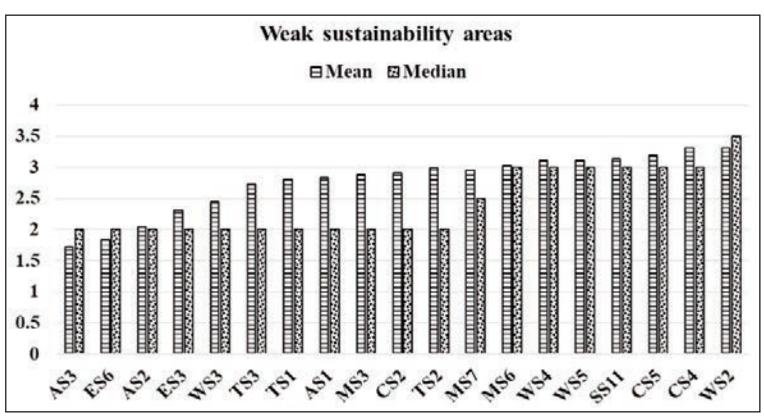

Fig. 4. Prioritization of weak sustainability areas based on least mean and median

such as fire extinguishers and fire alarms, clear guidelines for suitable lighting and ventilation, health and safety, the use of safety gloves in dangerous places, and the management of noise pollution. The variables which indicated the means and medians remarkably less than 4 may be considered as the weak areas. These weak areas should be given more preference to balance the efforts in all areas of sustainability. These results confirm the results achieved through frequency distribution.

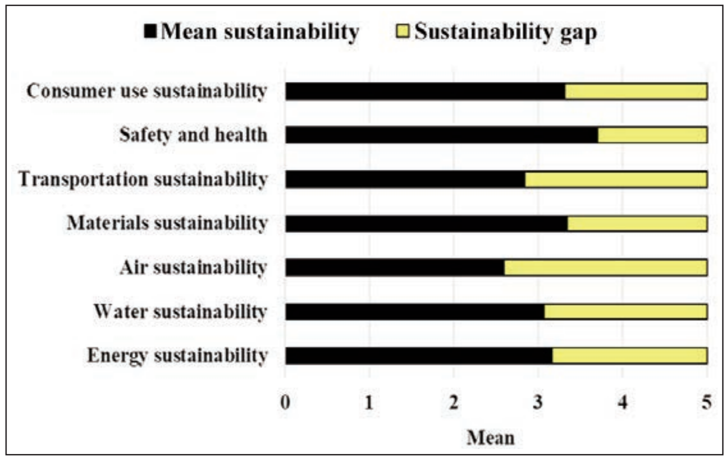

Fig. 5. Mean sustainability for seven factors

Comparison between seven major factors of the environmental sustainability

Figure 5 presents the comparison between the seven major factors of environmental sustainability based on the mean sustainability (i.e., grand mean) of each factor. The grand mean for each factor was calculated by taking the average of the means of all the variables within a factor. It can be observed that the safety and health factor looks superior to all the other six factors. However, a remarkable sustainability gap can be observed for each factor in figure 5. Hence, there is no strong factor of sustainability in the textile industry of Pakistan.

INSIGHTS FOR POLICYMAKERS AND PRACTITIONERS

This research provides various insights for policymakers and practitioners. The proposed survey instrument contains a strict and comprehensive environmental criterion to evaluate the existing practices in the textile industry. Based on the results, policymakers and practitioners can make possible policies to increase the practical implementation of the proposed tool. The results of the proposed survey help in the identification of various policies and practices. These policies can be used the improvement of the existing situation in the maximum number of textile companies. However, the development and implementation of the relevant policies cannot be achieved without the proper involvement of the government, the textile industry, and society. Today, international customers and retailers are under pressure to select the manufacturing destination based on strict environmental criteria. As a result, they are reconsidering the manufacturing destinations based on the environmental criteria. The manufacturers with poor environmental practices will be eliminated from the lists of international customers. Hence, the local governments should help the textile industry in the recent challenges. Otherwise, the gradual decrease in international customers will cause an economic crisis and unemployment. Such issues can be addressed through the implementation of various strategies. The first strategy is to increase awareness among all the concerned groups focusing on the topics such as social responsibility, implementation of eco-friendly techniques, benefits of the clean environment, and health and safety rules. Many textile companies in developing countries do not have enough resources to deal with environmental challenges. In this regard, government support is a very powerful tool for the implementation of eco-friendly practices. The collaboration of government, textile industry, and institutions is the best way to achieve sustainable development goals. In addition, the government should implement eco-friendly and practical policies, guidelines, and laws for the textile industry. Moreover, there should government, textile industry, and relevant institutions should develop effective mechanisms for monitoring environmental issues, such as wastewater, solid wastes, and sources of energy. In addition, the policymakers and practitioners should encourage the textile industry the adoption of ecofriendly techniques and technologies to save water, energy, and materials.

CONCLUSION

This research evaluates the environmental sustainability situation of the textile industry in Pakistan. It can be concluded that the Pakistani textile industry has not achieved an adequate level of sustainability in any area. The industry has some strong areas that include some health and safety variables. There are many areas in which the performance is weakest such as trapping and storing hazardous gases, using waste to produce energy, measuring the level of emissions, using renewable energy sources, and using waterless or reduced water techniques. Hence, these weakest areas need more attention. However, the textile companies need to focus on all the variables enlisted in the environmental sustainability implementation index. Moreover, the companies that have negligible interaction with international customers lack the implementation of environmental sustainability due to flexibility in the local laws. The companies involved in international trade tend the adoption of environmental sustainability practices due to the motivation and pressure from international customers. However, they are not very successful due to the national issues and weaknesses in the international certifications. Hence, the textile companies need special focus on the proper sustainability practices regardless of having or not having exposure to the international markets. Besides, the textile companies are unsuccessful in the satisfactory adoption of environmental sustainability due the issues such as lack of awareness and knowledge, lack of government support, flexibility in the local laws, flexibility in the international certifications, lack of monitoring by managers, ineffective utilization of resources, the non-interest of the top management, and improper production planning. In the end, it can be concluded that although the Pakistani textile industry has started taking certain steps regarding environmental sustainability, they are far behind the international standards and a lot of efforts are needed at a rapid pace. This study suggests that the implementation of environmental sustainability practices can be achieved through effective collaboration between policy makers, practitioners, and relevant institutions.

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Investigation of deformation properties of textured multifilament PES yarns

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ABSTRACT – REZUMAT

Investigation of deformation properties of textured multifilament PES yarns

In the process of texturing, smooth filaments are formed into crimpy yarns. By combining thermal and mechanical action, thermoplastic fibres acquire a permanent wavy shape.

Since textured multifilament yarns, formed from POY PES filaments, produced on machines with high-temperature heaters, are insufficiently studied, this paper analyses the deformation characteristics of yarns produced in industrial conditions using different process parameters (primary heater temperature, yarn speed, yarn stretching, peripheral speed of friction discs). Special attention is paid to the characteristics at the elastic limit, then at the creep limit, yield and breaking of multifilament textured yarns. A method is proposed which can determine the key points of deformation in the process of stretching textured polyester multifilament yarn, as well as the relationship between the values of force and elongation at the limits of elasticity, creep, end of creep zone, yield and break.

Keywords: *textured yarn, false twisting, elastic limit, creep limit, yield point, breaking force*

Investigarea proprietăților de deformare ale firelor multifilament texturate din PES

În procesul de texturare, filamentele netede sunt transformate în fire ondulate. Prin combinarea acțiunii termice și a celei mecanice, fibrele termoplastice capătă o formă ondulată permanentă.

Întrucât firele multifilament texturate, formate din filamente POY PES, produse pe mașini cu încălzitoare de temperatură înaltă, sunt insuficient studiate, această lucrare analizează caracteristicile de deformare ale firelor produse în condiții industriale folosind diferiți parametri de proces (temperatura încălzitorului primar, viteza firului, întinderea firului, viteza periferică a discurilor de frecare). O atenție deosebită se acordă caracteristicilor la limita elastică, apoi la limita de fluaj, deformarea și ruperea firelor texturate multifilament. Se propune o metodă prin care se pot determina punctele cheie de deformare în procesul de întindere a firului multifilament de poliester texturat, precum și relația dintre valorile forței și alungirii la limitele de elasticitate, fluaj, capătul zonei de fluaj, deformarea și ruperea.

Cuvinte-cheie: *fir texturat, torsiune falsă, limită elastică, limită de fluaj, punct de deformare, forță de rupere*

INTRODUCTION

In the process of texturing, the yarn is exposed to high temperatures and tensile and torsional forces, which affect the structure of the yarn and thus its properties (geometric, physical-mechanical, physical-chemical, etc.) [1, 2].

Modern technological solutions of frictional texturing by false twisting, are characterized by short heating zones with increased temperatures on the heaters and with a shortening of the heating time.

Texturing parameters significantly affect the properties of textured multifilament yarn, and thus their behaviour in subsequent processes of production of textile materials. The tensile forces of textured multifilament yarn in the production processes of textile materials significantly affect the final quality of the finished products. Poor quality of textile materials is very often obtained, although all preconditions in the process of preliminary design have been met. The reasons for such shortcomings should be sought in the irregularities in defining the tensile forces of textured multifilament PES yarns in the production processes of textile materials. The problem is especially pronounced in the texturing of partially oriented PES filament (POY – Partially Oriented Yarn), about which there is not enough data in the literature. Data from the literature mainly refer to data from laboratory conditions [3–5]. In paper [6], the influence of the parameters of the false twisting texture process on the structure and crimping properties of textured multifilament PES yarns produced in industrial conditions on a machine with high-temperature heaters were analysed.

The literature also contains information on the influence of texturing process parameters on the properties of multifilament POY PES yarns produced on texturing machines with classical primary heaters [7–10].

The literature offers a lot of information on the texturing of stretched polyester filament (FOY – Fully Oriented Yarn) which is less sensitive to changes in the parameters of the texturing process [11]. Also, there is information on the application of different texturing processes: Fully Oriented Yarn texturing procedures [12, 13].

In addition, the possibility of using recycled polyethylene terephthalate to make filament textured yarns was investigated and the properties of recycled PET filament yarns were compared with filament yarns made of new fibre-grade PET [14].

Since the properties of textured multifilament PES yarns produced on machines with high-temperature heaters are insufficiently studied, in this study the influence of texturing process parameters on the deformation properties of textured PES multifilament yarns produced in industrial conditions was analysed. Experiments in industrial conditions should enable the selection of optimal parameters of the texturing process, with the aim of increasing productivity and achieving energy savings. The obtained results should contribute to the economy of production of multifilament textured PES yarns.

MATERIALS AND METHODS

The experimental material was made in industrial conditions. Polyester multifilament yarn is produced on a machine for stretching friction texturing with high-temperature heaters: FTF-15 (ICBT, France). Technical-technological characteristics of the machine are: maximum speed of texturing: 1500 m/min; length of the first heater: 1.050 m; length of the second heater: 1.60 m; cooling zone: 1.24 m; friction aggregate: ICBT aggregate 1-5-1; working (5 pcs.) PU discs; C profile.

Samples of textured PES yarns of yarn count 167f36x1 dtex and 165f36x1 dtex were produced from POY PES multifilament of yarn count 278f36x1 dtex, manufactured by TWD Fibers (Germany). The POY polyester filament (poly (ethylene terephthalate)) used in this study is partially oriented with a very low degree of crystallinity (less than 5%), so its structure and properties can vary greatly by changing the parameters of the texturing process. A total of 108 industrial tests were performed, during which the texturing speeds (v) were changed, as follows: 500 m/min, 600 m/min, 700 m/min, 900 m/min, 1000 m/min and 1100 m/min. Then, the primary heater temperatures (T) of 350°C were applied; 400°C and 450°C, elongation coefficient (i) 1.667 and 1.687, and peripheral disk speed ratio and yarn speed (D/Y) of 2.15; 2.20 and 2.25. The temperature of the second heater had a constant value of 180°C.

The breaking characteristics of the experimental material were determined on an automatic dynamometer in accordance with the standard EN ISO 2062:2009. The breaking speed is a constant 500 mm/min. Using typical software, the typical force-tensile curves for the tested textured yarn pattern are defined. Typical curves are represented in the form of a function of a ninth-degree polynomial, with the coefficients of the determination being about 0.999 (figure 1).

By the analysis of the flow of the elongation force function, are determined the elastic limit (F_1, ε_1), the creep limit (F_2, ε_2), the end of the creep zone (F_3, ε_3), the yield after the creep zone (F_4, ε_4) and the break (F_5, ε_5) of experimental material (figure 1). In the case of textile materials, we are mainly talking about zones in which some kind of deformation dominates. For textured multifilament yarns, the given limits depend on the properties of the starting multifilament, but also on the process parameters of yarn production.

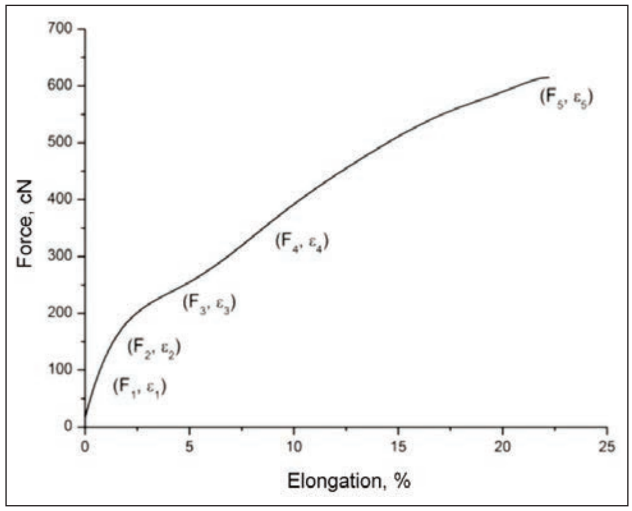

Fig. 1. Curve $F(\varepsilon)$ of multifilament polyester yarn

When stretching the yarn, the crimps, which were formed in the process of texturing, are initially straightened. Initially, a higher slope of the curve is noticeable i.e., a faster increase in force in relation to the stretching of the textured yarn to the point (F_1, ε_1). This point simultaneously represents the end of the elastic zone. Immediately after the elastic limit is the creep limit (F_2, ε_2). During further stretching, significant changes occur in the structure and all the way to the point (F_3, ε_3) there is a noticeable decrease in the slope of the force-elongation function. Then the slope increases again to the point (F_4, ε_4) and finally decreases until the interrupted textured yarn at the point (F_5, ε_5).

The elastic limit defines the recommended allowable load of textured yarns at which irreversible deformations of the material will not occur. The elastic limit of textured multifilament yarns was determined by analysing the flow function of tensile forces. By defining the local maximum of the first derivative of the function, where the second derivative of the function is equal to zero, the elastic limit is determined, as well as the parameters of forces and elongation at the elastic limit (F_1, ε_1).

The creep of textured multifilament yarns occurs by applying a load that causes stress in the yarn above the elastic limit. It is determined at the point of local minimum of the second derivative of the function i.e., at the corresponding zero of the third derivative of the function. At a given limit, the values of force and elongation at the creep limits are determined (F_2, ε_2). The creep limit of textured yarns is the upper acceptable load limit, to which the yarn can be subjected in subsequent technological processes, while the properties of the yarn are still acceptable for the production of textile products.

The creep zone begins at the creep limit and lasts until the textured yarn stops stretching faster and begins to provide significant resistance to the tensile force again. The end of the creep zone is determined at the point of a minimum of the first derivative of the function i.e., at the point where the second derivative of the function is equal to zero (F_3, ε_3).

Upon completion of the creep, the multifilament textured PES yarn again provides greater tensile resistance and the slope of the tensile force curve increases. This increase in force lasts until the moment when significant changes in the structure of monofilaments occur again due to stretching. The yield point after creep is determined at the point of local maximum of the first derivative of the elongation force function i.e., the zero of the second derivative of the function at a given point. This point on the graph (F_4, ε_4) can represent the maximum stress that the textured multifilament yarn will withstand in the processes of exploitation, to deform, but still not break.

Further stretching causes significant changes in the structure of the textured multifilament yarn, destruction of individual monofilaments and finally breaking of the multifilament yarn, which is marked by a dot (F_5, ε_5) on the graph (figure 1).

RESULTS AND DISCUSSION

In order to get the impression of changes in the values of force and elongation at the elastic limit, creep limit, end of creep zone, yield and break limits, graphs were chosen to show the given changes at the same ratio of peripheral disk speed and yarn speed (2.15) and the same stretching in the process of texturing (1.665).

Force and elongation were registered at the elastic limit of textured PES multifilament yarns. Based on the obtained results, figure 2 shows graphs that indicate the influence of temperature and texturing speed of multifilament yarns on their properties at the elastic limit.

The results show that textured multifilament yarns produced at a primary heater temperature of 350°C have force values at the elastic limit generally higher than yarns produced at a primary heater temperature of 450°C. Also, the trend of increasing force at the elastic limit with increasing texturing speed up to 1000 m/min is observed in yarns produced using a primary heater temperature of 350°C, and then a decrease in force was registered, unlike yarns produced using a texturing temperature of 450°C, where force growth trend up to a texturing speed of 1100 m/min. Elongation values at the elastic limit are generally higher for yarns produced by applying a higher texturing temperature.

The creep limit defines the upper allowed load limit of textured polyester yarns in the following technological processes of its processing.

The values of force and elongation were registered at the creep limit of textured polyester multifilament yarns. Based on the obtained results, Graphs are given in figure 3 showing the influence of the speed and temperature of texturing on the values of force and elongation.

The results show that in the case of textured multifilament yarns produced at a primary heater temperature of 350°C, the values of the force at the creep limit are higher than the yarns produced at a texturing temperature of 450°C. In addition, the trend of increasing force at the creep limit with increasing texturing speed up to 1000 m/min is observed in yarns produced using a primary heater temperature of 350°C, and then a decrease in force was registered, in contrast to yarns produced using a texturing temperature of 450°C, where is a trend of increasing force up to a texturing speed of 1100 m/min.

The values of force and elongation at the creep limit and elastic limit show analogous changes at appropriate texturing speeds and temperatures.

The end of the creep zone of the textured multifilament PES yarn ends at the moment when the tensile force begins to increase again faster than the elongation.

Figure 4 shows graphs indicating the influence of the primary heater temperature and texturing speed of

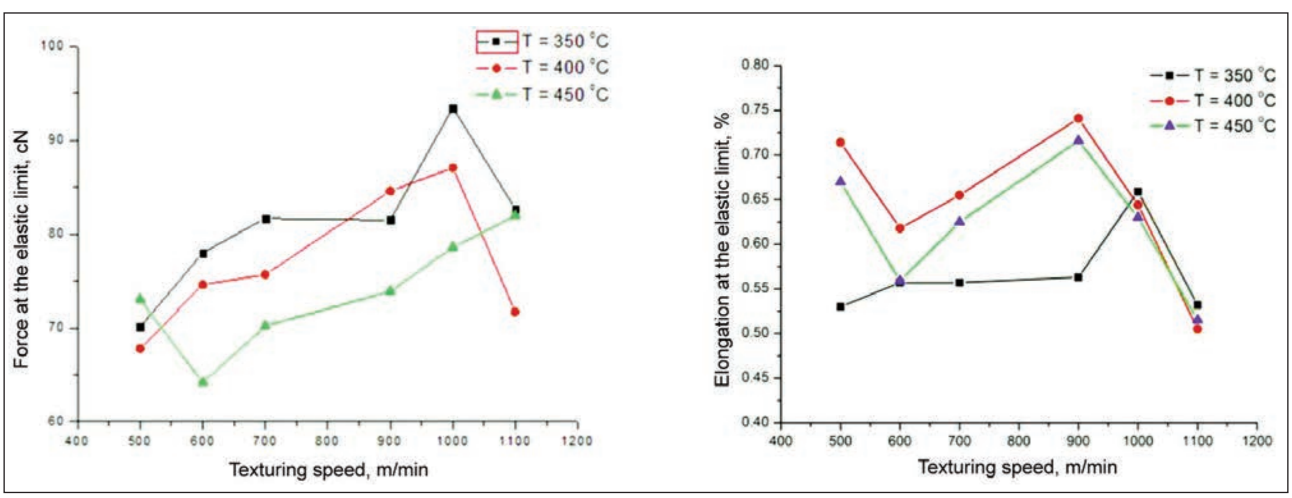

Fig. 2. The influence of texturing speed and temperature of primary heaters on force value and elongation at elastic limit (D/Y = 2.15, i = 1.665)

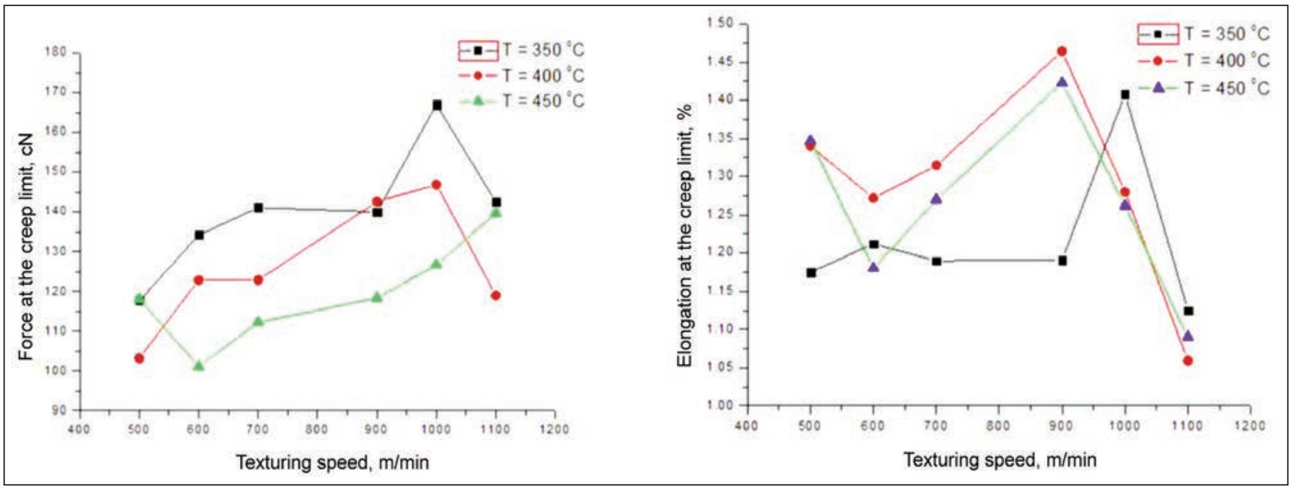

Fig. 3. The influence of texturing speed and temperature of primary heater on force value and elongation at creep limit (*D/Y* = 2.15, *i* = 1.665)

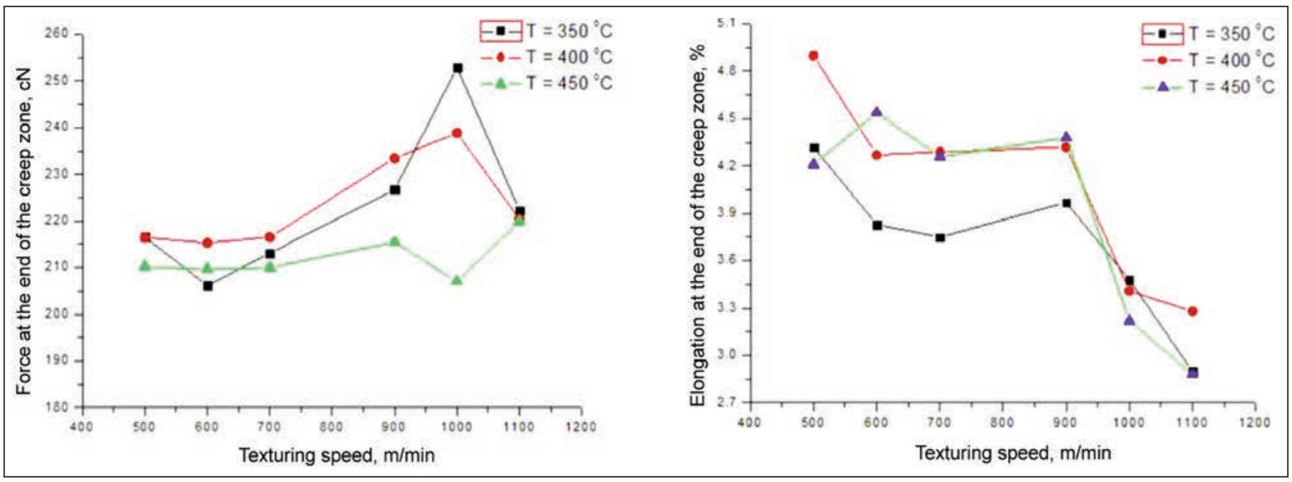

Fig. 4. The influence of texturing speed and temperature of the primary heater on the force value and elongation at the end of the creep zone (*D/Y* = 2.15, *i* = 1.665)

the polyester multifilament yarn on the properties at the end of the creep zone.

Analysis of the force value at the end of the creep zone at texturing temperatures of 350°C and 450°C shows that the force values are higher at a lower temperature, while the textured PES multifilament yarn elongates more at the end of the creep zone if produced at a higher primary heater temperature. Also, based on the obtained results, a significant decrease in elongation at the end of the creep zone can be stated in yarns produced at speeds higher than 900 m/min. The changes in the values of the forces in the creep zone are precisely the consequence of the uneven heat reception of the multifilament yarn, observed from the yarn surface towards the core. In his research, Eskin [15] showed that the difference in temperature of surface and core of yarn increases with increasing heater temperature, texture speed and decreases with yarn count, while the difference in temperature of yarn surface and core decreases with increasing heater length, which in this case is not a reason since these are HT heaters 1.050 m long.

Figure 5 shows graphs showing the influence of the temperature of the primary heater and the texturing speed of the polyester multifilament yarn on its properties at the yield point after creep.

The results show that textured yarns produced at a texturing speed of up to 900 m/min, at a primary heater temperature of 450°C have higher values of the force at the yield point compared to yarns produced at a primary heater temperature of 350°C. Elongations of textured yarns at the yield point have approximate values. Also, a trend of decreasing the value of force and elongation of the yarn at the yield point with increasing texturing speed was observed. There is a significant decrease in elongation at the yield point in yarns produced with texturing speeds above 900 m/min.

Figure 6 shows graphs showing the influence of primary heater temperature and texturing speed of polyester multifilament yarn on its breaking properties. Based on the obtained results, it can be noticed that the textured yarns produced at the temperature of the primary heater of 450°C have higher values of breaking force in relation to the yarns produced at the temperature of the primary heater 350°C. Textured multifilament PES yarns produced at a primary heater temperature of 400°C have higher breaking strength

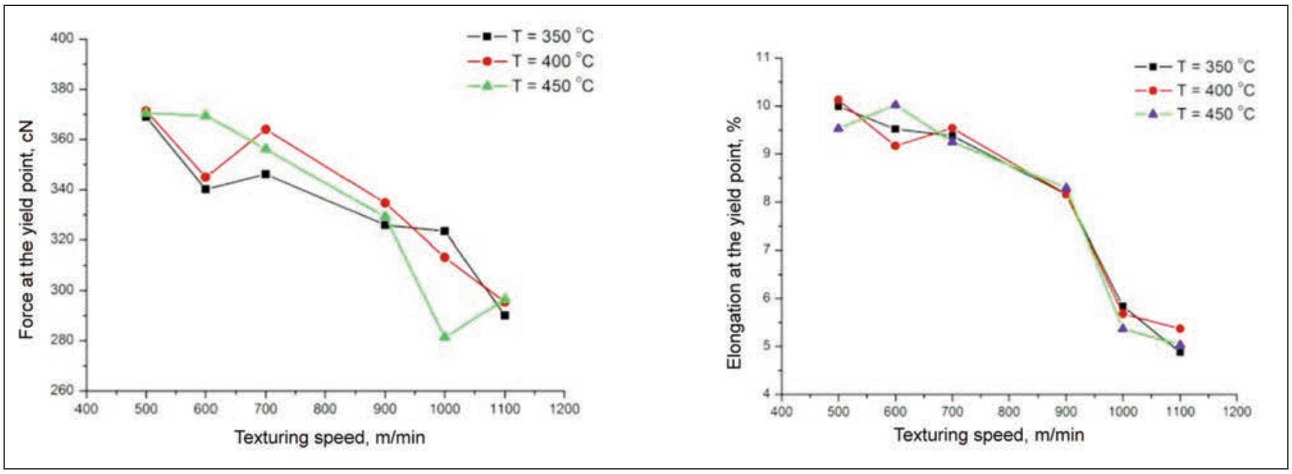

Fig. 5. The influence of texturing speed and temperature of the primary heater on the force value and elongation at the yield point (*D/Y* = 2.15, *i* = 1.665)

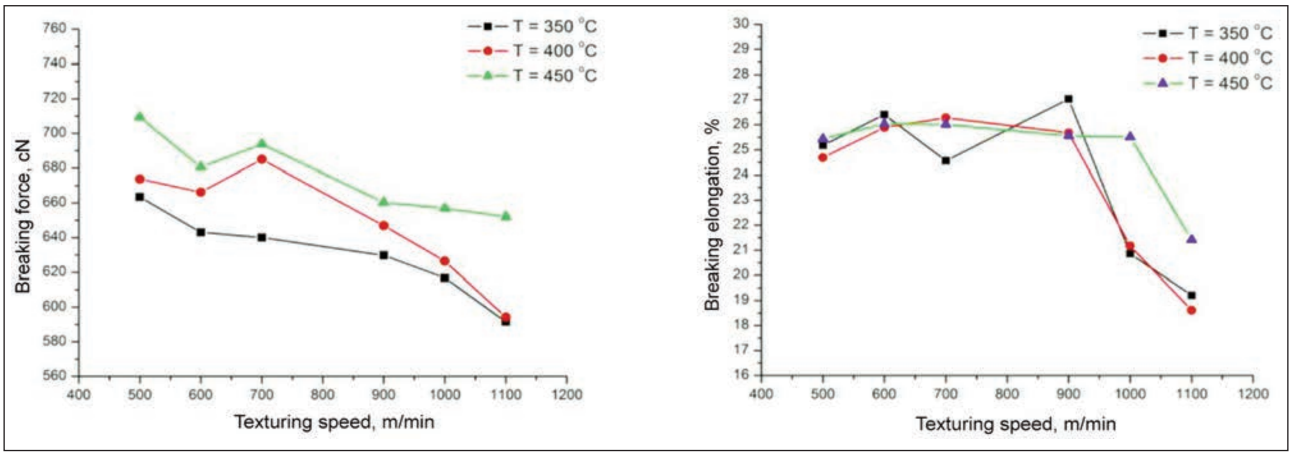

Fig. 6. The influence of texturing speed and primary heater temperature on breaking force and breaking elongation (*D/Y* = 2.15, *i* = 1.665)

values compared to yarns produced at a primary heater temperature of 350°C, and less than yarns produced at a primary heater temperature of 450°C. Also, a decrease in the breaking force of the yarn is observed with an increase in the texturing speed. Yarns produced at a texturing speed of 1100 m/min, at a primary heater temperature of 400°C, have approximate values of breaking force as yarns produced at a texturing temperature of 350°C, at the same other production process parameters. The breaking elongations of textured yarns have approximate values, with slightly higher values for yarns produced by a texturing temperature of 450°C at speeds of 1000 m/min and 1100 m/min. Also, there is a trend of decreasing the value of breaking force and breaking elongation with increasing texture speed above 900 m/min.

The higher temperature of the primary heater and longer exposure to temperature contribute to stress relaxation within the molecular chains of filament yarns, which affects the elasticity of the yarn. Simultaneous action of friction discs causes disorientation of macromolecular chains in the sense of twisting and bending in the process of false twisting, and higher temperature and longer retention of yarn in the heater contribute to greater disorientation of macromolecules in the process of false twisting and slightly lower value of force at the elastic and creep limit.

Relaxation of internal stresses in the yarn due to a higher temperature and longer temperature exposure is expressed in the values of yarn parameters at the yield point after the creep zone. Namely, during stretching, in the process of breaking on the dynamometer, the macromolecules are oriented in the direction of the yarn axis. It is expected that multifilament textured yarns produced by applying a higher texturing temperature have a better orientation of the macromolecular chains at the yield point, due to the lower internal stress of the yarns thus formed. This may be the reason mainly for slightly higher values of forces at the yield point and higher values of breaking forces of textured multifilament PES yarns, produced by applying higher texturing temperatures.

In order to preserve the mechanical characteristics of multifilament textured PES yarns, it is very important to define the allowable yarn loads in the following technological processes. Especially since all monofilaments of multifilament yarn could not absorb the same amount of heat, due to their position in the yarn, so their properties will differ enough that we

Table 1

PARAMETERS OF FUNCTION *a*, *b* FOR DETERMINING THE VALUE OF FORCE IN POINTS 1 TO 5					
Function	**$F = a \times \varepsilon^b$ (cN)**				
Parameters	**a**	**St.error**	**b**	**St.error**	**r^2**
v = 500 m/min; T = 350°C	94.99763	2.42722	0.60357	0.00889	0.99662
v = 500 m/min; T = 400°C	81.65465	2.32775	0.6616	0.00987	0.99652
v = 500 m/min; T = 450°C	88.03712	2.12453	0.64778	0.00832	0.99735
v = 600 m/min; T = 350°C	101.49837	3.02126	0.56914	0.01032	0.99444
v = 600 m/min; T = 400°C	94.26997	2.29022	0.60384	0.00835	0.99698
v = 600 m/min; T = 450°C	80.33149	1.77259	0.66029	0.00749	0.99811
v = 700 m/min; T = 350°C	99.92983	3.32977	0.57814	0.01173	0.99319
v = 700 m/min; T = 400°C	85.48915	2.00175	0.64161	0.00802	0.99768
v = 700 m/min; T = 450°C	88.13831	1.81877	0.63819	0.00707	0.99815
v = 900 m/min; T = 350°C	115.62203	3.14297	0.51605	0.00951	0.99358
v = 900 m/min; T = 400°C	109.67339	2.75136	0.54877	0.00882	0.99524
v = 900 m/min; T = 450°C	96.22174	2.64515	0.59987	0.00956	0.99558
v = 1000 m/min; T = 350°C	127.07795	2.19324	0.52338	0.00657	0.99676
v = 1000 m/min; T = 400°C	120.38161	2.14329	0.54593	0.00666	0.99702
v = 1000 m/min; T = 450°C	107.32115	3.00239	0.58121	0.01018	0.99416
v = 1100 m/min; T = 350°C	124.46485	1.87702	0.53296	0.00586	0.99755
v = 1100 m/min; T = 400°C	119.72414	1.50149	0.55417	0.00483	0.99849
v = 1100 m/min; T = 450°C	121.07555	2.22649	0.54629	0.00689	0.99687

cannot talk about the homogeneity of multifilament textured PES yarn. This inhomogeneity of the structure will in any case lead to variation in the quality of the multifilament yarn, to which special attention must be paid when predicting the properties of these yarns. A responsible approach to the analysis of the properties of textured multifilament yarns can achieve energy savings in the texturing process and contribute to the optimization of the production of yarns produced on machines with HT heaters.

