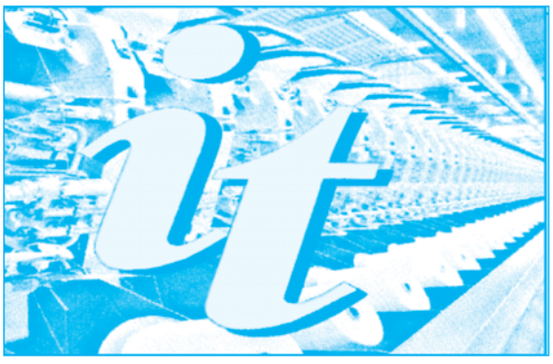


Industria Textilă

ISSN 1222–5347

6/2022

***ISI rated** journal, included in the **ISI Master Journal List** of the Institute of Science Information, Philadelphia, USA, starting with vol. 58, no. 1/2007, with **impact factor 0.828 and AIS 0.070 in 2021**.*

The journal is indexed by CrossRef, starting with no. 1/2017 having the title DOI: https://doi.org/10.35530/IT.

Edited in 6 issues per year, indexed and abstracted in:
Science Citation Index Expanded (SCIE), Materials Science Citation Index®, Journal Citation Reports/Science Edition, World Textile Abstracts, Chemical Abstracts, VINITI, Scopus, Toga FIZ technik, EBSCO, ProQuest Central, Crossref
Edited with the Romanian Ministry of Research, Innovation and Digitalization support

EDITORIAL STAFF

General Manager: Dr. Eng. Alexandra-Gabriela Ene
Editor-in-chief: Dr. Eng. Sabina Olaru
Onorific editor: Dr. Eng. Emilia Visileanu
Graphic designer: Florin Prisecaru
Translator: Cătălina Costea
Site administrator: Constantin Dragomir
e-mail: industriatextila@incdtp.ro

INDUSTRIA TEXTILA journal, edited by INCDTP BUCHAREST, implements and respects Regulation 2016/679/EU on the protection of individuals with regard to the processing of personal data and on the free movement of such data ("RGPD"). For information, please visit the Personal Data Processing Protection Policy link or e-mail to DPO rpd@incdtp.ro

Aknowledged in Romania, in the Engineering sciences domain, by the National Council of the Scientific Research from the Higher Education (CNCSIS), in group A
Journal edited in colaboration with **Editura AGIR**, 118 Calea Victoriei, sector 1, Bucharest, tel./fax: 021-316.89.92; 021-316.89.93; e-mail: editura@agir.ro, www.edituraagir.ro

Nanofiber production from rose water and mate plant extract solutions using environmentally friendly electrospinning

DOI: 10.35530/IT.073.06.202294B

ÇAĞLAR SİVRİ AMINODDIN HAJI

ABSTRACT – REZUMAT

Nanofiber production from rose water and mate plant extract solutions using environmentally friendly electrospinning

In this study, it was aimed to produce nanofibers from polyvinyl alcohol (PVA) polymer using natural solvents such as rose water, rose extract and mate plant extract by the environmentally friendly electrospinning or green electrospinning technique in other words and it was also aimed to investigate the morphological properties of produced nanofibers. For this purpose, nanofibers having 7 different morphologies were produced from 4% PVA aqueous solutions. The morphologies of the produced nanofibers were analysed by scanning electron microscopy (SEM). As a result of these analyses, it was observed that uniform nanofiber morphology was formed in nanofiber productions made with distilled water, while in the others, dense bead structure was formed at low voltages and nanofiber morphology with reduced bead amount at high voltages was observed. In all electrospinning experiments, it was observed that the nanofibers were randomly collected on the collector plate. It was observed that the nanofibers obtained from the solutions prepared from solvents other than distilled water, especially the one from the mate plant extract, had a low bead structure and a smooth morphology. These results showed that environmentally friendly nanofibers can be produced from natural solvents by electrospinning technique and their morphological properties can be improved via modification in process conditions. It is thought that the nanofibers produced within the scope of the study are candidate materials especially for health, hygiene and food applications since they are produced in pure properties without using any other additives.

Keywords: *green electrospinning, nanofibers, rose water, mate, PVA*

Producerea de nanofibre din soluții de apă de trandafiri și extract de plantă mate utilizând electrofilarea ecologică

În acest studiu, s-a urmărit producerea de nanofibre din polimer de alcool polivinilic (PVA) folosind solvenți naturali, cum ar fi apa de trandafiri, extractul de trandafiri și extractul de plantă mate, prin tehnica de electrofilare ecologică sau electrofilare „verde" și, de asemenea, s-a urmărit investigarea proprietăților morfologice ale nanofibrelor produse. În acest scop, din soluții apoase 4% PVA au fost produse nanofibre având 7 morfologii diferite. Morfologiile nanofibrelor produse au fost analizate prin microscopie electronică cu scanare (SEM). În urma acestor analize, s-a observat că s-a format o morfologie uniformă în producțiile de nanofibre realizate cu apă distilată, în timp ce în celelalte s-a format o structură densă a perlelor la tensiuni joase și s-a observat morfologia nanofibrelor cu cantitate redusă de perle la tensiuni înalte. În toate experimentele de electrofilare, s-a observat că nanofibrele au fost colectate aleatoriu pe placa colectoare. S-a observat că nanofibrele obținute din soluțiile preparate din alți solvenți decât apa distilată, în special cea din extractul de plantă mate, aveau o cantitate redusă de perle și o morfologie netedă. Aceste rezultate au arătat că nanofibrele ecologice pot fi produse din solvenți naturali prin tehnica de electrofilare și proprietățile lor morfologice pot fi îmbunătățite prin modificarea condițiilor de proces. Se crede că nanofibrele produse în cadrul studiului sunt materiale destitate în special pentru domeniile sănătate, igienă și aplicații alimentare, deoarece au proprietăți pure, fără a utiliza niciun alt aditiv.

Cuvinte-cheie*: electrofilare ecologică, nanofibre, apa de trandafiri, mate, PVA*

INTRODUCTION

Nanofibers are engineering materials with diameters below 1μm, a large surface area and a high number of interconnected pores [1]. These superior properties have made nanofibers an important candidate for a wide variety of applications such as medical textiles, filtration, isolation, sensing, aerospace, tissue engineering and energy applications [2, 3]. The electrospinning technique has become the most preferred method in the production of nanofibers in the last 20 years, but toxic solvents harmful to nature and human health have been used in many studies. In this context, the nature and human-friendly electrospinning method has gained importance recently, both for political and economic reasons and due to the demands of customers in this direction [4]. Deionized water and acetone have become widely used solvents in nanofiber production with this method which is also called green electrospinning.

Polyvinyl alcohol (PVA) is one of the most commonly used polymers in this method. Researchers produced nanofibers by electrospinning method using PVA polymer and deionized water and reported that the nanofibers obtained as a result of the analyses

were hygienic and environmentally friendly [5, 6]. In another study, researchers produced polyelectrolyte nanofibers with the help of water from a polymer solution of PVA, polyacrylic acid (PAA) and polyethylene imine (PEI) using the electrospinning method, and it was reported that the nanofibers have shown a good antimicrobial activity and an acceptable degree of strength according to the infrared (IR), scanning electron microscope (SEM) [7]. Bosworth and Downes (2012) developed environmentally friendly nanofibers with ideal morphological properties using the electrospinning method with the help of a sustainable acetone solvent [8].

In recent years, apart from PVA polymer, green electrospinning has been realized by using many different polymers such as polyamide 11 (PA 11) [9], chitosan [10], polycaprolactone (PCL)/collagen [11], polyvinylidene fluoride (PVDF)/ polyvinylpyrrolidone (PVP) [12] and polyethylene oxide (PEO) [13]. Apart from electrospinning, there are also studies in which environmentally friendly nanofiber production is carried out by the solution-blowing method, but these studies have not become widespread yet [14, 15].

The production of nanofibers with an environmentally friendly electrospinning technique is relatively common and promising in terms of many functional applications. Some of these applications are health, biomedical and drug distribution [16]. In the field of drug delivery, researchers have developed environmentally and human-friendly nanofiber structures that can distribute natural active substances to provide antimicrobial activity [17] and antioxidant activity [18] with the help of the green electrospinning technique. In another study, researchers developed nanofiber scaffolds using collagen/hydroxyapatite materials with the help of the green electrospinning technique. Another application area is packaging [20, 21]. In a study using pure water as a solvent, the researchers developed nanofibers for the active packaging area with the help of electrospinning [22]. Another application area is filtration [23]. In the article published in the journal Nature Scientific Reports, researchers have produced silk protein nanofibers for highly efficient, environmentally friendly, semi-transparent multifunctional air filters using the electrospinning technique [24].

In this study, the production and characterization of environmentally friendly nanofibers from PVA polymer were carried out using solvents obtained entirely from local sources in Turkey, such as rose water, rose extract, mate plant extract and pure water, which are described as environmentally friendly and green. To the best of our knowledge, no other study was found in which mate plant extract and rose extract extracted from the rose pulp harvested from the field were used as a solvent in the production of nanofibers.

EXPERIMENTAL WORK

Materials

In this study, PVA (100.000 g/mol) obtained from Sigma Aldrich company was used as the polymer. Four different solutions were prepared. In the first, commercial rose water, which was completely supplied from Turkey's domestic resources as a solvent, was obtained from Isparta Gülbirlik Cooperative. The first solution was prepared by adding 96 ml of rose water to 4 g of PVA polymer (4% wt) using this rosewater. For comparison, rose extract (pure rose water) was obtained by collecting roses directly from the rose fields in the Senir district of Isparta during the harvest season and keeping them in pure water at approximately 90°C and used within the scope of the study. For this second solution, 10 g of fresh rose leaves were extracted by adding 100 ml of hot water, and then a solution was prepared by adding 96 ml of pre-prepared rose extract to 4 g of PVA polymer (4% wt). For the third solution, the Mate plant, originating from South America, was obtained from a herbalist in Isparta and the extract has been prepared. Mate plant is an antioxidant plant containing 24 vitamins and minerals [25]. For this study, the extract was prepared by adding 10 g of mate plant leaves to 100 ml of hot water. The third solution was prepared by adding 96 ml of pre-prepared mate plant extract to 4 g of PVA polymer (4% wt). Finally, for comparison purposes, the fourth solution was prepared by adding 96 ml of distilled water to 4 g of PVA polymer (4% wt). The properties of the prepared solutions are given in table 1.