In industry, a conclusion is often made about the quality of yarn, in terms of mechanical characteristics, only on the basis of its breaking characteristics. That is not a good solution. Knowing the values of forces and elongation at the limits of elasticity and creep of textured multifilament PES yarns gives a true picture of the values of forces that the yarn can be loaded in the technological processes of processing into textile materials. In that way, the properties of the yarn will be preserved and thus the good quality of the finished product will be ensured in accordance with the design of the textile material and the requirements of the standard.

Taking into account all the above, the optimal parameters of the texturing process must be chosen as a compromise solution having in mind the texturing temperature, texturing speed, stretching of multifilament yarn in the manufacturing process, the ratio of peripheral disk speed and yarn speed, POY PES multifilament quality, machine condition and crimp characteristics of the textured yarn. The obtained results showed that the partially oriented polyester yarn used in this paper can be textured at significantly higher texturing speeds compared to the standard texturing speeds (up to 700 m/min) used for processing the yarns of tested yarn count.

Figures 7, *a–f* show the relationship of parameters at the limits of elasticity, creep, end of creep zone, yield and break. Therefore, only images showing the correlation of the analysed parameters in textured multifilament yarns produced at a temperature of 400°C are presented. The values of force (cN) and corresponding elongations (%) at given points are described by equations:

$$F = a \cdot \varepsilon^b \text{ (cN)} \quad (1)$$

Table 1 gives the parameters of function *a*, *b* for determining the value of force in points 1 to 5 (figure 1), at texturing temperatures of 350°C, 400°C and 450°C and speeds of 500 m/min, 600 m/min, 700 m/min, 900 m/min, 1000 m/min and 1100 m/min i.e., for all 108 samples made in industrial conditions. The obtained results (at different texturing speeds and temperatures) include all samples where the values of *D/Y* are 2.15, 2.20 and 2.25, as well as stretching 1.665 and 1.685, since this range of changes did not have a significant effect on the deformation properties of the textured multifilament yarns analysed in this study.

The results are presented for textured multifilament polyester yarns produced using the appropriate primary heater temperature and texturing speed with a defined ratio of peripheral disc speed and yarn and elongation speed in the production process. The results can be applied to predict the properties of textured PES multifilament yarns at appropriate production process parameters. In addition, the obtained results can be used to predict the properties of

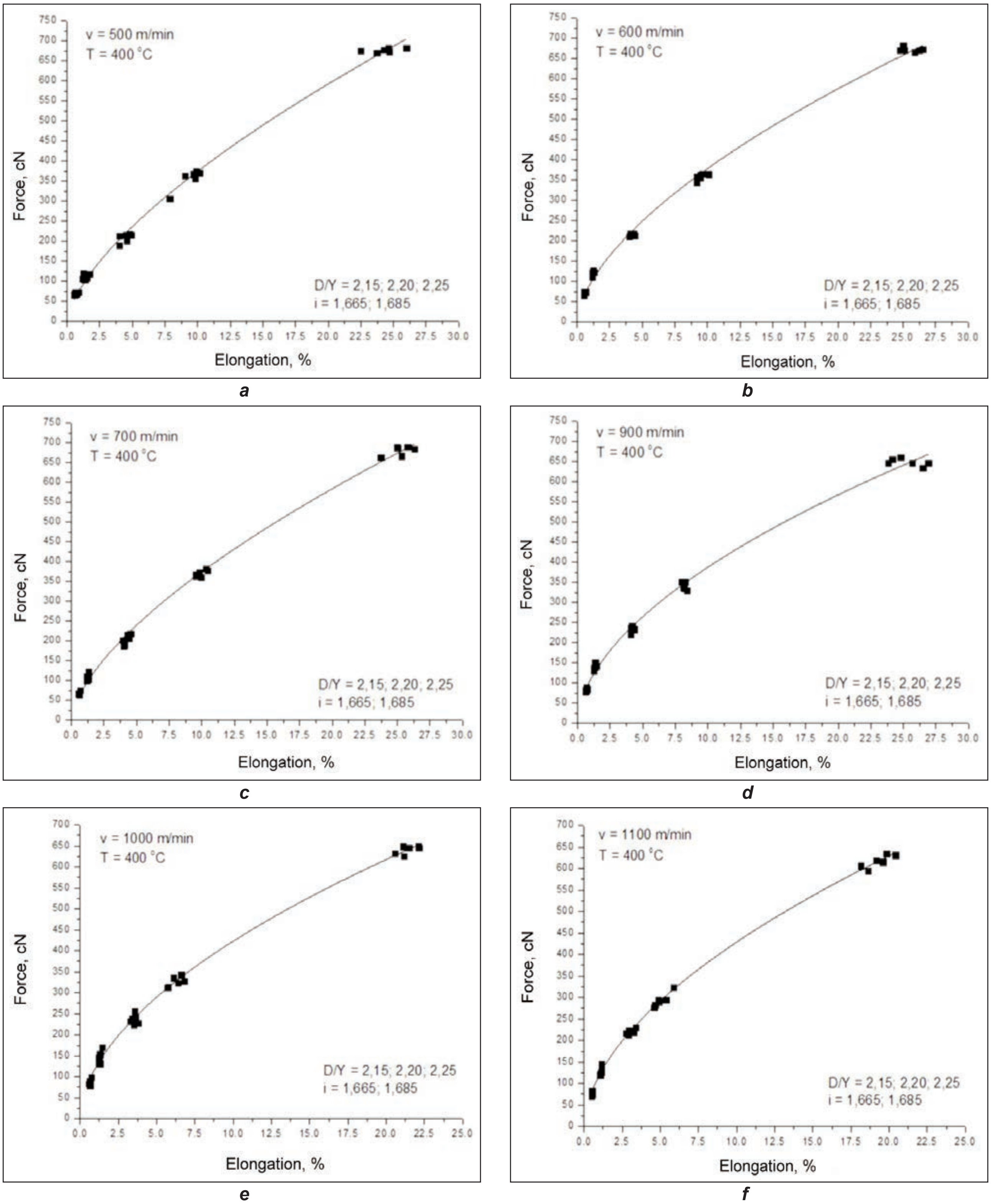

Fig. 7. Relationship of parameters at the limits of elasticity, creep, end of creep zone, yield and break: *a* – relationship of parameters (v = 500 m/min, T = 400°C); *b* – relationship of parameters (v = 600 m/min, T = 400°C); *c* – relationship of parameters (v = 700 m/min, T = 400°C); *d* – relationship of parameters (v = 900 m/min, T = 400°C); *e* – relationship of parameters (v = 1000 m/min, T = 400°C); *f* – relationship of parameters (v = 1100 m/min, T = 400°C)

textured multifilament PES yarns in subsequent production processes into textile products.

CONCLUSION

Knowledge of the deformation characteristics of textured multifilament PES yarn is very important from the aspect of predicting its behaviour in the processes of production into textile materials and products, as well as predicting the behaviour of textile products during exploitation.

The key points of deformation of textured multifilament PES yarn in the stretching process are defined and a method for determining the elastic limit, creep limit, end of creep zone and yield point after creep is proposed.

In addition, the results showed that the texturing temperature has an analogous influence on the values of the forces at the elastic and creep limits. It was found that lower texturing temperatures have a more favourable effect on the values of force at the elastic limit and force at the creep limit, while higher temperature values generally have a more favourable effect on elongation at the elastic limit and creep limit.

The influence of temperature on the value of the force at the yield point and on the breaking force of the yarn is opposite in relation to the changes in the value of the force at the elastic limit and at the creep limit. Namely, higher texturing temperatures generally give slightly higher values of the force at the yield point and higher values of the breaking force.

In order to contribute to the development of a method for predicting the behaviour of textured multifilament PES yarn in the next phases of processing, an equation is proposed that correctly connects the key points (force-elongation at the elastic limit, at the creep limit, at the end of the creep zone, at the yield point and yarn break) in the process of stretching the yarn, until it breaks.

The purpose of textured multifilament PES yarn and the tensile force of yarn in technological processes of production into textile materials must be observed simultaneously and the technological parameters of yarn texturing adjusted accordingly. In this way, energy savings in the texturing process can be achieved and contribute to the optimization of the production of textured multifilament PES yarn on machines with high-temperature heaters.

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Quality assessment of fabrics obtained from waste

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YITIK BEKIR

ABSTRACT – REZUMAT

Quality assessment of fabrics obtained from waste

The need for ready-made clothing and home textiles produced from natural and synthetic fibres is increasing day by day in order to meet the needs of the increasing world population. Recently, the concepts of sustainability and recycling have gained importance in the textile industry. The rapid change in today's trends has developed disposable habits. Due to the rapidly changing fashion trends, the product variety has increased and mass production has been preferred. Therefore, the priority for customers to choose the products was not the material used, but whether they fit the current fashion trend. Thus, the use and production of natural fibres should be increased to reduce environmental pollution and meet production demand. Thanks to recycling, it is possible to reuse the waste textile materials that we leave to nature. Due to the increase in agricultural production costs, it has become difficult to obtain the raw materials used for textiles. When a life cycle system is created for raw materials that evaluate them until it is produced in nature and then return to nature, production with textile waste recycling can be advantageous. Using natural waste fibres instead of natural virgin fibres to produce home textile products both reduces costs and makes production easier. In this study, recycled (waste) cotton was obtained by shredding white, 100% cotton woven duvet covers and sheets purchased from a private hospital. A 50%-50% waste-natural blend was created from the cotton obtained. 54 wire reference fabrics were woven using open-end yarns numbered Ne24 and Ne12 produced from this blend. The physical characteristics of the fabric were investigated. The results obtained were analysed statistically and the effect of the blend created on the fabric quality was comprehensively examined.

Keywords: *textile waste, recycling, sustainability, life cycle*

Evaluarea calității țesăturilor obținute din deșeuri

Nevoia de produse de îmbrăcăminte și textile de casă realizate din fibre naturale și sintetice crește pe zi ce trece, pentru a satisface nevoile populației mondiale în creștere. Recent, conceptele de sustenabilitate și reciclare au câștigat importanță pentru industria textilă. Schimbarea rapidă a tendințelor de astăzi a dezvoltat obiceiuri de unică folosință. Datorită tendințelor modei în schimbare rapidă, varietatea de produse a crescut și a fost preferată producția de masă. Prin urmare, prioritatea clienților de a alege produsele nu a fost materialul folosit, ci dacă acestea se potrivesc cu tendința actuală a modei. Astfel, utilizarea și producția de fibre naturale ar trebui să crească, pentru a reduce poluarea mediului și pentru a satisface cerințele din producție. Datorită reciclării, este posibilă reutilizarea deșeurilor de materiale textile, pe care le aruncăm în natură. Datorită creșterii costurilor de producție agricolă, a devenit dificilă obținerea materiilor prime utilizate pentru producerea materialelor textile. Atunci când se creează un sistem de ciclu de viață pentru materiile prime, care le evaluează de când sunt produse în natură și până revin în natură, producția pe baza reciclării deșeurilor textile poate fi profitabilă. Folosirea deșeurilor de fibre naturale în loc de fibre naturale virgine pentru fabricarea produselor textile pentru casă reduce costurile și facilitează producția acestora. În acest studiu, bumbacul reciclat (deșeu) a fost obținut prin mărunțirea huselor de pilote și a cearșafurilor albe, țesute din 100% bumbac, achiziționate de la un spital privat. Din bumbacul obținut a fost creat un amestec 50%-50% deșeuri-fibre naturale. 54 de țesături de referință au fost obținute folosind fire de Ne24 și respectiv, Ne12 produse din acest amestec. Au fost investigate caracteristicile fizice ale țesăturii. Rezultatele obținute au fost analizate statistic, iar influența amestecului creat asupra calității țesăturii a fost examinat cuprinzător.

Cuvinte-cheie*: deșeuri textile, reciclare, sustenabilitate, ciclu de viață*

INTRODUCTION

The textile industry is among the most important consumer goods industry. Textile materials are classified according to the market in which they will be sold. The sector is divided into three main activity sub-sectors characterized by different industry dynamics and success factors. For this reason, we can talk about ready-made clothing (fashion/design), interior textiles and technical textiles [1]. The formation step of the final product, the textile material, and the processes it goes through until it becomes a product, use and recycling gain importance. If the textile raw material is a natural fibre, it is easier to be evaluated as waste. The ready-made clothing industry has given priority to synthetic fibres by simplifying production to keep up with the developing world. Since the manufacturers have adopted the disposable concept in their sales policies, and easy production system has been preferred. Due to the population growth in the global world and fashion trends designed according to the wishes and desires of people, the natural product stock in textile products, whose consumption is increasing rapidly, has almost ended. Although the fact that the need cannot be met due to the high human population seems to be a factor, natural resources, environmental conditions and the policies followed by the countries are also effective. For this reason, the fact that natural resources will be depleted in a short time due to wrong policies should always be remembered. In this context, the importance of recovery increases even more [2, 3].

It is very difficult to produce using natural fibre in easy production methods. The quality of the material used is a determining factor in the cost. It is also known that the cost affects the sales policy negatively. The concept of health has always been prioritized in the choice of trend materials. When the concept of health comes to the fore, the tendency to natural products increases. Therefore, the cost of using natural products increases. The recycling of textile waste is not only an important tool to solve many environmental problems but also an important socio-economic and environmental sustainability tool [1]. Recycling in textiles is a method of reusing or reprocessing used clothing, fibrous materials and clothing parts by the intermediate manufacturing process [4]. Due to the low cost due to mass production and sales below the purchasing power, more purchases than needed have started. Due to mass production and falling costs, the volume of products purchased has also increased, but the quality has been compromised. Therefore, the volume of waste products has also increased. However, since these wastes generally contain low cotton, they are costly to recycle. The excess of synthetic products instead of the natural raw materials produced has led to the trend of cheap clothing. Due to the low-quality perception of the produced product, the long-term wearing and use of these products have decreased. The fashion industry, which is a global industry, has a great impact on people and the environment [5, 6].

In ecological life, there is a shortage of raw materials for the crowded world. If a sustainable product range is not implemented, there has been a tendency towards synthetic products instead of natural fibres for raw material supply in the textile sector. The fact that it is easy to provide raw material sources in rapid production has led to the preference for synthetic products over natural products. Thanks to the synthetic raw material used, the concepts of natural balance and human health have become meaningful. For example, while a carpet rug made from natural raw materials can be used for centuries, when synthetic products are used in production, it has only a few years of life. Apart from this, there is a linear relationship between the world population and the use of textile products. To meet the need for textile products, great efforts are made to recycle these products instead of destroying the waste products. Recycling has started with the recycling of wastewater and the use of this water in agricultural irrigation. In this context, treatment plants were built. Thanks to these treatment facilities, environmentally friendly businesses were established and the dyehouses used in the textile industry established their purification systems. In the textile sector, recycling systematically starts with mechanical separation and shredding. In this context, environmental wastes should be collected and processed for raw materials [3].

It is quite surprising that in the 1980s, within the framework of the concept of "redesign and reuse", the process of thinly slicing fabric pieces and processing them on hand looms and using these products in home textiles was done before the concept of recycling was known. Modern-style "reproduction" i.e., recycling, has found use in the production of blankets and home textiles in certain regions of Turkey (e.g., Uşak/Turkey) [3]. Materials obtained from recycling have been used as a "non-woven surface" in the textile industry. Felt is made from these non-woven surfaces. Other products were produced in the form of automotive textiles and cleaning cloths [3, 7]. When the raw material is decomposed in the products obtained from recycling, that is, when the content of the material from which the product is produced is known, if the material obtained is a natural fibre, it can be used for Open-end yarn production, if synthetic material is melted, it can be used in the textile industry or alternative sectors. Yarns produced in the open-end system are used as upholstery fabric knitting and knitwear [3, 7]. If the raw material is used directly in sustainable textile products without being separated as a blended fibre, it is expressed as low quality because the content of the obtained material is not known exactly and is evaluated in secondary textile products [7]. It is easier to recycle home textile products on a sectoral basis. If the raw material is a single product and the mixture is not fibre, it is easy to transform the product [3].

The surfaces woven from cotton, which is a natural fibre, with different production methods are recovered by mechanical methods. Waste materials are brought into fibre form again by passing through shredding machines and recycled cotton fibres are mixed with new cotton fibres in the proportions determined in accordance with the usage area and used in the yarn production line. It is of great importance to determine various physical, chemical and comfort properties by creating a surface with the recycled yarns obtained in this system, to present these materials to the market and to be accepted by consumers [6, 8]. As an example of the use of waste textile products, end-of-life textile products are collected and turned into cotton, and denim can be obtained from this recycled cotton [9]. Open-end spinning has an important place in these production systems. The obtained yarn properties, the material created with the help of some parametric properties of production, have new product properties. In this Open-end technology, which produces at maximum speed in the production settings and uses high technology, certain

settings in the machine must be meticulously selected in order to ensure high-performance yarn production with high-quality properties [10]. Machine settings have a significant effect on the quality of the yarn and the production quality. Today, the open-end rotor spinning system has become able to compete with the ring spinning system. The fact that open-end spinning machines are suitable for automation has developed together with technology, enabling it to surpass many other spinning systems and have a share of 30% worldwide [11].
In sustainable product designs, it is not enough to melt the product, cut it into strips, shred and produce it as Open-End yarn. Since recycling is long in terms of process and low in cost, other production methods are also included in the system. In the compact yarn production system, yarns that can be used in different fields are produced by using the shredding system to recycle the products produced from a single type of raw material [3]. Recycling is not just about home textiles. Clothes are made from textile materials produced as weaving and knitting. Before production, our people consciously collect the right recycling in the right place, thus expanding the usage area of the product, which is formed uniformly. Clothing and some home textile products, which are among the economic life cycle textile products, have very little life cycles. It is also possible to recycle textile products used in daily life with zero waste projects and contribute to the economy, raise awareness of customers and prevent environmental pollution [12–16].

MATERIAL AND METHOD

In this study, recycled (waste) cotton was obtained by shredding white, 100% cotton woven duvet covers and sheets purchased from a private hospital. A 50%-50% waste-natural blend was created from the cotton obtained. For Ne12 used as warp yarn in the compact yarn production line produced from this blend; 1500 rpm, exit roller speed of 24.19 m/min., used traveller model C1EL udr 63 and ring diameter of 40 mm (Titan). For Ne24, the weft yarn produced from the determined blend; 1700 rpm, exit roller speed 22.66 m/min., used traveller model C1EL udr 45 and ring diameter of 40 mm (Titan). The fabric was woven from this blend using compact yarns of Ne24 and Ne12. 177 grams/linear meter fabric is woven using Ne24 yarn for weft and Ne12 yarn for warp using reference (54 wire) plain weave. 54 wire reference fabric was woven with a weft density of 32 wire/cm and a warp density of 22 wire/cm. The properties of the fabric obtained are shown in table 1.

Table 1

EXAMINED WOVEN FABRIC STRUCTURES AND PROPERTIES	
Sample	**Specifications**
Fibre composition	Recycled-Natural 50%-50%
Weft	Ne 24 Compact Ring
Warp	Ne 12 Compact Ring
Yarn layers	Single
Warp density	22
Weft density	32
Weft yarn twist number (t/m)	552
Weft yarn twist factor (αe)	3.5
Warp yarn twist number (t/m)	795
Warp yarn twist factor (αe)	4.5
Weight	178
Fabric width (cm)	165

RESULTS AND DISCUSSION

10 samples were randomly selected from the edge and middle regions of the fabrics produced. The samples taken were examined for physical properties such as tensile strength, tear strength, bending strength, and air permeability according to TSE standards. The physical properties of the fabric obtained from recycling in the study are given in table 2.
The determination of whether recycling is logical to re-join life and the contribution of the place where it is located will be positive. In the textile sector, renewable products will gain an important place in the field of clothing and home textiles.
Tensile strength, tear strength, bending strength and air permeability of the fabric properties are shown in figures 1–4, respectively.

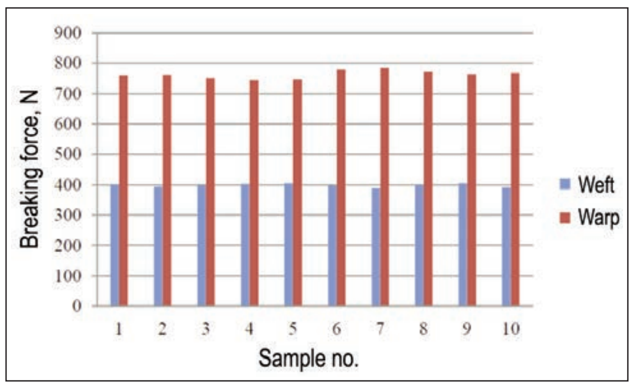

Fig. 1. Tensile strength plot

Figure 1 shows the tensile strength of the fabric produced for experimental work. When the data in table 2 are examined, the average tensile strength in the weft direction used in production was found to be 397.87 N. The warp tensile strength average of the recycled fabric was found to be 763.33 N. The standard deviation of weft grabbing strength was 5.37 and the warp breaking strength standard deviation of the sample obtained was determined as 12.29. In the light of the data obtained, there was no visible loss of value in tensile strength values. The average weft rupture elongation and standard deviation of the produced sample were determined as 9.26% and 0.28.

Table 1

REFERENCE FABRIC PHYSICAL PROPERTIES												
Fabric	Tensile strength				Tear strength (N)		Flexural strength (mg·cm)	Air permeability (mm/s)	Abrasion resistance (Tour)	Pilling (pilling/field)	Weight (g/m^2)	Thickness (mm)
	Breaking force (N)		Elongation at break (%)									
	Weft	Warp	Weft	Warp	Weft	Warp						
1	402.06	760.24	9.05	11.30	33.22	38.18	10.63	321.00	15230	138	177.80	0.41712
2	393.50	762.11	9.14	12.50	34.49	37.90	11.286	325.00	15230	132	178.00	0.38192
3	396.82	751.69	8.97	12.31	35.40	38.55	11.55	325.00	15230	141	178.20	0.38016
4	402.72	744.84	9.26	12.78	36.04	41.95	10.592	332.00	15230	140	178.60	0.42416
5	405.21	747.16	9.00	12.89	35.96	38.18	12.24	329.00	15230	147	177.95	0.41536
6	396.33	778.31	9.08	13.31	36.86	43.42	11.25	321.80	15230	136	177.95	0.39952
7	388.52	784.36	9.66	12.59	36.58	41.86	13.328	321.50	15230	139	177.88	0.46112
8	397.49	771.81	9.56	13.52	36.67	42.78	11.253	331.00	15230	140	178.41	0.43648
9	404.63	765.04	9.75	13.42	39.31	43.52	12.39	325.00	15230	142	178.20	0.43472
10	391.68	767.71	9.10	13.37	38.68	42.78	13.015	314.00	15230	144	178.20	0.38192
Mean	397.89	763.33	9.26	12.80	36.32	40.91	11.75	324.53	15230	141	178.12	0.41
Standard deviation	5.37	12.29	0.28	0.64	1.70	2.27	0.90	5.08	-	15.4	0.24	0.03

The average warp breaking elongation and standard deviation of the sample produced were determined as 12.80% and 0.64.

Figure 2 shows the tear strength graph of the samples produced. When the tear strength values are examined in table 2, the weft tear strength average was determined as 36.32 N and the standard deviation was 1.70. The warp tear strength was found to be 40.91 N and its standard deviation of 2.27. When the tear strength values of the fabric were examined, it was observed that there was no noticeable decrease.

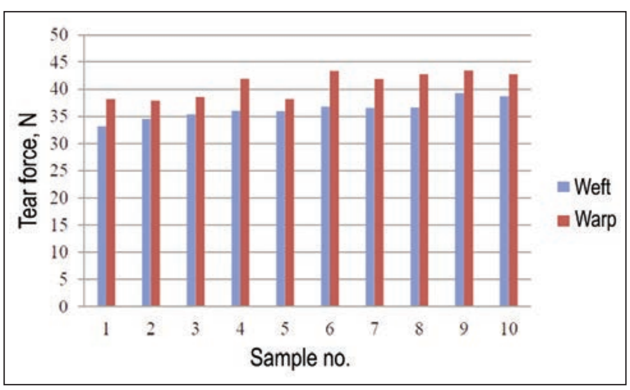

Fig. 2. Tear strength plot

Figure 3 shows the bending strength graph of the fabric produced. When the bending strength of the produced sample is examined in table 2, it has been determined as 11.77 mg·cm and its standard deviation as 0.90.

The air permeability graph of the sample fabric produced is shown in figure 4. When examined in table 2, the average air permeability value was found to be 324.53 mm/s and its standard deviation as 5.08. The

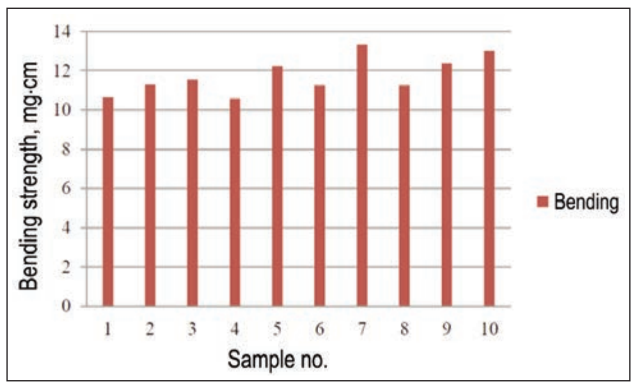

Fig. 3. Bending strength plot

production method, kniwasing type and yarn twist value of the fabric produced can significantly affect this air permeability.

The pilling graphic of the fabric produced is shown in figure 5. When examined in table 2, the pilling value abrasion resistance was determined as an average of 140 in 15230 turns and its standard deviation as

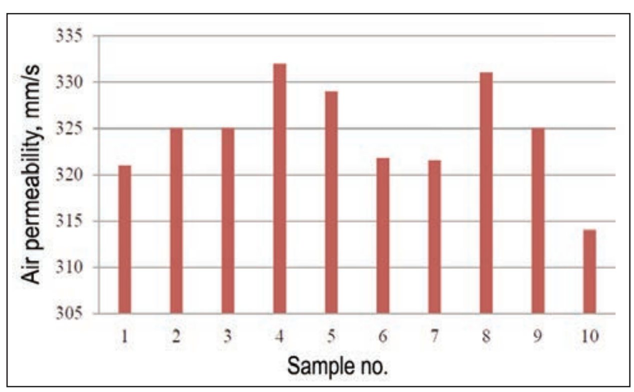

Fig. 4. Air permeability chart

15.40. This stage has been observed to have a good performance considering that the pilling value is a product obtained from recycling. When the pilling value is given for the twist values given to the yarn in the yarn formation and the abrasion resistance, it can be observed that the pilling value varies. Since the sample was prepared in an ongoing production facility, the settings of 552 t/m for weft and 795 t/m for warp in the system were taken. Pilling value, during

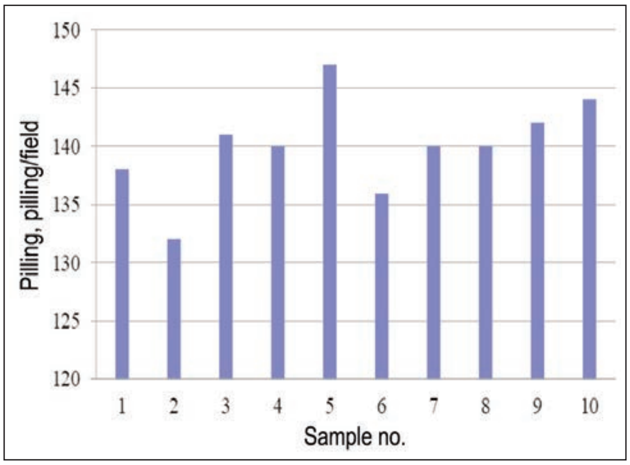

Fig. 5. Pilling chart

yarn formation, yarn twist, yarn count and yarn hairiness can affect values [14].

The physical properties of the yarn used in production affect many physical properties of the fabric formed. When the fabric production parameters are progressed step by step with the in-house machine settings starting from the raw material, the physical factors of the fabric can be influenced.

CONCLUSIONS

When the results were evaluated, it was observed that the quality parameters of the fabric prepared with the blend of cotton obtained from recycling were lower than expected. In another fabric obtained from average good cotton, tear strength and tensile strength are higher. The quality of cotton obtained from recycling has an effect on the quality of previous processes. The breaking strength was 14% lower than expected in the weft direction and 11% lower in the warp direction. Tear strength was observed at 13% in the weft direction and 10% in the warp direction. On the other hand, the other two properties were observed as low between 6% and 8%. When the physical properties and quality parameters of the produced sample are examined, it may be possible to produce yarn with the desired quality if the mixture is adjusted in appropriate proportions for recycling. If the texture type and knitting type are selected correctly in the material (bedlinens, towels, mats, rugs, etc.) obtained according to the production method of the yarn (open-end, compact, ring etc.), the quality level is similar to that of the material produced from virgin raw materials can be achieved. Physical quality parameters deteriorate because textile products are exposed to various chemical processes (for example, washing with detergent) and mechanical stresses until they reach the end of their life and become waste. Therefore, a low-quality product is obtained by using only these waste materials. It is possible to obtain high-quality yarn when natural fibres are mixed with fibres obtained from waste textiles in certain proportions (for example, 50–50%). It is foreseen that these yarns can be used especially in home textile products. It would be more appropriate to use it as a natural product in order to maintain the quality performance in woven or knitted raw (not finished) fabric.

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Is transformational leadership instrumental to environmental sustainability? A perspective of Pakistani textile sector

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ABSTRACT – REZUMAT

Is transformational leadership instrumental to environmental sustainability? A perspective of Pakistani textile sector

This study proposes to highlight the role of transformation leadership in enabling environmental sustainability efforts. In this regard, a mediating role of green human resource management is investigated to understand the association between transformation leadership and environmental sustainability. The study follows a quantitative and cross-sectional research approach. A self-administered questionnaire was used to collect the responses from 200 managerial-level employees of ISO-14001 certified textile organizations in Lahore, Pakistan. Furthermore, the study hypotheses were tested by applying linear regression and Hayes' Process in SPSS to determine the interconnected dependence of the study variables. The findings of the study demonstrate that transformational leadership plays an instrumental role in the implementation of environmental sustainability strategy. The results also reveal that green human resource management significantly mediates the relationship between transformational leadership and environmental sustainability. The research outcomes portray a stringent need to apply the transforming abilities of the organizational leaders for fostering environmental initiatives; a contribution to a broader cause of global environmental sustainability.

Keywords: *transformational leadership, environmental sustainability, green human resource management, textile sector, Pakistan*

Este leadership-ul transformațional important în sustenabilitatea mediului? O perspectivă a sectorului textil din Pakistan

Acest studiu își propune să evidențieze rolul leadership-ului transformațional în facilitarea eforturilor de sustenabilitate a mediului. În acest sens, rolul de mediere al managementului ecologic al resurselor umane este investigat, pentru a înțelege asocierea dintre leadership-ul transformațional și sustenabilitatea mediului. Studiul urmează o abordare de cercetare cantitativă și transversală. Un chestionar auto-administrat a fost folosit pentru a colecta răspunsurile de la 200 de angajați la nivel managerial din organizațiile textile certificate ISO-14001 din Lahore, Pakistan. Mai mult, ipotezele studiului au fost testate prin aplicarea regresiei liniare și a procesului Hayes în SPSS, pentru a determina dependența interconectată a variabilelor de studiu. Concluziile studiului demonstrează că leadership-ul transformațional joacă un rol esențial în implementarea strategiei de sustenabilitate a mediului. Rezultatele arată, de asemenea, că managementul ecologic al resurselor umane mediază în mod semnificativ relația dintre leadership-ul transformațional și sustenabilitatea mediului. Rezultatele cercetării prezintă o nevoie stringentă de a aplica abilitățile de transformare ale liderilor organizaționali, pentru promovarea inițiativelor de mediu; o contribuție la o cauză mai extinsă a sustenabilității globale a mediului.

Cuvinte-cheie: *leadership transformațional, sustenabilitatea mediului, managementul ecologic al resurselor umane, sectorul textil, Pakistan*

INTRODUCTION

It has become essential for leaders to understand the antecedents of motivating organizational members to deal with the increasing complexities of a fast-changing environment. Leaders influence the work behaviours of the employees to get positive outcomes from the organizational procedures and processes. This positive influence not only helps to keep the employees motivated but triggers the efficacy of improved business practices [1]. In the workplace, leaders possess the authority of evaluating and monitoring the performance of the employees. Hence, leaders' behaviour may craft the behaviour of the employees in a manner desired by the organization. According to a few initial researches, transformational leadership is a kind of leadership that allows leaders and followers to work together for a better motivation level [2, 3]. The consequent high level of motivation enables the employees to follow the direction given by their leader to accomplish the organizational goals. Furthermore, transformational leadership enables the leaders and followers to create beneficial outcomes for achieving the desired tasks [4]. This prevalent leadership style can sensitize the employees about their work practices through collaborative efforts to achieve the desired results. For this, transformational leadership exhibits a helping behaviour that initiates holistic efforts for adopting better and more creative work practices [5]. Considering the importance of transformational leadership, organizations need to understand how they can adopt this leadership style to deal with vigorous environmental challenges; such as natural environment protection.

Like other major business challenges, sustainability also needs the attention of organizational leaders. The Brundtland Commission report [6] takes credit for introducing sustainability as "meeting the needs of the present without compromising the ability of future generations to meet their needs". This report included a focus on sustainable social development along with creating long-term ecological impacts.

Sustainability primarily encompasses a three-dimensional business perspective: profit, people and planet, commonly known as the Triple Bottom Line (TBL) approach [7]. A World's Economic and Social Survey report [8] emphasizes exerting holistic efforts to embrace sustainability. According to Pless and Maak [9], sustainability needs the relational and collaborative nature of leadership for embedding in organizational culture. Moreover, instilling the TBL approach in business operations poses various challenges for the leadership of an organization [10]. According to Crews, five major challenges for the leaders to implement sustainability are: engaging the stakeholders, creating a sustainability culture, continuous learning, inclusive approach, and disclosure.

A study on the Turkish hospitality industry reveals that transformational leadership has an affirmative impact on adopting sustainability measures [11]. According to this study, transformational leaders facilitate environmental-friendly or green business strategies by building psychological capital; a positive state of an individual's mind for development [12]. Another study depicts that green business strategies are applied through green human resource practices involving environmentally responsible employees [13]. Thus, an integrated approach of transformational leaders may help to transform the employees by encouraging green human resource practices within an organization. For instance, transformational leaders may focus on developing mechanisms to enhance the green competencies of employees [14]. Such employees may ultimately become able to contribute to achieving the ecological goals of a sustainable organization. Therefore, it is pertinent to learn about the role of transformational leadership in supporting the eco-friendly/green business practices of an organization.