Table 1

SOLUTION PROPERTIES USED IN NANOFIBER PRODUCTION

Solution acronym	Polymer and concentration (%)	Solvent and concentration (%)
RWPVA	PVA (4%)	Rose water (96%)
REPVA	PVA (4%)	Rose extract (96%)
MTPVA	PVA (4%)	Mate extract (96%)
DWPVA	PVA (4%)	Distilled water (96%)

Electrospinning

In this study, environmentally friendly nanofiber production was carried out using the electrospinning technique under variable process conditions. Electrospinning is the most widely used technique in the production of nanofibers today. In this technique, production is carried out with a simple mechanism that can be installed at an affordable cost. The electrospinning apparatus consists of an electronically controlled syringe pump, a syringe, a high-voltage power supply and a collector plate. As can be understood from the configuration of the device, principally the polymer fed from the syringe is subjected to an electrostatic force at a certain voltage (kV) and collected on the collector plate in the form of nanofibers [26]. In this study, an Electrospinning device belonging

Table 2

PROCESS PARAMETERS APPLIED IN ELECTROSPINNING			
Voltage (kV)	**Collector-nozzle distance (cm)**	**Polymer feeding rate (ml/h)**	**Solution**
13	6	0.35	DWPVA
13	6	0.45	RWPVA
21	12	0.45	RWPVA
9	6	0.35	REPVA
13	8	0.35	REPVA
19	8	0.35	MTPVA
23	10	0.35	MTPVA

to Inovenso Ltd & Inc. Company originating from Turkey was used. During the operation, the ambient temperature was between 27–32 ºC and the relative humidity was between 35% and 45%. The process parameters applied for electroproduction are given in table 2.

Scanning Electron Microscope (SEM) analysis

Alignment and morphological properties of the obtained nanofibers were characterized using an SEM instrument (LEO 440, Technical Sales Solutions, Beaverton, OR, ABD).

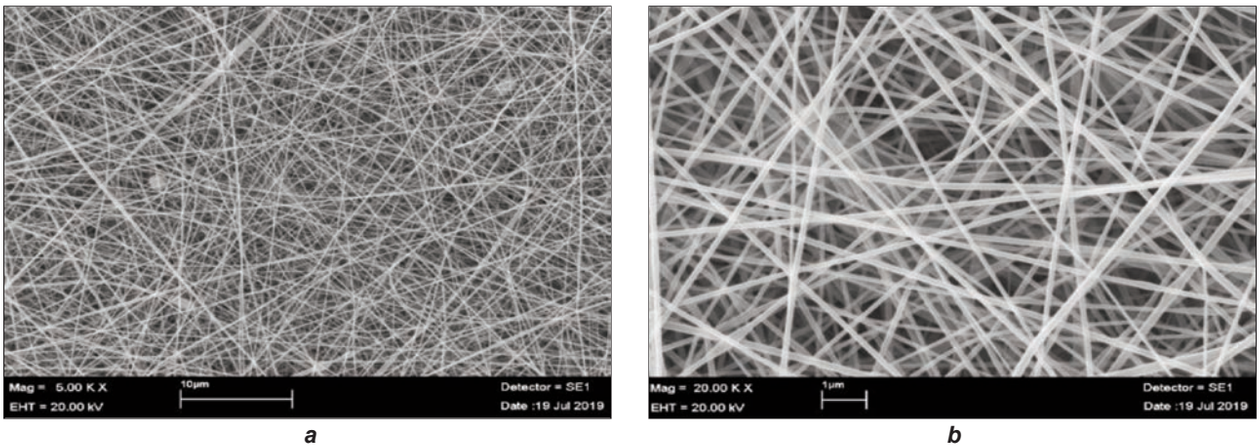
RESULTS AND DISCUSSIONS

In this study, nanofibers were produced from DWPVA, RWPVA, REPVA, and MTPVA solutions, respectively, by the electrospinning method and the morphologies of the produced nanofibers were characterized using SEM.

In figure 1, SEM images of nanofibers produced from the DWPVA solution obtained by dissolving PVA in pure water at 13 kV voltage, 6 cm collector-nozzle distance and 0.35 ml/h process conditions are given. It was observed that the produced nanofibers were randomly collected on the collector and the fibre distribution was randomly oriented. Also, no bead formation was observed.

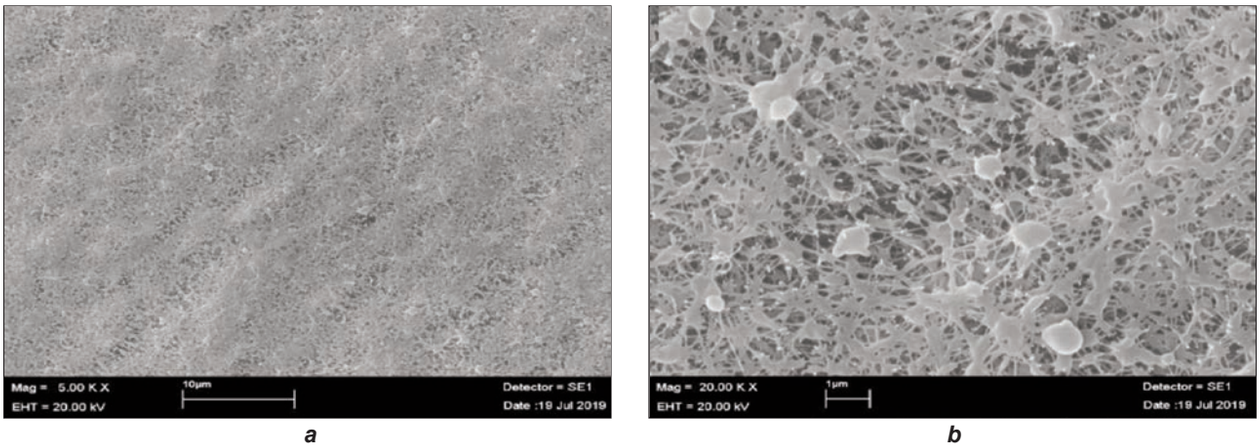
In figure 2, SEM images of nanofibers produced from the RWPVA solution in process conditions of 13 kV voltage, 6 cm collector-nozzle distance and 0.45 ml/h polymer feeding rate were given. When the images were examined, it was observed that although fibre formation was observed, a high number of beads occurred.

In figure 3, SEM images of nanofibers produced from the RWPVA solution in process conditions of 21 kV



a *b*

Fig. 1. SEM images of nanofibers produced from DWPVA solution: *a* – 5 kX; *b* – 20 kX



a *b*

Fig. 2. SEM images of nanofibers produced from RWPVA solution: *a* – 5 kX; *b* – 20 kX

voltage, 12 cm collector-nozzle distance and 0.45 ml/h polymer feeding rate were given. When the images were examined, it was observed that beads also occurred under these process conditions, but the fibre formation was relatively more apparent than in the previous one. This partial improvement in fibre structure is thought to be a result of operating under higher voltage conditions.

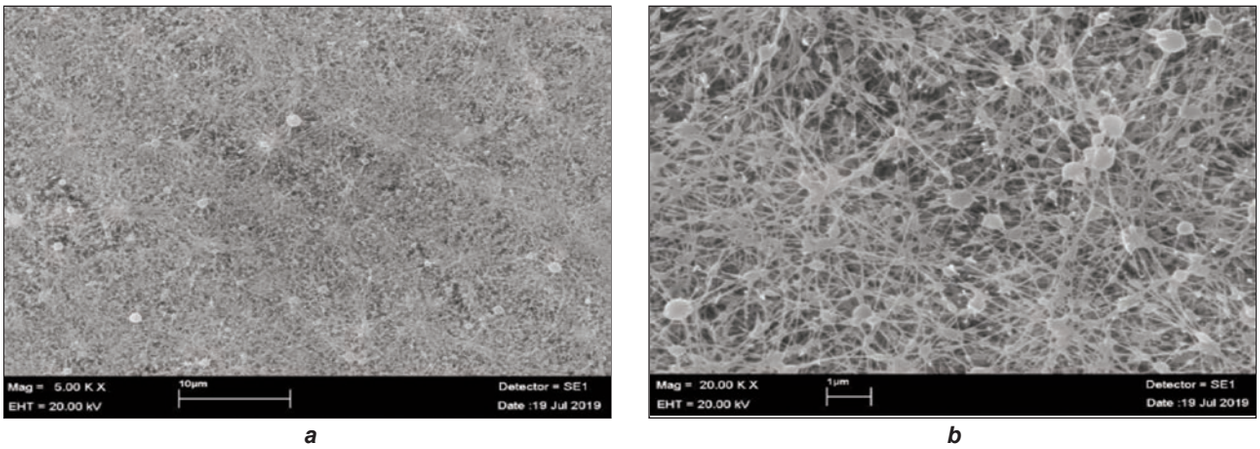
In figure 4, SEM images of nanofibers produced from the REPVA solution in process conditions of 9 kV voltage, 6 cm collector-nozzle distance and 0.35 ml/h polymer feeding rate were given. When the images were examined, it was observed that although fibre formation was observed, intense bead formation also occurred.

In figure 5, SEM images of nanofibers produced from the REPVA solution in process conditions of 13 kV voltage, 8 cm collector-nozzle distance and 0.35 ml/h polymer feeding rate were given. When the images were examined, it was seen that the bead formation decreased slightly with the increase in voltage, and the fibrous structure became more noticeable. The results obtained so far are in accordance with studies by different researchers in the literature and especially confirm the voltage-bead formation relationship [27, 28].

In figure 6, SEM images of nanofibers produced from the MTPVA solution in process conditions of 19 kV voltage, 8 cm collector-nozzle distance and 0.35 ml/h polymer feeding rate were given. When the images were examined, bead formation was observed in the nanofibers, but it was also seen that the fibre structure is evident.

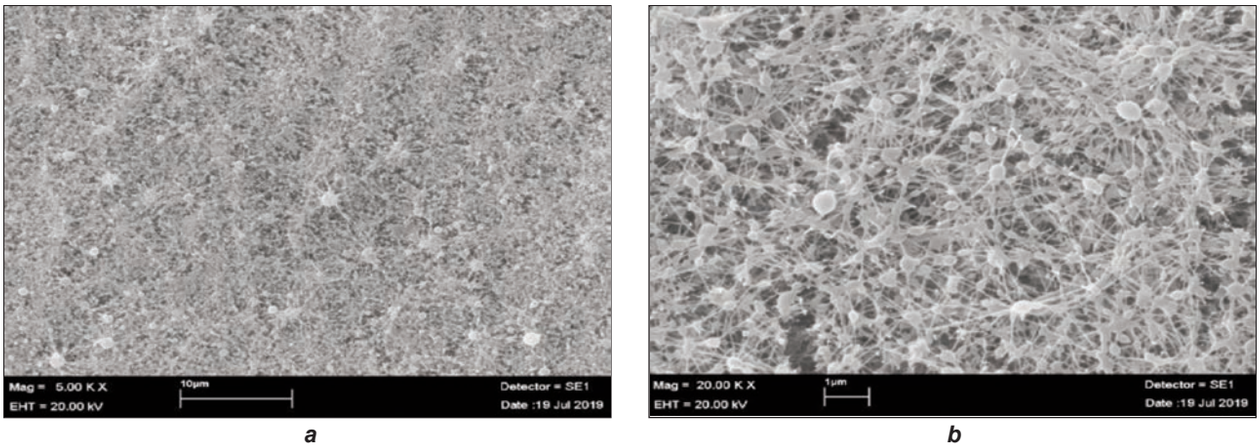
In figure 7, SEM images of nanofibers produced from the MTPVA solution in process conditions of 23 kV voltage, 10 cm collector-nozzle distance and 0.35 ml/h polymer feeding rate were given. When the images were examined, it was seen that the bead formation decreased significantly with the increase of the voltage applied to the electrospinning area and the nanofibers with regular morphology were randomly collected on the collector plate. The results obtained in this part of the study are compatible with the results of the nanofibers produced using the RWPVA solution and the literature information in this field.

In other relevant literature, there are also studies in which structures such as carbon nanotubes are added to the polymer solution, unlike increasing the voltage applied to the electrospinning area to reduce bead formation and enhance the nanofiber structures [29, 30]. Future studies of the current research, it is



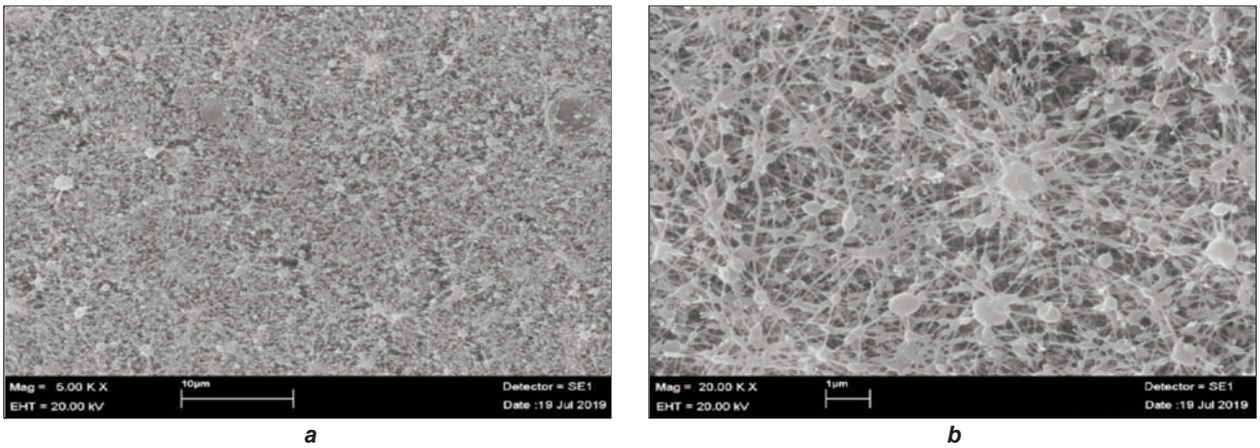
a *b*

Fig. 3. SEM images of nanofibers produced from RWPVA solution: *a* – 5 kX; *b* – 20 kX



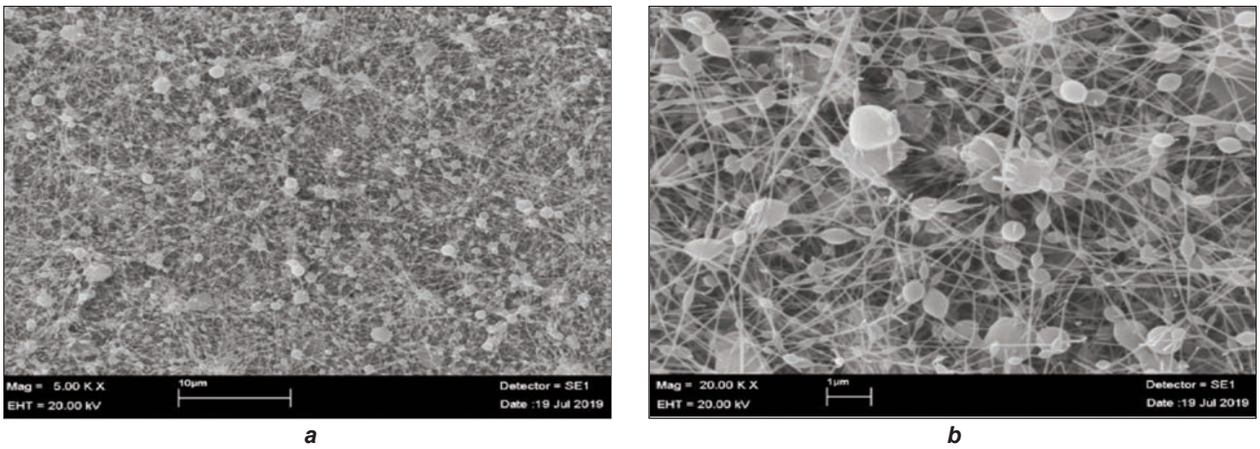
a *b*

Fig. 4. SEM images of nanofibers produced from REPVA solution: *a* – 5 kX; *b* – 20 kX



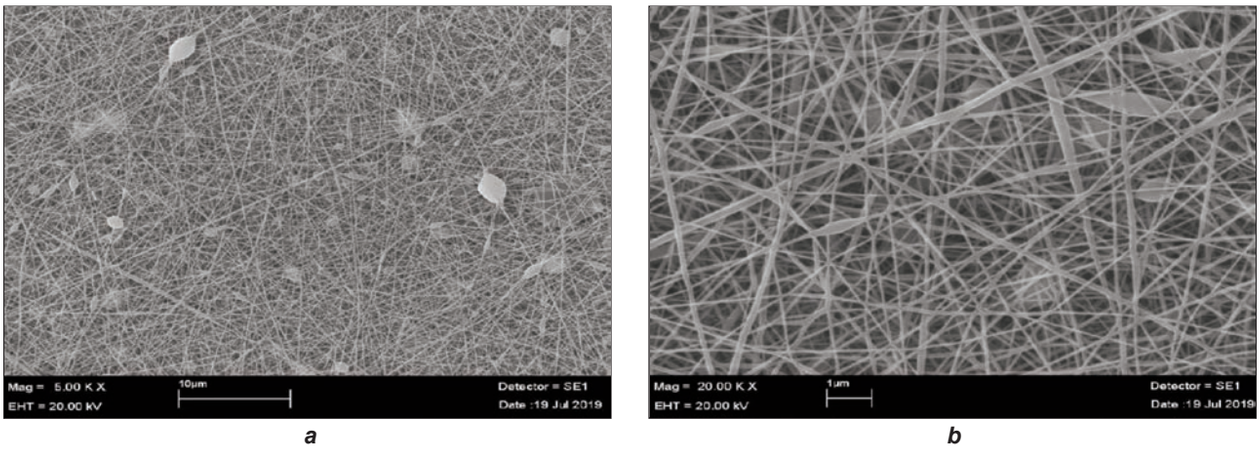
a *b*

Fig. 5. SEM images of nanofibers produced from REPVA solution: *a* – 5 kX; *b* – 20 kX



a *b*

Fig. 6. SEM images of nanofibers produced from MTPVA solution: *a* – 5 kX; *b* – 20 kX



a *b*

Fig. 7. SEM images of nanofibers produced from MTPVA solution: *a* – 5 kX; *b* – 20 kX

aimed to add nature-friendly structures/particles to the solution to diversify and improve the morphology of nanofibers to be produced.

CONCLUSIONS

In this study, environmentally friendly nanofiber production was carried out under varying process conditions (voltage, collector-nozzle distance, feed rate) with the help of the electrospinning technique using commercially available rose water, harvested rose extract and mate plant extract as solvents. To be a reference product, PVA polymer was first dissolved in pure water, then nanofiber production was carried out by electrospinning, and as a result of SEM analysis, it was observed that nanofibers had uniform morphology and fibre distribution. In nanofiber production studies carried out with rose water under 2 different process conditions, a partial decrease in the number

of beads that formed in the fibres was observed with the increase of the voltage applied to the electrospinning area. In nanofiber production studies carried out with rose extract under 2 different process conditions, it was observed that pilling occurred in high amounts, especially in low-voltage production and fibre formation came to the forefront with increasing voltage. In nanofiber production studies carried out under 2 different process conditions in which Mate plant extract was used as a solvent, beads formed at low voltage as in previous studies, but a critical decrease was observed in the number of beads when the voltage was increased, and the fibre morphology was found to be almost as uniform as the morphology of the nanofibers obtained in the reference production carried out with distilled water. These results show that especially the applied voltage has critical importance considering process conditions. Environmentally friendly nanofibers were successfully produced from all solvents used in the study. These nanofibers have the potential to be an ideal material for areas such as health, hygiene and food, where naturalness, biocompatibility and sustainability are important and necessary. Since nanofibers produced using mate plant extract have a more uniform morphology, they may have the potential to be used in applications such as drug release, tissue engineering and wound healing where fibre orientation is important.