This study will focus on identifying the association between transformational leadership and environmental sustainability in the textile manufacturing sector of Pakistan. A mediating role of green human resource practices will also be highlighted in determining the association between transformational leadership and environmental sustainability. Overall, this research will be a significant contribution to enriching the existing literature in this area. Finally, subsequent arguments will consist of the literature review, methodology, data analysis and discussion of the results of the research.

LITERATURE REVIEW

Transformational leadership

James MacGregor Burns [3] conceptualized transformational leadership from a political framework by explaining the phenomenon as the leadership's ability to inspire others to achieve extraordinary results. Later, Bass [6] presented transformational leadership from an organizational perspective wherein, transformational leaders inspire and empower the followers to grow and develop themselves in line with the organizational course. According to Bass, transformational leaders motivate their followers to generate a high level of motivation and organizational commitment. Furthermore, transformational leaders encourage the employees of an organization to develop creative solutions for organizational problems through its four main components: idealized influence, inspirational motivation, intellectual stimulation and individualized consideration [4].

For an idealized influence, transformational leaders act in a way that exemplifies them as role models for their followers or employees. The leaders are admired, trusted and respected by their fellow beings leading to creating a collective sense of purpose [15]. Moreover, transformational leaders motivate their employees by giving meaning to their tasks. The employees are encouraged to work in teams, a positive future state is displayed and clear communication is done to keep the employees motivated [4]. Additionally, intellectual stimulation is done by inspiring the employees to be creative and innovative to address organizational issues in new and better ways [16]. It happens when new ideas are not considered alienated in organizations. Furthermore, transformational leaders focus on individual followers' coaching, mentoring and facilitation. Leaders offer new learning opportunities, interactive communications and personalized growth to the employees for improved organizational performance [15].

Transformational leadership also includes an impression of bringing change/transformation to the organization [9] especially when it comes to a critical organizational change; for example, environmental sustainability. Few empirical researches reveal a positive role of transformational leadership in promoting environmentally-responsible business practices among employees [14, 17]. The findings of these studies emphasize that transformational leaders motivate and facilitate the employees to adopt green business practices, for a larger cause of embracing sustainability.

Environmental sustainability and transformational leadership

Environmental Sustainability is one of the biggest challenges faced by human beings at present. The negligent activities of humans such as deforestation, increased carbon emission, climate change, pollution and depletion of natural fossil fuels have destroyed the safety threshold of planetary boundaries [18]. In this regard, the concept of environmental sustainability encompasses the body of knowledge, practices and strategies that may lead to the protection of the natural environment from hazardous human activities [19]. The adoption of eco-friendly practices includes an enduring commitment of organizational leadership to translate its environmental goals into business decisions by developing an environmental management system [20]. Consequently, this environmental management system enables the organizations to work according to the sustainability parameters. A study conducted in the Jordanian banking sector [21] revealed that transformational leadership significantly influences organizational performance. Leaders employing this leadership approach not only develop better employee satisfaction and commitment but also effectively bolster organizational performance.

In recent times, addressing environmental challenges is also an innovative way of gaining a competitive advantage [22, 23]. That is why, sustainable organizations tend to incorporate responsible/ethical work practices which lead to better organizational performance; especially in terms of social and environmental sustainability. Considering this, sustainability also demands the attention of organizational leaders adopt innovative practices and develop a competitive and sustainable place not only for themselves but for the society at large [24].

According to Robertson and Barling, pro-environmental behaviours of organizational leaders depict a vital role in making organizations environmentally sustainable. It is primarily because the leadership of sustainable organizations has an enhanced focus on employee motivation through career development, skill improvement and a safe work environment [25] to accomplish the ecological goals. Nonetheless, the transformative ability of leaders helps organizations in combating ecological issues by ensuring the provision of employee engagement, motivation, creativity and resilience [11]. Thus, it is inevitable for organizations to comprehensively understand the role of transformational leadership in embracing environmental sustainability.

Green human resource management and transformational leadership

For environmental sustainability, the notion of green management has emerged as an imperative managerial insinuation that promises increased profitability without damaging the natural environment [26]. Green management practices offer an admirable opportunity to promote the eco-friendly behaviours of the employees for better environmental outcomes [27]. In addition to this, a study has proposed green human resource management as an essential measure of eco-friendly business practices which significantly impacts organizational performance [28]. Green human resource practices assist to impart environmental-friendly skills and proficiencies to the employees allowing them to lessen the negative environmental footprint [13]. The knowledge and abilities instilled by green human resource practices perform a significant role in creating environmental awareness among employees; particularly in developing economies [29]. However, leadership's commitment to deal with sustainability challenges is inevitable for implementing environmentally responsible business practices.

A study on medical firms in Northeast China reveals that transformational leaders inspire the employees to adopt eco-friendly business practices through green human resource practices [14]. According to Jia, Liu, Chin and Hu, the transforming abilities of leaders use green human resource management to establish the norms of cooperation, innovation and creativity for fostering environmental-friendly behaviours of employees. Similarly, an empirical study on small and medium-size enterprises claimed a noteworthy impact of transformational leadership on green human resource management [19]. The findings of this empirical research propose that transformational leaders encourage green practices among employees which ultimately adds to the environmental performance of the organization. For instance, transformational leaders may help to motivate the employees and stimulate their intellect through green training; a green human resource practice which facilitates ecological learning [30]. Resultantly, these environmentally-responsible employees positively contribute to the ecological performance of an organization [13].

Green human resource management and environmental sustainability

According to research, green human resource practices, focused on developing environmentally-responsible employees, are found to have a substantial impact on the environmental sustainability efforts of an organization [31]. Consequently, the competent employees feel motivated to follow the organization's direction for achieving the ecological goals [32]. Moreover, green human resource management is an influential approach for building ecology-oriented employee behaviours and attitudes [33], necessary to support environmental sustainability within an organization. Research on the hotel industry of Jordan depicts that green human resource practices help to foster employee engagement with environmental initiatives [34]. Similarly, an enhanced focus on adopting eco-friendly/green human practices such as green training may aid to create green skills and competencies among employees to embrace environmental sustainability [13].

Furthermore, a constructive mediating role of green human resource management has also been studied to determine how transformational leadership influences the environmental performance of an organization via eco-friendly behaviours and attitudes of employees [14, 35]. The findings of these studies highlight the facilitating part of green human resource management in implementing better business practices for embracing sustainability.

It is pertinent to mention that there is limited literature available on these research variables in the manufacturing sector of emerging economies of South Asia such as Pakistan, Bangladesh, and India. Regarding the research background of this study, Pakistan being a developing country is facing numerous environmental issues [36] including serious climate change, industrial waste, deforestation, soil degradation, shortage of clean water, depletion of fossil fuels and many more [37]. Irresponsible state behaviour and negligent corporate policies have deteriorated the natural environment conditions. Nevertheless, a few research efforts in the recent past have illustrated the role of transformational leadership and green human resource practices in dealing with the ecological concerns within the Pakistani manufacturing context [38–40]. But the existing literature lacks a comprehensive understanding of these concepts for developing sustainable and resilient business operations in the Pakistani industrial sector. Hence, this research will provide meaningful insights by presenting an empirical analysis of transformational leadership and environmental sustainability efforts in the textile industry of Pakistan; a novel perspective for any such research. Last but not least, the following hypotheses are suggested for the study:

H1: Transformational leadership is significantly and positively related to environmental sustainability.

H2: Transformational leadership is significantly and positively related to green human resource management.

H3: Green human resource management is significantly and positively related to environmental sustainability.

H4: Green human resource management significantly mediates the association between transformational leadership and environmental sustainability.

Figure 1 presents a proposed conceptual model for this research. The model is developed based on a literature review and subsequently proposed hypotheses which will be empirically tested in this study. The conceptual model for this study involves transformational leadership as an independent variable, environmental sustainability as a dependent variable and green human resource management as a mediating variable. The empirical analysis of this model will determine the association of these variables in the textile sector of Pakistan.

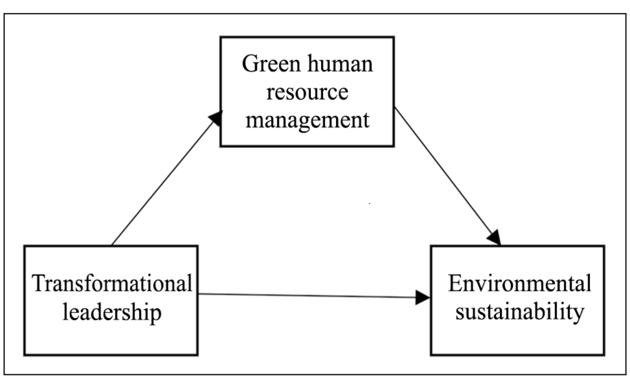

Fig. 1. Conceptual model

METHODS

The research applied a quantitative and cross-sectional approach. ISO-14001 qualified textile organizations of Lahore, Pakistan were selected to test the research hypotheses. These organizations were selected primarily because the manufacturing processes of these organizations may involve different environmental issues such as air, land or water pollution. The international clientele of this industrial sector also imposes stringent environment-oriented challenges for the organizations to deal with. Hence, it is meaningful to investigate the influence of transformational leadership on the environmental sustainability efforts of textile manufacturing organizations operating in Pakistan (table 1). The data was sought from the individual employees through purposive sampling and Cochran's formula [41] was used to identify the sample size. So, the minimum sample size calculated was 246 respondents (with a margin of error = 0.05 and p = 0.2) to examine the hypotheses of the study. However, valid responses received were 200 showing a response rate of almost 81%. According to the estimated sample specifics (table 2), 75% of respondents were male and 25% of respondents in the study were female. Additionally, 10% of the respondents were top-level managers, 50% respondents were middle managers and 40% respondents were lower-level managers. A majority of the respondents belonged to the age group of 36–45 years (48%). Lastly, all the respondents had at least 5 years of work experience.

Further, the data was collected by using a self-administered questionnaire developed by adopting items from the research literature. For this, ten items for transformational leadership were adopted from a study by Bass and Rigio [42] including "Leaders in my organization are trusted and admired" and "Leaders in my organization adopt effective communication strategies to engage the employees". In addition to this, a ten-item scale was used for measuring the perception of employees about green human resource management in their organizations. The scale was developed by Mamun [43] to measure the awareness of green human resource management among employees of a South Asian country, Bangladesh. The sample items for this variable included "Green job designs are practised in my organization" and "My organization offers green training to the employees". Lastly, six items for environmental sustainability were adopted from a study by Jabbour [44]. A sample item for measuring this variable was "My organization focuses on energy conservation". The reliability analysis of the questionnaire was performed by using Cronbach's alpha value for individual scales. The Cronbach's alpha values for transformational leadership, green human

Table 1

QUESTIONAIRE CONRTENT	
Variable	**Items**
Transformational Leadership	**Q1:** The leadership of my organization go out of the way to make subordinates feel good to be around them. **Q2:** The leadership of my organization help subordinates with their self-development. **Q3:** The leadership of my organization help subordinates to understand visions of the organization through the use of tools, such as images, stories, and models. **Q4:** The leadership of my organization ensure subordinates get recognition and/or rewards when they achieve difficult or complex goals. **Q5:** The leaders of my organization are trusted and admired. **Q6:** The leadership of my organization provide challenges for subordinates to help them grow. **Q7:** Leaders in my organization adopt effective communication strategies to engage the employees **Q8**: The leadership of my organization rarely gives direction or guidance to others. **Q9:** The subordinates do not follow the leadership of my organization out of fear. **Q10:** The leadership of my organization provide an empathic shoulder when others need help.
Green Human Resource Management	**Q1:** In my organization, great effort goes into selecting candidates committed to environmental issues. **Q2:** Green job designs are practised in my organization. **Q3:** My organization offers green training to the employees **Q4:** In my organization environmental training is designed to enhance employees' environmental skills & knowledge. **Q5:** My organization exerts strong efforts to develop eco-friendly culture. **Q6:** My organization encourages employees to apply environmental knowledge in their jobs. **Q7:** In my organization performance appraisal includes environmental incidents, responsibilities, concerns and policy. **Q8:** In my organization employees get a reward for environmental management. **Q9:** In my organization employee gets rewarded for acquiring specific environmental competencies. **Q10:** In my organization employees are involved to become environmentally responsible.
Environmental Sustainability	**Q1:** My organization emphasizes reducing waste within the entire value chain process. **Q2:** My organization contributes to complying with environmental regulations. **Q3:** My organization contributes to preventing and mitigating environmental crises. **Q4:** My organization spends on developing/using renewable energy sources. **Q5:** My organization contributes to limiting environmental impact. **Q6:** My organization focuses on energy conservation.

Table 2

SAMPLE SPECIFICS		
Characteristics	**Categories**	**Percentage (N=200)**
Gender Mean = 0.37 SD = 0.41	Male	75%
	Female	25%
Age Mean = 36.5 SD = 6.16	25 years & Under	5%
	26 – 35 years	20%
	36 – 45 years	48%
	46 – 55 years	15%
	55 years & Above	12%
Managerial-level Mean = 1.89 SD = 0.76	Top	10%
	Middle	50%
	Lower	40%
Experience Mean = 12.75 SD = 9.26	5 – 10 years	20%
	11 – 15 years	55%
	16 years & Above	25%

Note: SD = Standard Deviation.

resource management and environmental sustainability were calculated to be 0.892, 0.847 and 0.855; respectively.

Moreover, a five-point Likert scale involving a range of Strongly Disagree = 1 to Strongly Agree = 5 was used to quantify the responses against individual statements. The analysis of data was done by using Statistical Package for the Social Sciences (SPSS) software. Finally, linear regression and macro Process [45] analysis were used to test the hypotheses of the study.

DATA ANALYSIS AND RESULTS

The data reliability was calculated through Cronbach's alpha which shows the internal consistency of the items included in the questionnaire. The acceptable value of Cronbach's alpha is considered to be 0.5 or above [46]. Table 3 shows that the Cronbach's alpha values for all the three variables of the study were above 0.5 and hence, the instrument was reliable for the analysis purpose. The descriptive statistics including the mean and standard deviation of the factors are also depicted in table 3.

Furthermore, the AVE (average variance extracted) value shows the convergent validity of the factor and should be 0.5 or more [47]. Table 3 also presents the CR (composite reliability) values to measure the content validity of the factors. The CR value should be greater than 0.7 for model reliability.

Hypotheses testing

To test the H1, H2 and H3 of the study, linear regression analysis was conducted. The results in table 4 depict a significant and positive effect of transformational leadership on environmental sustainability ($\beta = 0.687$, $p = 0.000$ and $t = 6.934$) and green human resource management ($\beta = 0.826$, $p = 0.000$ and $t = 6.527$). These results finally prove H1 and H2 of the study. Therefore, it can be inferred that transformational leadership plays a vital role in facilitating the environmental initiatives of an organization. Similarly, green human resource management is strongly influenced by the transforming abilities of organizational leaders.

Table 4 proves that green human resource management and environmental sustainability are significantly and positively correlated ($\beta = 0.615$, $p = 0.000$ and $t = 5.503$). The results portray that eco-friendly human resources practices, such as instilling green competencies among employees, may help to yield better environmental impacts. Hence, H3 is also accepted.

Additionally, the R-square values depicted in table 4 exist within the standard limit between 0 and 1 [48] and explain the percentage change in dependent variables caused by the independent variables. Moreover, all the VIF values are below 5 which means there is no sign of multicollinearity in the model [49]. Finally, these results prove the first three hypotheses of the study tested through linear regression.

Mediation analysis

The Andrew Hayes Process [45] using model 4 was performed for the mediation analysis. The results shown in table 5 present an indirect effect of transformational leadership on environmental sustainability while using green human resource management as a mediator.

It can be inferred from the results mentioned in table 5 that green human resource management significantly mediates the relationship between transformational leadership and environmental sustainability (95% CI: 0.067, 0.285). Thus, H4 is proved and accepted.

Table 3

DESCRIPTIVE STATICS OF SSE COMPOSITE DAILY RETURNS FOR THE SAMPLE PERIOD DECEMBER 1990 – DECEMBER 2020

Variables/Factors	N	Cronbach's Alpha	Mean	SD	AVE	CR
Transformational Leadership	10	0.892	4.229	0.72	0.58	0.87
Green Human Resource Management	10	0.847	4.101	0.68	0.51	0.84
Environmental Sustainability	6	0.855	4.192	0.70	0.53	0.85

Note: SD = standard deviation, AVE = average variance extracted, CR = composite reliability

Table 4

LINEAR REGRESSION ANALYSIS DATA

Factors	Transformational Leadership → Environmental Sustainability	Transformational Leadership → Green Human Resource Management	Green Human Resource Management → Environmental Sustainability
β Coefficient	0.687	0.826	0.615
p-value	0.000	0.000	0.000
T value	6.934	6.527	5.503
R-Square	0.403	0.532	0.401
VIF	1.387	1.872	1.776
Sample Mean	0.622	0.725	0.556
Standard Deviation	0.085	0.083	0.092

Note: VIF = variance inflation factor.

Table 5

MEDIATION ANALYSIS

Indirect Effect	Effect	Boot SE	Boot LLCI	Boot ULCI
Transformational Leadership → Green Human Resource Management → Environmental Sustainability	0.508	0.0427	0.067	0.285

Note: CI = confidence interval, SE = standard error.

DISCUSSION AND CONCLUSION

This study aims to augment the existing literature in the domain of transformational leadership and environmental sustainability through an empirical analysis of the Pakistani textile manufacturing sector (ISO-14001 certified). The findings of the research point toward the promising development of environmental sustainability notion and its drivers in this developing region of the world i.e., Pakistan. To explain this, the study encompassed transformational leadership as a key component of organizational structure that facilitates the ecological initiatives of textile organizations.

Overall, the findings of the study corroborate with the present literature and show a significant and positive correlation between transformational leadership and environmental sustainability [14, 17, 20]. It can be inferred from the findings of H1 that the transforming abilities of the leaders can play a vital role in enabling an organization to become environmentally responsible. Transformational leaders tend to offer responsible leadership thereby, creating a positive influence on employees [9] to accomplish the ecological objectives of their organization [10]. Transformational leaders may also encourage and motivate the employees to get engaged in their work for better organizational performance [1]. This high level of work engagement may subsequently lead to the adoption of pro-environment business practices that are part of the manufacturing process. Resultantly, these motivated and engaged employees employ their intellect for a positive contribution to achieving the environment-related goals of an organization; such as conserving natural resources [50]. Hence, transformational leadership may help to develop a favourable work environment mandatory to support business sustainability. These findings are now validated in a developing country's context, thus, posing a dire need for the organizational leaders to perform their transforming roles in enabling textile organizations to become sustainable and resilient.

Furthermore, the results of H2 have illustrated a substantial and positive effect of transformational leadership on green human resource management. The literature shows that transformational leaders have a keen focus on practising environmentally-responsible human resource activities; whether it be employee training, performance appraisal or selection [14]. It has been found that transformational leaders motivate employees to learn and adopt innovative business practices [1, 42]. These innovative business practices may also include green human resource practices for developing eco-friendly behaviours and attitudes among employees [10, 13, 20, 38].

Although, the role of transformational leadership has been extensively studied in building a competitive advantage [51] very limited literature is available on the association between transformational leadership and green human resource management in developing economies. Therefore, this research offers a contextual novelty to the literature and refers to an imperative understanding that transformational leadership can have a dynamic part in instilling green human resource practices in Pakistani textile organizations.

Additionally, findings of H3 suggest that green human resource management strongly influences the environmental sustainability initiatives of an organization. This result is in line with the previous literature that supports the role of green human resource management in facilitating the implementation of environmental strategies of an organization [31]. Moreover, it can be said that green human resource management may help to impart the desired level of capabilities, skills and competencies to the employees necessary for the protection of the natural environment [38, 43, 44]. For instance, green training ensures the delivery of relevant knowledge to the employees that may influence the employee motivation level for better involvement in environmental management efforts [13, 30]. This provision of environmental knowledge for employees may also result in their individualized facilitation for better performance.

Finally, the results of H4 depict a meaningful mediation of green human resource management in determining the association between transformational leadership and environmental sustainability. The struggling sustainable organizations need to understand that the transforming abilities of their leaders cannot bear fruitful results for sustainability efforts unless the adoption of green human resource management is ensured. For instance, transformational leaders can motivate and assist their employees to get engaged in learning innovative business practices mandatory for better environmental performance [35, 40, 41]. This employee engagement can be enhanced by having a deep focus on developing an environmentally-responsible human capital through varied human resource activities. This may lead to embarking on an organization on the journey toward environmental sustainability.

Implications

The outcomes of this study provide meaningful understandings for the leaders/managers of textile manufacturing organizations who want to improve the environmental performance of their organizations. All the progressive textile manufacturers need to promote transformational leadership within their organizations because it helps to motivate and encourage the employees to effectively follow the direction given by their leadership/organization. Hence, transformational leadership is strongly recommended for sustainable organizations to achieve their ecological goals. Furthermore, the leaders of growing textile manufacturers should critically examine the benefits of adopting green human resource management for their better comprehension of using such innovative practices. For instance, integrating environmental efforts into employee performance appraisal can be a pertinent step toward implementing environmental initiatives. Lastly, the governmental authorities of Pakistan need to take firm steps in developing an environmental policy framework for the manufacturing sector of the country. This framework must include a comprehensive check and balance system for enhancing organizational efficiency in terms of protecting the natural environment.

In addition to this, there are a few theoretical implications of the study. The existing literature does not offer adequate insights into the role of transformational leadership in promoting the environmental efforts of an organization. Therefore, this study is valuable in determining the relationship between transformation leadership and environmental sustainability through the mediating role of green human resource management. The research results enrich the literature by offering Pakistan a unique research context to study these emerging variables. Last but not least, the findings of the research pose a grave need to explore the antecedents and consequences of transformational leadership in stimulating the environmental sustainability efforts of an organization. Hence, it can be safely said that transformational leadership is instrumental for environmental sustainability and its related concerns; thus, contributing toward a larger cause of environmental sustainability.

Recommendations

This study is a preliminary effort to investigate these variables in an emerging economy's context which leaves a space for further deliberation in future research. Therefore, more comprehensive research with advanced analysis should be performed in sustainable organizations across other business sectors of Pakistan. Further research efforts will allow an inclusive understanding of environmental sustainability efforts in this region. A cross-cultural or cross-country analysis may also augment the research outcomes of environmental sustainability.

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Old maps and the effectiveness of chitosan as antimicrobial agent

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ABSTRACT – REZUMAT

Old maps and the effectiveness of chitosan as antimicrobial agent

In the case of tangible cultural heritage items made of natural fibres, biodegradation due to microorganisms can lead over time to undesirable deterioration, including physical, mechanical and chemical damage as well as aesthetic alteration of materials. In this study, the antifungal activity tests were performed on 3 old maps (on silk, on canvas and on paper) using the AATCC 30-2004 test method. Map samples were immersed in a chitosan solution (10 g/l) and evaluated using Scanning Electron Microscopy (SEM) with a Field Emission Scanning Electron Microscope (ULTRA 55, ZEISS). The process showed that, due to its antimicrobial effect, chitosan treatment is effective for removing external agents and microorganisms present on fibre surfaces. The technique is simple, efficient and the results indicated that chitosan can be transformed into a very good and cheap antimicrobial solution for the conservation and preservation of heritage objects.

Keywords: *old maps, natural fibres, fungi, impurities, chitosan, antimicrobial*

Hărțile vechi și eficiența chitosanului ca agent antimicrobian

În cazul bunurilor materiale din patrimoniul cultural realizate din fibre naturale, biodegradarea datorată microorganismelor poate duce în timp la o deteriorare nedorită, inclusiv degradarea fizică, mecanică și chimică, precum și la afectarea proprietăților estetice ale materialelor. În acest studiu, teste privind activitatea antifungică au fost efectuate pe 3 hărți vechi (pe mătase, pânză și hârtie) folosind metoda de testare AATCC 30-2004. Mostrele de hartă au fost scufundate într-o soluție de chitosan (10 g/l) și evaluate utilizând microscopia electronică cu scanare (SEM). S-a folosit un microscop electronic cu scanare cu emisie de câmp (ULTRA 55, ZEISS). Procesul a arătat că, datorită efectului său antimicrobian, tratamentul cu chitosan este eficient pentru îndepărtarea agenților externi și a microorganismelor prezente pe suprafețele fibrelor. Tehnica este simplă, eficientă și poate fi transformată într-o soluție antimicrobiană foarte utilă și ieftină, care poate fi folosită pentru conservarea și prezervarea obiectelor de patrimoniu.

Cuvinte cheie: *hărți vechi, fibre naturale, fungi, impurități, chitosan, antimicrobian*

INTRODUCTION

People are becoming increasingly aware of the importance of the human values that form the common heritage that must be passed on to future generations and at the same time, it must be protected. It is our duty to transmit these values as we have found them and to contribute to their preservation, protection and promotion, they remain living testimonies of the old tradition [1–4]. The role of cultural heritage in defining the national identity is unquestionable [5, 6], each community identifies itself through the cultural inheritance received and transmitted from generation to generation [7–9].

In 1962, UNESCO considered it necessary to protect both natural and man-made environments that are of cultural interest. This approach to defining cultural heritage can also be seen in "The Architectural Heritage Charter in Amsterdam" (1975). All these normative definitions can be found in detail in the Granada Convention for the Protection of European Architectural Heritage (1985). Beginning with the mid-1970s, international documents were drawn up that tried to define the general criteria for the purpose of being reunited in a code all the documents – the tangible and intangible achievements of the human activities that become valuable – must be protected. The tangible component of the cultural heritage includes works of art, manuscripts, photographs, maps and various documents, but also buildings, locations, paintings, sculptures, etc.

In this were analysed three aged heritage maps from different archives, made of natural fibres, that are highly susceptible to biodegradation due to microorganisms, impurities etc.:

- an old map of Switzerland, on a sheet of paper glued to the canvas, dating from 1866;
- the old map of Crișana, on paper, dating from 1919;
- the double silk map or escape map dates from 1953; this type of map was first made during World War II, being used by the British and US military to escape behind enemy lines.

The tangible cultural heritage items are very sensitive, especially when made of natural fibres; they are very susceptible to biodegradation due to microorganisms, dust etc. Classical methods [10–13] for species identification given in this study offer an accurate image of the fungal biodeterioration process on heritage textiles samples which were analysed. Antifungal activity tests on map materials were determined by AATCC Test Method 30-2004.

Some studies analysed the mechanism, innovation and safety of chitosan on textiles and antibacterial proprieties; biocompatibility, biodegradability and bioactivity of chitosan and its importance for humans [14–27]. In Romania, it was also investigated the use of chitosan in the surface modification of textile fabric and its antimicrobial effects. We can mention in this sense the papers of: Enescu [28], Buşilă et al. [29], Bou-Belda et al. [30] and Indrie et al. [31] etc.

Application of chitosan solutions on natural fibres [32–37] has given very good results in removing the impurities so that it can be a very good and cheap antimicrobial solution [38–40].

ANTIFUNGAL ACTIVITY AND ASSESSMENT ON MAP MATERIALS

Material & method

The antifungal activity tests were performed on old maps samples using the AATCC 30-2004 test method [41] in the laboratories of Ege University, Dokuz Eylül University, Turkey, University of Oradea, Romania, Trakia University, Faculty of Technics and Technologies, Bulgaria.

The aim of this test method was to determine the susceptibility of textile materials to mildew and rot and to evaluate the efficacy of fungicides on textile materials. *Aspergillus niger* ATCC 6275 was grown on the Czapek Dox Agar at 28°C for approximately 10 days to produce abundant growth spore formation. The spores were collected by appropriate methods [42–47] and the prepared spore suspension was used as the inoculum.

- the double silk map or escape map dates from 1953; this type of map was made during World War II, being used by the British and US military to escape behind enemy lines;
- the old map of Crișana (Romania), on paper, dating from 1919;
- an old map of Switzerland, on a sheet of paper glued to the canvas, dating from 1866.

Test specimens: sample A – Map on silk, B – Map on paper support, from 1919; C – Map on paper, book from 1866; discs were cut, 1.5±0.1 cm diameter. The discs were pre-wet without rubbing or squeezing in water containing 0.05% of a nonionic wetting agent (Triton X-100) and placed on the Agar surface. 0.1 ml of the inoculum was distributed evenly over each sample disc by means of a sterile pipette. Duplicated test materials were incubated for 10 days at 28°C.

Application of chitosan for treatment of the aged maps

Chitosan Medium Molecular Weight was purchased from Sigma Aldrich, for the treatment of the samples (figure 1), at the Textile and Paper Department, Universitat Politècnica de València, Spain; acetic acid was supplied by Panreac. The concentration prepared for chitosan was 10 g/l. It was added 5 ml/l of Acetic acid, because of the chitosan solubility in water at acid pH. The resulted solution was magnetically stirred (24 hours).

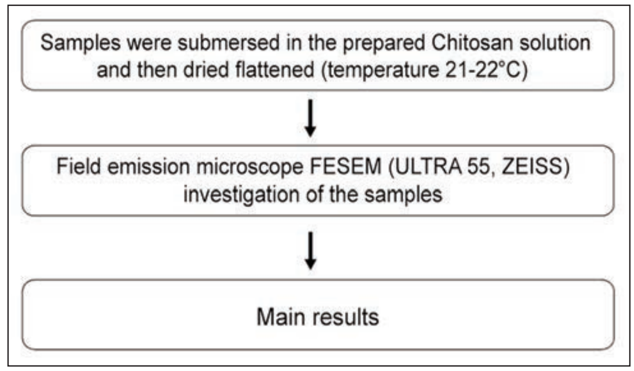

Fig. 1. Method of investigation of old maps samples treatment with chitosan

Samples were submersed in a chitosan solution (10 g/l) and passed through two squeezing rolls. Afterwards, samples were flattened dried at room temperature (21–22 °C) for 24 hours.

The observation of the samples was carried out by means of Scanning Electron Microscopy (SEM) with a Field Emission Scanning Electron Microscope (ULTRA 55, ZEISS). Every treated map was placed on a flat surface. To increase the conductivity of the materials, each sample was covered with a very thin gold layer [15]. The samples were analysed with the appropriate magnification and with an acceleration voltage of 1 KV.

RESULTS & DISCUSSION

At the end of the incubation period, the percentage of the surface area of the discs covered with the growth of *Aspergillus niger* was observed macroscopically and microscopically. Antifungal activity tests result of map materials were given in figure 2.

The main purposes of this test method [48–53] are to determine the susceptibility of materials to mildew and rot and to evaluate the efficacy of fungicides on textile materials. Mildew resistance in textile material is defined as resistance to the development of unsightly fungal growths and accompanying unpleasant, musty odours on textile materials exposed to conditions favouring such growths while rot resistance in textile material, resistance to deterioration of a textile material as a result of fungal growth in or on it [41].

According to the macroscopic observations (figure 2), the contact zones were seen for all specimens, clearly. These results show that all map materials have rot resistance, but not mildew resistance.

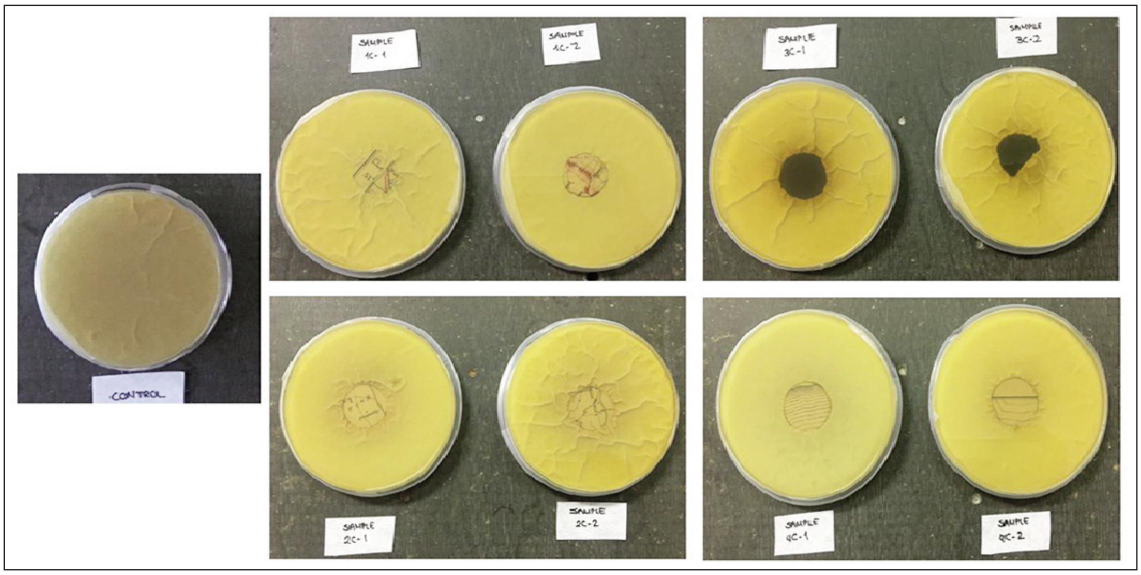

Fig. 2. AATCC Test Method 30 results of all specimens

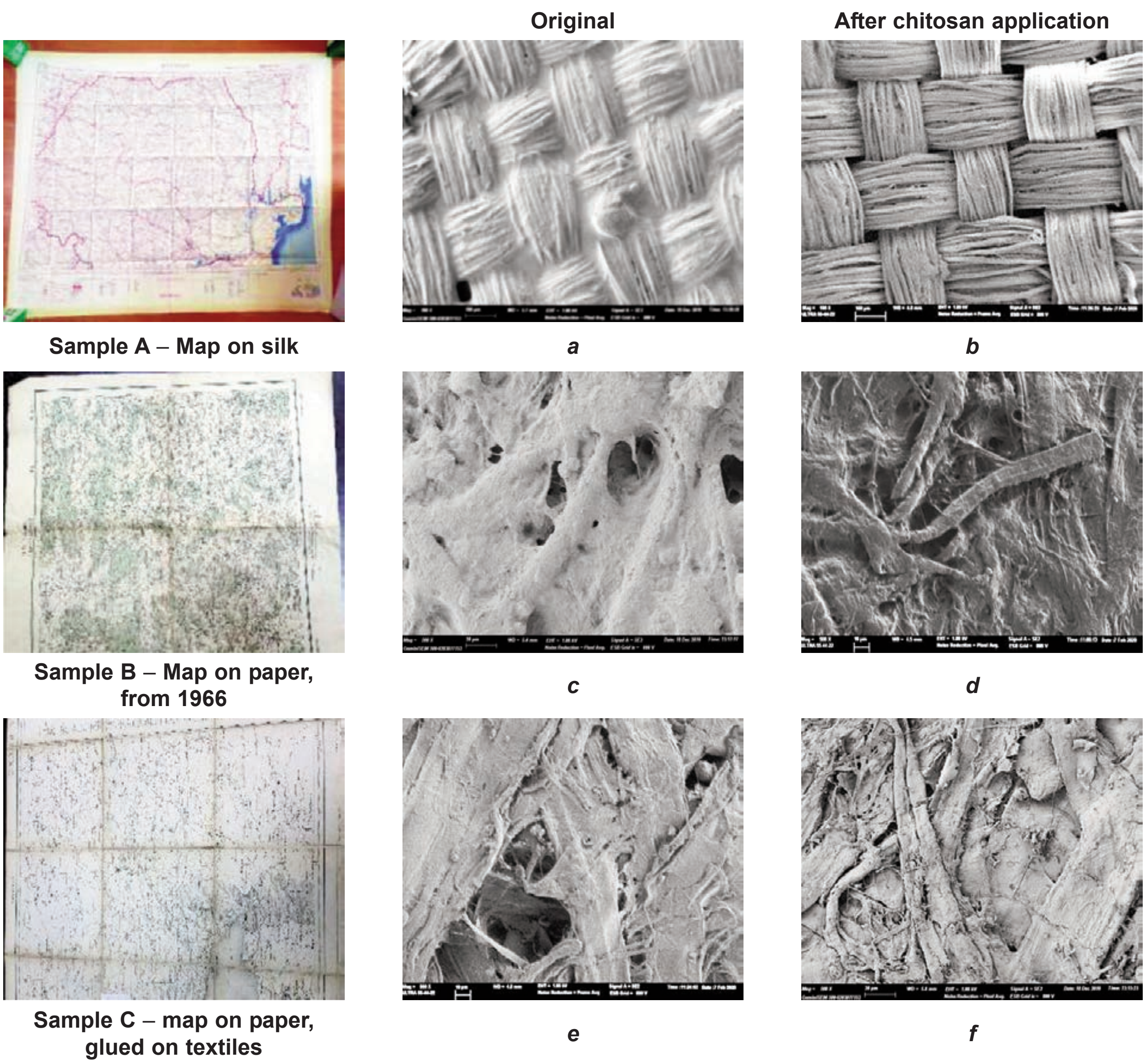

Fig. 3. SEM images reflecting the effect of chitosan treatment on the samples of aged maps: *a* – SEM image of the fibres from sample A at 100 × magnification; *b* – SEM image of the fibres from sample A at 100 × magnification; *c* – SEM image of the fibres from sample B, at 500 × magnification; *d* – SEM image of the fibres from sample B, at 500 × magnification; *e* – SEM image of the fibres from sample C, at 500 × magnification; *f* – SEM image of the fibres form sample C, at 500 x magnification

Results-application of chitosan on the samples

The effect of chitosan treatment on the samples of aged maps can be observed in figure 3, which shows SEM images at different magnifications. Sample A shows some kind of fine coating which disappears when treated with chitosan, despite some little particles that can still be appreciated on the surface. Sample B shows a surface partially coated and some fibres morphology can be sensed below the coating. Once the sample has been treated, some differences can be appreciated. The coating still remains although it seems to be in the deepest fibres, and not on the ones placed on the upper part. It seems that the most superficial ones have lost the superficial coating. Something similar also occurs in the case of sample C. Once the chitosan treatment is applied, fibres seem to have lost the superficial coating from the original samples. When the chitosan treatment is applied, it can be clearly observed that the small particles have disappeared. Antifungal activity tests and new results on map materials were done and they did not reveal microorganisms after applying chitosan to the test samples.