REFERENCES

[1] Tiyek, İ., Arısal Çetin, E., *Production of Zinc Borate koped P(AN-VAc) nanofiber textile surfaces by electrospinning method and their thermal characterization*, In: Journal of the Faculty of Engineering and Architecture of Gazi University, 2021, 36, 4, 1893–1908

[2] Oteyaka, M., Oze,l E., Yıldırım, M., *Experimental Study on Relationship of Applied Power And Feeding Rate on Production of Polyurethane Nanofibre*, In: Gazi University Journal of Science, 2014, 26, 4, 611–618

[3] Sivri, Ç., *Development of nanofiber structures having novel morphologies differentiated with the help of organic acids*, In: The Journal of The Textile Institute, 2017, 108, 11, 1879–1887

[4] Horzum, N., Muñoz□Espí, R., Hood, M.A., Demir, M.M., Crespy, D., *Green electrospinning, Green Electrospinning*, De Gruyter, 2019, 1–9, https://doi.org/10.1515/9783110581393-001

[5] Lin, S., Wang, R., Yi, Y., Wang, Z., Hao, L., Wu, J., Hu, G., He, H., *Facile and green fabrication of electrospun poly(vinyl alcohol) nanofibrous mats doped with narrowly dispersed silver nanoparticles*, In: International Journal of Nanomedicine, 2014, 9, 3937–3947

[6] Hell, S., Ohkawa, K., Amer, H., Potthast, A., Rosenau, T., *Dialdehyde Cellulose Nanofibers by Electrospinning as Polyvinyl Alcohol Blends: Manufacture and Product Characterization*, In: Journal of Wood Chemistry and Technology, 2018, 38, 96–110

[7] Sridhar, R., Sundarrajan, S., Vanangamudi, A., Singh, G., Matsuura, T., Ramakrishna, S., *Green Processing Mediated Novel Polyelectrolyte Nanofibers and Their Antimicrobial Evaluation*, In: Macromolecular Materials and Engineering, 2014, 299, 283–289

[8] Bosworth, L.A., Downes, S., *Acetone, a Sustainable Solvent for Electrospinning Poly(ε-Caprolactone) Fibres: Effect of Varying Parameters and Solution Concentrations on Fibre Diameter*, In: Journal of Polymers and the Environment, 2012, 20, 879–886

[9] Mailley, D., *Fabrication of nanofibrous mats by "green" electrospinning for liquid microfiltration applications*, PhD Thesis, Université de Strasbourg, Strasbourg, 2018

[10] Pervez, M.N., Stylios, G.K., *An Experimental Approach to the Synthesis and Optimisation of a 'Green' Nanofibre,* In: Nanomaterials, 2018, 8, 6, 383, 1–20

[11] Miele, D., Catenacci, L., Rossi, S., Sandri, G., Sorrenti, M., Terzi, A., Giannini, C., Riva, F., Ferrari, F., Caramella, C., Bonferoni, M.C., *Collagen/PCL Nanofibers Electrospun in Green Solvent by DOE Assisted Process. An Insight into Collagen Contribution,* In: Materials, 2020, 13, 21, 4698, https://doi.org/10.3390/ma13214698

[12] Irfan, M., Uddin, Z., Ahmad, F., Rasheed, A., Qadir, M.B., Ahmad, S., Aykut, Y., Nazir, A., *Ecofriendly development of electrospun antibacterial membranes loaded with silver nanoparticles*, In: Journal of Industrial Textiles, 2021, https://doi.org/10.1177/15280837211012590

[13] Al-Azab, M., Mitchell, G.R., Davis, F.J., Mohan, S.D., *Sustainable electrospinning of nanoscale fibres,* In:Procedia Manufacturing, 2017, 12, 66–78

[14] Polat, Y. , Yangaz, M.U., Çalışır, M.D., Gül, M.Z., Demir, A., Ekici, B., Kılıç, A, *Effect of air pressure on nanofiber production in solution blowing method,* In: Journal of the Faculty of Engineering and Architecture of Gazi University, 2020, 35, 4, 1719–1728

[15] An, S., Jo, H.S., Li, G., Samuel, E., Yoon, S.S., Yarin, A.L., *Sustainable Nanotextured Wave Energy Harvester Based on Ferroelectric Fatigue-Free and Flexoelectricity-Enhanced Piezoelectric P(VDF-TrFE) Nanofibers with BaSrTiO3 Nanoparticles,* In: Advanced Functional Materials, 2020, 30, 25, https://doi.org/10.1002/adfm.202001150

[16] Malik, S., Sundarrajan, S., Hussain, T., Nazir, A., Ayyoob, M., Berto, F., Ramakrishna, S., *Sustainable nanofibers in tissue engineering and biomedical applications*, In: Mat. Design Process Comm., 2020, https://doi.org/10.1002/mdp2.202

[17] Peršin, Z., Ravber, M., Kleinschek, K.S., Knez, Ž., Škerget, M., Kurecic, M., *Bio-nanofibrous mats as potential delivering systems of natural substances*, In: Textile Research Journal, 2017, 87, 444–459

[18] Wang, L., Wang, C., Wang, L., Zhang, Q., Wang, Y., Xia, X., *Emulsion electrospun polylactic acid/Apocynum venetum nanocellulose nanofiber membranes with controlled sea buckthorn extract release as a drug delivery system*, In: Textile Research Journal, 2020, 91, 1046–1055

[19] Castilla-Casadiego, D., Maldonado, M., Sundaram, P., Almodovar, J., *"Green" electrospinning of a collagen/hydroxyapatite composite nanofibrous scaffold*, In: MRS Communications, 2016, 6, 4, 402–407

[20] Rodríguez-Sánchez, I.J., Fuenmayor, C.A., Clavijo-Grimaldo, D., Zuluaga-Domínguez, C.M., *Electrospinning of ultra-thin membranes with incorporation of antimicrobial agents for applications in active packaging: a review,* In: International Journal of Polymeric Materials and Polymeric Biomaterials, 2020, 70, 15, 1053–1076

[21] Aman-Mohammadi, M., Rostami, M.R., Raeisi, M., Tabibi-Azar, M., *Production of Electrospun Nanofibers from Food Proteins and Polysaccharides and Their Applications in Food and Drug Sciences*, In: Jorjani Biomedicine Journal, 2018, 6, 4, 62–77

[22] Felix, M., Jimenez, C.R., Romero, A., Guerrero, A., *PVA-based electrospun nanofiber mats of potential use in active packaging,* In: International Journal of Environmental & Agriculture Research (IJOEAR), 2016, 2, 8, 7–14

[23] Lv, D., Zhu, M., Jiang, Z., Jiang, S., Zhang, Q., Xiong, R., Huang, C., *Green Electrospun Nanofibers and Their Application in Air Filtration*, In: Macromolecular Materials and Engineering, 2018, 303, 12, https://doi.org/10.1002/mame.201800336

[24] Min K., Kim S., Kim S., *Silk protein nanofibers for highly efficient, eco-friendly, optically translucent, and multifunctional air filters*, Scientific Reports, 8, Doi:10.1038/s41598-018-27917-w, 2018.

[25] Ziemlewska, A., Nizioł-Łukaszewska, Z., Bujak, T., Zagórska-Dziok, M., Wójciak, M., Sowa, I., *Effect of fermentation time on the content of bioactive compounds with cosmetic and dermatological properties in Kombucha Yerba Mate extracts*, In: Scientific Reports, 2021, 11, https://doi.org/10.1038/s41598-021-98191-6

[26] Banciu, C., Băra, A., Chițanu, E., Marinescu, V., Sbârcea, G., Ion, I., *The effect of process parameters on the electrospun polystyrene fibers*, In: Industria Textila, 2018, 69, 4, 263–269, http://doi.org/10.35530/IT.069.04.1481

[27] Subrahmanya T.M., Arshad, A.B., Lin, P.T., Widakdo, J., Makari, H.K., Austria, H.F.M., Hu, C., Lai, J., Hung, W.S., *A review of recent progress in polymeric electrospun nanofiber membranes in addressing safe water global issues*, In: RSC Advances, 2021, 11, 9638–9663

[28] Liu, Y., Dong, L., Fan, J., Wang, R., Yu, J., *Effect of applied voltage on diameter and morphology of ultrafine fibers in bubble electrospinning,* In: Journal of Applied Polymer Science, 2011, 120, 592–598

[29] Ramakrishna, A., Fujihara, K., Teo, W.E., Lim, T.C., ve Ma, Z., *An Introduction to Electrospinning and Nanofibers*, World Scientific Publishing, London, UK, 2005

[30] Köysüren, Ö., Köysüren, H.N., *Polivinil alkol kompozit nanoliflerin hazırlanması ve katı-faz polivinil alkol'ün fotokatalitik bozunması,* In: Gazi Üniversitesi Mühendislik Mimarlık Fakültesi Dergisi, 2018, 33, 4, 1411–1418

Authors:

ÇAĞLAR SİVRİ[1], AMINODDIN HAJI[2]

[1]Bahçeşehir University, Faculty of Engineering and Natural Sciences, Department of Management Engineering, Ciragan Cd. Yali Sk. No=1, 34349, Istanbul, Türkiye

e-mail: caglar.sivri@eng.bau.edu.tr

[2]Department of Textile Engineering, Yazd University, Yazd 8915818411, Iran

e-mail: ahaji@yazd.ac.ir

Corresponding author:

ÇAĞLAR SİVRİ

e-mail: caglar.sivri@eng.bau.edu.tr

A study of the functionality of conventional pigmented inks in furnishing electrical conductivity to textiles

DOI: 10.35530/IT.073.06.202159

MUHAMMAD ALI
MUHAMMAD OWAIS RAZA SIDDIQUI
MUHAMMAD ZUBAIR
LONG LIN

ABSTRACT – REZUMAT

A study of the functionality of conventional pigmented inks in furnishing electrical conductivity to textiles

Electronic textiles technologies are finding widespread use in numerous sectors of our daily lives. One of the main enabling technologies for e-textiles is the additive deposition of functional material. The functional coatings that are used for such applications are based on a variety of materials such as conductive polymers, carbon-based materials, metals etc. There are several limitations associated generally with the commercially available conductive inks for non-textile substrates. The major limitations include (but are not limited to) high cost, inferior performance in terms of washing and creasing and difficulty in application, etc. In this study, we have evaluated two commercially available conductive inks and compared their washing and creasing performance with a conventional pigment printing system.

Keywords: *conductive textiles, carbon black, surface resistivity, pigment printing, e-textiles*

Un studiu al funcționalității cernelurilor pe bază de pigment convenționale în asigurarea conductivității electrice a materialelor textile

Tehnologiile textilelor electronice sunt utilizate pe scară largă în numeroase sectoare ale vieții noastre de zi cu zi. Una dintre principalele tehnologii de realizare a e-textilelor este depunerea aditivului pe materialul funcțional. Acoperirile funcționale, care sunt utilizate pentru astfel de aplicații, se bazează pe o varietate de materiale, cum ar fi polimeri conductivi, materiale pe bază de carbon, metale etc. Există câteva limitări asociate în general cu cernelurile conductive disponibile în comerț pentru substraturi netextile. Limitările majore includ (dar nu se limitează la) costuri ridicate, performanțe inferioare în ceea ce privește spălarea și șifonarea și dificultatea de aplicare etc. În acest studiu, am evaluat două cerneluri conductive disponibile în comerț și am comparat performanța lor de spălare și șifonare cu un sistem convențional de imprimare cu pigment.