CONCLUSIONS

The procedure described in this study is simple and it does not need high technological resources. Once the product is solved, a chitosan solution can be applied to it. The treatment is easy to apply and capable to remove part of the odd substance on the samples, reducing the potential damage which can be conferred to the sample. According to observations, the results highlight that all the samples have rot resistance but not mildew resistance. Chitosan treatment shows good compatibility, biodegradability, and environment friendly and it has revealed adequate efficiency in removing the odd agent on the fibre surfaces. It can also have a long-term future antibacterial effect. The findings of the study suggest a potential application of chitosan on textiles, such as those analysed: silk, paper, textile support of the aged maps, to provide the optimal physical and antimicrobial properties.

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The impact of technological innovation from domestic innovation, import and FDI channels on carbon dioxide emissions of China's textile industry

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ABSTRACT – REZUMAT

The impact of technological innovation from domestic innovation, import and FDI channels on carbon dioxide emissions of China's textile industry

Technological innovation is the key to reducing carbon dioxide (CO_2) emissions. In order to analyse the role of technological innovation from domestic innovation, import and FDI channels in the CO_2 emissions reduction of China's textile industry (CTI), this study uses OLS models to study the impact of domestic innovation, import technology spill over and FDI technology spillover on CO_2 emissions and CO_2 emission intensity of CTI respectively. The research results show that domestic innovation has significantly reduced CTI's CO_2 emissions and CO_2 emission intensity, while import technology spillover has increased them. FDI technology spillover has increased CO_2 emission intensity, but its impact on CO_2 emissions isn't significant. Therefore, China should take domestic R&D investment as the key measure to reduce CTI's CO_2 emissions in the future and continue to improve the level of independent innovation. China should also attract more low-carbon and green international investment and avoid becoming the "pollution heaven" for high-emission capital. The level of technology embedded in the imported textile products should be improved further. The use of various technological innovation strategies not only reduces CTI's CO_2 emissions but also makes positive contributions to China's goal of "carbon peaking and carbon neutralization".

Keywords: *China's textile industry, carbon dioxide emissions, technological innovation, domestic innovation, import, FDI*

Impactul inovației tehnologice din canalele interne de inovare, import și FDI asupra emisiilor de dioxid de carbon ale industriei textile din China

Inovația tehnologică este cheia reducerii emisiilor de dioxid de carbon (CO_2). Pentru a analiza rolul inovației tehnologice din canalele de inovație internă, import și investiția străină directă (FDI) în reducerea emisiilor de CO_2 ale industriei textile din China (CTI), acest studiu utilizează modele OLS pentru a determina impactul inovației interne, răspândirea tehnologiei de import și a tehnologiei FDI asupra emisiilor de CO_2 și respectiv, intensitatea emisiilor de CO_2 ale CTI. Rezultatele cercetării arată că inovația internă a redus semnificativ emisiile de CO_2 ale CTI și intensitatea emisiilor de CO_2, în timp ce răspândirea tehnologiei de import le-a crescut. Răspândirea tehnologiei FDI a crescut intensitatea emisiilor de CO_2, dar impactul acesteia asupra emisiilor de CO_2 nu este semnificativ. Prin urmare, China ar trebui să adopte investițiile interne în cercetare și dezvoltare ca măsură cheie pentru a reduce emisiile de CO_2 ale CTI în viitor și să continue să îmbunătățească nivelul de inovare independentă. China ar trebui, de asemenea, să atragă mai multe investiții internaționale cu emisii scăzute de carbon și ecologice și să evite să devină „raiul poluării" pentru capitalul cu emisii ridicate. Nivelul de tehnologie încorporat în produsele textile importate ar trebui îmbunătățit în continuare. Utilizarea diferitelor strategii de inovare tehnologică nu numai că reduce emisiile de CO_2 ale CTI, dar aduce și contribuții pozitive la obiectivul Chinei de „reducere a emisiilor de carbon și de neutralizare a carbonului".

Cuvinte-cheie*: industria textilă din China, emisii de dioxid de carbon, inovație tehnologică, inovație internă, import, FDI*

INTRODUCTION

Global climate warming is a common problem faced by human beings. Reducing carbon dioxide (CO_2) emissions has become a key measure for all nations to combat climate warming. Xi Jinping, the president of China, announced at UN General Assembly in September 2020 that China "strives to peak carbon emissions by 2030 and achieve carbon neutrality by 2060". At the Climate Ambition Summit in December 2020, Xi further promised that "by 2030, China's CO_2 emissions per unit of GDP will drop by more than 65%, compared with 2005 and the proportion of non-fossil energy consumption will reach 25% of primary energy consumption". These promises set clear time and quantity targets for China's CO_2 emissions and reducing CO_2 emissions has become an urgent task for Chinese governments at all levels.

The textile industry is one of the traditional pillar industries of China's economy and has made remarkable contributions to promoting economic growth and social development. The textile industry is also one of the important sources of China's CO_2 emissions. In 2019, the CO_2 emissions of China's textile industry (CTI) exceeded 22 million tons and it was still a large one. Therefore, reducing CTI's CO_2 emissions is of great significance for China to achieve the goal of "carbon peaking and carbon neutralization" and transfer to a green and low-carbon development model.

The key to reducing CO_2 emissions is technological innovation, which reduces energy consumption and CO_2 emissions by improving energy efficiency, producing more low-carbon products and optimizing industrial structure. In an open economy, the sources of technological innovation include not only domestic innovation activity but also technology spillovers from import and foreign direct investment (FDI) [1]. In the reduction of CTI's CO_2 emissions, what role do these three channels of technological innovations play? What's the difference between them? Therefore, it has great empirical significance to study the impact of technological innovation of these three channels on CTI's CO_2 emissions for answering these questions. And it will provide a beneficial reference to guide CTI to rationally make use of their CO_2 emissions reduction effects.

The research on the impact of technological innovation on CO_2 emissions began with the study of the relationship between exogenous technological innovation and environmental problems. Then academia studied it under the framework of the endogenous growth model and the commonly used research methods include the STIRPAT model, EKC model, CGE model and LDMI method et al. Regarding the relationship between technological innovation and CO_2 emissions, most scholars believe that it has a positive impact on reducing CO_2 emissions. Lu [2] found that breakthrough low-carbon technological innovation had a reduced effect on CO_2 emissions by using China's Provincial Spatial Panel data. Daniel [3] confirmed that environmental innovation did contribute to CO_2 emissions reduction in the EU-27 countries between 1992 and 2014. Meanwhile, some scholars believe that the CO_2 emissions reduction effect of technological innovation is inconclusive and it may even increase CO_2 emissions. The rebound effect explicitly reveals that technological innovation promotes the decrease of product cost and price, then increases external demand and will lead to an increase in CO_2 emissions, instead of a decrease [4]. The research of Li [5] proved that technological innovation had a rebound effect on China's CO_2 emissions, about 9% – 75%. Chen [6] found that the impact of China's general domestic technological progress on CO_2 emissions was complex. In Central and West China, it reduced CO_2 emissions, whereas in East China it slightly increased emissions.

On the impact of technological innovation from domestic innovation, import and FDI channels on CO_2 emissions, Chinese scholars have achieved some research findings. Bi [7] confirmed that the horizontal spillover effect, forward linkage spillover effect and backward linkage spillover effect of FDI all reduced the CO_2 emission intensity of China's industry. Guo [8] found that import technology spillover reduced China's CO_2 emissions. When it increased by 1%, the CO_2 emissions would decrease by 0.513%. But Alfred [9] held the opposite opinion based on the research on Turkey. Ma [10] studied the impact of technological innovation from domestic innovation activity, direct technology introduction and indirect technology introduction (FDI and import) channels on China's CO_2 emission intensity for the first time. The results showed that domestic innovation activity, FDI and import reduced CO_2 emission intensity, while export increased that and the effect of direct technology introduction was not significant.

Regarding the research on the impact of technological innovation from different channels on the CO_2 emissions of the textile industry, the literature is rare. Only Ignas [11] studied the impact of international trade on the CO_2 emissions of the EU clothing industry, excluding the textile industry. As to the research on CTI's CO_2 emissions, existing literature focuses on the measurement of CO_2 emissions and their relationship with economic development. Lu [12] and Gong [13] proved the weak decoupling relationship between GDP and CO_2 emissions of textile and garment industry in China and Xinjiang respectively. There are some shortcomings in these researches, such as poor data timeliness and rough distinguishment between the textile industry and garment industry. Furthermore, previous research has not paid sufficient attention to the impact of technological innovation on CTI's carbon emissions and there is also a lack of research from the channels of domestic innovation, import and FDI.

Under the overall requirements of innovative development and green development, it is of great practical urgency and value to explore the impact of technological innovation from domestic innovation, import and FDI channels on CTI's CO_2 emissions.

Meanwhile, academia has not yet done research in this field. Given this fact, this study first calculates and analyses CTI's CO_2 emissions and CO_2 emission intensity from 2003 to 2019. Then it constructs OLS models to investigate the impact of domestic innovation, import technology spillover and FDI technology spillover on CTI's CO_2 emissions and CO_2 emission intensity respectively. Analysing the different impacts of the three channels of technological innovation, can not only provide evidence suggesting policy recommendations targeting CTI's CO_2 emissions reduction but also address the research gap in this field.

METHODOLOGY AND DATA SOURCES

Estimation model

Referring to the research method of Ma [10], this study takes CO_2 emissions and CO_2 emission intensity of CTI as dependent variables and domestic innovation, import technology spillover and FDI technology spillover as independent variables, then constructs regression equations to investigate the impact of domestic innovation, import technology spillover and FDI technology spillover on CTI's CO_2 emissions (Model 1) and CO_2 emission intensity (Model 2) respectively. Thus, the impact of technological innovation from different channels on the CO_2 emissions of CTI can be comprehensively analysed. The equations are as follows:

$$\ln(CM_t) = C + \ln(R\&D_t) + \ln(FDI_t) + \ln(IMP_t) + \varepsilon \quad (1)$$

$$\ln(CMI_t) = C + \ln(R\&D_t) + \ln(FDI_t) + \ln(IMP_t) + \varepsilon \quad (2)$$

CM and *CMI* represent CTI's CO_2 emissions and CO_2 emissions intensity in year *t*. *R&D* represents CTI's domestic innovation in year *t*. *FDI* and *IMP* represent FDI technology spillover and import technology spillover of CTI in year *t*. *C* represents the constant and ε represents the residual.

Variables explanation and data sources

CO_2 emissions: Since there is no direct statistical data on CO_2 emissions in China, most scholars usually use the energy consumption of a specific industry to calculate CO_2 emissions indirectly. Referring to the method provided by IPCC [14], this study calculates CTI's CO_2 emissions by adding up the CO_2 emissions of the nine main energy CTI consumes, including raw coal, coke, coke oven gas, crude oil, gasoline, kerosene, diesel oil, fuel oil and natural gas. The equation is as follows:

$$CM = \sum E_i \times \rho_i \times \mu_i \quad (3)$$

where *CM* represents CTI's CO_2 emissions, E_i represents the consumption of energy *i*, $i = 1, 2, \ldots, 9$, ρ_i and μ_i represent the coal equivalent coefficient and carbon emission coefficient of energy *i*.

CO_2 emission intensity refers to the amount of CO_2 emitted per 10,000 CNY of GDP. It's measured by the ratio of CTI's CO_2 emissions to its total output to calculate CO_2 emission intensity.

Domestic innovation: It's measured by the domestic R&D capital stock of CTI and calculated by the perpetual inventory method.

Import technology spillover: Import is a major channel of technology spillover. Referring to the LP model proposed by Lichtenberg [15], which is used to measure the foreign R&D capital stock spilt from international trade channels, this study uses the following formula to calculate import technology spillover:

$$S_t^{imp} = \sum_{j \neq k} \frac{S_{jt}^{rd}}{Y_{jt}} M_{jkt} \quad (4)$$

S_t^{imp} represents import technology spillover of CTI in year *t*. S_{jt}^{rd} represents the domestic R&D capital stock of country *j* in year *t*. Y_{jt} represents the GDP of country *j* in year *t*. M_{jkt} represents the total value of textile industry products imported by country *k* from country *j* in year *t*. The bilateral trade between China and OECD countries accounts for a large proportion of China's foreign trade and the world's R&D investment is mainly concentrated in OECD countries, mostly in the United States, Japan, Germany, France, Italy, Britain, Canada, South Korea and other countries. Therefore, this study chooses these eight countries as the source countries for spilling R&D capital to China and then measures import technology spillover of CTI.

FDI technology spillover: FDI is another major channel of technology spillover. Similarly, referring to the LP model, the calculation formula for FDI technology spillover of CTI is as follows:

$$S_t^{fdi} = \sum_{j \neq k} \frac{S_{jt}^{rd}}{K_{jt}} FDI_{jkt} \quad (5)$$

S_t^{fdi} represents FDI technology spillover of CTI in year *t*. S_{jt}^{rd} represents the domestic R&D capital stock of country *j* in year *t*. K_{jt} represents the total fixed capital formation of country *j* in year *t*. FDI_{jkt} represents the textile industry FDI of country *k* from country *j* in year *t*.

The above data are obtained from China Statistical Yearbook, China Statistical Yearbook on Science and Technology, China Energy Statistical Yearbook and the UN Comtrade Database. The time series is 2003–2019.

CO_2 EMISSIONS OF CHINA'S TEXTILE INDUSTRY

CO_2 emissions and CO_2 emission Intensity

The CO_2 emissions of CTI declined from 28.81 million tons in 2003 to 22.72 million tons in 2019 (table 1), more than 20%. Its share in the industry had also been declining from 2.56% to 0.88%, lower

Table 1

THE CO_2 EMISSIONS AND CO_2 EMISSION INTENSITY OF CTI

Year	CO_2 emissions (million tons)	Share in industry (%)	CO_2 emission intensity (kg/10,000 CNY)
2003	28.81	2.56	384
2004	33.38	2.48	333
2005	31.64	2.02	256
2006	32.89	1.93	220
2007	34.54	1.90	190
2008	31.58	1.55	152
2009	29.58	1.42	132
2010	27.76	1.30	99
2011	23.71	1.04	73
2012	19.31	0.83	60
2013	34.03	0.90	94
2014	25.34	0.89	66
2015	23.44	0.87	59
2016	24.97	0.97	61
2017	25.03	1.00	69
2018	22.60	0.89	81
2019	22.72	0.88	92

than the share of CTI's total output (2.31%). This reveals that CTI has made remarkable achievements in reducing CO_2 emissions. In addition to eliminating the backward production capacity with high energy consumption and CO_2 emissions, a large part of the reduction is attributed to technological innovation activities, such as technological transformation and upgrading.

The CO_2 emission intensity of CTI showed a sharp decline and a slight rise during 2003–2019 (table 1). It first dropped from 384kg/10,000 CNY in 2003 to 59 in 2015. Then it slowly increased to 92 in 2019 and there was still more than 3/4 decline compared with 2003. CTI's CO_2 emission intensity has always been lower than the industry average and is currently only 37.99% of it. This shows that the CO_2 emissions caused by per unit output of CTI are relatively low, compared to the industry. However, the slow increase of CO_2 emission intensity since 2016 reminds us that CTI must always put more emphasis on curbing CO_2 emissions and not relaxing.

CO_2 emissions structure

The CO_2 emissions structure of CTI has shifted from being dominated by raw coal and supplemented by fuel oil and diesel oil to mainly natural gas with raw coal as a supplement (table 2). In 2003, the main source of CO_2 emissions was raw coal, followed by fuel oil, diesel, gasoline and natural gas. The total CO_2 emissions of these five energies accounted for 99.35% of CTI and that of raw coal accounted for about 78.34%. From 2004 to 2015, the share of raw coal had been always higher than 80%, even reaching the maximum of 87.59% in 2015. It indicates that CTI relies heavily on raw coal and reducing the use of raw coal is the key to cutting down CTI's CO_2 emissions. In 2016, as the use of natural gas (especially liquefied natural gas) increased significantly, the CO_2 emissions share of raw coal fell below 80% for the first time, to 66.95%. Then it dropped to 22.38% in 2019, while the CO_2 emissions from natural gas increased sharply to 69.68%. As a result, CTI's CO_2 emissions have made a great structural adjustment from raw coal-based to natural gas-based with raw coal as a supplement. It also proves that optimizing energy structure is beneficial to CO_2 emissions reduction. The CO_2 emissions share of coke oven gas increased from 0.33% in 2003 to 4.86%, while fuel oil dropped from 8.17% to 0.69%. And gasoline and diesel both dropped to about 1%.

EMPIRICAL RESULTS AND DISCUSSIONS

Robustness check and co-integration test

This study first does a robustness check for each variable and the results show that they all pass the robustness check at a 10% significance level. The results of the co-integration test show that there is a co-integration relationship among the variables. Due to space limitations, the results of the robustness check and co-integration test are not presented here.

Empirical results

This study uses OLS models to analyse the impact of technological innovation from the channels of domestic innovation, import technology spillover and FDI technology spillover on CTI's CO_2 emissions (Model 1) and CO_2 emission intensity (Model 2) respectively. The estimation results are shown in table 3.

Table 2

THE CO_2 EMISSIONS STRUCTURE OF CTI

Year	Raw coal	Coke	Coke oven gas	Crude oil	Gasoline	Kerosene	Diesel oil	Fuel oil	Natural gas
2003	78.34%	0.31%	0.33%	0.00%	3.92%	0.57%	5.79%	8.17%	2.56%
2004	80.33%	0.19%	0.17%	0.03%	2.74%	0.27%	7.60%	7.85%	0.83%
2005	84.65%	0.26%	0.11%	0.03%	2.28%	0.29%	5.70%	5.72%	0.97%
2006	84.81%	0.28%	0.09%	0.02%	2.49%	0.25%	5.58%	5.50%	0.98%
2007	85.38%	0.29%	0.10%	0.02%	2.49%	0.22%	5.62%	4.91%	0.97%
2008	81.82%	0.46%	0.12%	0.03%	3.06%	0.19%	7.27%	5.11%	1.93%
2009	82.99%	0.39%	0.43%	0.03%	3.82%	0.06%	6.69%	3.67%	1.92%
2010	81.32%	0.51%	0.65%	0.00%	4.18%	0.08%	7.19%	3.66%	2.41%
2011	82.78%	0.46%	0.61%	0.00%	3.85%	0.06%	6.50%	2.80%	2.94%
2012	84.20%	0.44%	1.04%	0.00%	3.76%	0.03%	4.65%	2.06%	3.81%
2013	83.92%	0.23%	0.00%	1.95%	0.02%	2.30%	0.99%	8.09%	2.51%
2014	86.96%	0.23%	0.71%	0.00%	2.42%	0.01%	2.76%	1.42%	5.50%
2015	87.59%	0.23%	1.12%	0.00%	2.55%	0.03%	0.34%	0.08%	8.05%
2016	66.95%	0.16%	1.40%	0.00%	2.07%	0.01%	2.28%	1.06%	26.06%
2017	46.17%	0.15%	3.03%	0.00%	2.25%	0.01%	3.77%	1.14%	43.48%
2018	33.47%	0.25%	4.00%	0.01%	1.33%	0.00%	1.42%	0.97%	58.54%
2019	22.38%	0.15%	4.86%	0.00%	1.06%	0.01%	1.17%	0.69%	69.68%

Table 3

THE ESTIMATION RESULTS		
Parameter	**Model 1**	**Model 2**
	Coefficient	**Coefficient**
C	3.679** [2.504]	–2.351*** [–0.819]
RD	–0.344* [–1.815]	–0.427** [–0.427]
IMP	0.370** [0.874]	2.635*** [0.828]
FDI	–0.182 [–0.973]	0.350** [0.957]
Adj-R2	0.680	0.870

Note: ***, **, * represent significance levels of 1%, 5% and 10%, respectively, *t* values are shown in parentheses.

Technological innovation from domestic innovation has significantly reduced CTI's CO_2 emissions, while the import technology spillover has increased it and the effect of the FDI technology spillover isn't significant. The impact coefficient of domestic innovation on CTI's CO_2 emissions is –0.344, which demonstrates that improving the technological innovation level by increasing domestic R&D investment will help mitigate CTI's CO_2 emissions. The reason is that textile enterprises attach more and more important to improving independent innovation capability. Through continuously increasing R&D investment, they're able to alleviate the pressure from environmental regulations and maintain their competitive edge in the market. The impact coefficient of import technology spillover is 0.370, which means importing foreign textile products has a negative environmental externality and it plays a role in increasing CTI's CO_2 emissions, instead of reducing them. The reason may be that level of technology embedded in the imported textile products is relatively low. The impact coefficient of the FDI channel is –0.182, not significant.

Technological innovation from domestic innovation also has reduced CTI's CO_2 emission intensity, while import technology spillover and FDI technology spillover have increased it. All the impact coefficients of these three channels have passed the significance test. The impact coefficient of domestic innovation is –0.427, which indicates that increasing domestic R&D investment helps reduce CTI's CO_2 emission intensity. That of import technology spillover is 2.635, which also confirms the negative environmental externality of importing foreign textile products. The impact coefficient of FDI technology spillover is 0.35. It means that FDI also has negative environmental externalities and it increases CTI's CO_2 emission intensity. This proves the "Pollution Heaven Hypothesis" [16] to a certain extent, that is, FDI in CTI has the effect of transferring pollution. Therefore, it is necessary to raise the environmental protection standards for foreign capital to enter CTI.

CONCLUSIONS AND POLICY SUGGESTIONS

This study uses OLS models to investigate the impact of domestic innovation, import technology spillover and FDI technology spillover on CTI's CO_2 emissions and CO_2 emission intensity respectively, to analyze the differences in the effects of technological innovation through these three channels on CTI's CO_2 emissions. The research results are as follows:

Technological innovation from domestic innovation has significantly reduced CTI's CO_2 emissions and CO_2 emission intensity, while import technology spillover has increased them. FDI technology spillover has increased CO_2 emission intensity, but its impact on CO_2 emissions isn't significant. This demonstrates that increasing domestic R&D investment to promote technological innovation levels does reduce CTI's CO_2 emissions. Importing foreign textile products has negative environmental externality and it aggravates environmental pollution by intensifying the carbon emissions. FDI in CTI has increased CO_2 emission intensity and has the effect of transferring pollution.

Therefore, China should take domestic R&D investment as the key measure to reduce CTI's CO_2 emissions in the future and continue to improve the level of independent innovation. China should also attract more low-carbon and green international investment and avoid becoming the "pollution heaven" for high-emission capital. At the same time, the level of technology embedded in the imported textile products should be improved further. Thus, CTI's CO_2 emissions can be further reduced and this can make positive contributions to China's goal of "carbon peaking and carbon neutralization" eventually.

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An overview of hemp for fibre market opportunities for Romania

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ABSTRACT – REZUMAT

An overview of hemp for fibre market opportunities for Romania

Hemp has been cultivated by man for its multiple uses: its solid fibres for textiles, its nutritious oilseeds and the medicinal and therapeutic properties of its resin. Hemp is a technical plant that has been cultivated in Romania for over 2,000 years, its main use being to obtain fibres for making clothing. Before 1989, in Romania hemp was cultivated in large areas, exceeding 50,000 hectares, ranking 4th in the world. After 1989, interest in cultivating hemp declined, and by 2008 this crop has almost disappeared.
Starting from national production capacity, this paper is presenting an overview of the textile market in Europe, with a view on the hemp market, and the marketing possibilities for Romanian hemp, based on calculations retrieved from official data available on INTRACEN and the National Institute of Statistics of Romania.
The study of production capacities was analysed in terms of cultivated areas and productions obtained in Romania, reported in official national statistics. For a market projection, the data were extracted from the trade map database. The export potential was studied taking into account the harmonized standard codes for hemp.

Keywords: *textile industry, hemp for fibre, market analysis, export potential*

Cultura de cânepă pentru fibre, o oportunitate de piață

Cânepa a fost cultivată de-a lungul timpului pentru multiplele sale utilizări: fibrele rezistente pentru industria textilă, semințele cu conținut ridicat de substanțe nutritive și proprietățile medicinale și terapeutice ale rășinii de cânepă. Cânepa este o plantă tehnică care se cultivă în România de peste 2.000 de ani, principala sa utilizare fiind obținerea de fibre pentru confecționarea îmbrăcămintei. Înainte de 1989, în România cânepa era cultivată pe suprafețe mari, depășind 50.000 de hectare, ocupând locul 4 în lume. După 1989, interesul pentru cultivarea cânepei a scăzut, iar până în 2008 această cultură aproape a dispărut.
Pornind de la capacitatea de producție națională, această lucrare prezintă o imagine de ansamblu asupra pieței cânepii din Europa și a posibilităților de comercializare a cânepii românești, pe baza calculelor preluate din datele oficiale disponibile pe INTRACEN și ale Institutului Național de Statistica din România.
Studiul capacităților de producție a fost analizat din punct de vedere al suprafețelor cultivate și al producțiilor obținute în România, raportate în statisticile naționale oficiale. Pentru o proiecție a pieței, datele au fost extrase din baza de date trade map. Potențialul de export a fost studiat ținând cont de codurile standard armonizate pentru cânepă.

Cuvinte cheie: *industrie textilă, cânepă pentru fibre, analiză de piață, potențial de export*

INTRODUCTION

Hemp, *Cannabis sp.,* family *Cannabinaceae,* is an annual herbaceous plant with palmate leaves. *Cannabis sativa* is grown for its stem (textile fibre) and seeds (chènevis for birds and oil). Hemp is native to Central Asia and has spread to China, all of Asia and the basin Mediterranean. Hemp has been cultivated by man for its multiple uses: its solid fibres for textiles, its nutritious oilseeds and the medicinal and therapeutic properties of its resin [1].

Traditionally, hemp is grown for either seed or fibre. Hemp seeds contain approximately 30% protein, 25% starch, and 30% oil [2, 3]. At a time when it is important to consume sustainably and responsibly, hemp appears to be a very interesting ecological material for textile production, because i) its cultivation requires a small amount of water; ii) cultivation does not require pesticides or insecticides; iii) hemp is a plant that stores CO_2 in the soil, allowing it to regenerate very quickly; iv) clothing and accessories made from hemp are durable, resistant and above all biodegradable (provided that are used use only natural processes and materials for dyeing and making), they avoid the accumulation of waste [4]. Optimisation of hemp varieties with higher cellulose content in the fibre and lower pectin and lignin cross-linkages could reduce the retting necessities, thus improving the strength of the obtained fibre while saving time and labour [4, 5].

Little by little, the general public is becoming aware of the ecological footprint of fashion. Synthetic, non-biodegradable fibres are found in thousands of tons in the oceans and the stomachs of aquatic fauna and conventional cotton, often GMO, depletes water resources.

From an agronomic point of view, hemp is particularly interesting because:

- Hemp breaks the cycle of diseases [2].
- Like all spring crops, it allows a break in crop rotations based on autumn crops and limits the reproduction of weeds [5].
- In organic as in conventional, hemp is not very sensitive to diseases and insects. It does not need any fungicide or insecticide. If the emergence takes place in good conditions, it is a stuffy plant that does not require any weeding (neither chemical nor mechanical) [3, 6].
- Hemp can easily find its place in a rotation and it is a very good rotation head in organic farming. Its taproot leaves an excellent soil structure for the next crop [2, 7].
- Drought resistant, it does not require irrigation and is not susceptible to pouring.
- Hemp makes it possible to reduce the IFT (an indicator of the frequency of phytosanitary treatments) of the farm and thus promote the development and action of the microflora and microfauna of the soil, a guarantee of its proper functioning [1].

The hemp for fibre has antibacterial properties that are effective against many pathogenic bacteria. Alkaloids, flavones and saponins are active biological substances found in hemp fibre. It was reported that hemp fibre is having antimicrobial activity against *Escherichia coli, Staphylococcus aureus* [8], and *Pseudomonas aeruginosa* [9, 10]

Starting from national production capacity, this paper is presenting an overview of the textile market in Europe, with a view on the hemp market, and the marketing possibilities for Romanian hemp, based on calculations retrieved from official data available on Intracen and the National Institute of Statistics of Romania.

MATERIAL AND METHODS

The study of production capacities was analysed in terms of cultivated areas and productions obtained in Romania during 2014–2020. For a market projection, the data were extracted from the trade map database. The export potential was studied taking into account the harmonised standard codes for hemp for fibre, as follows: 530210 True hemp “Cannabis sativa L.”, raw/retted; 530290 True hemp “Cannabis sativa L.”, processed but not spun; tow and waste of hemp, incl. yarn waste.

The potential export value of hemp supplied by various countries to a specific market, expressed in US dollars, is calculated as supply × demand (corrected for market access) × bilateral ease of trade. Supply and demand are projected into the future based on GDP and population forecasts, demand elasticities and forward-looking tariffs. Ease of trade is based on the ratio of actual trade between the selected exporter and specified market relative to the hypothetical trade if the exporter had the same share in the specified market as it has in world markets.

RESULTS AND DISCUSSIONS

Hemp is a technical plant that has been cultivated in Romania for over 2,000 years, its main use being to obtain fibres for making clothing. Hemp stalks contain different weights of fibre, namely hemp from local populations and wild hemp 10–12%, and improved varieties 26–32%, these being influenced by variety, technological conditions and soil and climatic conditions [11].

Before 1989, in Romania hemp was cultivated in large areas, exceeding 50,000 hectares, ranking 4th in the world. After 1989, interest in cultivating hemp declined, and by 2008 this crop has almost disappeared (figure 1).

Hemp gives good results in areas with a cool and humid climate, where it can occupy large areas in

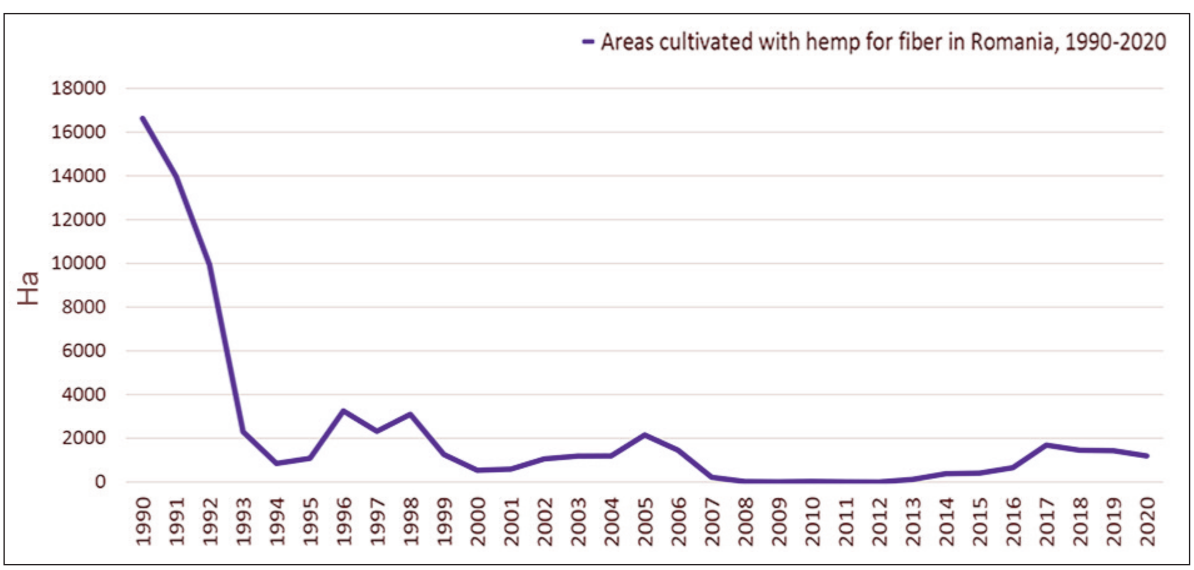


Fig. 1. Areas cultivated with hemp for fibre in Romania, 1990–2020 [12]

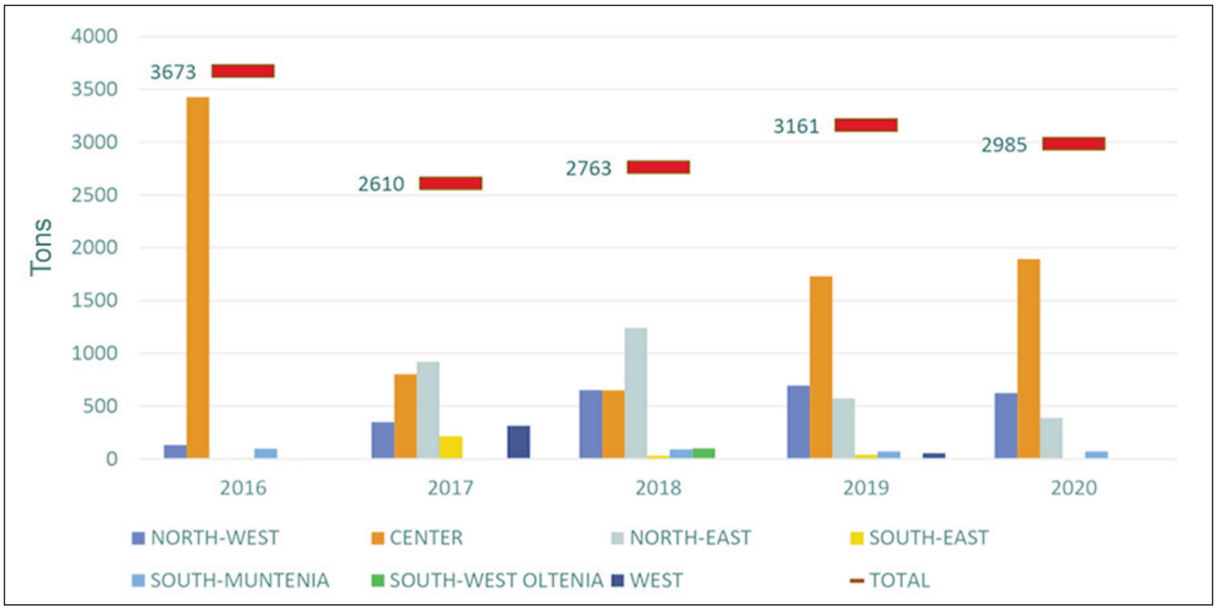


Fig. 2. Areas cultivated with hemp for fibre in Romania, by development regions, 2016–2020 [12]

rotation with potatoes, flax, sugar beet and oats. The largest areas cultivated with hemp are located in the Center Region of Romania (multiannual average of 251.8 ha) and the North-East Region of Romania (multiannual average of 317.7 ha) (figure 2).

Almost the entire quantity of hemp produced in Romania is going to export in countries such as Germany, Spain and Netherlands (figure 3). Although the processing capacity of the harvest is low, still this crop could be a profitable business, and this will be further discussed in this paper.

The Export Potential Indicator identifies the potential export value for any exporter in a given product and target market based on an economic model that combines the exporter's supply, the target market's demand, market access conditions, and bilateral linkages between the two countries. The potential export value in 2026 is based on projections of supply, demand, market access conditions and bilateral ease of trade, expressed in dollars.

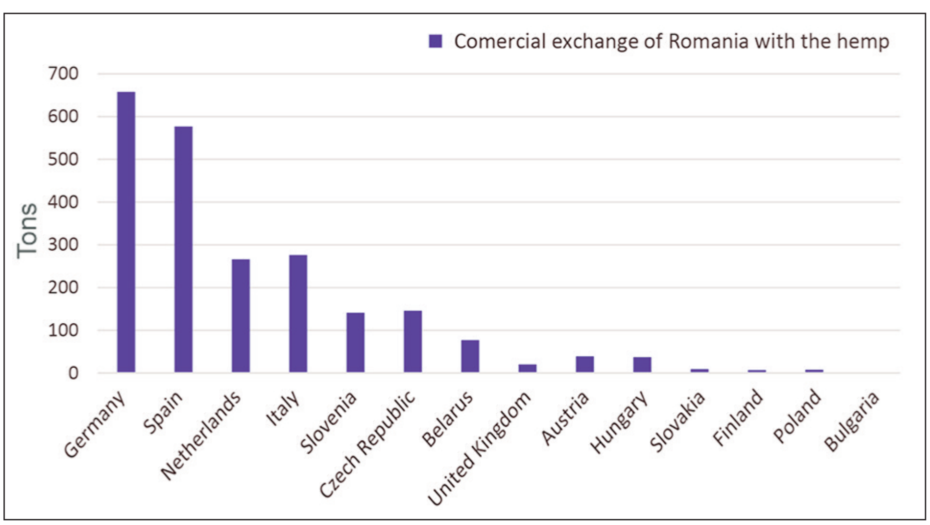


Fig. 3. Commercial exchange of Romania with the hemp [13]

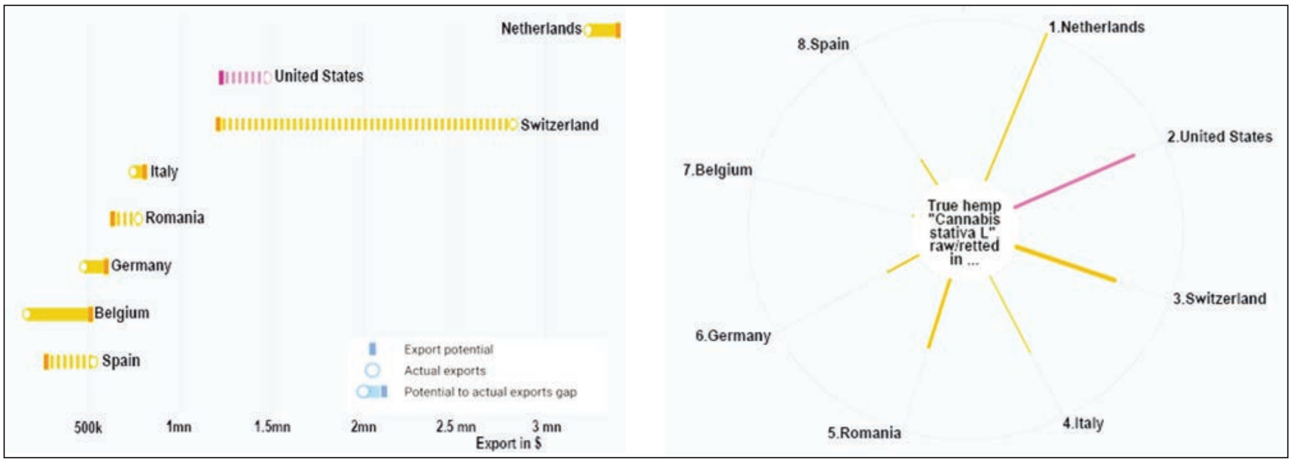
Market potential for 530210 True hemp "Cannabis sativa L.", raw/retted

The world suppliers with the greatest potential to export 530210 True hemp "Cannabis sativa L.", raw/retted to World are the Netherlands, the United States and Switzerland (figure 4, *a*). The Netherlands shows the largest absolute difference between potential and actual exports in value terms, leaving room to realize additional exports worth 1.2 million dollars. Romania's export potential for hemp is 604.8 thousand $, while actual exports value 777.0 thousand $. The untapped potential remaining in individual countries is 383.0 thousand $. Regarding the ease of trade, Switzerland has the closest export links with the rest of the world, followed by the United States and Romania. The lowest values are for Netherlands, Spain and Italy. At the same time, the Netherlands has the highest supply capacity (bullet size in fig. 4, *b*) in 530210 True hemp "Cannabis sativa L.", raw/retted, followed by the United States and Switzerland. The lowest supply potential (line width in figure 4, *b*) is for Germany, Spain and Belgium (figure 4, *b*).

Romania export market analysis for 530210 True hemp "Cannabis sativa L."

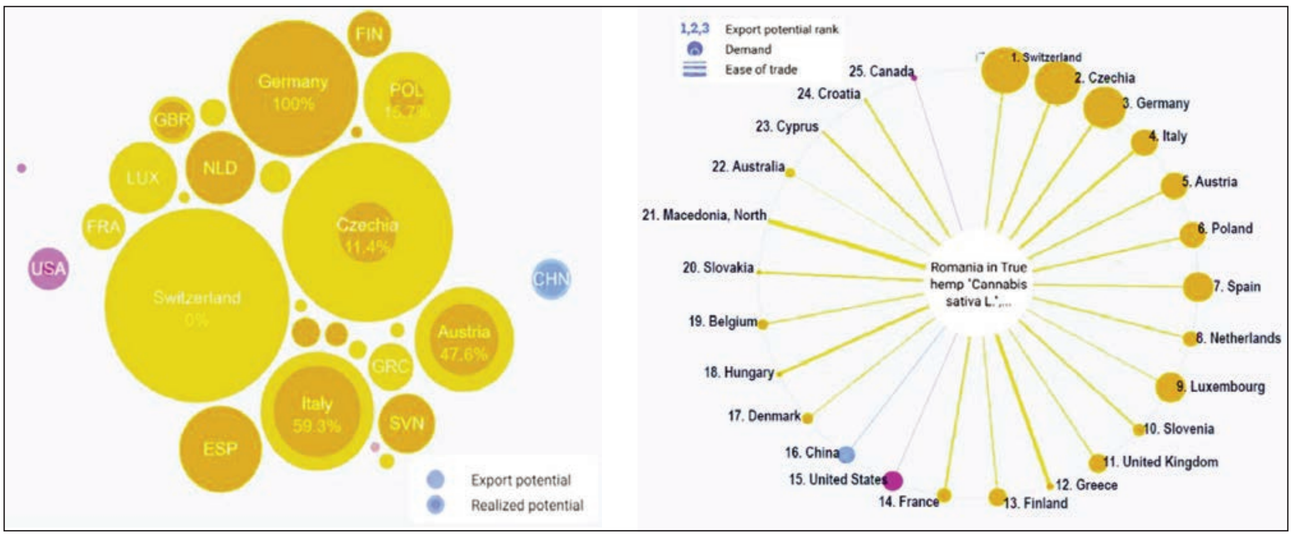
The markets with the greatest potential for Romania's exports of 530210 True hemp "Cannabis sativa L.", raw/retted are Switzerland, Czechia and Germany (figure 5, *a*).

Switzerland shows the largest absolute difference between potential and actual



a *b*

Fig. 4. Data on:
a – countries with market potential for raw/retted hemp, 2020; *b* – potential export for raw/retted hemp [13]



a *b*

Fig. 5. Data on: *a* – Romania's export market for raw/retted hemp, 2020 data; *b* – analysis of Romania's export potential for raw/retted hemp [13]

exports in value terms, leaving room to realize additional exports of approximately 148 thousand $.

Romania has the closest export links (line width in figure 5, *b*) with Macedonia, North. Switzerland is the market with the highest demand potential for 530210 True hemp "Cannabis sativa L.", raw/retted. (figure 5, *b*).

Market potential for 530290 True hemp "Cannabis sativa L.", processed, not spun

The world suppliers with the greatest potential to export 530290 True hemp "Cannabis sativa L.", processed, not spun to World are Netherlands, Romania and Italy (figure 6, *a*).

The Netherlands shows the largest absolute difference between potential and actual exports in value terms, leaving room to realize additional exports worth 1.2 million $. The total untapped export potential of True hemp "Cannabis sativa L.", processed, not spun was evaluated to 4.1 million $.

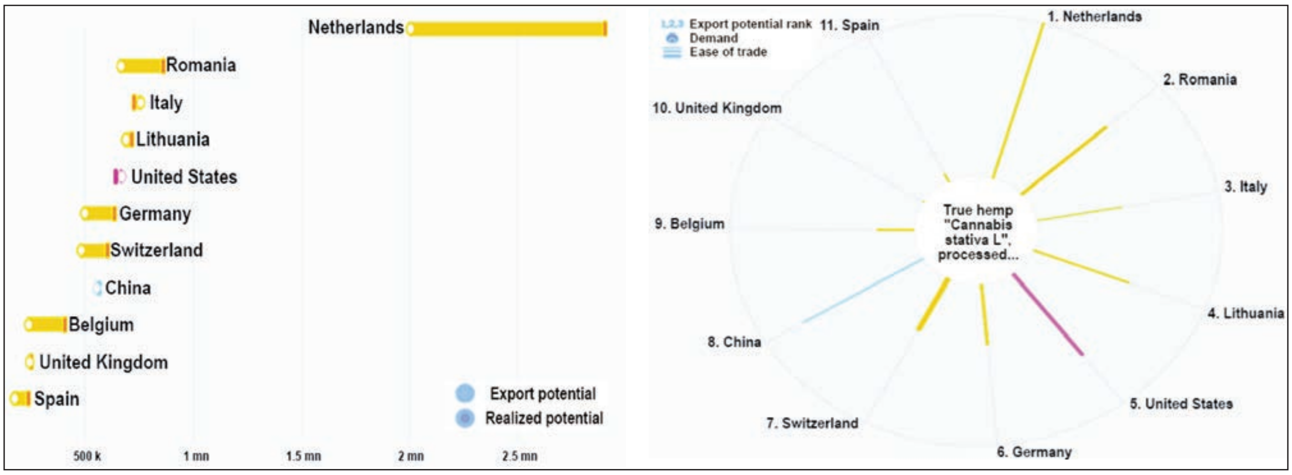
Switzerland has the closest export links with World, followed by the United States and Romania. The ease of trade is lowest for countries such as China, Spain and Italy. The Netherlands has the highest supply capacity (line length in figure 6, *b*) is 530290, followed by China and United States (figure 6, *b*). The lowest supply capacity is for Belgium, Spain and UK.

Romania export market analysis for 530290 True hemp "Cannabis sativa L.", processed, not spun

For the product: 530290 True hemp "Cannabis sativa L.", processed but not spun; tow and waste of hemp, incl. yarn waste, Romania's exports represent 8.5% of world exports for this product, its ranking in world exports is 6.

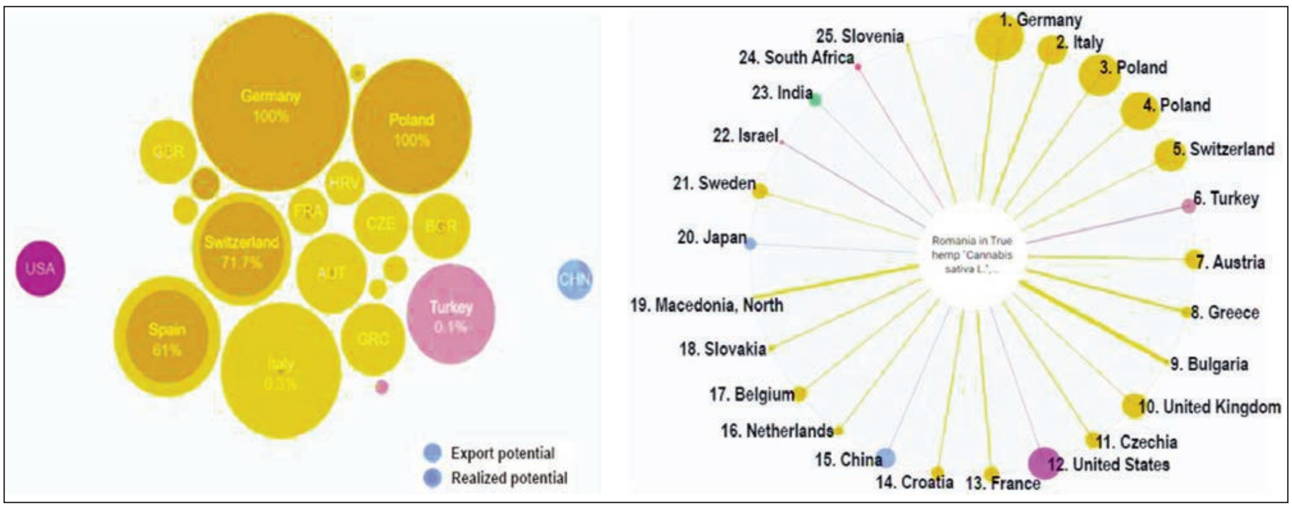
The markets with the greatest potential for Romania's exports of 530290 True hemp "Cannabis sativa L.", processed, not spun are Germany, Italy and Poland. Italy shows the largest absolute difference between potential and actual exports in value terms, leaving room to realize additional exports worth $88.5 k.

Romania has the closest export links (line width in figure 7, *b*) with Bulgaria (figure 7, *b*). Germany is the



a *b*

Fig. 6. Data on: *a* – countries with market potential for processed, not spun hemp 2020; *b* – potential export for processed, not spun hemp [13]



a *b*

Fig. 7. Data on: *a* – Romania's export market for processed, not spun hemp 2020; *b* – analysis of Romania's export potential for processed, not spun hemp [13]

market with the highest demand potential for 530290 True hemp "Cannabis sativa L.", processed, not spun, from Romania.

Cultivation of hemp for fibre could be a promising alternative for market diversification, as currently, hemp fibre is attempting a new economic breakthrough in several manufactured forms [14]:

- Special pulp, such as Bible paper and cigarette paper.
- L'insulation: light, economical, recyclable hemp wool; rigid panels.
- Compounds or related materials (plastic + hemp) are used to make a matter first ready-to-use for industry (moulded products).
- Building materials (mortar and concrete of hemp) use the chenevotte, woody residue of the stem.
- The litters for animals in chenevotte are very absorbent.
- The mulching soils (absorbent power, insulator, neutral pH and stable at wind).
- Pellet soil improvers help to regenerate the humus.
- Hemp fabrics and clothing: some companies are trying to revive their manufacturing.

By emphasizing its specificity of cultivation in the total absence of phytosanitary treatment and its "carbon sink" outlets replacing highly energy-intensive materials (mineral fibres) and/or elements of highly insulating construction systems (hemp concrete, hemp "wools") [1, 5, 6, 12], the hemp sector has in various countries of the European Union been able to benefit from advantages such as coupled support or integration into green policies. However, hemp cultivation is strictly regulated by EU regulations regarding cultivation and seed importers while tetrahydrocannabinol is constantly observed.

CONCLUSIONS

Currently, hemp (fibre) is attempting a new economic breakthrough in several manufactured forms for the textile industry, paper industry, constructions industry, and agriculture practices.

Hemp cultivation presents environmental benefits related to green deal priorities, such as Carbon storage, Breaking the cycle of diseases, Soil erosion prevention, Biodiversity, and low or no use of pesticides. Hemp cultivation does not impose troublesome parameters, but the harvesting and processing are implying specific machinery. However, demand for hemp for fibre is high, and this product could be a promising alternative for market diversification in Romanian trade. Better promotion of the properties and the possibilities of capitalization of hemp could lead to the return of this crop in our agriculture, to increase the farmers' incomes. The problem must be approached from head to toe, in the sense of first identifying potential buyers to properly size the cultivated areas. In this sector, too, storage spaces are an essential problem, which requires an immediate sale after harvest or in an initial phase of processing. Consuming sustainably and responsibly means reconsidering a range of materials, including hemp fibres.

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Crude oil futures to manage the price risk of textile equities: An empirical evidence from India

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ABSTRACT – REZUMAT

Crude oil futures to manage the price risk of textile equities: An empirical evidence from India

The textile sector in India is the oldest manufacturing sector. As the raw materials for this sector are sourced from the petrochemical industries, the earnings of Indian textile companies are dependent on the crude oil price. The crude price in the international market has become more volatile and hence, the equity price of Indian textile companies has become more volatile. This study aims to develop two price risk management strategies for Indian textile equities. Using the vector autoregressive (VAR) model, a price forecast model, further the possibility of cross hedge for textile equities with the help of crude futures is examined using the Granger causality test and Pearson correlation statistics. The results of the study showed that crude futures price in India is one of the price determinants of textile industry stock prices.

***Keywords**: Crude oil futures, textile industry, stock prices, vector autoregressive (VAR) model, Granger causality test, Pearson correlation coefficient*

Contracte futures pe petrol brut pentru a gestiona riscul de preț al tranzacționării acțiunilor din industria textilă: Analiză empirică privind India

Sectorul textil din India este cel mai vechi sector de producție. Întrucât materiile prime pentru acest sector provin din industriile petrochimice, câștigurile companiilor textile indiene depind de prețul țițeiului. Prețul țițeiului pe piața internațională a devenit mai volatil și, prin urmare, prețul acțiunilor companiilor indiene din industria textilă a devenit mai volatil. Acest studiu își propune să dezvolte două strategii privind managementul riscului de preț pentru acțiunile din sectorul textil indian. Folosind modelul vector autoregresiv (VAR), un model de previzionare a prețurilor, posibilitatea de acoperire încrucișată (cross hedge) pentru acțiunile din industria textilă cu ajutorul contractelor futures pe petrol brut este examinată folosind testul de cauzalitate Granger și statisticile de corelație Pearson. Rezultatele studiului au arătat că prețul futures pe petrol în India este unul dintre factorii determinanți ai prețului acțiunilor din industria textilă.

***Cuvinte cheie**: contracte futures pe petrol brut, industria textilă, prețurile acțiunilor, modelul vector autoregresiv (VAR), testul de cauzalitate Granger, coeficientul de corelație Pearson*

INTRODUCTION

The textile sector of India is one of the oldest industries in the Indian economy dating back several centuries. The flair for modernization and impact of technological innovation has resulted in the practice of different technologies in this Industry. While the traditional methods of hand spun and hand oven are still in practice at the rudimentary level, the capital-intensive, sophisticated mills, and power looms are also prevalent at the advanced level in this sector. Indian textile and apparel industry employs more than 45 million people across the country and is estimated to be worth US$ 100 billion in FY19. Indian textile and apparel industry contributed 2% to the GDP, 12% to the export earnings and 7% to the industry output (by value) in 2018–2019. India held 5% of the global trade in textiles and apparel in 2018–2019.

Increasing per capita income of the Indian citizens, penetration of the organized retail, combined with low manpower and production cost will drive demand for textiles in India. Various government policies favouring the textile industries like the Production Linked Incentive (PLI) Scheme to the tune of US$ 1.44 Billion, Support to the handloom weavers and entrepreneurs through the MUDRA scheme which provides loans at 6% with a credit guarantee of three years, will fuel the growth of the Indian textile sector. Even though the textile sector has a positive outlook in the medium to long term, investors tend to shy away from these stocks. The volatility in the textile stock prices keeps the investors at bay [1–5]. Instability in the cost of production is one of the key factors for such volatility. Cleveland [6]and Halawani & Al Dabbagh [7] stated that synthetic polymers produced by the petrochemical industries are the major raw material suppliers for synthetic textile industries. The core materials used in the petrochemical industries are the by-products of crude and the crude oil price in the international market are not stable [8–11].

The volatile crude prices have made Indian and Bahrain textile stocks more volatile; this is evident from the previous studies [12–14]. Hence, active price risk management is very much essential to protect the incomes from volatility and price fluctuations of Indian textile stocks. The purpose of this empirical study is to develop a price forecast model using VAR methodology and to examine the feasibility of cross hedge for Indian textile stocks with the help of crude futures.

For this empirical study, the empirical results suggested that in VAR (2) model, 6 out of 10 selected companies showed statistically significant coefficients with crude futures. Further 5 selected companies' stock prices follow Welspun India Company's stock price. For 6 selected companies the granger causality test p-values are less than 0.05, this proved that the crude futures price in India causes the textile equity prices. The Pearson correlation coefficient values of Welspun India, ICLI, KPR and Trident with crude futures are less than – 0.50. This indicates that the textile stock prices in India are negatively correlated with crude oil futures prices. Hence the cross hedge for the Indian textile industry with crude oil futures is feasible.

LITERATURE REVIEW

Price forecasts and cross hedging of equity with the help of commodity futures and vice versa have become the subject of interest today with many academicians and practitioners [15–18]. Crude oil or other energy futures are actively traded derivatives in several economies and cross hedges with these instruments are widely examined by many researchers. However, a future derivative with an active market and a great volume will be the right tool to hedge the risk in the portfolio. A study by Singh & Sharma [19] states that for variables crude oil and Sensex, the long-run equilibrium relationship is evident during and pre-crisis phase [20]. Batten et al. [21, 22] stated that the areas of stock and energy sector integrations are critical to managing the risk. Olson et al. [23] studied that the oil and gas equity index was the most effective cross hedge for energy stocks. The integration of oil market and equity markets in many economies is studied by many researchers, for example [22, 24–30].

Many practitioners and academicians have used econometric models to forecast stock and other asset prices. Meher et al. [1] have used a mixed ARIMA methodology to forecast the stock prices of pharmaceutical companies in India. To forecast the natural rubber demand Khin et al. [31] have used a vector error correction model. To compute the hedge ratio VAR coefficients are used by Gatarek and Johansen [32]. Kumar et al. [33] argued that the ARIMA model represents a very popular methodology in the case of financial and agricultural forecasting. Kumar [34] uses VAR to predict the foreign tourist arrival in India. To understand the impact of interest rates on funding costs Nkcubeko Nomsobo and Wyk [35], and Citak [36] have used VAR models [37]. The above-cited studies show that the performance of the manufacturing industries is affected by the volatile crude price and many studies have shown the relationship between crude price and equity market movements. Couples of studies have examined the possibility of the cross hedge with crude for equities. However, the study on forecast models or hedging strategies for Indian textile equities is not covered so far in the academic literature.

DATA AND METHODOLOGY

In this empirical study, the daily closing prices of selected textile equities and nearby crude futures (that is crude futures whose expiry is very close to the present date), are used. Based on market capitalisation and the textile stocks for which trading data are available since 2010 in NSE, India websites are selected as sample stocks. For the same period, the nearby expiring crude futures prices are gathered from the official website of Multi commodity exchange (MCX), India. The selected companies are Alok industries (AI), Arvind textile (AT), GAR Fibers (GF), Himatseide (HIM), PR mill (KPR), Page Industries (PI), Raymond (RAY), Trident (TRI), Welspun India (WI) and ICLI.

The linear regression model was applied in the pioneer works of time-series predictions. When the multiple independent variables data were available, the multiple regression models were used to forecast the value of the dependent variable. In the vector autoregressive model, all the variables in the system are treated as endogenous variables. The value of each endogenous variable is the function of its own lagged values and past values of all other endogenous variables in the VAR system. As Brooks [38] and Gujarati et al. [39] have suggested, this study has used Augmented Dickey-Fuller (ADF) test to check the stationarity of a time series.

The following equation shows the general form of the bivariate VAR model.

$$TE_t = \beta_{TE0} + \beta_{TE1} TE_{t-1} + \ldots + \beta_{TEk} TE_{t-k} + \\ + \alpha_{TEk} CF_{t-1} + \ldots + \alpha_{TEk} CF_{t-k} + u_{TEt} \quad (1)$$

$$CF_t = \beta_{CF0} + \beta_{CF1} CF_{t-1} + \ldots + \beta_{CFk} CF_{t-k} + \\ + \alpha_{CFk} TX_{t-1} + \ldots + \alpha_{TEk} NR_{t-k} + u_{CFt} \quad (2)$$

Where TE in equation 1 is the textile equity price, which is dependent on its past values, past values of crude futures price (CF) and u_{TEt} is the white noise error term. Similarly, the CF in equation 2 is crude oil future price, which is the function of its past values and past values of textile equity price (TE) and u_{CFt} is the white noise error term. t in the above two equations is the time index. This study accommodates the above-stated eleven endogenous variables in the model, they are 10 selected Indian textile equities and crude futures price series (table 1).

Table 1

DESCRIPTIVE STATISTICS							
Panel b: Tyre stock and crude oil future prices							
Indian textile equities	**Mean**	**Maximum**	**Minimum**	**Std. Dev.**	**Skewness**	**Kurtosis**	**Jarque-Bera**
Alok Industries	10.66	55.75	1.45	8.78	1.31	4.51	869.68
Arvind	79.39	178.90	15.35	47.78	0.27	1.59	215.03
Crude Futures	4101.68	7201.00	1289.00	1087.39	0.31	2.43	67.63
Gar Fibers	546.70	2250.35	37.70	552.38	0.99	3.18	377.59
Himatseide	147.10	418.40	23.05	114.96	0.67	2.05	255.20
KPR Mill	361.30	924.15	38.60	266.33	0.14	1.49	224.26
Page Industries	12599.68	36005.95	1212.50	8524.70	0.30	2.06	117.12
Raymond	500.16	1132.40	182.70	213.26	0.98	3.00	364.62
Trident	4.19	10.69	0.74	2.72	0.29	1.78	171.38
Welspun India	42.33	117.50	2.25	32.02	0.17	1.71	169.58
ICLI	71.50	243.46	1.18	69.62	0.63	1.98	248.21
Panel B: Textile stock and crude oil future returns							
Alok Industries	0.00	1.58	–0.24	0.05	13.83	434.49	17690006.00
Arvind	0.00	0.18	–0.18	0.03	0.24	7.55	1983.41
Crude Futures	0.00	0.20	–0.33	0.02	–0.65	25.22	46890.56
Gar Fibers	0.00	0.16	–0.18	0.03	0.65	9.20	3790.53
Himatseide	0.00	0.21	–0.30	0.03	0.44	11.41	6767.19
KPR Mill	0.00	0.42	–0.20	0.04	0.97	10.68	5928.46
Page Industries	0.00	0.13	–0.20	0.03	0.13	8.05	2419.97
Raymond	0.00	0.18	–0.11	0.02	0.52	8.00	2470.85
Trident	0.00	0.18	–0.21	0.03	–0.16	8.75	3134.98
Welspun India	0.00	0.28	–0.15	0.03	0.97	9.51	4370.08
ICLI	0.00	0.18	–0.23	0.03	–0.25	9.03	3466.73

Using the V-look up the function of MS excel the missing values are adjusted and 2272 price observations from 1st September 2010 to 31st December 2020 are obtained. The logged returns of crude futures prices and select textile equity prices are computed using the log function $r_{ji,t} = \ln\left(\frac{P_{ij,t}}{P_{ij,t-1}}\right)$, where $P_{ij,t}$ and $P_{ij,t-1}$ are the closing prices of crude futures and textile equity returns for day's *t* and *t-,* respectively.

ANALYSIS AND DISCUSSIONS

Descriptive statistics for the prices and logged returns of crude futures and textile equity are shown in table 1. The mean daily returns of crude futures and spot textile equities are zero, but the corresponding standard deviations of the daily returns are much higher. The presence of fat tails is evident from the very high kurtosis for all the return series. The negative skewness statistics for Crude futures, Trident and ICLI indicate extreme losses (longer left tail). The right tail or the gain is evident from the positive skewness statistics in Alok Industries, Arvind textile, GAR fibres, Himatseide, KPR mill, Page industries, Raymond and Welspun India return series. The Jarque-Bera statistics of all the return series signify that the series is not normally distributed.

Table 2 shows the Augmented Dickey-Fuller test statistics for the unit root test. The p-values in panela of table 2 are not significant at a 95% confidence level. Hence the textile equity and crude futures price series are not stationary in their level form. In panel b of table 2, the p-value is less than 0.05 and the test critical values at 1%, 5% and 10% are greater than t-statistic values. Hence all selected textile equity price series and crude futures price series are stationary after first-order difference or these series are *I*(1). In this empirical study, EViews 10 package is used, VAR model was estimated by taking a default lag length of 2. Lag length criteria is a post estimation special function available in EViews to identify the optimal lag length using information criteria values. Popular information criteria values presented in many time series works are Akaike information criteria (AIC), Schwarz criteria (SC) and Hanna Quinn (HQ), these values are shown in table 3. In table 3, the optimal lag identified by the model is 2. The AIC and HQ criteria statistics are minimum in lag 2, hence lag length 2 is considered an optimal lag to estimate the VAR model.

Table 2

AUGMENTED DICKEY-FULLER TEST FOR UNIT ROOT					
Panel a: Textile stock and crude oil future prices					
Prices	**t - Statistic**	**Test critical Values**			***p*-value**
		1% level	**5% level**	**10% level**	
Alok Industries	–2.218899	–3.433036	–2.862613	–2.56739	0.1997
Arvind	–1.425063	–3.433033	–2.862612	–2.56739	0.5714
Crude Futures	–1.851389	–3.433033	–2.862612	–2.56739	0.3558
Gar Fibers	1.737824	–3.433033	–2.862612	–2.56739	0.9997
Himatseide	–1.221266	–3.433033	–2.862612	–2.56739	0.6674
KPR Mill	–0.204059	–3.433033	–2.862612	–2.56739	0.9355
Page Industries	–0.703031	–3.433033	–2.862612	–2.56739	0.8441
Raymond	–1.487999	–3.433033	–2.862612	–2.56739	0.5398
Trident	–0.948192	–3.433035	–2.862612	–2.56739	0.7731
Welspun India	–1.49303	–3.433035	–2.862612	–2.56739	0.5372
ICLI	–1.054705	–3.433033	–2.862612	–2.56739	0.7354
Panel b: Textile stock and crude oil futures returns					
Alok Industries	–41.9026	–3.433035	–2.862612	–2.56739	0.0001
Arvind	–46.27492	–3.433035	–2.862612	–2.56739	0.0001
Crude Futures	–46.82717	–3.433035	–2.862612	–2.56739	0.0001
Gar Fibers	–49.21685	–3.433037	–2.862613	–2.56739	0.0001
Himatseide	–46.20995	–3.433035	–2.862612	–2.56739	0.0001
KPR Mill	–45.89185	–3.433035	–2.862612	–2.56739	0.0001
Page Industries	–44.73537	–3.433035	–2.862612	–2.56739	0.0001
Raymond	–44.60491	–3.433035	–2.862612	–2.56739	0.0001
Trident	–43.67916	–3.433035	–2.862612	–2.56739	0.0001
Welspun India	–29.48399	–3.433036	–2.862613	–2.56739	0.0001
ICLI	–46.94806	–3.433035	–2.862612	–2.56739	0.0001

Source: Authors computations using textile equity and crude futures price series.

Table 3

VAR LAG ORDER SELECTION CRITERIA			
Lag	**AIC**	**SC**	**HQ**
0	–47.10051	–47.07260*	–46.98997
1	–47.11223	–46.7772	–46.98997
2	–47.11297*	–46.4709	–47.09033*
3	–47.10019	–46.151	–46.75377
4	–47.09085	–45.8346	–46.63236

Source: Authors computations using textile equity and crude futures price series.