Cuvinte-cheie*: materiale textile conductive, negru de fum, rezistivitate la suprafață, imprimare cu pigment, e-textile*

INTRODUCTION

Owing to its several applications, the electronic textiles (e-textiles) sector is attracting significant interest from the research community in academia and industry. As a result, the associated technologies are rapidly developing [1–3]. To fabricate various components of an electronic system on a textile fabric, one of the frequently employed methods is the printing of functional material to impart the desired functionality to the textile substrate [4]. For such printing, printing inks possessing a broad range of electrical characteristics are used [5]. The technology of conductive inks is not new. Instead, the printing of conductive inks on non-textile substrates is a well-developed technology [6, 7]. However, in the case of printing onto a textile fabric, such inks are generally not able to meet the performance requirements in terms of washing and creasing etc. [8]. Work is being done to produce inks that are suitable for imparting conductivity [9], magnetism, or other functionalities to the textile substrate. For this purpose, a broad range of materials is used, such as conductive polymers [10–17], gold [18], silver [19–21] or copper-nanoparticles [22], carbon-based conductive materials such as graphite [23], graphene [24, 25] and carbon nanotubes [26] etc. Some of these materials have considerably higher costs while some suffer from a lack of performance and functionality. For instance, carbon black pigments are generally considered to be lower in cost compared to other conductive materials such as silver nanoparticles. However, such materials are known to possess inferior electrical conductivity compared to metal nanoparticles. In this work, we have tested commercially available, carbon-based electrically conductive inks and compared their performance with that of a conventional pigment printing system for textiles. The results showed that even a conventional pigment printing ink system can be used to produce ink films possessing a broad range of electrical conductivity and therefore, it is promising for several e-textiles application areas.

MATERIALS AND METHODS

Commercial inks

The surface resistivity and the durability (resistance to washing and creasing) of the conventional pigment printing inks were compared against two commercially

available highly conductive carbon-based inks, listed in table 1. The surface resistivity values that are shown in table 1 relate to a 25 microns thick ink layer deposited on a polyimide film.

Table 1

COMMERCIAL CONDUCTIVE INKS USED IN THE STUDY			
Product	**Supplier**	**Description**	**Surface resistivity (Ω/□)**
C2030519P4 Carbon/ Graphite ink	Gwent Electronic Materials Ltd	Carbon sensor paste	13–20
SD 2843 HAL	Peters GmBH	Carbon conductive ink	10

Pigment printing ink

The Printofix pigment printing system from Clariant (Archroma), details of which are provided in table 2, was used in this work.

Table 2

CLARIANT'S PRINTOFIX PIGMENT SYSTEM	
Product name	**Description**
Printofix Thickener CSN liq	Thickener
Printofix Binder 83 liq	Binder for pigment print system
Printofix Black H-RT	Carbon black pigment dispersion

Substrate

Textile substrates such as 100% Cotton, 100% Polyester and PC blends do not possess electrical conductivity on their own and thus are good insulators [27]. The substrates used in this study are plain woven100% cotton fabric and 100% Polyester fabric. The specifications are provided in table 3. Due to low GSM, the 100% polyester fabric was coated with Printofix Binder 83 in its as-supplied form. Printofix Binder 83 is a typical binder for pigment printing and it was used as a primer layer on the 100% polyester fabric. The GSM of fabric is known to affect its properties such as conductivity after the application of a conductive ink/coating. However, the objective of the present study was to compare cotton and polyester for their suitability as substrates for functional printing. Thus, the effects of GSM variation were not studied.

Table 3

SPECIFICATIONS (PROVIDED BY SUPPLIER) OF TEXTILE SUBSTRATES USED IN THE STUDY		
Substrate	**Weave**	**GSM (g/m^2)**
100% cotton	1 × 1 plain	80
100% polyester	1 × 1 plain	55

Testing and characterisation

The inks were drawn on the substrates using a hand coater apparatus. K-bar no 6 was used for this purpose. Washing tests were performed according to BS EN ISO 105:CO6 (Test A1M). For the creasing test, the ASTM F 2749-09 test method was adopted. The surface resistivity of the samples was measured using an electrode designed to cover the 9 cm^2 area of the sample. The electrode was pressed onto the substrate using a 500 g weight.

RESULTS AND DISCUSSION

After printing, the samples were cured according to the curing conditions specified by the ink manufacturer. The results of these washing tests are summarised in table 4.

Table 4

WASHING TESTS RESULTS OF COMMERCIAL INKS				
Ink name	**Substrate**	**Surface resistivity (Ω/□)**		
		Before wash	**After wash**	**% Increase**
Gwent C2030519P4	Uncoated Cotton	20.83	81.9	293.18
Gwent C2030519P4	Coated Polyester	19.14	77.4	304.39
Peters SD 2843 HAL	Uncoated Cotton	59.96	NR	-
Peters SD 2843 HAL	Coated Polyester	42.5	307	622.35
Printofix ink	Uncoated Cotton	716	838	17.04
Printofix ink	Coated Polyester	688	721	4.79

Note: NR refers to 'no reading', i.e., the surface resistivity was higher than 100 MΩ.

Before washing, the surface resistivity of ink layers produced from the commercial inks was considerably lower than the surface resistivity of the films produced from the Printofix pigment ink. However, the films produced from the commercial inks were less durable, as indicated by a significantly greater increase in surface resistivity after washing.

Furthermore, as shown in figure 1, commercial inks were removed from large areas of the fabrics during washing. This showed that the commercial inks tested were not suitable for printing fine lines, a quality that is often required of prints when printing electrical interconnects or resistive patterns.

Furthermore, the increase in the surface resistivity, when an ink film was deposited on Printofix Binder 83 coated polyester fabric, was less than that in the surface resistivity of the film of the same ink deposited onto uncoated cotton fabric. Thus, the creasing resistance of only the ink films produced on Printofix Binder 83 coated polyester fabric was tested. The durability of the ink films to withstand up to five creasing cycles was tested and the surface resistivity was

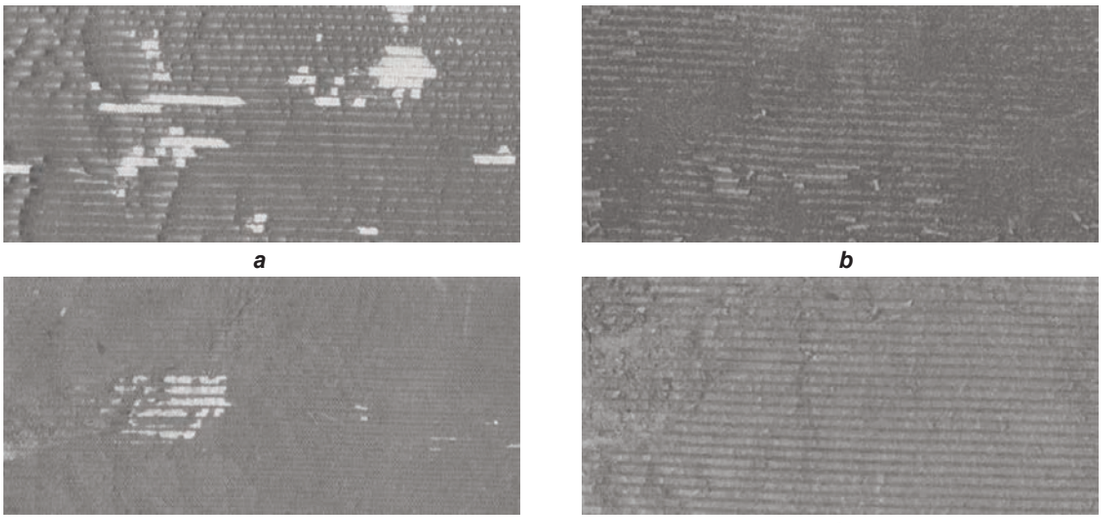


Fig. 1. Image recorded after washing of: *a* – Peters carbon ink on coated polyester; *b* – Peters carbon ink on uncoated cotton; *c* – Gwent carbon ink on coated polyester; *d* – Gwent carbon ink on uncoated cotton

recorded after each cycle. The results are tabulated in table 5. The results of creasing tests indicate that the overall increase in the surface resistivity of the films produced from the Printofix pigment ink was considerably lower compared to the increase in surface resistivity of films produced from the commercial inks.

Due to the promising results obtained for the Printofix pigment system, print pastes containing different amounts of the Printofix Black H-RT pigment were prepared. The formulations (table 6) were prepared in the same manner as normal printing inks are prepared for the textile printing. The only exception is that a binder was not added. This is because the primary objective here was to estimate the decrease that occurs in electrical resistivity upon increasing the pigment loading in the ink formulation. The resistance of the printed samples was recorded using an interdigitated electrode (provided by Peratech Holdco Limited, UK) which provided the advantage of being able to measure the electrical resistance of multiple parallel resistor elements as shown in figure 2. The resistance values obtained are tabulated in table 7.

Table 5

SURFACE RESISTIVITY OF INKS RECORDED DURING CREASE TESTING OF INK FILMS

Ink composition	Surface resistivity (Ω/□)						
	Number of crease cycles						% Increase
	0	1	2	3	4	5	
Peters SD 2843 HAL carbon ink	28	63	98	157	196	411	311.00
Gwent C2030519P4 carbon ink	20	71	170	302	432	550	450.00
Printofix Ink	660	667	667	672	680	699	7.42

Table 6

COMPOSITION OF PRINT PASTES CONTAINING PRINTOFIX BLACK H-RT PIGMENT

Pigment (Printofix Black T-M)			Thickener			Water	
w/w% of total	Calculated amount (g)	Actual amount (g)	w/w% of total	Calculated amount (g)	Actual amount (g)	Calculated amount (g)	Actual amount (g)
4	0.8	0.800	1.8	0.360	0.360	18.84	18.98
6	1.2	1.214	1.8	0.360	0.363	18.44	18.451
8	1.6	1.604	1.8	0.360	0.361	18.04	18.042
10	2.0	2.004	1.8	0.360	0.360	17.64	17.660
12	2.4	2.401	1.8	0.360	0.363	17.24	17.241
14	2.8	2.800	1.8	0.360	0.362	16.84	16.844
16	3.2	3.196	1.8	0.360	0.362	16.44	16.442

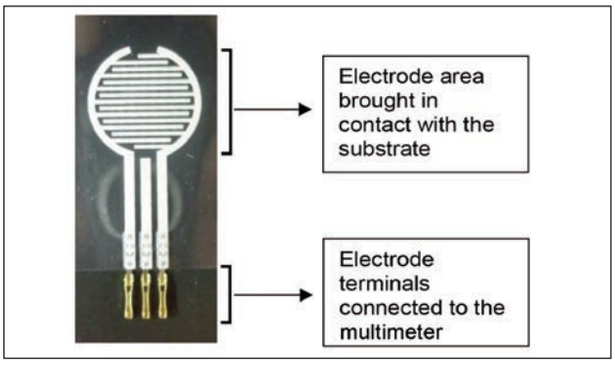


Fig. 2. Interdigitated electrode used for resistance measurement

Table 7

DC ELECTRICAL RESISTANCE MEASURED USING INTERDIGITATED ELECTRODE	
Amount of pigment Printofix Black TM (wt %)	**Resistance (Ω)**
4	45
6	24
8	17
10	15
12	12.5
14	11.5
16	11.5

CONCLUSION

In this work, we have tested commercially available, carbon-based conductive inks and compared their washing and creasing performance with that of a conventional pigment printing system for textile substrates. We found, as expected, that the surface resistivity of ink layers produced using commercial inks was considerably lower compared to the surface resistivity of ink films produced from a conventional pigment print system. However, the washing and creasing performance of the conventional pigment print system was considerably superior compared to that of the commercial conductive inks. This can be attributed to the fact that conventional pigmented carbon black systems contain pigment grades that have the low surface area and thus they can be added to the formulation in relatively large quantities. Furthermore, the polymeric binders preferably used in conventional pigment printing produce films that are soft and flexible and thus they are better able to withstand washing and creasing actions to which textiles are subjected during the end use. This clearly shows that such a conventional pigment print system can be fine-tuned with relative ease for a range of functional applications. The amount of pigment can be easily increased for further improvement in electrical conductivity as demonstrated in this study.