The VAR estimate coefficients with standard error and t-statistics are shown in table 4. A total of 253 coefficients are estimated and a total of 42 coefficients are statistically significant with a 95% confidence level. All the significant coefficients are shown in bold letters in table 4. In each cell there are three values given, they are coefficient, standard error and t-statistic. The coefficient statistics for the first lag of crude future is statistically significant for Arvind mills stock price with a p-value of 0.032. The current crude future price will give more influence on the textile equity price after 2 days. Out of 10 selected textile companies, 6 companies' stock prices follow the n–2 price of crude futures and hence, 6 coefficient statistics are statistically significant with the second lag of crude futures. The p-values of such significant coefficients are 0.0004 for Arvind Mills, 0.0221 for GAR Fibers, 0.0186 for Himatseide, 0.0027 for Page Industries, 0.0004 for Raymond and 0.0026 for Welspun. In addition to crude futures, the competitor's stock price is also a major determinant of textile stock prices in the Indian market. Arvind mills, Gar Fibers, Himatseide, ICLI, KPR Mill, Trident and Welspun India companies' stock prices are influencing the prices of other textile companies. Among the above-stated price determinants for Indian textile stocks, crude futures and Welspun India are influencing the stock price of many textile stocks.

The equation given by the VAR system to forecast the selected textile stock prices are given in the following equations. Here only significant coefficients are taken into consideration.

$$AI = C(1) \times AI(-1) + C(10) \times HIM(-2) + C(22) \times WI(-2) \quad (3)$$

$$AT = C(28) \times CF(-1) + C(29) \times CF(-2) + WI(-2) \quad (4)$$

Table 4

VAR (2) REGRESSION ESTIMATIONS

Variable	AI	AM	CF	GF	HIM	ICLI	KPR	PI	RAY	TRI	WI
	0.10	–0.01	0.00	0.02	0.00	0.00	0.01	0.00	0.02	0.00	0.00
AI (–1)	–0.02	–0.01	–0.01	–0.01	–0.01	–0.02	–0.01	–0.01	–0.01	–0.01	–0.01
	[4.62]	[–0.87]	[–0.27]	[2.15]	[0.05]	[0.16]	[0.80]	[–0.34]	[1.44]	[0.31]	[0.11]
	0.03	0.00	0.01	0.01	0.00	0.00	0.00	–0.01	–0.01	0.00	–0.01
AI (–2)	–0.02	–0.01	–0.01	–0.01	–0.01	–0.02	–0.01	–0.01	–0.01	–0.01	–0.01
	[1.54]	[0.05]	[1.19]	[0.76]	[0.01]	[0.17]	[–0.00]	[–1.18]	[–0.67]	[–0.16]	[–0.70]
	0.02	0.02	–0.01	0.06	0.09	0.01	0.04	–0.01	0.00	0.14	0.05
AM (–1)	–0.04	–0.03	–0.02	–0.02	–0.03	–0.03	–0.02	–0.02	–0.02	–0.03	–0.03
	[0.51]	[0.64]	[–0.60]	[2.81]	[3.46]	[0.30]	[2.07]	[–0.28]	[0.18]	[5.01]	[1.93]
	–0.01	0.00	–0.01	0.01	0.05	0.05	0.03	–0.01	0.07	0.10	0.01
AM (–2)	–0.04	–0.03	–0.02	–0.02	–0.03	–0.03	–0.02	–0.02	–0.02	–0.03	–0.03
	[–0.18]	[0.18]	[–0.48]	[0.67]	[1.97]	[1.38]	[1.51]	[–0.52]	[3.03]	[3.57]	[0.53]
	0.02	0.06	0.02	0.00	–0.04	0.05	0.02	0.01	0.01	–0.02	–0.03
CF (–1)	–0.04	–0.03	–0.02	–0.02	–0.03	–0.04	–0.02	–0.02	–0.02	–0.03	–0.03
	[0.50]	[2.23]	[0.80]	[0.17]	[–1.55]	[1.38]	[0.73]	[0.49]	[0.50]	[–0.66]	[–1.26]
	0.07	0.09	0.05	0.05	0.06	–0.01	0.02	0.06	0.08	0.03	0.08
CF (–2)	–0.04	–0.03	–0.02	–0.02	–0.03	–0.04	–0.02	–0.02	–0.02	–0.03	–0.03
	[1.53]	[3.51]	[2.15]	[2.28]	[2.35]	[–0.16]	[1.05]	[3.00]	[3.54]	[0.94]	[3.01]
	0.05	–0.03	–0.01	–0.07	–0.01	–0.04	–0.02	0.01	0.00	–0.02	0.01
GF (–1)	–0.04	–0.03	–0.02	–0.02	–0.03	–0.04	–0.02	–0.02	–0.02	–0.03	–0.03
	[1.21]	[–0.98]	[–0.49]	[–3.07]	[–0.51]	[–1.08]	[–0.93]	[0.53]	[0.02]	[–0.70]	[0.37]
	0.01	0.04	–0.03	0.00	0.01	0.09	0.09	–0.05	0.02	0.07	0.07
GF (–2)	–0.04	–0.03	–0.02	–0.02	–0.03	–0.04	–0.02	–0.02	–0.02	–0.03	–0.03
	[0.16]	[1.42]	[–1.20]	[–0.06]	[0.32]	[2.29]	[3.70]	[–2.45]	[0.65]	[2.22]	[2.48]
	–0.03	0.00	–0.01	0.03	–0.01	0.03	0.04	0.02	0.04	–0.02	0.01
HIM (–1)	–0.04	–0.02	–0.02	–0.02	–0.02	–0.03	–0.02	–0.02	–0.02	–0.03	–0.02
	[–0.84]	[–0.19]	[–0.59]	[1.51]	[–0.36]	[0.99]	[1.75]	[1.14]	[1.81]	[–0.83]	[0.30]
	0.10	0.00	0.03	0.05	0.00	0.05	0.00	–0.01	0.00	0.03	0.02
HIM (–2)	–0.04	–0.02	–0.02	–0.02	–0.02	–0.03	–0.02	–0.02	–0.02	–0.03	–0.02
	[2.55]	[–0.19]	[1.59]	[2.55]	[0.01]	[1.407]	[0.15]	[–0.37]	[0.22]	[1.29]	[0.83]
	0.00	0.01	0.01	–0.02	0.01	–0.03	–0.01	0.01	0.00	0.00	0.01
ICLI (–1)	–0.03	–0.02	–0.01	–0.01	–0.02	–0.02	–0.01	–0.01	–0.01	–0.02	–0.02
	[0.11]	[0.87]	[0.57]	[–1.77]	[0.31]	[–1.47]	[–0.63]	[0.67]	[–0.29]	[0.09]	[0.48]
	–0.04	–0.02	0.02	–0.01	–0.01	–0.03	–0.02	0.00	–0.03	–0.04	0.01
ICLI (–2)	–0.03	–0.02	–0.01	–0.01	–0.02	–0.02	–0.01	–0.01	–0.01	–0.02	–0.02
	[–1.44]	[–1.35]	[1.78]	[–0.54]	[–0.70]	[–1.41]	[–1.59]	[0.18]	[–2.14]	[–1.99]	[0.59]
	0.03	0.03	0.02	–0.03	–0.03	0.05	–0.03	0.02	0.01	0.04	0.06
KPR(–1)	–0.04	–0.03	–0.02	–0.02	–0.03	–0.04	–0.02	–0.02	–0.02	–0.03	–0.03
	[0.62]	[1.17]	[1.09]	[–1.24]	[–0.99]	[1.21]	[–1.11]	[0.99]	[0.58]	[1.33]	[1.99]
	–0.02	0.00	–0.04	0.01	0.00	0.02	–0.06	0.04	–0.04	–0.04	–0.02
KPR(–2)	–0.04	–0.03	–0.02	–0.02	–0.03	–0.04	–0.02	–0.02	–0.02	–0.03	–0.03
	[–0.54]	[–0.00]	[–1.68]	[0.57]	[–0.12]	[0.53]	[–2.66]	[1.82]	[–1.67]	[–1.18]	[–0.86]
	–0.06	0.03	–0.02	0.02	0.02	–0.01	–0.02	0.06	–0.01	0.00	–0.01
PI (–1)	–0.05	–0.03	–0.02	–0.03	–0.03	–0.04	–0.03	–0.02	–0.03	–0.03	–0.03
	[–1.30]	[0.96]	[–0.94]	[0.80]	[0.53]	[–0.34]	[–0.76]	[2.63]	[–0.42]	[–0.11]	[–0.38]
	–0.02	–0.01	0.01	–0.02	–0.04	0.00	–0.03	0.00	–0.02	0.01	–0.04
PI (–2)	–0.05	–0.03	–0.02	–0.03	–0.03	–0.04	–0.03	–0.02	–0.03	–0.03	–0.03
	[–0.40]	[–0.27]	[0.44]	[–0.95]	[–1.13]	[–0.03]	[–1.04]	[0.00]	[–0.90]	[0.25]	[–1.36]

Table 4 (*continuation*)

VAR (2) REGRESSION ESTIMATIONS											
Variable	**AI**	**AM**	**CF**	**GF**	**HIM**	**ICLI**	**KPR**	**PI**	**RAY**	**TRI**	**WI**
RAY (–1)	0.06	–0.04	0.02	–0.03	–0.03	0.00	0.04	0.00	0.02	–0.06	–0.06
	–0.05	–0.03	–0.02	–0.02	–0.03	–0.04	–0.02	–0.02	–0.03	–0.03	–0.03
	[1.32]	[–1.39]	[0.75]	[–1.12]	[–0.97]	[0.09]	[1.78]	[0.01]	[0.78]	[–1.92]	[–1.93]
RAY(–2)	–0.02	0.02	–0.01	0.01	0.02	–0.07	0.04	0.04	0.01	0.01	0.00
	–0.05	–0.03	–0.02	–0.02	–0.03	–0.04	–0.02	–0.02	–0.03	–0.03	–0.03
	[–0.38]	[0.59]	[–0.32]	[0.61]	[0.68]	[–1.72]	[1.49]	[1.80]	[0.54]	[0.22]	[–0.02]
TRI (–1)	0.05	0.03	0.01	0.03	0.05	0.09	0.04	0.01	0.03	0.06	0.03
	–0.04	–0.02	–0.02	–0.02	–0.02	–0.03	–0.02	–0.02	–0.02	–0.02	–0.02
	[1.30]	[1.25]	[0.69]	[1.54]	[1.95]	[2.86]	[1.81]	[0.42]	[1.43]	[2.57]	[1.30]
TRI (–2)	0.00	0.01	–0.01	–0.03	0.00	0.03	0.00	0.01	0.00	–0.10	0.00
	–0.04	–0.02	–0.02	–0.02	–0.02	–0.03	–0.02	–0.02	–0.02	–0.02	–0.02
	[–0.07]	[0.47]	[–0.51]	[–1.51]	[0.00]	[1.00]	[–0.15]	[0.40]	[0.01]	[–3.90]	[0.16]
WI (–1)	0.01	0.01	0.01	0.02	0.01	0.06	0.02	–0.04	0.02	–0.02	0.08
	–0.04	–0.02	–0.02	–0.02	–0.02	–0.03	–0.02	–0.02	–0.02	–0.02	–0.02
	[0.40]	[0.56]	[0.44]	[1.04]	[0.49]	[1.77]	[0.80]	[–2.19]	[0.80]	[–0.76]	[3.62]
WI (–2)	0.11	0.06	0.05	0.03	0.04	0.01	0.05	0.03	0.05	0.01	0.05
	–0.04	–0.02	–0.02	–0.02	–0.02	–0.03	–0.02	–0.02	–0.02	–0.02	–0.02
	[2.88]	[2.67]	[2.55]	[1.62]	[1.96]	[0.28]	[2.57]	[1.67]	[2.48]	[0.46]	[2.13]
C	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	[–0.03]	[0.43]	[–0.05]	[2.85]	[0.67]	[1.47]	[1.78]	[2.71]	[–0.18]	[0.89]	[1.04]

$$GF = C(70) \times AI(-1) + C(72) \times AT(-1) + C(75) \times CF(-2) + C(76) \times GF(-1) + C(79) \times HIM(-2) + C(92) \quad (5)$$

$$HIM = C(95) \times AT(-1) + C(96) \times AT(-2) + C(98) \times CF(-2) + C(114) \times WI(-2) \quad (6)$$

$$ICLI = C(123) \times GF(-2) + C(134) \times TRI(-1) \quad (7)$$

$$KPR = C(141) \times AT(-1) + C(146) \times GF(-2) + C(152) \times KPR(-2) + C(160) \times WI(-2) \quad (8)$$

$$PI = C(167) \times CF(-2) + C(169) \times GF(-1) + C(176) \times PI(-1) + C(184) \quad (9)$$

$$RAY = C(188) \times AT(-2) + C(190) \times CF(-2) + C(196) \times ICLI(-2) + C(206) \times WI(-2) \quad (10)$$

$$TRI = C(210) \times AT(-1) + C(211) \times AT(-2) + C(215) \times GF(-2) + C(219) \times ICLI(-2) + C(226) \times TRI(-1) + C(227) \times TRI(-2) \quad (11)$$

$$WI = C(236) \times CF(-2) + C(238) \times GF(-2) + C(234) \times KM(-1) + C(251) \times WI(-1) + C(252) \times WI(-2) \quad (12)$$

R-squared and adjusted R-squared in table 5 show the goodness-of-fit. Durbin-Watson statistic is used to test whether the residual series of the estimated VAR model are serially correlated; test values are very close to 2. This indicates that the residuals in the series are free from autocorrelation. Hence the estimated VAR are a good fit and these models can be used to forecast the short-run prices of textile stocks in India.

Table 5

FITNESS SUMMARIES FOR ESTIMATED VAR EQUATIONS			
VAR estimation for	**Durbin-Watson Stat**	**R-squared**	**Adjusted R-squared**
ALOK INDUSTRIES	1.9890	0.0348	0.0253
ARVIND	1.9899	0.0202	0.0105
GAR FIBERS	1.9864	0.0261	0.0166
HIMATSEIDE	1.9966	0.0214	0.0118
KPR MILL	2.0028	0.0355	0.0261
PAGE INDUSTRIES	1.9963	0.0195	0.0099
RAYMOND	1.9929	0.0309	0.0214
TRIDENT	1.9957	0.0379	0.0285
WELSPUN INDIA	1.9817	0.0361	0.0266
ICLI	1.9974	0.0236	0.0140

Source: Authors computations using textile equity and crude futures price series.

Table 6

PEARSON CORRELATION COEFFICIENTS AND GRANGER CAUSALITY TEST STATISTICS			
Textile company name	Correlation coefficients with crude future		Granger causality test (p-values)
	With price series	With return series	
Alok Industries	0.083	0.096	0.1679
Arvind	–0.315	0.047	0.0001
Gar Fibers	–0.430	0.036	0.0321
Himatseide	–0.420	0.042	0.0111
ICLI	–0.688	0.032	0.3133
KPR Mill	–0.553	–0.008	0.1797
Page Industries	–0.389	0.052	0.0099
Raymond	–0.162	0.050	0.0012
Trident	–0.552	0.015	0.222
Welspun India	–0.651	0.063	0.0027

Source: Authors computations using textile equity and crude futures price series.

The second objective of this empirical study is to examine the feasibility of cross hedge for Indian textile equities using crude futures. Even today the Pearson correlation is widely used to examine the hedging and cross hedge possibility. In this study, Pearson correlation and Granger causality test statistics are shown to analyse the feasibility of cross hedge. Table 6 shows the Pearson correlation for price and return series of textile stocks with crude future prices; all selected companies' prices except Alok Industries are negatively correlated with crude futures prices. Among 10 selected companies, 4 companies show a negative correlation of less than 0.50. The p-values for the Granger causality test are shown in the last column of table6. The null hypothesis is that the crude futures do not Granger cause selected textile companies. Six out of 10 selected companies show a p-value less than 0.05, indicating that the crude futures price in India is influencing the textile stock prices. As the textile stock prices are negatively correlated with crude futures and crude futures prices cause textile prices, hedging the price risk of Indian textile stocks is possible with crude futures.

CONCLUSIONS

The volatile equity market will adversely affect the investor's portfolio. The volatile crude oil price has adversely affected the performance and market capitalisation of textile companies in India. This empirical study aimed to develop two price risk management tools for textile stocks in India. VAR methodology is used to develop the daily price prediction model for textile stocks in India. VAR (2) multivariate model indicates that the crude oil futures and competitive firms' stock prices will influence the price of textile stocks in India. 6 companies out of 10 have significant coefficients with crude futures in the VAR 2 model. Further 5 selected companies out of 10 have shown significant coefficients in the VAR model with Welspun India Company's stock piece. The Pearson correlation coefficients and the p-values of Granger causality tests proved that the crude oil futures prices and textile stock prices are negatively correlated. One can take the short position in crude futures to minimize the textile stock portfolio risks. Investors and traders in textile stocks can use this VAR model to forecast the daily price and manage the price risk. Further using multivariate econometric models one can find the optimal hedge ratios for these cross hedges.

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Descriptive statistics for plane structures of the multilayer matrix for tissue haemostasis and regeneration

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ABSTRACT – REZUMAT

Descriptive statistics for plane structures of the multilayer matrix for tissue haemostasis and regeneration

Bleeding, severe and infected wounds need to be cared for to facilitate recovery and prevent infection. The specific requirements imposed on dressings for the treatment of these wounds depend fundamentally on the type of lesion; moreover, they are based on the creation of an optimal environment that allows epithelial cells to move easily to facilitate regeneration. The objective of the research is to provide a multilayer medical device with composite characteristics, usable for basic medical interventions on superficial burns with thermal origin (flame and melts) occurred on anatomical regions protected by clothes (so except face and eyes). The outer, second and interfacing layers have specific characteristics. Regarding this aspect, 5 variants of woven textile structures were designed and made that differed in the nature of the raw material, the density of the length/fineness of the threads in the weft, the density in the weft and the binding. To characterize the populations of flat structures used to make the first layer of the matrix, methods specific to descriptive statistics were used. The following fundamental statistical indicators were calculated for each of the 3 variables considered defining (mass, thickness and absorption capacity): mean, dispersion and standard deviation; median and quartiles; eccentricity (skewness) and vaulting (kurtosis) for asymmetry and highlighting the cases in which interventions should be performed (on the technological flow or on the programming scheme). The results obtained by the statistical analysis of the groups of results allowed the findings to be generalized to larger populations, so for the whole set from which the respective sample was extracted. Depending on location and the severity of wounds resulting from shooting, explosions or fire (wounds that result in bleeding, impaired vital functions, the impotence of an anatomical segment, celsiene signs, etc.), the first layer of the matrix can be made of woven textile materials. After correlating the physico-mechanical characteristics of the textile structures with the subsequent processes (realization of layer II, layer III and functionalization), the technical and physico-mechanical characteristics of the multilayer matrix will be determined, and the location areas and the field of use (for haemostasis, regeneration of connective tissues or their simultaneous combination) will be established.

Keywords: *dressings, descriptive statistics, textile structures, haemostasis, tissue regeneration*

Statistica descriptivă pentru structurile plane ale matricei multistrat pentru haemostaza și regenerarea țesuturilor

Sângerarea, rănile severe și infectate trebuie îngrijite pentru a facilita recuperarea și a preveni infecția. Cerințele specifice impuse pansamentelor pentru tratarea acestor răni depind fundamental de tipul leziunii; mai mult, ele se bazează pe crearea unui mediu optim care permite celulelor epiteliale să se deplaseze cu ușurință, pentru a facilita regenerarea. Obiectivul cercetării este de a oferi un dispozitiv medical multistrat cu caracteristici compozite, utilizabil pentru intervenții medicale de bază pentru arsuri superficiale de origine termică (flacără și topire), apărute pe regiuni anatomice protejate de îmbrăcăminte (deci cu excepția feței și a ochilor). Straturile exterior, de mijloc și de interfață au caracteristici specifice. În ceea ce privește acest aspect, au fost proiectate și realizate 5 variante de structuri textile ţesute, care se deosebesc prin natura materiei prime, finețea firelor în bătătură, desimea în bătătură și tipul legăturii. Pentru caracterizarea populaţiilor de structuri plane utilizate la realizarea primului strat al matricei s-au folosit metode specifice statisticii descriptive. Pentru fiecare dintre cele 3 variabile considerate definitorii (masă, grosime și capacitate de absorbție) au fost calculați următorii indicatori statistici fundamentali: media, dispersia și abaterea standard; mediana și cuartilele; excentricitatea (asimetria) și vaulting (kurtosis) pentru asimetrie și evidențierea cazurilor în care ar trebui efectuate intervenții (pe fluxul tehnologic sau pe schema de programare). Rezultatele obţinute prin analiza statistică a grupelor de rezultate au permis generalizarea constatărilor la populaţii mai mari, deci pentru întregul set din care a fost extrasă proba respectivă. În funcție de localizare și de severitatea rănilor rezultate din împușcare, explozii sau incendii (răni care au ca rezultat sângerarea, afectarea funcțiilor vitale, impotența unui segment anatomic, semne celsiene etc.), primul strat al matricei poate fi realizat din materiale textile țesute. După corelarea caracteristicilor fizico-mecanice ale structurilor textile cu procesele ulterioare (realizarea stratului II, stratului III și funcționalizarea), se vor determina caracteristicile tehnice și fizico-mecanice ale matricei multistrat și se vor stabili zonele de amplasare și domeniul de utilizare (pentru hemostază, regenerarea țesuturilor conjunctive sau combinarea lor simultană).

Cuvinte-cheie*: pansamente, statistică descriptivă, structuri textile, hemostază, regenerarea țesuturilor*

INTRODUCTION

Wounds are open traumas that entail a discontinuity of the skin or mucous membranes (a factor of continuity). An injury can occur in the event of an accident or after surgery. In general, bleeding, severe and infected wounds should be cared for to facilitate recovery and prevent infection [1].

The specific requirements imposed on dressings for the treatment of these wounds depend fundamentally on the type of lesion. For example, strong exudative lesions require dressings with a high absorption capacity that are capable of removing excess exudate. Another important parameter is the speed of water vapour transmission of membranes and films used as dressings [2]. High values of this parameter can cause excessive wound dehydration, while biomaterials with a low rate of water vapour transmission can cause maceration of the lesion due to excess fluid, causing pain and slowing recovery [1, 3]. The type of lesion and its phase influences the rate of water loss due to evaporation. Thus, healthy skin and minor lesions have a water vapour transmission rate of approximately 150–200 g/m^2 per day, while that of first-degree burns is in the range of 250–300 g/m^2 per day, and wounds with granulation tissue have values between 5000 and 5200 g/m^2 per day.

Furthermore, the dressing must be stable long enough to prevent premature changes, which sometimes disrupt the newly formed tissue and cause patient discomfort. Thus, knowledge of the degradation kinetics of the biopolymeric dressing is essential [5].

When selecting the biomaterial used in the treatment of wounds, factors such as healing time; care costs; frequency of dressing changes; and the need to use other products, such as secondary dressings, antibiotics and analgesics, etc., must also be considered [4, 6]. Sometimes it may be necessary to use more than one product, but in general, this approach should be avoided. Some dressings, such as antimicrobial dressings, may have a negative impact on cell function; therefore, they should be used for a limited time and only in specific cases.

The new generations of dressings are based on creating an optimal environment that allows epithelial cells to move easily for regeneration. Such optimal conditions include a humid environment around the wound, efficient circulation of oxygen to help cells and tissues regenerate, and low bacterial contamination. Other factors that contribute to the development of a wide range of dressings include different types of wounds (e.g., acute, chronic, exuding and dry lesions, etc.) and the fact that no dressing is suitable for treating all wounds. In addition, the wound healing process has several different phases, which cannot be addressed with a single type of dressing. A multilayer medical device with composite characteristics, usable for basic medical interventions on superficial burns with thermal origin (flame and melts) occurred on anatomical regions protected by clothes (so except face and eyes) was developed. The outer layer acts as a carrier, insulator and protector of underlying layers; the second layer has the purpose of managing the liquid composition in the lesion area; the interfacing layer with the lesion must be non-adherent, biologically inert and microporous. The selection of textile structures for layer I is presented. Regarding this aspect, 5 variants of woven textile structures were designed and developed that differentiated in the nature of the raw material, the length density, the fineness of the threads in the weft, the density in the weft and the binding.

MATERIAL AND METHODS

Fabric development

The fabric variants were made using the design parameters presented in table 1.

The yields obtained for weaving are similar to those of weavers that process cotton yarns and cotton-type yarns (85–90%).

These structures can be introduced in the manufacturing process because no special interventions are required for the adjustment, installation, or placement of special devices for braking or tensioning yarns. Related to this aspect, it was considered necessary to characterize the fabric variants in terms of physical and mechanical characteristics, because this allowed the identification of variants that could be used further to make the other layers of the matrix.

Characterization of statistical populations

To characterize the populations of plane structures used to make the first layer of the matrix, methods specific to descriptive statistics were used [7]. Thus, with the help of a specialized program, it was possible to rigorously describe the distributions resulting from the experiments performed in the accredited laboratories of INCDTP. Specifically, the following fundamental statistical indicators were calculated for each of the 3 defined variables (mass, thickness and absorption capacity): mean, dispersion and standard deviation; median and quartiles; eccentricity (skewness) and vaulting (kurtosis) for asymmetry and highlighting the cases in which interventions should be performed (on the technological flow or on the programming scheme). The values are shown in tables 2, 3 and 4.

Additionally, box-plot charts were made that highlight the indicators of level (average, median), dispersion and extreme cases. In figure 1, only the graphs of those variants of structures (for all 3 variables) that indicated the presence of extreme values are presented.

The variables “mass”, “thickness” and “absorption capacity” did not vary greatly in any of the 5 variants studied.

Values with:

– indicative 8 – value 178.5 g/m^2, for variant BZNT1, variable “mass”

Table 1

DESIGN PARAMETERS						
Coding of the woven textile support	**Fibrous composition**		**Fineness/Length density**		**D_b yarn/ 10 cm**	**Encrypted link (includes edge encryption, with platinum linking from left to right)**
	Warp	**Weft**	**Warp**	**Weft**		
BZNT1	100% bbc	80% bbc/ 20% fibres with ZnO	Nm50/2	Nm68/2	240	Atlas: -(2-6-8-9-11//2-4-9-11-12//1-4-5-7-12// 1-5-7-8-10//2-3-8-10-11//2-3-4-6-11// 1-4-6-7-9//1-7-9-10-12// 2-3-5-10-12//1-3-5-6-8//)-
BBT1	100% bbc	100% bamboo	Nm50/2	Nm34/1	250	Comb 1: -(2-3-7-11//2-4-10-12//1-3-5-9-11// 1-3-4-6-8-10-11-12//2-4-5-7-9-10-12// 1-3-5-9-11//1-4-10-12//)-
BLT1	100% bbc	100% lenpur	Nm50/2	Nm34/1	200	
BAT1	100% bbc	100% acetate	Nm50/2	130dtex	350	Comb 2: -(2-3-5-7-9-11//1-4-5-6-8-10-12//2-3-5-7//2-3-7//1-3-5-7//1-4-5-6-8-10-12// 2-3-57-9-11//1-3-5-7-9-10-11//1-8-10-12//2-8-12//2-8-10-12// 1-3-5-7-9-10-11//1-4-6-8-10-12//)-
BBT2	100% bbc	100% bbc	Nm50/2	Nm60/2	255	Plaid: -(2-3-4-5-6-7//1-3-4-5-6-7//2-3-5-7//2-3-4-5-6-7//1-3-4-5-6-7//1-8-9-10-11-12// 2-8-9-10-11-12//2-8-10-12//1-8-9-10-11-12//2-8-9-10-11-12//1-3-5-7-9-11// 1-4-6-8-10-12//2-3-5-7-9-11// 2-4-6-8-10-12//1-3-5-7-9-11//1-4-6-8-10-12//2-3-5-7-9-11//2-4-6-8-10-12// 1-3-5-7-9-11//1-4-6-8-10-12//)-

Table 2

STATISTICS OF BZNT1, BBT1 AND BLT1										
Statistical indicators		**Mass**			**Thickness**			**Absorption capacity**		
		BZNT1	**BBT1**	**BLT1**	**BZNT1**	**BBT1**	**BLT1**	**BZNT1**	**BBT1**	**BLT1**
Mean		176.330	169.130	166.860	0.5720	0.5380	0.5720	54.8190	120.2310	117.4900
Median		176.300	169.150	167.100	0.5700	0.5400	0.5700	54.8300	120.2000	117.6000
Std. deviation		0.9878	0.3368	0.5758	0.01033	0.01229	0.00789	0.13715	0.73398	0.58963
Variance		0.976	0.113	0.332	0.000	0.000	0.000	0.019	0.539	0.348
Skewness		0.601	0.723	–1.104	0.272	–0.431	–0.407	-0.487	0.726	0.140
Std. error of skewness		0.687	0.687	0.687	0.687	0.687	0.687	0.687	0.687	0.687
Kurtosis		1.566	0.384	0.475	–0.896	–1.461	–1.074	0.384	–0.406	0.203
Std. error of kurtosis		1.334	1.334	1.334	1.334	1.334	1.334	1.334	1.334	1.334
Minimum		174.8	168.7	165.7	0.56	0.52	0.56	54.55	119.33	116.60
Maximum		178.4	169.8	167.5	0.59	0.55	0.58	55.00	121.50	118.60
Percentiles	25	175.725	168.800	166.475	0.5600	0.5275	0.5675	54.7450	119.6400	116.8750
	50	176.300	169.150	167.100	0.5700	0.5400	0.5700	54.8300	120.2000	117.6000
	75	176.850	169.275	167.250	0.5800	0.5500	0.5800	54.9250	120.6750	117.8000

– indicative 4 – value 169.8 g/m^2, for the BBT1 variant, the “mass” variable

are located at a distance of 1.5–3 box lengths and should not be excluded from the series of determinations.

Interpretation of the statistical data:

1. The variables “mass” and “absorption capacity” for variants BBT1, BLT1, RVN1, as well as “thickness” variants BLT1, RVN1, BAT1 has a distribution of 50% of the values directed to the right; in addition, the median being directed to the upper edge of box, so high values are predominant. For the variables

Table 3

STATISTICS OF BAT1 AND BLT1 AND BBT2							
Statistical indicators		**Mass**		**Thickness**		**Absorption capacity**	
		BLT1	**BBT2**	**BLT1**	**BBT2**	**BLT1**	**BBT2**
Mean		136.130	184.132	0.4510	0.7110	109.6600	121.9880
Median		136.250	184.050	0.4500	0.7100	109.7500	121.8500
Std. deviation		0.5376	0.5618	0.00738	0.00816	0.56608	0.33960
Variance		0.289	0.316	0.000	0.000	0.320	0.115
Skewness		–0.716	0.616	–0.166	0.000	–0.436	0.631
Std. error of skewness		0.687	0.687	0.687	0.687	0.687	0.687
Kurtosis		–0.140	–0.943	–0.734	–1.393	–0.541	–1.287
Std. error of kurtosis		1.334	1.334	1.334	1.334	1.334	1.334
Minimum		135.1	183.5	0.44	0.70	108.70	121.60
Maximum		136.7	185.0	0.46	0.72	110.50	122.50
Percentiles	25	135.800	183.650	0.4475	0.7000	109.2000	121.7575
	50	136.250	184.050	0.4500	0.7100	109.7500	121.8500
	75	136.700	184.700	0.4600	0.7200	110.1000	122.4125

“mass” and “absorption capacity” in the case of the BBT2 variant, the median is directed towards the lower edge of the box, so it can be stated that the distribution is directed to the left and the small values are predominant.

2. Distribution form indicators for woven textile variants, respectively:

Variant BZNT1

a) 50% of the values obtained for the mass are below 176.3 g/m^2, 25% being in the range [176.3; 176.8] and 25% are over 176.8 g/m^2.
b) 25% of the values obtained at thickness are below the value of 0.56 mm and 25% are above the value of 0.58 mm, 50% of the values being included in this interval defined by the minimum and maximum value.
c) 25% of the values of absorption capacity are below 54.7%, 50% are in the range [54.7; 54.9] and 25% are over 54.9%.
d) The skewness indicators have the values of 0.601 for mass and 0.272 for thickness, which highlights the extent to which the average moves away from the median; implicitly, the normal distribution curves moved away from the middle, moving to the right. In the case of the variable “absorption capacity”, the curve moved to the left, and the skewness value was negative.
e) Kurtosis indicators have positive values, 1,566 for mass and 0.384 for absorption capacity. The curve is leptokurtic and has a negative value for the variable thickness (–0.896), the curve is platykurtic.

Variant BBT1

a) 25% of the values obtained for the mass are below the value of 168.8 g/m^2, 25% being in the range [168.8; 169.1], and 25% are in the range [169.1; 169.3] and 25% are over 169.3 g/m^2.
b) 50% of the values obtained in thickness are in the range [0.528; 0.55], 25% being below the determined minimum value and 25% being above the determined maximum value.
c) 25% of the values of the absorption capacity are below 119.6%, 50% are in the range [119.6; 120.7] and 25% are over 120.7%.
d) The skewness indicators have positive values for mass and absorption capacity, and the curves move to the right and have negative values for thickness, so the curve moves to the left.
e) The kurtosis indicators have a positive value of 0.384 for the mass, so the curve is leptokurtic (small scattering of values) and respectively has negative values for the variables thickness (–1,461) and absorption capacity (–0,406); therefore, the curves is platykurtic.

Variant BLT1

a) 50% of the values obtained for the mass are in the range [166.48; 167.25], 25% being below the minimum value and 25% being above the determined maximum value.
b) 50% of the values obtained at thickness are below the value of 0.57 mm, 25% are above the value of 0.58 mm, and 25% are located in the range [0.57; 0.58].
c) 25% of the absorption capacity values are below 116.87%, 50% are in the range [116.87; 117.8] and 25% are above the upper limit of the range.
d) The skewness indicators have positive values for the variable absorption capacity, the curve moving to the right. For the other two variables the values are negative, –1.104 for mass and –0.407 for thickness, the curves moving to the left.
e) The kurtosis indicators have positive values of 0.475 for mass and 0.203 for absorption capacity, the curve is leptokurtic, and the variable thickness is negative (–1.074), the curve is platykurtic (large spread of values).