ACKNOWLEDGEMENTS

The authors would like to acknowledge NED University of Engineering & Technology, Karachi, for the moral support provided during the study.

REFERENCES

[1] Gemperle, F., et al., *Design for wearability,* In: Second International Symposium on Wearable Computers, 1998
[2] Marculescu, D., *E-textiles: toward computational clothing,* In: Pervasive Computing, IEEE, 2003, 2, 1, 89–95
[3] Troster, G., Kirstein, T., Lukowicz, P., *Wearble computing: Packaging in textiles and clothes*, In: 14th European Microelectronics and Packaging Conference & Exhibition, Wearble Computing Lab, ETH Zurich: Friedrichshafen, Germany, 2003
[4] Kannaian, T., Janarthanan, M., Thilagvathi, G., *An overview of electronic textiles,* In: The Institute of Engineers (India) Journal – Textiles, 2010, 90
[5] Child, A.D., DeAngelis, A.R., *Static dissipative textile and method for producing the same*, U.P.a.T. Office, Editor., USA, 2004, 18
[6] Savage, J., *Screen Printing Materials and Procedures*, In: Handbook of Thick Film Technology, P.J. Holmes and R.G. Loasby, Editors., Electrochemical Publications Ltd: Ayr., 1976
[7] Kosloff, A., *Screen Printing Electronic Circuits*, In: Screen Printing Techniques., The Signs of the Times Publishing Co: Cincinnati, 1981
[8] Karaguzel, B., et al., *Flexible, durable printed electrical circuits,* In: Journal of the Textile Institute, 2009, 100, 1, 1–9
[9] Jackie, E., Denise, M., *Superconducting screen printing ink and process for producing a thick superconducting film using this ink*, USPTO, Editor., USA, 1991
[10] Adams, L.W., Gilpatrick, M.W., Gregory, R.V., *Method for generating a conductive fabric and associated product*, U.P.a.T. Office, Editor., Milliken Researh Corporation: USA, 1994, 27
[11] Bhadra, S., et al., *Progress in preparation, processing and applications of polyaniline,* In: Progress in Polymer Science, 2009, 34, 8, 783–810
[12] Blanchet, G.B., Fincher, C.R., Gao, F., *Polyaniline nanotube composites: A high-resolution printable conductor,* In: Applied Physics Letters, 2003, 82, 8, 1290–1292
[13] Chen, M.X., *Printed electrochemical devices using conducting polymers as active materials on flexible substrates,* In: Proceedings of the IEEE, 2005, 93, 7, 1339–1347

[14] DeAngelis, A.R., Child, A.D., Green, D.E., *Patterned conductive textiles*, U.P.a.T. Office, Editor, Milliken Research Corporation: USA, 1997, 7
[15] Foitzik, R.C., et al., *Soluble poly-3-alkylpyrrole polymers on films and fabrics,* In: Synthetic Metals, 2005, 155, 1, 185–190
[16] Foitzik, R.C., Kaynak, A., Pfeffer, F.M., *Application of soluble poly(3-alkylpyrrole) polymers on textiles,* In: Synthetic Metals, 2006, 156, 7–8, 637–642
[17] Hwang, Y.S., Son, Y., Lee, Y., *Printed Circuit Patterns of Conducting Polymer,* In: Molecular Crystals and Liquid Crystals, 2007, 472, 113–122
[18] Nur, H.M., et al., *Ink-jet printing of gold conductive tracks,* In: Journal of Materials Science: Materials in Electronics, 2002, 13, 4, 213–219
[19] Locher, I., Troster, G., *Enabling Technologies for Electrical Circuits on a Woven Monofilament Hybrid Fabric,* In: Textile Research Journal, 2008, 78, 7, 583–594
[20] Merilampi, S., Laine-Ma, T., Ruuskanen, P., *The characterization of electrically conductive silver ink patterns on flexible substrates,* In: Microelectronics Reliability, 2009, 49, 7, 782–790
[21] Bao, L.R., Wei, B., Xiao, A.Y., *Conductive Coating Formulations with Low Silver Content,* In: 2007 Proceedings 57th Electronic Components and Technology Conference, 2007
[22] Park, B.K., et al., *Direct writing of copper conductive patterns by ink-jet printing,* In: Thin Solid Films, 2007, 515, 19, 7706–7711
[23] Azim, S.S., et al., *Studies on graphite based conductive paint coatings,* In: Progress in Organic Coatings, 2006, 55, 1, 1–4
[24] Jang, B.Z., Zhamu, A., *Nano graphene platelet-based conductive inks*, USPTO, Editor, USA, 2008
[25] Wang, S., et al., *High Mobility, Printable, and Solution-Processed Graphene Electronics,* In: Nano Letters, 2009, 10, 1, 92–98
[26] Baughman, R.H., Zakhidov, A.A., de Heer, W.A., *Carbon Nanotubes-the Route Toward Applications,* In: Science, 2002, 297, 5582, 787–792
[27] Bhat, N., Benjamin, Y., *Surface resistivity behavior of plasma treated and plasma grafted cotton and polyester fabrics,* In: Textile Research Journal, 1999, 69, 1, 38–42

Authors:

MUHAMMAD ALI[1], MUHAMMAD OWAIS RAZA SIDDIQUI[1],
MUHAMMAD ZUBAIR[2], LONG LIN[3]

[1]NED University of Engineering & Technology, Department of Textile Engineering,
University Road, 75270, Karachi, Pakistan

[2]North Carolina State University, College of Textiles, Raleigh NC 27695, USA

[3]School of Materials and Chemical Engineering, Ningbo University of Technology,
201 Fenghua Road, Ningbo, China

Corresponding author:

MUHAMMAD ALI
e-mail: alimughal@neduet.edu.pk

Textile artefacts conservation using nanomaterials – Review

DOI: 10.35530/IT.073.06.202263

MIHAELA-CRISTINA LITE
RODICA ROXANA CONSTANTINESCU
ELENA-CORNELIA TĂNĂSESCU
OVIDIU GEORGE IORDACHE
NICOLETA BADEA

ABSTRACT – REZUMAT

Textile artefacts conservation using nanomaterials – Review

Continuous research is necessary for the field of cultural heritage conservation to maintain up-to-date knowledge regarding new treatments and methods for preserving artefacts. Cultural heritage conservation is not only necessary for preserving the memory of our predecessors but is also meaningful for future generations. History museums around the world contain impressive collections of heritage textiles in various stages of degradation. The main method of preservation is maintaining the objects a microclimate to limit degradation by adjusting the temperature, humidity, and brightness of the rooms in which they are exposed or stored. Biodegradation is influenced by the presence of microorganisms, the availability of oxygen, temperature, humidity, light, and chemical factors (pH, electrolytes, etc.). This paper aims to provide scientific information on how heritage textiles have been studied and characterized, as well as the methods of preservation reported in the literature. Particular attention is being paid to nanomaterials, as they have been intensively studied for various applications and demonstrated to exhibit antimicrobial effects, which can be utilized to treat heritage objects and slow down degradation processes.

Keywords: *historical textiles, conservation, nanomaterials, microbial degradation, characterization*

Conservarea artefactelor textile folosind nanomateriale – studiu de literatură

Cercetarea continuă este necesară pentru ca domeniul conservării patrimoniului cultural să mențină cunoștințele la zi, cu privire la noile tratamente și metode de conservare a artefactelor. Conservarea patrimoniului cultural nu este necesară doar pentru păstrarea memoriei predecesorilor noștri, ci este și semnificativă pentru generațiile viitoare. Muzeele de istorie din întreaga lume conțin colecții impresionante de textile de patrimoniu aflate în diferite stadii de degradare. Principala metodă de conservare este menținerea obiectelor într-un microclimat pentru a limita degradarea prin reglarea temperaturii, umidității și luminozității încăperilor în care sunt expuse sau depozitate. Biodegradarea este influențată de prezența microorganismelor, disponibilitatea oxigenului, temperatură, umiditate, lumină și factori chimici (pH, electroliți etc.). Această lucrare își propune să ofere informații științifice despre modul în care au fost studiate și caracterizate textilele de patrimoniu, precum și despre metodele de conservare raportate în literatura de specialitate. Se acordă o atenție deosebită nanomaterialelor, deoarece acestea au fost studiate intens pentru diverse aplicații și s-a demonstrat că prezintă efecte antimicrobiene, care pot fi utilizate pentru a trata obiectele de patrimoniu și pentru a încetini procesele de degradare.

Cuvinte-cheie: *textile istorice, conservare, nanomateriale, degradare microbiană, caracterizare*

INTRODUCTION

Since the advent of the first civilizations, textiles have been indispensable objects for mankind. Textiles have a long history and reflect the different levels of social and cultural development and the evolution of technology and materials used by different civilizations [1]. The term "textiles" comes from the Latin language (texere) and means "to weave". Textile materials are obtained from textile fibres that are transformed into yarns, which are then subjected to various operations, such as weaving, knitting, crocheting, knotting, etc. Finally, textiles are subjected to finishing processes (e.g., dyeing) [2]. The final products represent an interconnection of the resources, technology, and lifestyle of society during the time at which the textiles were manufactured. Hence, the interest of the archaeology research community in conserving textile artefacts originates from the importance of textiles as a relevant index of exchange economics and available technology, in addition to their aesthetics and traditions in civilization as clothing [3, 4]. Textile artefacts are sensitive and susceptible to degradation *via* depolymerization, leading to fading and low resistance to tears [5]. The biodegradation of textile objects depends on their composition.

Compared to synthetic fibres, natural fibres are much more susceptible to degradation [6]. Additionally, natural fibres degrade at a different rate depending on their nature. The main component of vegetable fibre is cellulose. In addition, fibres contain lignin and other organic, noncellulose components. The susceptibility of textiles to degradation is strongly influenced by the presence of these components, as well as their

nature. The presence of noncellulose components, such as lignin and wax, increases the resistance to degradation. On the other hand, pentosans and pectins present in the composition of plant fibres decrease the resistance to degradation [7]. In animal fibres, the main component is proteinaceous and includes keratin (wool), fibroin and sericin (silk) [8].

Recent progress in nanoscience has paved the way for a wide range of possibilities due to the broad spectrum of applicability of new nanomaterials [9]. Many studies have demonstrated that certain nanoparticles (NPs) exhibit deacidification, UV-blocking and antimicrobial properties, which make them attractive candidates for conservation treatments [10–12]. Studies have also examined the use of metals, metal oxides, and metal composites for textile finishing due to the antimicrobial properties of these materials [13].

This paper aims to provide scientific documentation on how textile cultural heritage has been studied and characterized, as well as describe the methods of preservation reported in the literature. Particular attention is being focused on the nanomaterials used, especially silver NPs (AgNPs), as they exhibit a well-known antibacterial effect, which can be exploited in treating heritage objects to slow down the degradation processes.

TEXTILES BIODEGRADATION

The biodegradation of textile objects is a slow process that depends on the composition of the objects and occurs in the following stages: biodeterioration, biofragmentation and assimilation. The biodegradation of textiles is the result of several combined degrading factors, such as mechanical degradation, thermal degradation and degradation due to the presence of moisture, oxygen, ultraviolet light and environmental pollutants [14]. Due to these factors, a large number of microorganisms adhere to the surface of textiles. Biofragmentation is the process by which the population of microorganisms grows and secretes enzymes and free radicals, reducing the degree of polymerization. As a result, the macromolecules break down into oligomers, dimers, and monomers. Assimilation involves metabolic products being released from microorganisms and the adhesion of these products to the surface of textiles [15].

CHARACTERIZATION OF TEXTILE ARTEFACTS

The analysis of heritage objects must be performed, as much as possible, by nondestructive or microdestructive techniques that do not affect the integrity of the artefacts. The main characterization techniques used in the field are presented below.

Textural analysis of textile artefacts

The techniques used to perform textural analysis are based on microscopy. The textural analysis provides information on the type of fibre, its diameter, and the degradation state of the objects [16]. Scanning electron microscopy (SEM) is among the common microscopy techniques used to evaluate fibre morphology and assess the possible deposits formed during the degradation processes [17].

Structural analysis of textile fibres

The main techniques used for the structural analysis of materials are X-ray diffraction (XRD), thermogravimetry (TGA), differential scanning calorimetry (DSC), gel permeation chromatography (GPC), viscometry and others. XRD is a non-destructive technique and can be used to evaluate the crystallinity of textiles, while TGA and DSC are microdestructive techniques used to observe the thermal stability and phase transition of samples [18, 19]. GPC, also known as size-exclusion chromatography (SEC), is a microdestructive technique for determining the molar mass distribution (Mw) of polymers [20]. Furthermore, the textile's average degree of polymerization can be calculated by performing viscometry measurements. Thus, it is possible to assess the changes in textile fibres [21].

Chemical composition and metal assessment

Fourier transform infrared spectroscopy (FTIR) is a technique that is commonly used to determine the functional groups present in the chemical composition of samples. By coupling an attenuated total reflection (ATR) module to this technique, the analysis can be performed directly on the samples and no additional sample preparation is necessary, unlike the traditional technique [22, 23]. Therefore, nondestructive analysis of the chemical composition can be conducted. Moreover, the information can be completed by performing Raman spectroscopy, a complementary technique that can provide information regarding the dyes used on textile fabrics [24].

For assessing metals, X-ray fluorescence spectroscopy (XRF) or energy-dispersive X-ray spectroscopy (EDX) are the most appropriate techniques for textile artefacts, as they are nondestructive or microdestructive (for EDX) and previous sample preparation is not necessary. Moreover, these techniques can also provide information regarding nonmetallic elements [25]. However, these techniques can provide only semiquantitative information and are unable to detect metal traces. For quantitative analysis, atomic absorption spectroscopy (AAS) or inductively coupled plasma (ICP) might be performed. Nevertheless, the main disadvantage of these techniques is related to the expense of the instruments and resources, as well as the necessary sample preparation [26, 27].

Chromatic analysis

In the field of conservation-restoration of heritage objects it is important that the treatment does not change the colour of the artefacts or, in the case of restoration, slightly intensifies the colour tones, for objects that have faded over time [26]. The most common method to evaluate chromatic changes involves recording the visible spectrum of a sample,

using a special spectrophotometer, which reports the data as in the CIE L*a*b* system of colours [29].

Microbiological analysis

Microbial contamination of textile artefacts can be achieved by fingerprinting or clone library construction methods. The first step is to perform cell lysis, followed by isolation, fragmentation, and amplification of DNA residues, by polymerase chain reaction (PCR) [30]. Next, the clone library construction method involves inserting DNA fragments into vectors, which are implanted into host cells. Afterwards, functional screening and/or sequencing-based screening is performed [31]. The fingerprinting method involves analysing PCR products by electrophoresis [32].

CONSERVATION OF TEXTILE ARTEFACTS

The main method of preservation is to maintain a suitable microclimate, in which the relative humidity is 65% and the temperature does not exceed 22°C [33]. In addition to maintaining the microclimate, the literature describes several physical and chemical methods for disinfecting heritage objects with the aim of preventing biodegradation [34]. The physical methods described in the literature are inducing dehydration to inhibit the growth of microorganisms, exposing the artefacts to gamma rays using cobalt 60 isotopes and exchanging the oxygen in the atmosphere with inert gases, such as argon or carbon dioxide [35, 36]. Chemical methods involve the use of biocidal substances that belong to different classes of compounds, such as alcohols (e.g., ethanol), alkylating agents (e.g., ethylene oxide and formaldehyde), azole compounds (e.g., imidazole, triazole, thiabendazole), quaternary ammonium salts (e.g., dimethyl-lauryl-benzyl ammonium bromide and lauryl-dimethyl-carboethoxy-methyl ammonium bromide), and, more recently, essential oils [37–39].

NANOMATERIALS IN ARTEFACTS CONSERVATION

The nanostructures studied for their potential application in cultural heritage conservation are metal (e.g., AgNPs), metal-oxide (e.g., TiO_2, MgO, ZnO) and hydroxide NPs (e.g., $Ca(OH)_2$ or $Ba(OH)_2$) and modified nanoclays (e.g. Montmorillonite hybrids), due to their antimicrobial and deacidification properties [40–44].

Nanomaterials in stone and cellulose-based artefact conservation

Another mechanism to prevent the degradation of cultural heritage objects involves deacidification. Hydroxide NPs, such as calcium, magnesium, and barium hydroxide NPs, have been applied on limestone, paper, wood, and canvas artefacts through brushing or spraying during restoration and conservation processes. Due to their alkaline character, these hydroxide NPs proved to be efficient for deacidifying artefacts and hence decelerating the degradation process [45–47]. Moreover, in addition to their deacidification efficiency, $Ca(OH)_2$ NPs also exhibited antifungal properties, which can be enhanced by mixing with TiO_2 and/or ZnO NPs. Such antifungal coatings have been used to protect limestone monuments against deterioration [48].

The antimicrobial properties of certain oxide NPs, such as MgO, ZnO, and TiO_2, are strongly related to their photocatalytic mechanism. These NPs have been intensively studied in the process of conserving and restoring calcareous stone, paper, and wood heritage [11, 49, 50].

Water repellence is another mechanism that leads to microorganism growth inhibition. SiO_2, Al_2O_3, and SnO_2 NPs have been used for wood and stone artefacts and even stone building conservation due to their water-repellent properties [51].

The use of AgNPs has also been intensively studied for applications in cultural heritage conservation. AgNPs and AgNP-based nanocomposites are well-known antimicrobial agents due to Ag cytotoxicity [52]. AgNPs are a promising conservation treatment due to their antimicrobial effectiveness and because they can be easily and greenly synthesized from various plant extracts [11, 40]. AgNPs and AgNP-based nanocomposites have been used as conservation treatments for stone [53], paper [11, 54], and even parchment artefacts [55].

Another category of nanomaterials studied for cultural heritage conservation are nanoclays. Halloiste, sepiolite, montmorillonite, and laponite have been applied for wood, paper, and stone deacidification, cleaning, and surface protection [44].

Nanomaterials in textile conservation

NPs have been employed in finishing textiles to manufacture functional textile fabrics, such as antimicrobial textiles, UV-absorbers, water-repellents, and dirt repellents [56, 57]. Inspired by the studies conducted on paper deacidification, the use of alkaline nanomaterials, such as calcium or magnesium hydroxide, has been proposed to protect the canvas from acidic degradation [58]. The most intensely studied nanomaterial for textile artefact conservation is AgNPs due to their remarkable antimicrobial properties. The literature describes several methods for AgNP deposition, such as solution immersion, layer-by-layer deposition, and sonochemical methods (figure 1) [59].

The Beata Gutarowska research group conducted a study that assessed microorganism contamination in several museums and archives. In the Central Museum of Textiles in Lodz, an average number of 2.5×10^2 microbes was found in the air, consisting of 15.44% fungi and 84.56% bacteria. Additionally, the average number of microbes on the surfaces was 1.5×10^2, consisting of 30.73% fungi and 69.27% bacteria. The identified microbes are listed in table 1 [60]. Gutarowska proposed a disinfection method using a misting chamber in which silver colloid was injected with heated and humidified air and sprayed from four sides (Patent no. P-399 507) [61].