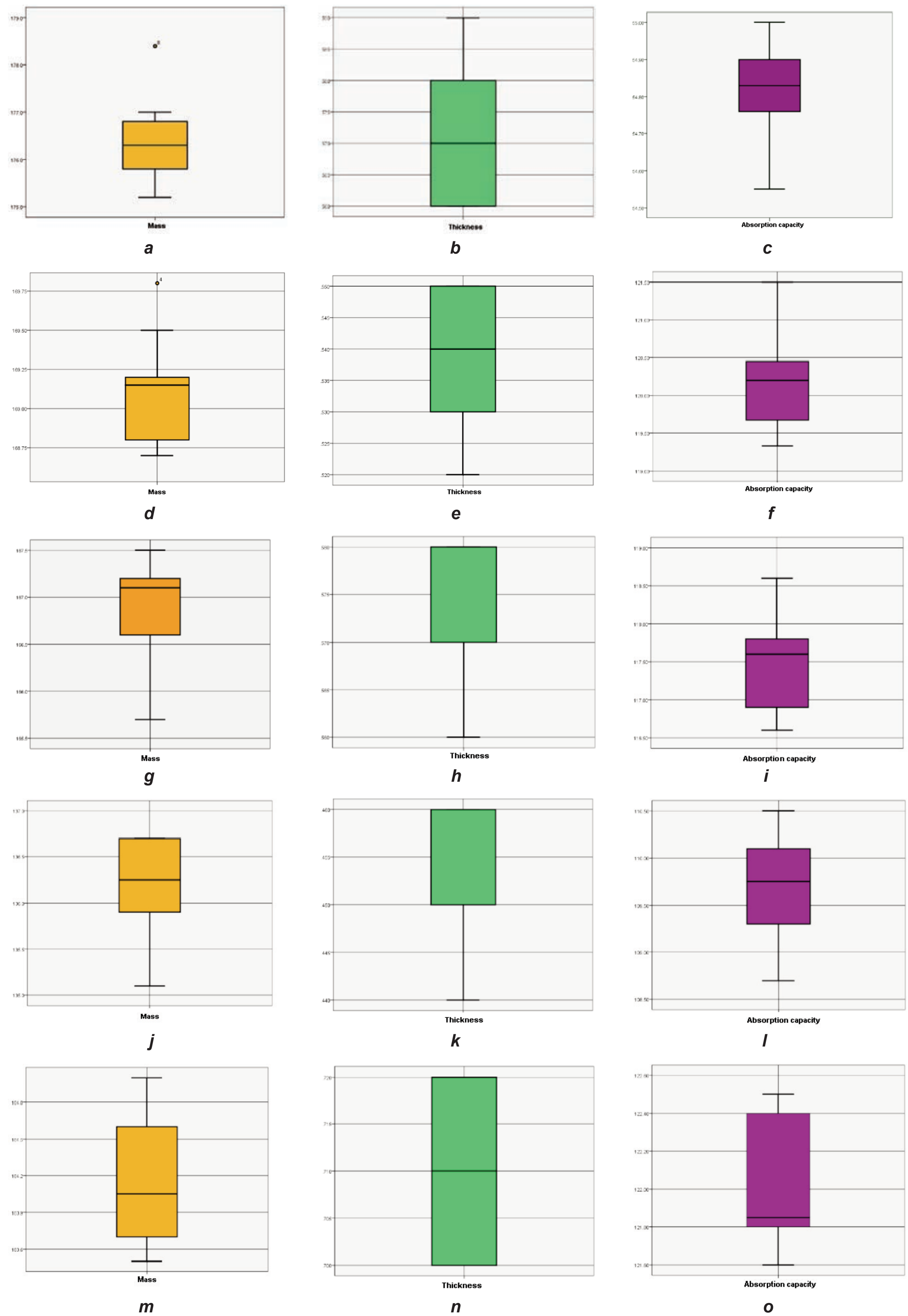

Fig. 1. Boxplot charts for: *a* – BZNT1 mass; *b* – BZNT1 thickness; *c* – BZNT1 absorption capacity; *d* – BBT1 mass; *e* – BBT1 thickness; *f* – BBT1 absorption capacity; *g* – BLT1 mass; *h* – BLT1 thickness; *i* – BLT1 absorption capacity; *j* – BAT1 mass; *k* – BAT1 thickness; *l* – BAT1 absorption capacity; *m* – BBT2 mass; *n* – BBT2 thickness; *o* – BBT2 absorption capacity

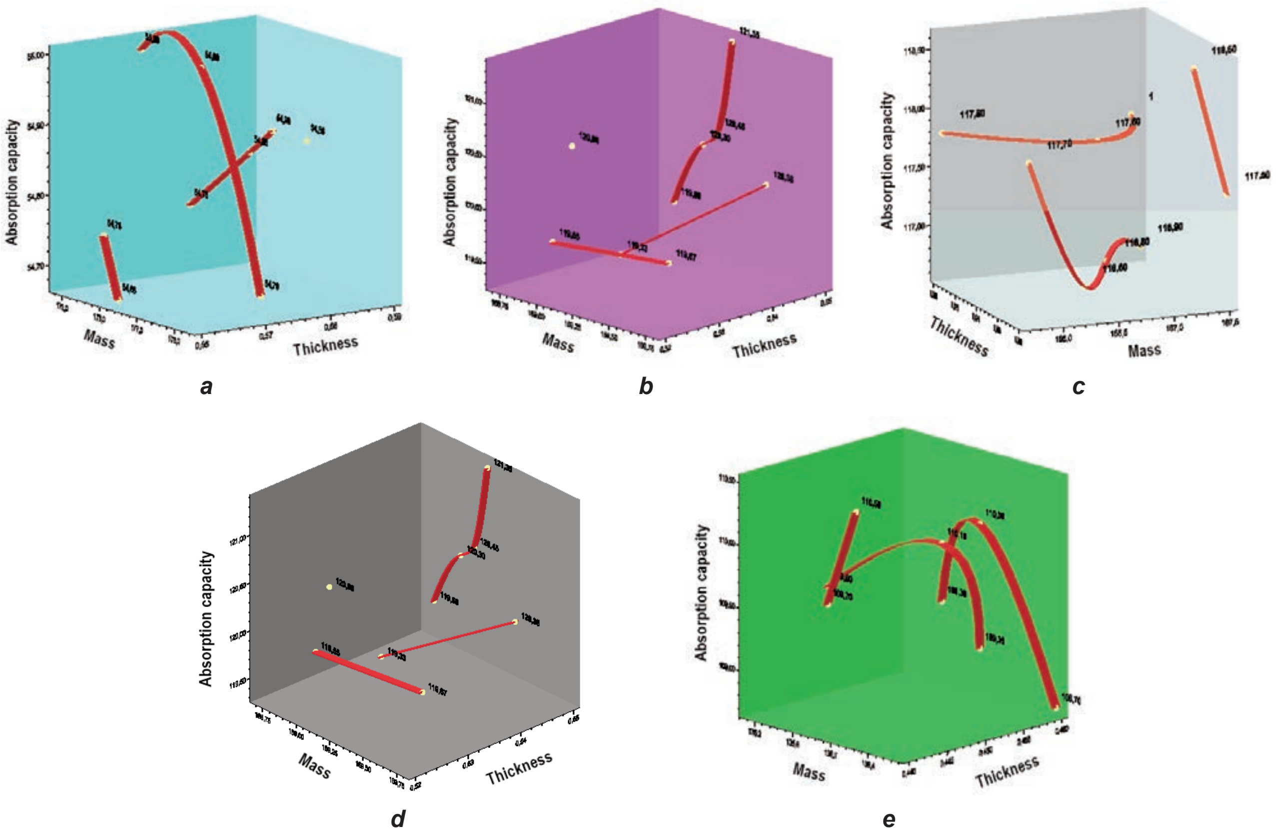

Fig. 2. Band graphs for: *a* – BZNT1; *b* – BBT1; *c* – BLT1; *d* – BAT1; *e* – BBT2

Variant BAT1

a) 25% of the values obtained for the mass are below 135.8 g/m^2, 25% being in the range [135.8; 136.3], 25% are in the range [136.3; 136.7] and 25% are over 136.7 g/m^2.

b) 50% of the thickness values obtained are in the range [0.448; 0.46], 25% being below the determined minimum value and 25% are above the maximum value.

c) 25% of the values of the absorption capacity are below 109.2%, 50% are in the range [109.2; 110.1] and 25% are over 110.1%.

d) The skewness indicators have negative values for all 3 variables, and the curves move to the left.

e) Kurtosis indicators have negative values of –0.140 for mass, –0.734 for thickness and –0.541 for absorption capacity, which proves that there is a large spread of values; hence, the curve is platykurtic.

Variant BBT2

a) 25% of the values obtained for the mass are below 183.6 g/m^2, 25% being in the range [183.6; 184.0], 25% are in the range [184.0; 184.7] and 25% are over 184.7 g/m^2.

b) 50% of the values obtained in thickness are in the range [0.70; 0.72], 25% being below the determined minimum value and 25% being above the determined maximum value.

c) 25% of the values of the absorption capacity are below 121.7%, 50% are in the range [121.7; 122.4] and 25% are over 122.4%.

d) The skewness indicators have positive values for all 3 variables, so the curves move to the right. It should be emphasized that, in the case of the thickness variable, the value of 0 that was obtained proves that there are no differences between the mean and the median, with the distribution being normal.

e) Kurtosis indicators have negative values for all 3 variables, and the curves are platykurtic, so there is a large spread of values.

Interactive band-type graphics

The representation was made using band graphs, in which the interpolation was performed using the 3rd degree Lagrange interpolation polynomial [7, 8]. It was not considered necessary to increase the degree of the polynomial (ex. 5) because with the increase in the degree of the interpolation polynomial, the error of approximation in the points far from them increased (the function samples were preserved, and there was a polynomial variation in the intervals between the points corresponding to the average). In addition, the use of the 3rd degree Lagrange polynomial was considered to lead to a reasonable trade-off between accuracy and complexity (figure 2). The coefficients of the Lagrange polynomial were determined based on the conditions of coincidence between the values of the interpolation function and the interpolation polynomial at the given discrete set points [8].

CONCLUSIONS

Statistical mathematical analysis was used to select textile structures for a multilayer medical device for treating burns.

The results obtained by the statistical analysis of the groups allowed the findings to be generalized to larger populations, i.e., the entire set from which the respective sample was extracted.

Depending on the location and the severity of wounds resulting from shooting, explosions or fire (wounds that result in bleeding, impaired vital functions, the impotence of an anatomical segment, celestine signs, etc.), the first layer of the matrix can be made of woven fabrics.

After correlating the physico-mechanical characteristics of the textile structures with the subsequent processes (realization of layer II, layer III and functionalization), the technical and physico-mechanical characteristics of the multilayer matrix will be determined, and the location areas and the field of use (for haemostasis, regeneration of connective tissues or their simultaneous combination) will be established.

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Tactile and mechanical investigation of screen printed specimens with puff effect

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ABSTRACT – REZUMAT

Tactile and mechanical investigation of screen printed specimens with puff effect

The subject of this paper was the investigation of the tactile and mechanical characteristics of printed specimens achieved using the manual technique of screen printing. The specimens are printed using ink enriched with a puff base. The puff base gives the print a three-dimensional shape and surface characteristics. This paper aims to investigate whether such prints can be used to improve the ergonomic characteristics of a product that undergoes in-hand manipulation. To determine the possibility of using a screen printing technique with a puff effect for ergonomic purposes, two experiments were performed. The first experiment involved subjective investigation of the tactile properties of the prints which are important since the end-users are people. The second experiment involved laboratory testing of the resistance of prints to mechanical rubbing (colour rendering) which is important since the prints should be able to endure a lot of in-hand manipulation. The specimens were printed using the manual screen printing technique on four different textile substrates. Apart from the substrate, the amount of added puff substance in ink and the screen printing mesh count varied. After testing the mechanical resistance to rubbing, colour differences were calculated. Based on the results obtained, resistance to mechanical effect was confirmed, and it was determined which prints have the best resistance and tactile features. Further investigations will be focused on investigating the same type of printing on different materials, and discovering how can prints with puff effect contribute to in-hand object manipulation.

Keywords: *Puff effect, screen printing, mechanical resistance*

Investigarea tactilă și mecanică a probelor serigrafiate cu efect în relief

Subiectul acestei lucrări a fost investigarea caracteristicilor tactile și mecanice ale probelor imprimate prin tehnica manuală a serigrafiei. Probele sunt imprimate cu cerneală îmbogățită cu o bază în relief. Baza în relief conferă imprimării o formă tridimensională și caracteristici de suprafață. Scopul acestei lucrări este de a investiga dacă astfel de imprimări pot fi folosite pentru a îmbunătăți caracteristicile ergonomice ale unui produs, care este supus manipulării manuale. Pentru a determina posibilitatea utilizării unei tehnici de serigrafie cu efect în relief în scop ergonomic, au fost efectuate două experimente. Primul experiment a implicat investigarea subiectivă a proprietăților tactile ale imprimărilor, ceea ce este important, deoarece utilizatorii finali sunt oamenii. Cel de-al doilea experiment a constat în testarea în laborator a rezistenței imprimărilor la frecare mecanică (stabilitatea culorii), un aspect important deoarece imprimările ar trebui să poată suporta suficientă manipulare manuală. Probele au fost imprimate folosind tehnica de serigrafie manuală pe patru substraturi textile diferite. În afară de substrat, cantitatea de substanță în relief adăugată în cerneală și numărul de plase de serigrafie au fost variate. După testarea rezistenței mecanice la frecare, s-au calculat diferențele de culoare. Pe baza rezultatelor obținute s-a confirmat rezistența la frecare mecanică și s-a determinat care imprimări au cele mai bune rezistențe și caracteristici tactile. Investigațiile ulterioare se vor concentra pe analiza aceluiași tip de imprimare pe diferite materiale și pe descoperirea modului în care imprimările cu efect în relief pot contribui la manipularea manuală a obiectelor.

Cuvinte-cheie*: efect în relief, serigrafie, rezistență mecanică*

INTRODUCTION

Screen printing is a printing technique that enables printing on almost all types of materials (paper, textiles, plastics, etc.), as well as printing on objects of different shapes, profiles and sizes [1]. In the printing process, the most important component is the printing plate, which is a combination of a screen and a stencil. Between the screen and the substrate is a stencil, which carries printed information. The stencil, by its shape, closes certain parts of the screen, preventing the ink to get through to the substrate while other parts not covered by the stencil allow the ink to be transferred to the substrate. The elements that the stencil has closed are called non-printing elements, and those that are left open are called printing elements [2]. Using screen-printing thicker layers of ink can be printed (12 mm and more) which is one of the major advantages over other printing techniques. Also, a wide range of printing inks can be used including special additives [2–4]. The puff base is one of the first special additive and effect in the screen printing technique (figure 1). Ink with the addition of a puff base expands when printed and warmed up adding to the raised, soft print effect. The puff base was modified by adding a heat-active swelling agent. The print has a rough texture visually; however, it feels soft and rubbery to the touch. The touch is reminiscent of velvet and plush. Usually, it is used to create interesting designs that provide texture.

With the addition of a puff base, the printing is standardly done and the print is placed through a drying tunnel. During the drying process, the ink reacts to heat and swells, creating a raised or 3D effect on the substrate [5].

In recent years, ergonomic design has encouraged a renewed interest in users, manufacturers and researchers. In the past, product design has always been emphasized in its function, and it was always considered in the direction of improving efficiency. The task of a product that undergoes in-hand manipulation was only to fulfil the primary function for which it was made and to suit most potential users. However, in recent years, approaches have changed and new important segments have been introduced that have received particular attention in design, such as the comfort and consistency of how a product is used considering the capabilities of a potential customer.

There were several reasons for the emergence of these new principles, one of them being the rise in upper extremity musculoskeletal disorders. These disorders are widespread in industries that use hand tools. Products subject to in-hand manipulation must be safe and easy to use and tend to reduce the load transferred to the upper limbs to avoid the risk of musculoskeletal injuries [6]. The surface in contact with the palm should not be so smooth as to be slippery, nor rough so much to be abrasive. The friction properties of the surfaces that come in contact with the palm are complex because the skin is highly elastic and oil-resistant. Varnished wooden surfaces give better subjective estimations than metal or plastic of similar smoothness. The rubber is similar to wood but becomes "sticky" during use [7]. Lewis, Carré, and Tomlinson [8] investigated the impact of friction between the fingers as well as the palms and objects of sports equipment, with the assumption that the surface of the product material can strongly influence how well an athlete plays. Not only does it determine how well the equipment can be caught and manipulated, but it also accelerates a safer and more stable grip and performance. The interactions of the hand with a frisbee were also explored. Researchers believe that the basics of skin tribology can play a key role in the development of optimized sports equipment, but there are still gaps in understanding and modelling the surface texture of the product and how much it affects comfort [8]. Considering that screen printing can print ink in a thick layer, which gives a print of high coverage properties and has great resistance to external influences, there is a potential that screen printing can be used to improve the ergonomic characteristics of similar products undergo in-hand manipulation. Screen printing has already been explored and suggested to be used in the printing of Braille [9], and this paper will explore the possibility of using screen printing with the addition of puff base to increase the ergonomic qualities of products intended for in-hand manipulation. In this research, textile is used as a printing substrate since the screen printing technology with the addition of puff effect is usually done on textile. Textile is widely used in our daily life and its tactile design is significant [10].

METHODOLOGY

This research aims to test the hypothesis through experiments. The hypothesis is that the specimens printed with the manual screen printing technique with the addition of a puff base in the ink can be used to improve the ergonomic characteristics of products that undergo in-hand manipulation. The puff base adds new qualities to the printed colour. The print gets a third dimension and its tactile surface characteristics change in addition to the visual senses, it can be tactile experienced. The printed specimens were investigated subjectively, where, through the survey where respondents estimated the tactile characteristics of prints. The survey included 10 respondents, 5 males and 5 females. All respondents were between 25 and 35 years old. After the subjective study, an objective study was carried out to check the mechanical characteristics of the prints, namely the resistance to mechanical rubbing (colour rendering).

Fig. 1. Screen printing with puff effect

The resistance to mechanical influence study was carried out in a laboratory setting, similar to the research [11–13] and the 105-X12:2016 standard [14].

Materials and experimental apparatus

The samples were printed by the manual screen printing technique on a carousel machine manufactured by TSH Printer LTD GMBH, model no. S.6S4T.B. All prints are printed in black on water-based Teflex ink. Teflex manufacturer's puff base was added to the ink in three different percentages of 10%, 20% and 30%. In addition to the percentage of puff base, the size of the screen printing mesh count varied. The screen printing mesh count of 63 l/cm and 120 l/cm were used. Given the variations of the two factors mentioned, six different types of prints were obtained (table 1). The screen printing mesh is made of silk and is woven with the ordinary type of weaving. Synthetic rubber squeegee 75 shore was used. After printing, each print was dried at 133° C for 30 seconds. The prints are printed on different textile substrates. Mixed textile material (97% cotton, 3% cotton) with a weight of 10.01 g/m^2, 100% viscose with a weight of 2.10 g/m^2, 100% polyester with a weight of 1.66 g/m^2 and 100% cotton with the weight of 1.08 g/m^2 were used. Material characterization was done according to ISO1833 standard for material composition and ISO 3801 for fabric weight. Each material was printed with three identical 100% coverage print samples of 135 × 30 mm to conduct statistical analysis. The printing duration of each substrate was 5 seconds per print, which can be translated to a printing speed of 34 mm/s for each print.

Testeks ft411 Electronic Crockmeter instrument was used for testing colourfastness of printed specimen to dry rubbing. The device applies a constant vertical pressure (9 N +/– 10%) with a rubbing head diameter of 16 mm and a stroke of 104 mm in length according to ISO 105-X12:2016 [14]. A similar methodology was used in the research of Lilić, Kašiković and Miketić (2019) [15]. The rubbing head is coated with a cotton canvas in contact with the test specimen. The canvas needed to be changed from time to time due to the occurrence of dirt. The scanning, measurement, visual assessments and analysis of the test specimens were performed before and after three cycles of fifty repetitions (50, 100 and 150). The samples were scanned using the Canon CanoScan 5600F at 600 spi in full colour for archiving and subsequent image analysis. The measurement of the CIE Lab colour coordinates was done using the HP 200 colourimeter instrument, illumination D65, 2° standard observer and d/8 measurement geometry.

Table 1

CATEGORIZATION OF PRINTED SPECIMENS		
Print type specimen name	**Screen printing mesh count (l/cm)**	**Added puff base amount in the ink (%)**
Print type 1	63	10
Print type 2	63	20
Print type 3	63	30
Print type 4	120	10
Print type 5	120	20
Print type 6	120	30

Procedure

The first part of the experiment was the subjective estimation of the printed samples. The task of the respondents was to fill in the survey. By physically touching the printed specimens, they needed to select from the group of specimens consisting of 6 different types of prints for one material type, the print that best suits the given characteristic. Accordingly, their task was to select a print type that was the smoothest/roughest, aesthetically best/aesthetically worst, most pleasant to the touch/most unpleasant to the touch, and the firmest/softest. As there were 4 different substrates, the specimens were divided into 4 different groups, and the survey was divided into 4 different parts. Each part was focused on one type of substrate material and the characteristics evaluated were the same for all parts. The second part of the experiment was conducted through laboratory testing. The resistance of the specimens to mechanical rubbing was investigated. The CIE lab coordinates of specimens were first measured and scanned before testing, and then the samples were treated in 3 cycles with 50 repetitions each. Scanning and measurement were performed between each cycle. Colourimetric of the samples were taken using HP 200. The CIE lab values for each specimen were measured three times. From these, the mean values were calculated, which are further used for calculating the colour differences of the print specimens. Colour differences were calculated according to the CIE 2000 (ΔE_{00}) colour difference formula [16, 17]:

$$\Delta E_{00} = \sqrt{\frac{\Delta L'}{k_L S_L} + \frac{\Delta C'}{k_C S_C} + \frac{\Delta H'}{k_H S_H} + R_T \cdot \frac{\Delta C' \Delta H'}{S_C S_H}} \quad (1)$$

where $\Delta L' = L'_1 - L'_2$ is a difference in lightness value, $\Delta C = C'_1 - C'_2$ is a difference in chromatic value, $\Delta H = 2\sqrt{C^1_1 C^1_2} \sin \frac{\Delta h'}{2}$ is a difference in hue value and parametric weighting factors $k_L = k_C = k_H = 1$.

Differences that were calculated were the difference in the colour of the print before rubbing and after 50 repetitions, the difference in the colour of the print before rubbing and after 100 repetitions and the difference in the colour of the print before rubbing and after 150 repetitions. Also, the differences in the colour of the prints between the 50th and 100th repetition, between the 50th and 150th repetition and between the 100th and 150th repetition were calculated. The colour differences were compared by the type of substrate and by print type. Colour difference values can be translated to human perception reference as ΔE_{00} lower than 0.2 – the difference is not perceivable, ΔE_{00} between 0.2 and 1 – the difference is noticeable, ΔE_{00} between 1 and 3 – the difference can be seen, ΔE_{00} between 3 and 6 – the difference is easy to see and ΔE_{00} over 6 – obvious difference [14, 15] used in this paper.

RESULTS AND DISCUSSION

Figure 2 shows the results of tactile estimations of prints given in a survey. Based on the mean values of the results obtained, it was discovered that the print combination of amount off puff base and the screen printing mesh count named type 1 (accordingly to table 1), regardless of the substrate on which it was printed, was chosen as the aesthetically best print. As the aesthetically worst print, print type 6 was selected, regardless of the substrate. Print type 1 for mixed textile material was selected as the firmest print. Print type 2 was selected as the firmest print on polyester and for viscose and cotton, it was print type 3. On the mixed textile material (cotton and elastin), viscose and polyester, print type 4 was selected as the softest, while for cotton, print type 6 was selected. For the most pleasant to the touch characteristic for mixed textile material, viscose and polyester type 4 were rated as the best. For cotton, it was the print type 1. The print type that was rated as the most unpleasant to the touch, regardless of the substrate, was specimen named type 6. The roughest specimen for polyester was type 2, while for the other materials it was the print type 6. The smoothest type of print is type 1, regardless of the material of the substrate.

Colour differences values calculated as a result of the mechanical rubbing experiment are shown graphically in figure 3, while the appearance of printing specimens (a group of printed samples printed on substrate viscose) and their change during testing cycles are shown in figure 4. It was often the case that printed specimens in the first rubbing cycle received a darker colour, and by the further process of rubbing the print began to lighten increasingly resembling the original colour. Some printed specimens began to lighten after the 50th repetition and some after the 100th. Therefore, as shown graphically in figure 3. after more rubbing, rather than increase, the colour differences were reduced. For example, colour differences calculated between samples before testing and after 150 repetitions are lower than it was calculated after 100 repetitions for the mixed textile substrate (97% cotton and 3% elastin) in the combination of print type 2.

The print type printed on mixed textile material with the lowest colour difference was 1 (ΔE = 0.70) and the print type with the highest colour difference was 6 (ΔE = 2.64). The print type that was printed on viscose with the lowest colour difference was 1 (ΔE = 1.09) and the print type with the highest colour difference was 2 (ΔE = 7.52). The print type printed on polyester with the lowest colour difference was 3 (ΔE = 1.57) and the print type with the highest colour difference was 4 (ΔE = 3.46). The print type printed on cotton with the lowest colour difference was 1 (ΔE = 1.19) and the print type with the highest colour difference was 2 (ΔE = 3.09). Print type 1 was the most durable print type for mixed textile, viscose, and

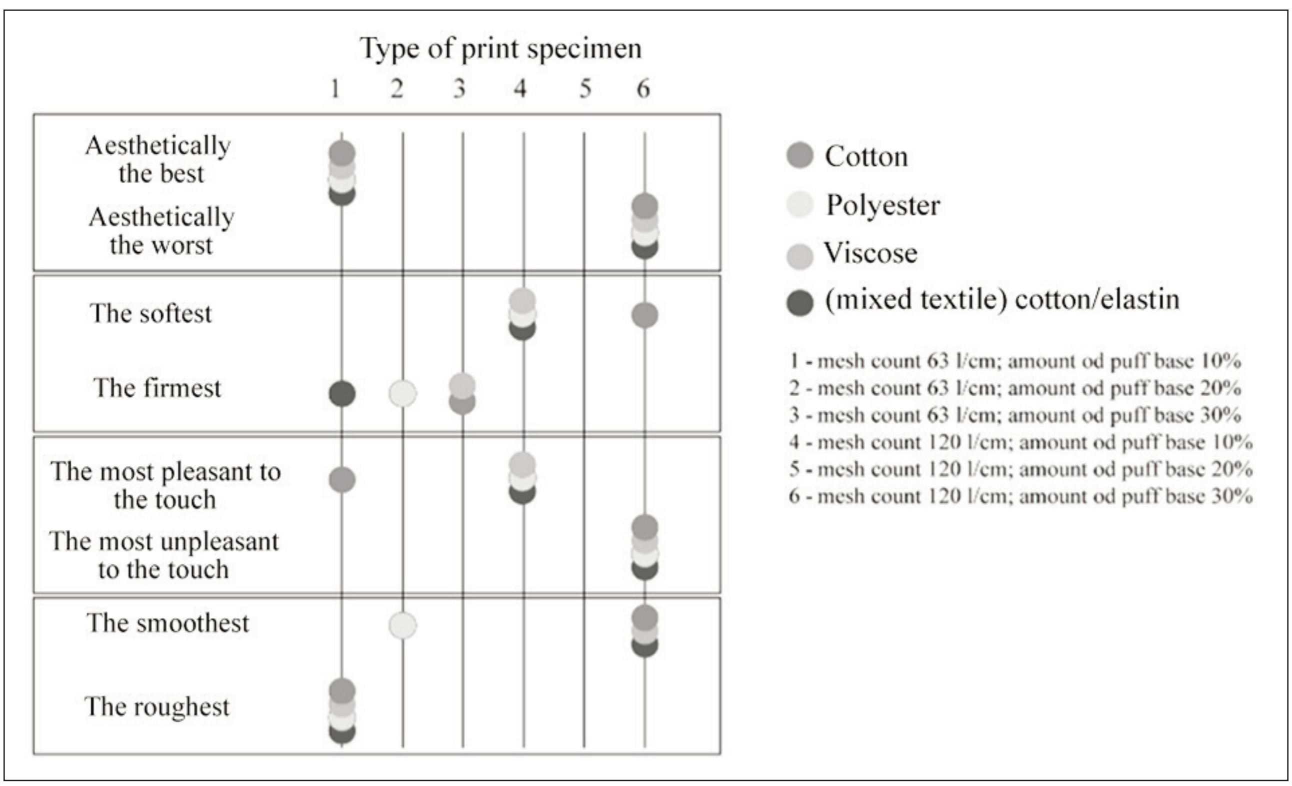

Fig. 2. Graphical presentation of subjective estimation results

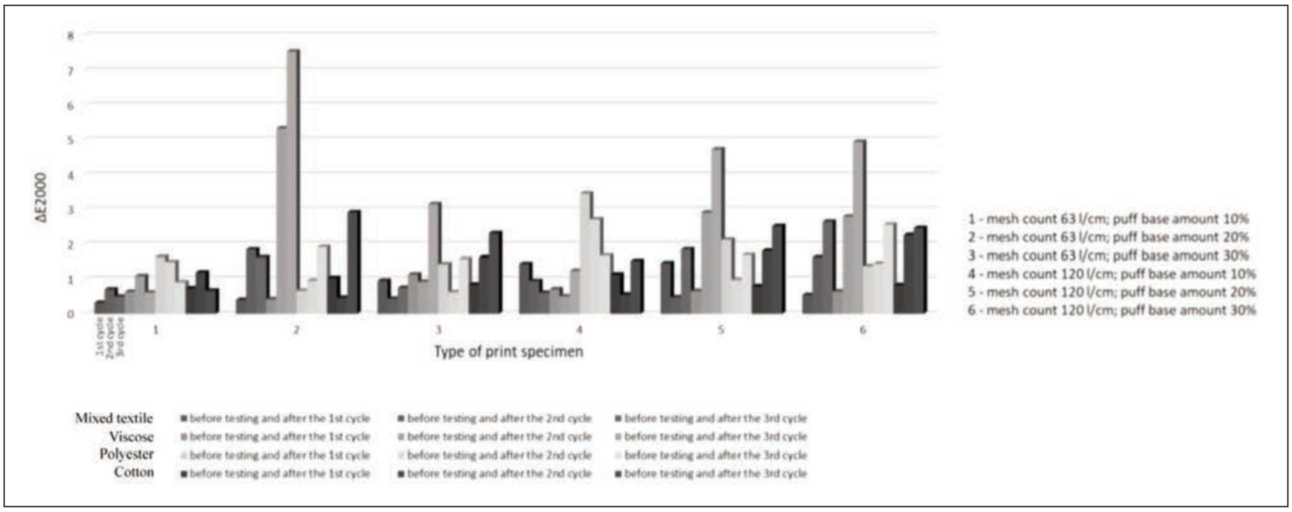

Fig. 3. Graphical representation of colour difference results

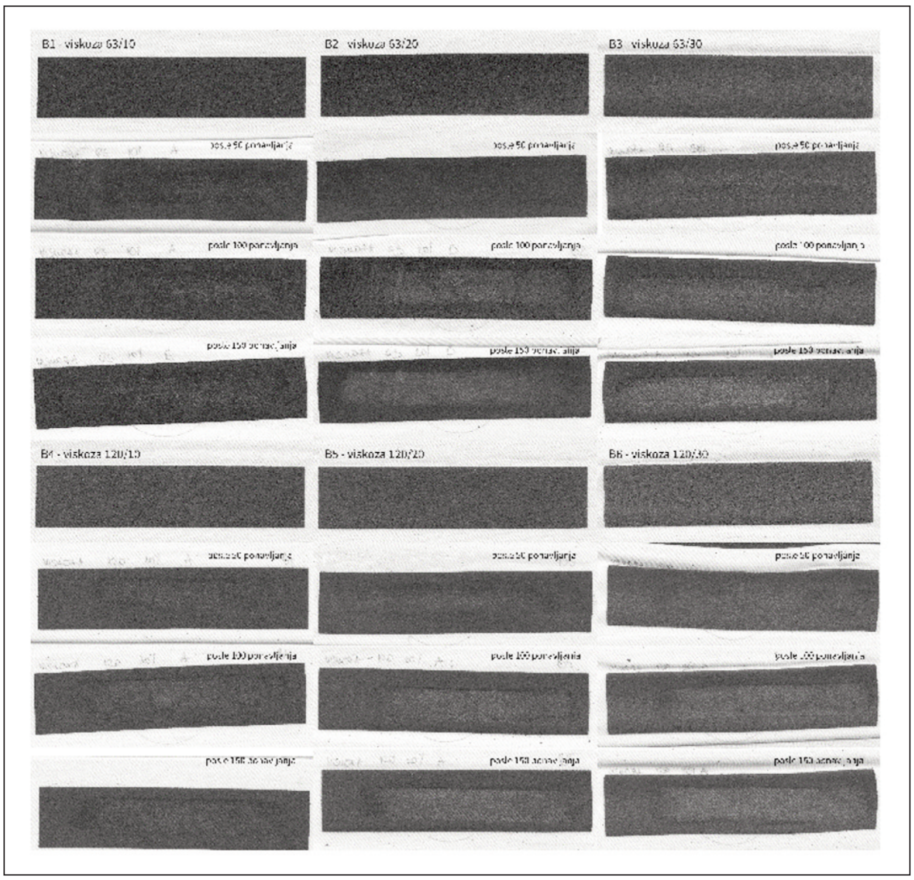

Fig. 4. The appearance of the specimens during testing on substrate viscoselts

cotton substrates. Print type 3 was the most durable print type for polyester. A print type 2 was the least durable print type for the substrates made of viscose and cotton. For polyester, the least durable print type was 4. Print type 6 was the least durable print for the mixed textile material. Based on all the results, print types 1, 2, and 3 provided the most resistant print to mechanical rubbing printed on all four materials. These prints have the same characteristic as the screen printing mesh count (63 l/cm). Print types 4, 5, and 6 provided the least resistant print type to mechanical rubbing printed on all four materials. These types of print have the same screen printing mesh count of 120 l/cm and the unfavourable combination was a screen printing mesh count of 120 l/cm and 30% amount of the puff base added in the ink. Similar results of the influence of mesh count on mechanical rubbing have been obtained in the research of Vladić et al. [11]. The most durable material appeared to be mixed material and the material with the least durable print was viscose.

CONCLUSION

Based on the obtained results, it can be concluded that there are valid reasons for introducing screen printing techniques in the process of enhancing the ergonomics characteristics of products. The usability of screen printed samples with the addition of a puff base in the ink was examined through subjective as well as objective investigation. As a result of subjective research, these prints proved to be highly well received by respondents. Every investigated tactile feature can be achieved in a proper printing combination of substrates and print type (the combination of the amount of puff base in the ink and screen printing mesh count). Besides the tactile feature, in order for these prints to be used for the improvement of the ergonomics characteristics of the products, they need to fulfil certain mechanical characteristics, such as resistance to rubbing. The results of the mechanical testing show that the prints are very resistant. Observing altogether subjective and objective results it can be concluded that print types achieved in the combination of screen printing mesh count of 63 l/cm or 120 l/cm and 10% of the added amount of puff base in the ink, regardless of the substrate, gave the best results is this research. Further research will include an investigation of the screen printing technique with added puff special effect printed on a wider range of substrates, and an investigation of its impact on in-hand manipulation.

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Synthesis and characterization of novel resorcinol based trisazo reactive dye ligand and its different metal complexes for cotton dyeing

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ABSTRACT – REZUMAT

Synthesis and characterization of novel resorcinol based trisazo reactive dye ligand and its different metal complexes for cotton dyeing

The goal of this study was to create a new trisazo reactive dye ligand from 6-nitro-2-aminophenol-4-sulphonic acid, resorcinol derivative, and vinyl sulphone para ester, as well as their metal complexes with Fe (II), Ni (II), Cu (II), and Zn (II). The diazotization of 6-nitro-2-aminophenol-4-sulphonic acid was followed by coupling to resorcinol in an alkaline medium for the synthesis of a mono-azo dye ligand. To make reactive dye, diazotized vinyl sulphone para ester was coupled with 6-nitro-2-aminophenol-4-sulphonic acid resorcinol derivative in an alkaline medium. Metal complexes of reactive dyes with 3d transition metals such as iron, nickel, copper, and zinc have also been created. The novel synthesized reactive dyes were applied to cotton to see how well they dyed. Spectro-analytical techniques were used to authenticate the compositions of all newly synthesized substances. The prepared reactive dyes were also used on textiles for dyeing features such as light fastness and wash fastness and were found to have high values of 4–5 on the grey scales, and 4–5 on the blue scales.

Keywords: *resorcinol, diazotization, azo dye, coupling reaction, metal complexes, dyeing, fastness properties*

Sinteza și caracterizarea noului ligand de colorant reactiv trisazo pe bază de rezorcinol și diferiții săi complecși metalici pentru vopsirea bumbacului

Scopul acestui studiu a fost acela de a crea un nou ligand de colorant reactiv trisazo din acid 6-nitro-2-aminofenol-4-sulfonic, derivat de rezorcinol și vinil sulfonă para ester, precum și complecșii lor metalici cu Fe (II), Ni (II), Cu (II) și Zn (II). Diazotarea acidului 6-nitro-2-aminofenol-4-sulfonic a fost urmată de cuplarea la rezorcinol într-un mediu alcalin pentru sinteza ligandului de colorant mono-azoic. Pentru a crea colorantul reactiv, vinil sulfona para ester diazotat a fost cuplat cu derivatul de rezorcinol al acidului 6-nitro-2-aminofenol-4-sulfonic într-un mediu alcalin. Au fost creați, de asemenea, complecși metalici de coloranți reactivi cu metale de tranziție 3d, cum ar fi fierul, nichelul, cuprul și zincul. Noii coloranți reactivi sintetizați au fost aplicați pe bumbac pentru a se observa procesul de vopsire. Au fost folosite tehnici spectro-analitice pentru identificarea compozițiilor tuturor substanțelor nou sintetizate. Coloranții reactivi preparați au fost utilizați și pe materiale textile pentru determinarea caracteristicilor de vopsire, precum rezistența la lumină și rezistența culorii la spălare și s-au dovedit a avea valori ridicate de 4–5 pe scara de gri și, respectiv, 4–5 pe scara de albastru.

Cuvinte-cheie: *rezorcinol, diazotare, colorant azoic, reacția de cuplare, complecși metalici, vopsire, proprietăți de rezistență a culorii*

INTRODUCTION

Azo dyes are the most common type of artificial colours, accounting for sixty to seventy per cent of all synthetic dyes now in use [1]. Because of their significantly maximum absorbance values, medium to excellent fastness, good solubility, high technological applications, variety in structures, availability of a wide range of raw ingredients, and simple synthetic techniques, azo dyes are extensively used and synthesized [2]. Azo substances are nitrogen compounds that do not exist in nature and are constantly being studied in technology and academia, azo synthetic dyes are perhaps the most used colourants in the world and make up the biggest class of azo substances [3]. Numerous azo variants of resorcinol have been studied for a multiple-use because of their suitability for textile fabric [4]. Azo colourants are used in the colouration of fibres, photo electronics, photonic storage devices, biochemical processes printmaking technologies as well as diagnostic, culinary research and biochemistry [5]. In electrical toners, transition metal chelates of azo dye ligands are used as charge regulating materials, dyes in electricity paints, and the electromagnetic separator. Reactive dyes, direct dyes, vat dyes, and metal complex dyes are among the different types of textile dyes. Reactive dyes are frequently used to colour viscose textiles, direct and vat dyes were once used to colour celluloid materials, but their value has decreased since the advent of reactive dyes [6]. Reactive dyes beat direct dyes in terms of reliability to processing, beautiful hues throughout a diverse variety, high smoothing performance, excellent wash fastness, and improved light fastness [7]. Reactive dyes are the cheapest to manufacture and simplest to use than other dyes. Reactive dyes are chemicals that can combine directly with a surface to create a covalent dye-substrates bonding [8]. Reactive dyes are by far the most frequently utilized category of dyes for colouring cellulosic fabrics due to their great characteristics like dissolution rate, ease of installation, diversity of processing techniques, accessibility of a variety of hues, luminance of vibrant colours, accordance with the desired rinse and light fastness, and reasonable cost [9]. The textile material is dyed using reactive colours in a somewhat alkaline solution [10]. In current studies, six novel trisazo reactive dye and metal complexes were synthesized, characterized, and treated with a cotton cloth.

Simultaneously, spectro-analytical techniques were used to investigate the structure, and qualitative properties of ligand reactive colourant, and its complexes with transition metals.

MATERIALS AND METHODS

Materials

Sigma Aldrich supplied all of the types of products. Standard techniques were used to purify the solvents. The Nicolet IR 100 single beam FTIR spectrometer (Fourier-Transform) was used to generate the FTIR spectra. UV-visible spectrophotometer (UV Genesys spectrophotometer) was used to elucidate the UV-Visible absorption spectrum of all dyestuff's solutions.

Diazotization of 6-napsa and vinyl sulphone para ester

300 ml water was taken and 23.4 g of 6-nitro-2-aminophenol-4-sulphonic acid (6-napsa) was added to it with agitation. 7.3 g $NaNO_2$ (0.105 moles) was added to it and agitated for 5–10 minutes. Then $CuSO_4$ (4 g) dissolved in 5 ml of warm water was poured into it instantly and stirred for one hour. In the end, 4–5 g sulfamic acid was introduced to kill extra nitrous acid. Diazotized 6-napsa was prepared. In an ice jacketed beaker, 0.04 moles of vinyl sulphone para ester (11.72 g) were taken. 60 g ice, 120 ml water and 0.12 moles HCl (14.6 ml) were mixed. 0.043 moles of $NaNO_2$ (2.92 g) were added to it and agitated. The temperature was maintained near 0–5°C by ice addition, and stirrings were sustained for one hour. At the completion of the reaction, 5 g of sulfamic acid was introduced to abolish spare nitrous acid.

Resorcinol solution and coupling with diazotized 6-napsa

0.1 moles of resorcinol (11.1 g) were added in 300 ml water in an ice-jacketed beaker, agitated well. Using a burette, diazotized 6-napsa was mixed dropwise in resorcinol solution. To retain pH 8.0-8.5, Na_2CO_3 (25%) was added. The beaker was jacked out after the whole addition of diazotized 6-napsa substance, the beaker was jacketed out, and agitation was continued till ambient temperature (25°C). Five equivalent shares of coupled substance were made. 0.02 moles of 6-napsa-resorcinol monoazo dye ligand were present in one part.

Azoreactive anchor attachment

Na_2CO_3 (25%) was used to increase the pH up to 7–7.5 of un-metalized or metalized dye ligand, jacketed with ice, 30 g ice mixed in it, diazoanium compound of vinyl sulfone paraester was added slowly, pH 8–8.5 retained by Na_2CO_3 solution (25%) and the 0–2°C temperature was maintained by ice addition till completion of coupling, agitation was sustained for one hour. Ultimate dye jacketed out, mixed and agitated till room temperature [1].

Metallization

10% HCl solution was applied to decrease pH up to 5.5–6 of un-metalized dye and heated up to 50–60°C. 1–2 drops of conc. H_2SO_4 was added in 0.02 moles of each metal salt in 20 ml water and heated up to 50–60°C to acquire a clear solution. In monoazo dye ligand, respective metal salt solution was added slowly and maintained the temperature at 50–60°C for 30–40 min. Identification of metallization progress was identified by comparative paper chromatography [1].

Dye separation from water by filtration, drying and grinding

The pH was reduced up to 6.8 of synthesized unmetallized 6-napsa-resorcinol trisazo reactive dye or 6-napsa-resorcinol metal chelates trisazo reactive dye by conc. HCl. By salting out on a volume basis, separation was done. For about three hours, the whole dye was stirred for good filtration. Filtration of dye was carried out by using an aspirator; an oven was used at 50–60°C to dry the synthesized trisazo reactive dye (residue) and was saved for further applications and characterization after complete drying and grinding of dye.

Dyeing procedure

Mercerized cotton cloths were dyed with reactive dyes and prepared for the current research. The "Tumble Dyeing" procedure was utilized for colouring cotton cloth. The lab scale dyeing recipe was used as, dying salt NaCl (5.0 g) and Na_2CO_3 (0.5 g), one drop of 5 M NaOH, X gram weight of cotton textile. One per cent solution of reactive dye was taken and dyed at a rate of six per cent, three per cent and one per cent concerning X (weight of cotton cloth). 9 g of one per cent dye solution was added in 91 g of water for six per cent dyeing of cotton cloth, 4.5 g of one per cent dye was added in 95.5 g of water for three per cent dyeing of cotton fabric, and 1.5 g of one per cent dye solution added in 98.5 g water for one per cent dyeing of cotton cloth, when X was 1.5 g. 45 minutes at 85°C was the dyeing duration (figure 1).

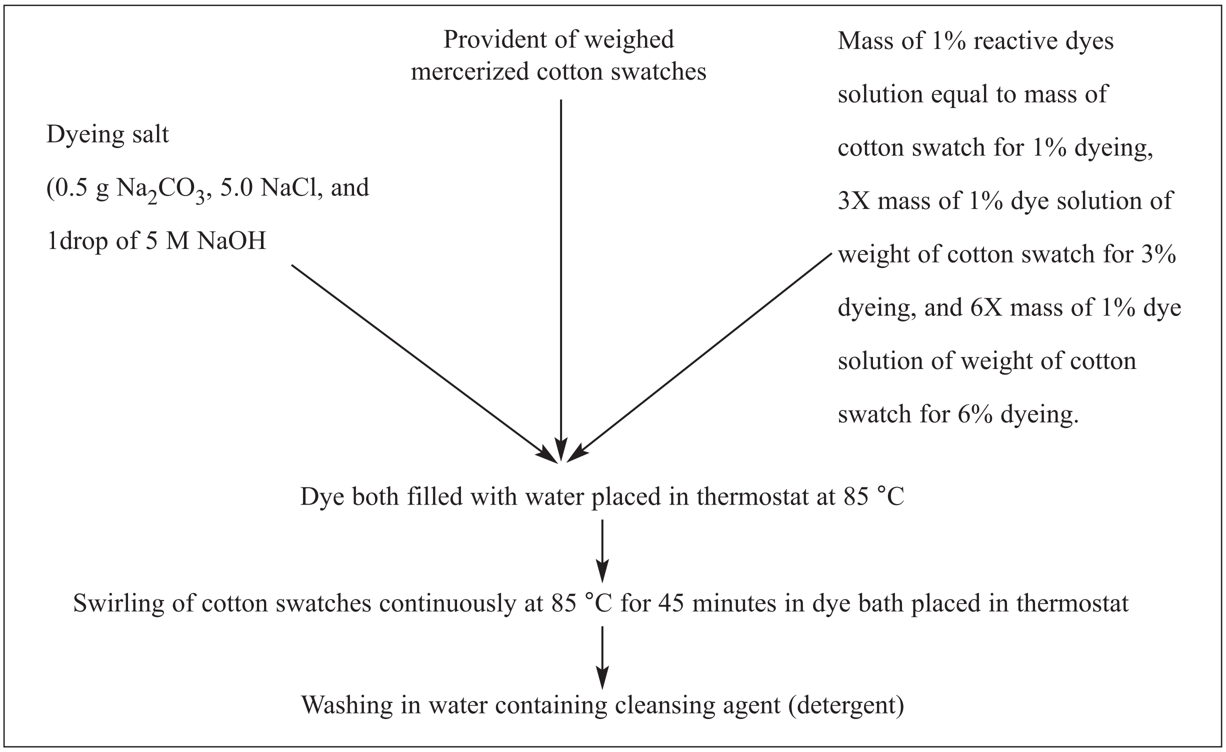

Fig. 1. Dyeing graph (flow diagram of dyeing procedure)

RESULTS AND DISCUSSION

Five trisazo reactive dyes metal complex reactive dyes have been prepared by applying the universal technique of diazotization, coupling, and metallization, in this current research effort. The coupler employed was resorcinol. Three pairing places have been offered by it in electrophilic substitution reaction. Moreover, diversity of shades and excellent fastness qualities has been shown by metal complex reactive dyes of resorcinol. Resorcinol has been coupled with a diazonium salt, ensuring the development of a new monoazo dye ligand, in this investigation. This dye ligand has been metallized in a direction to advance the fastness properties and to acquire a diversity of shades. Predictably, it will be obliged to native growth of artificial reactive dyestuffs, and exclude overseas importations.

Shade cards interpretation

To signify each colourant, a minute portion of four inches four-sided piece or 15 cm by 15 cm coloured swatch was prepared by cutting dyed cotton cloth as a shad card. Printed the tag of the dyestuff on these shade cards. These were utilized to measure the hue of synthesized trisazo reactive dye product in command to yield textiles that were within the typical Pantone colour equivalent choice, shade cards represented the colour criteria [3]. Colour fastness was restrained distinctly for variations in the hue of the trial sample (colour declining) and stain of an undyed firm that approached into contact with the sample throughout the examination (dye flow) on the grey scales.

Synthesis of 6-Napsa-Resorcinol reactive dye series

In this series of dyes, five samples were prepared by diazotization of 6-napsa, coupling with resorcinol, metallization and further attachment with diazotized vinyl sulphone para ester as a reactive anchor. The first dye was unmetabolized, whereas the others were iron (II), nickel (II), copper (II), and zinc (II) complexes. Figure 2 demonstrates the detail of the synthetic scheme as under.

Characterization of 6-napsa-resorcinol-reactive dye series by UV-Visible Spectrum

Reddish-brown dye with λ_{max} 440 nm and absorbance 1.68 was un-metalized dye 101 (un-metallized 6-napsa-resorcinol reactive dye). Yellowish-brown dye with $\lambda_{max.}$ 430 nm and absorbance 1.55 was its iron (II) chelate (dye 102), displaying a hypsochromic shift of 10 nm with a 0.13 hypochromic effect. Reddish-brown dye (dye 103) with $\lambda_{max.}$ 450 nm and absorbance 1.80 was nickel (II) chelate of dye ligand 101, presenting a bathochromic shift of 10 nm with 0.12 hyperchromic effect. Tan dye with $\lambda_{max.}$ 460 nm and absorbance 1.70 was copper (II) chelate (dye 104) of dye 101, with the presentation of the bathochromic shift of 20 nm and 0.02 hyperchromic effect. Reddish-brown dye with $\lambda_{max.}$ 445 nm and absorbance 1.58 was zinc (II) chelate (dye 105) of dye ligand 101, performing a bathochromic shift of 5 nm and 0.10 hypochromic effect (figure 3).

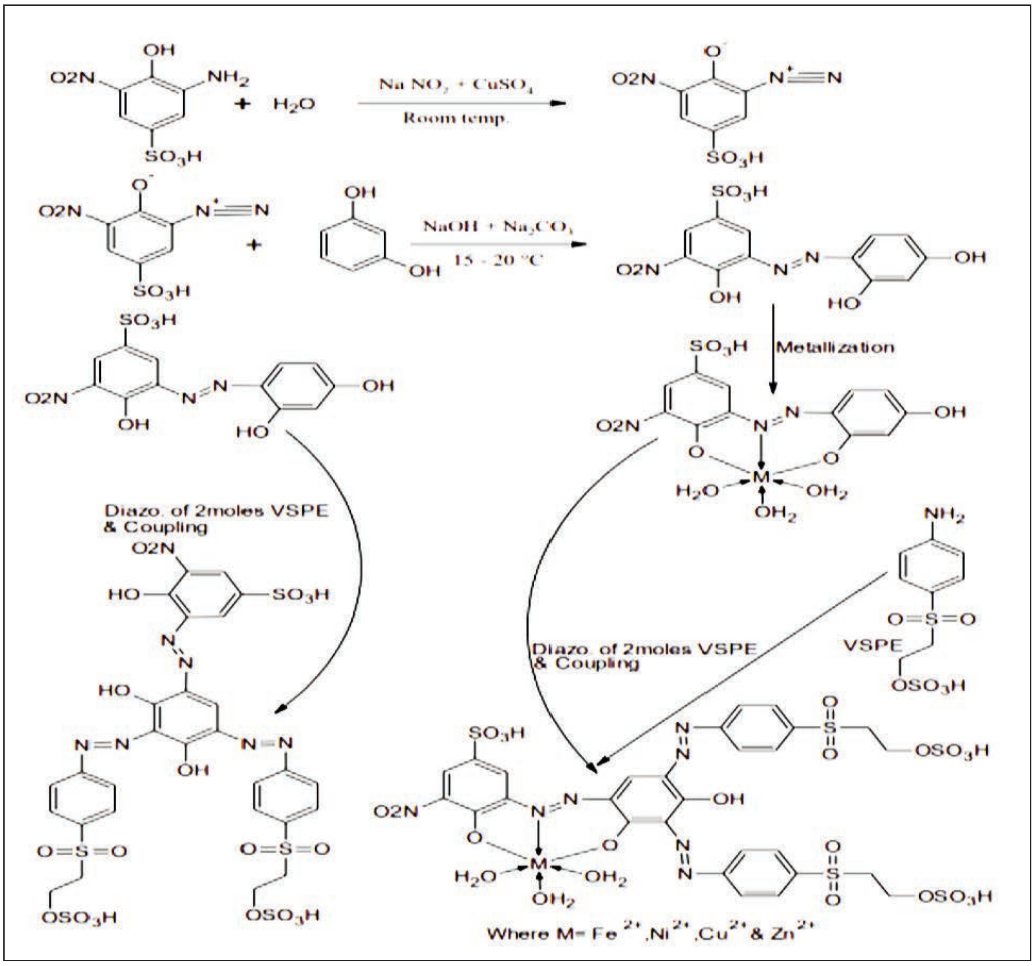

Fig. 2. Scheme of 6-napsa-resorcinol reactive dye series

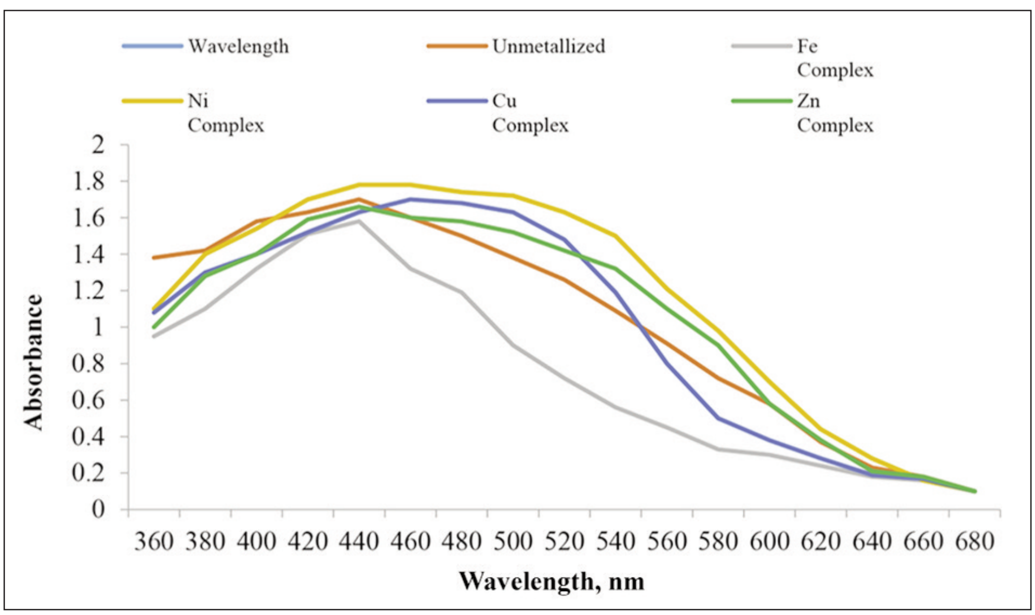

Fig. 3. UV-Visible Spectrum of 6-napsa-resorcinol-reactive dye series

Dyeing procedure

The same dyeing procedure was adopted for the dyeing of 6-napsa reactive dyes as given in the experimental section (figure 1).

Shade cards of 6-napsa-resorcinol reactive dye series

The data given in table 1 is also supported by figure 4, shade card. It is detailed and discussed in the experimental section.

Table 1

FASTNESS PROPERTIES OF SYNTHESIZED REACTIVE DYES		
Dye #	**Washing fastness**	**Light fastness**
101	2-3	2-3
102	3-4	4
103	4-5	4-5
104	3-4	4-5
105	2-3	3

The dyed fabric swatches were compared with an internationally recognized Pantone matching system for all shad cards. The un-metalized dye 101 (un-metallized 6-napsa-resorcinol reactive dye) had Pantone matching number 4725 for one per cent shade, 4705 for three per cent shade and 462 for six per cent shade. Dye 102 (6-napsa-resorcinol iron complex reactive dye) had Pantone matching number 4685 for one per cent shade, 4655 for three per cent shade and 464 for six per cent shade. Dye 103 (6-napsa-resorcinol nickel complex reactive dye) had Pantone matching number 4725 for one per cent shade, 1405 for three per cent shade and 161 for six per cent shade. Dye 104 (6-napsa-resorcinol copper complex reactive dye) had Pantone matching number 470 for one per cent shade, 1405 for three per cent shade and 4695 for six per cent shade. Dye 105 (6-napsa-resorcinol zinc complex reactive dye) had Pantone matching number 4745 for one per cent shade, 1405 for three per cent shade and 161 for six per cent shade [1].

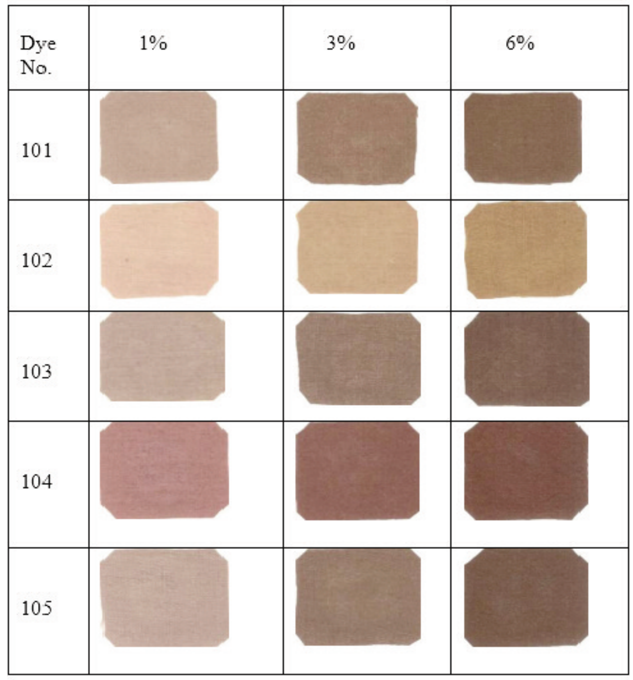

Fig. 4. Shade cards of 6-napsa-resorcinol reactive dye series

FTIR studies of 6-napsa-resorcinol reactive dye series

All detailed features by 6-napsa-resorcinol trisazo fibre reactive dyes were revealed from FTIR Spectral studies. The FTIR spectra of paternal coupler molecule (resorcinol), 6-napsa, un-metallized-6-napsa-resorcinol reactive dye, 6-napsa-resorcinol Fe-complex reactive dye, 6-napsa-resorcinol Ni-complex reactive dye, 6-napsa-resorcinol Cu-complex reactive dye and 6-napsa-resorcinol Zn-complex reactive dye are shown by figure 5, *a–g*, respectively. The foremost frequencies in FTIR spectrum of 6-napsa are, 3421 cm^{-1} by enolic –OH absorbance, 3090 cm^{-1} by C-H stretching aromatic, 2851 cm^{-1} by N-H stretching, 1649 cm^{-1} C=C stretching, 1591 cm^{-1} C-C (aromatic) stretching, 1031 cm^{-1} by N-O, 1335 cm^{-1} by S=O, 1137 cm^{-1} by SO_3H, 1150 cm^{-1} by C-O stretching, 1145 cm^{-1} by C-N [1]. FTIR spectrum of resorcinol revealed foremost frequencies, 3211 cm^{-1} by enolic –OH, 1590 cm^{-1} by C=C of the aromatic ring, 1495 cm^{-1} by C-C (aromatic) stretching, 1150 cm^{-1} by C-O stretching, 3050 cm^{-1} by C-H stretching [1]. Most of the dyes of this series had all the specific absorptions including N=N in the range of 1410-1580 cm^{-1} and as a demonstrative of this dye series [1]. Un-metallized-6-napsa-resorcinol reactive dye displayed FTIR absorptions, 3447 cm^{-1} and 3451 cm^{-1} by enolic OH, and NH stretching, 3010 cm^{-1} by C-H stretching aromatic, 1675 cm^{-1} by C-C (aromatic) stretching and 1520 cm^{-1} by NH bending, 1420 cm^{-1} by N=N stretching and bending, 1070 cm^{-1} by N-O, 1137 cm^{-1} by C-O stretching, 1189 cm^{-1} by C-N stretching, and 1325 cm^{-1} by S=O [1]. 6-napsa-resorcinol Fe-complex reactive dye showed FTIR absorptions, 3423 cm^{-1} by water, enolic OH and NH stretching, 2933 cm^{-1} by (C-H aromatic) stretching, 1593 cm^{-1} by C=C (aromatic) stretching and NH bending, 1474 cm^{-1} by N=N stretching and bending by 1446 cm^{-1}, 1218 cm^{-1} by SO_3H, 1135 cm^{-1} by C-O stretching, 1046 cm^{-1} by N-O, 1148 cm^{-1} C-N stretching, and 1350 cm^{-1} by S=O [3]. 6-napsa-resorcinol Ni-complex reactive dye exhibited wide-ranging FTIR absorptions, 3570 cm^{-1} by water, enolic OH and NH stretching, 3080 cm^{-1} by (C-H aromatic) stretching,1597 cm^{-1} by C-C (aromatic) stretching and NH bending, 1515 cm^{-1} by N=N stretching, and 1446 cm^{-1} bending, 1028 cm^{-1} by N-O, 1350 cm^{-1} by S=O, 1138 cm^{-1} by C-O stretching, 1145 cm^{-1} by C-N stretching, and 1179 cm^{-1} by SO_3H [24]. 6-napsa-resorcinol Cu-complex reactive dye presented extensive FTIR absorptions, 3421 cm^{-1} owing to water, enolic OH and NH stretching, 3080 cm^{-1} by (C-H aromatic) stretching,1589 cm^{-1} by C=C (aromatic) stretching and NH bending, 1459 cm^{-1} by N=N stretching, and 1459 cm^{-1} bending, 1028 cm^{-1} by N-O, 1350 cm^{-1} by S=O, 1133 cm^{-1} by SO_3H, 1137 cm^{-1} by C-O stretching, and 1143 cm^{-1} by C-N stretching [1]. 6-napsa-resorcinol Zn-complex reactive dye offered widespread FTIR absorptions, 3457 cm^{-1} owed to water, enolic OH and NH stretching, 2930 cm^{-1} by (C-H aromatic) stretching,1593 cm^{-1} by C=C (aromatic) stretching and NH bending, 1507

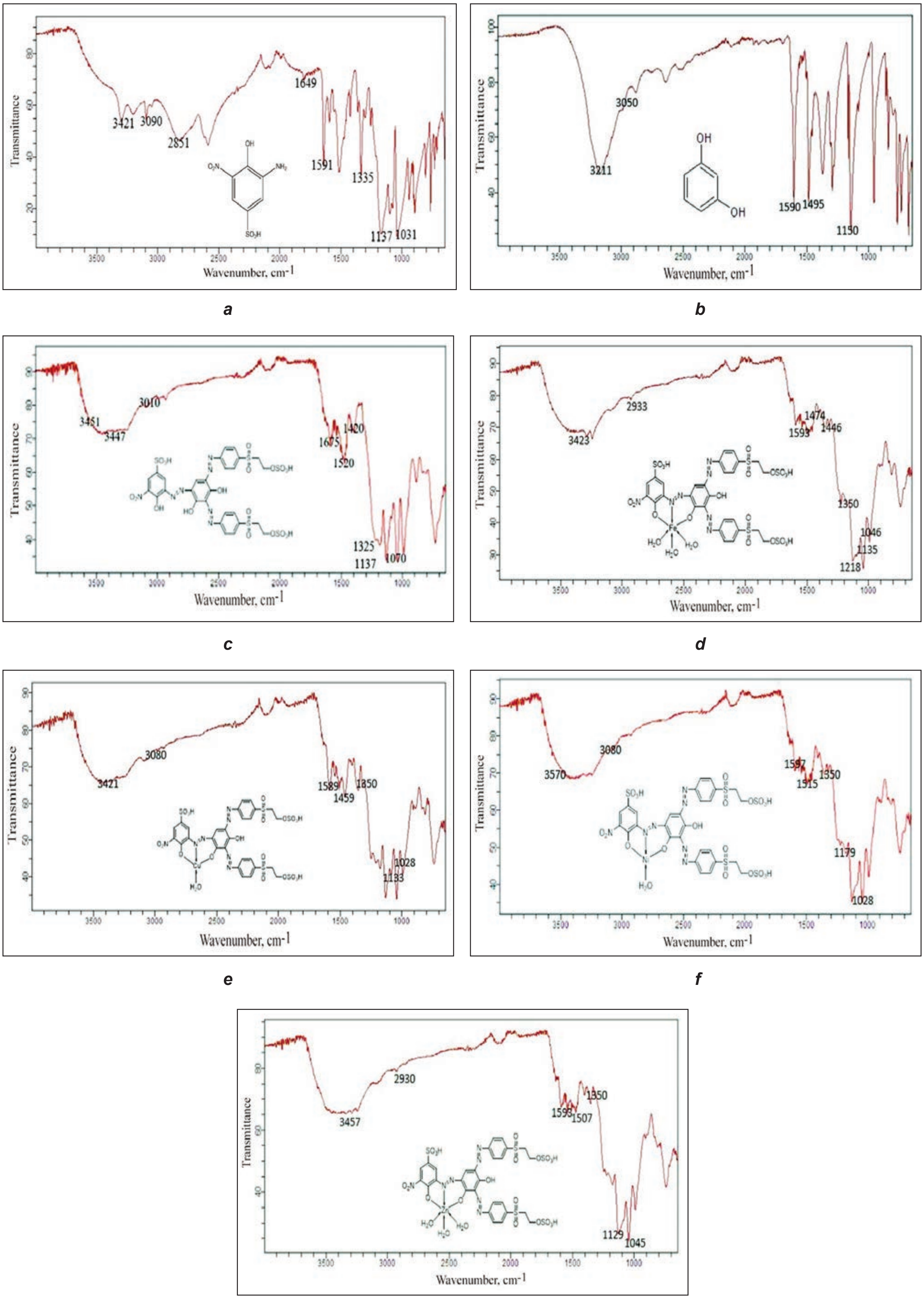

Fig. 5. FTIR spectra: *a* – 6-napsa; *b* – Resorcinol; *c* – un-metallized-6-napsa-resorcinol reactive dye; *d* – 6-napsa-resorcinol Fe-complex reactive dye; *e* – 6-napsa-resorcinol Ni-complex reactive dye; *f* – 6-napsa-resorcinol Cu-complex reactive dye; *g* – 6-napsa-resorcinol Zn-complex reactive dye

cm^{-1} by N=N stretching and bending, 1350 cm^{-1} by S=O, 1129 cm^{-1} by SO_3H, NO_2, 1045 cm^{-1} by C-O stretching, and 1145 cm^{-1} by C-N stretching [1].

Dyeing results of synthesized reactive dye series

The reactive dyes created in this current study were coloured to mercerized cotton cloths. The dyeing procedure has already been discussed in the experimental section. The reactive dyes created from the new derivatization of resorcinol were confirmed for their characteristics by testing coloured cotton cloths. These properties comprised, washing fastness and light fastness. The values are given in table 1. Shade cards, figure 4, show dyeing results [10].

Dyeing properties of synthesized reactive dyes

Reactive dyes created from the new derivatization of resorcinol with advanced colouring properties have been discovered to be very gorgeous. The wash fastness and light fastness were found to have high values of 4–5 on the grey scales, and 4–5 on the blue scales respectively by maximum metal chelate trisazo reactive dyes. 6-napsa-resorcinol copper chelate trisazo reactive dye manifested the highest values of wash fastness, and light fastness, among all 6-napsa-resorcinol metal chelates trisazo reactive dyes, and established itself at the top one for its dyeing properties. The un-metalized 6-napsa-resorcinol trisazo reactive dye ligand revealed minimal values of wash fastness, and light fastness, as expected due to the presence of free hydroxyl groups. Metal chelates formation of 6-napsa-resorcinol trisazo reactive dyes ligand enhanced the entire dyeing properties like wash fastness, and light fastness, substantially. The colouring characteristics of reactive dyes made from the new derivatization of resorcinol are specified in table 1.

CONCLUSIONS

From the unique derivatization of resorcinol, a novel azo reactive dye ligand and its Fe^{2+}, Ni^{2+}, Cu^{2+}, and Zn^{2+} complexes were created, and their structures were characterized. The spectroscopic studies have revealed the structure of the unmetallized dye ligand and its metal complexes. These reactive dyes have been defended by achieving high exhaustion and fixation values. The structures of the chelates generated between the trisazo reactive dye ligand and metal ions (Fe^{2+}, Ni^{2+}, Cu^{2+}, and Zn^{2+}) can be clarified using the information obtained from this investigation, as shown in figure 2. Finally, in the dyeing of cotton fabric, all newly synthesized reactive dyes evaluated performed flawlessly. In the future, we will work to improve the dyeing specifications to enhance the quality of these dyes in corporate dyeing procedures. Reactive dyes made from the new derivatization of resorcinol are intended to replace imports from other countries and aid in the development of cost-effective and economical synthetic reactive dyes in Pakistan.

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