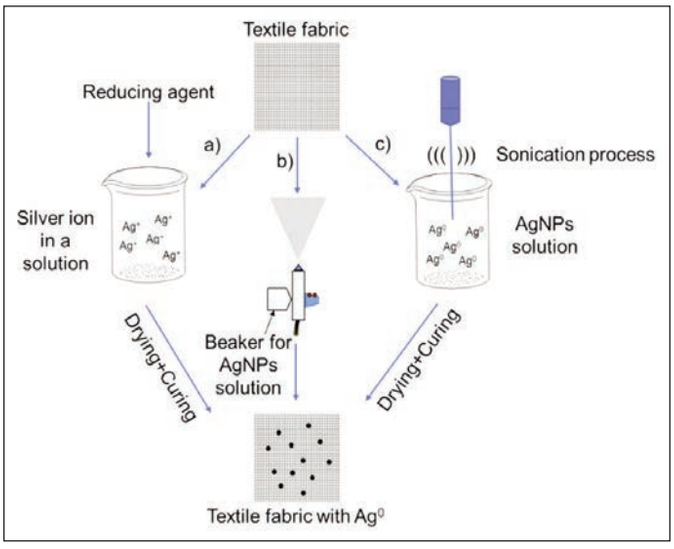


Fig. 1. Methods for AgNP deposition: *a* – solution immersion; *b* – layer-by-layer deposition; *c* – sonochemical deposition [59]

Table 1

MICROORGANISMS IDENTIFIED IN THE CENTRAL MUSEUM OF TEXTILES IN LODZ [60]

Type of microorganism	Microorganism species
Gram-negative rods	-
Gram-positive cocci	*Micrococcus sp., Kocuria varians/rosea, Staphylococcus xylosus*
Gram-positive endospore-forming rods	*Bacillus sp., Bacillus firmus, Bacillus pumilus, Bacillus subtilis, Brevibacillus laterosporus, Lactobacillus delbrueckii*
Mesophilic actinomycetes	-
Moulds	*Alternaria alternata, Alternaria consortiale, Aspergillus niger, Aspergillus versicolor, Botrytis sp., Cladosporium sp., Cladosporium cladosporoides, Mucor hiemalis, Mucor racemosus, Penicillium carneum, Penicillium polonicum, Penicillium radicola, Rhizopus nigricans*
Yeast-like fungi	*Candida sphaerica, Rhodotorula mucilaginosa*

Based on these data, Katarzyna Pietrzak described in a later publication that the AgNPs misting was effective in disinfecting cotton fabrics, demonstrating a high efficiency in reducing bacterial development on cotton fabrics (from 87% to 99%) [62].

The researchers also studied the antimicrobial properties of AgNPs against biofilm formation by *Pseudomonas sp.* on pre- and post-Columbian archaeological textiles and suggested that AgNP treatments can be very promising in the antimicrobial protection of archaeological textiles [63]. The percentages of microbe reductions are shown in table 2.

Table 2

THE REDUCTION IN MICROORGANISM NUMBERS (R) AFTER TREATING THE COTTON FABRIC WITH AgNPs [62, 63]

Microorganism	R (%)
Bacillus subtilis I	87.39
Escherichia coli	99.95
Staphylococcus aureus	99.65
Pseudomonas aeruginosa	97.10
Aspergillus niger	31.57
Penicillium chrysogenum	53.54

Given the abundance of publications that document the remarkable antimicrobial properties of AgNPs and the applicability of AgNPs for disinfecting textiles, AgNPs constitute a promising treatment with a wide range of possible variates in the field of artefacts conservation [64–66]. The new challenges consist of finding optimal synthesis pathways to fulfil both the efficiency and environmental friendliness, as well as the cost-effectiveness criteria [64, 66, 67]. Therefore, green alternatives constitute an attractive solution that involves the use of enzymes, microorganisms, oligosaccharides, polysaccharides, DNA, bacteria, yeast, fungi, plant extracts, and sometimes intact plants for AgNP synthesis [68].

Other nanomaterials, such as TiO_2 and ZnO, can be exploited for this purpose, as they also demonstrate antibacterial activity [69–71].

CONCLUSIONS

It is impossible to prevent the degradation of heritage objects. Degradation can occur slowly or quickly, depending on the nature of the object and the storage conditions. The analysis of degradation processes that impact textile fabrics can be performed using a variety of techniques. Several preservation methods have been reported in the literature, including the following: physical methods (dehydration, exposure to gamma radiation, change of atmosphere, etc.) and chemical methods (alcohols, phenols, alkylating agents, azoles, quaternary ammonium compounds, essential oils, etc.). Recently, special attention has been given to nanomaterials, such as alkali NPs ($Ca(OH)_2$ or $Ba(OH)_2$) due to their deacidification properties; silica NPs (SiO_2) due to their hydrophobic character, which provide water-repellent properties; etal oxide NPs (TiO_2 and ZnO NPs), due to their UV-blocking and antimicrobial properties; and AgNPs due to their antimicrobial properties and versatility.

ACKNOWLEDGMENTS

This work was supported by the Ministry of Research and Innovation within Program 1 – Development of the national RD system, Subprogram 1.2 – Institutional Performance – RDI excellence funding projects, contract no. 4PFE/2021, with contribution from POCU program (the European

Social Fund from the Sectoral Operational Programme Human Capital 2014-2020, through the Financial Agreement with the title “Training of PhD students and post-doctoral researchers in order to acquire applied research skills–SMART”), contract no. 13530/16.06.2022 – SMIS code: 153734.

REFERENCES

[1] Timar-Balazsy, A., Eastop, D., *Chemical Principles of Textile Conservation*, 1998
[2] Madhav, S., Ahamad, A., Singh, P., Mishra, P. K., *A review of the textile industry: Wet processing, environmental impacts, and effluent treatment methods*, In: Environmental Quality Management, 2018, 27, 31–41, https://doi.org/10.1002/tqem.21538
[3] Good, I., *Archaeological Textiles: A Review of Current Research*, In: Annual Review of Anthropology, 2001, 30, 209–226
[4] Andersson Strand, E., Frei, K., M., Gleba, M., Mannering, U., Nosch, M-L., Skals, I., *Old Textiles – New Possibilities*, In: European Journal of Archaeology, 2010, 13, 2, 149–173, https://doi.org/10.1177/1461957110365513
[5] Bou-Belda, E., Indrie, L., Ilies, D. C., Hodor, N., Berdenov, Z., Herman, G., Caciora, T., *Chitosan – a non-invasive approach for the preservation of historical textiles*, In: Industria Textila, 2020, 71, 6, 576–579, https://doi.org/10.35530/IT.071.06.1756
[6] Ueland, M., Howes, J.M., Forbes, S.L., Stuart, B.H., *Degradation patterns of natural and synthetic textiles on a soil surface during summer and winter seasons studied using ATR-FTIR spectroscopy*, In: Spectrochimica Acta Part A: Molecular and Biomolecular Spectroscopy, 2017, 185, 69–76, https://doi.org/10.1016/j.saa.2017.05.044
[7] Tiano, P., *Biodegradation of Cultural Heritage: Decay Mechanisms and Control Methods*, In: CNR-Centro di Stud. Sulle Cause Deperimento e Metod. Conserv. Opere d’Arte, 2001, 9, 1–37
[8] Szostak-Kotowa, J., *Biodeterioration of textiles*, In: International Biodeterioration & Biodegradation, 2004, 53, 165–170, https://doi.org/10.1016/S0964-8305(03)00090-8
[9] Baglioni, P., Carretti, E., Chelazzi, D., *Nanomaterials in art conservation*, In: Nature Nanotechnology, 2015, 10, 4, 287–290, https://doi.org/10.1038/nnano.2015.38
[10] Afsharpour, M., Hadadi, M., *Titanium dioxide thin film: Environmental control for preservation of paper-art-works*, In: Journal of Cultural Heritage, 2014, 15, 5, 569–574, https://doi.org/10.1016/j.culher.2013.10.008
[11] Fouda, A., Abdel-Maksoud, G., Abdel-Rahman, M.A., Salem, S.S., Hassan, S.E.D., El-Sadany, M.A.H., *Eco-friendly approach utilizing green synthesized nanoparticles for paper conservation against microbes involved in biodeterioration of archaeological manuscript*, In: International Biodeterioration and Biodegradation, 2019, 142, 160–169, https://doi.org/10.1016/j.ibiod.2019.05.012
[12] Cinteza, L.O., Tanase, M.A., *Multifunctional ZnO Nanoparticle: Based Coatings for Cultural Heritage Preventive Conservation*, Chapter in: Thin Films, Ed. Ares, A. E., 2020, https://doi.org/10.5772/intechopen.94070
[13] Bhandari, V., Jose, S., Badanayak, P., Sankaran, A., Anandan, V, *Antimicrobial Finishing of Metals, Metal Oxides, and Metal Composites on Textiles: A Systematic Review*, In: Industrial and Engineering Chemistry Research, 2020, 61, 1, 86–101, https://doi.org/10.1021/acs.iecr.1c04203
[14] Lite, M.C., Sandulache, I.M., Secareanu, L.O., Mitran, E.C., Iordache, O., Perdum, E., *Accelerated weathering tests on protein fibers*, In: Annals of The University of Oradea Fascicle of Textiles, Leatherwork, 2020, 21, 1, 55–60
[15] Ueland, M., Howes, J.M., Forbes, S.L., Stuart, B.H., *Degradation patterns of natural and synthetic textiles on a soil surface during summer and winter seasons studied using ATR-FTIR spectroscopy*, In: Spectrochimica Acta Part A: Molecular and Biomolecular Spectroscopy, 2017, 185, 69–76, https://doi.org/10.1016/j.saa.2017.05.044
[16] Akyuz, S., Akyuz, T., Cakan, B., Basaran, S, *Investigations of the historic textiles excavated from Ancient Ainos (Enez – Turkey) by multiple analytical techniques*, In: Journal of Molecular Structure, 2014, 1073, 37–43, https://doi.org/10.1016/j.molstruc.2014.03.068
[17] Ilies, D.C., Herman, G.V., Caciora, T., Ilies, A., Indrie, L., Wendt, J., Axinte, A., Diombera, M., Lite, C., Berdenov, Z., Albu, A., *Considerations Regarding the Research for the Conservation of Heritage Textiles in Romania*, Chapter in Waste in Textile and Leather Sectors, 2020, Ed. Ayşegül Körlü, https://doi.org/10.5772/intechopen.91393
[18] Park, C.H., Kang, Y.K., In, S.S., *Biodegradability of cellulose fabrics*, In: Journal of Applied Polymer Science, 2004, 94, 1, 248–253, https://doi.org/10.1002/app.20879
[19] Zhu, P., Sui, S., Wang, B., Sun, K., Sun, G., *A study of pyrolysis and pyrolysis products of flame-retardant cotton fabrics by DSC, TGA, and PY-GC-MS*, In: Journal of Analytical and Applied Pyrolysis, 2004, 71, 2, 645–655, https://doi.org/10.1016/j.jaap.2003.09.005
[20] Pawcenis, D., Koperska, M.A., Milczarek, J.M., Łojewski, T., Łojewska, J., *Size exclusion chromatography for analyses of fibroin in silk: Optimization of sampling and separation conditions*, In: Applied Physics A: Materials Science and Processing, 2014, 114, 2, 301–308, https://doi.org/10.1007/s00339-013-8143-z
[21] Zhang, X., Yuan, S., *Measuring Quantitatively the deterioration degree of ancient silk textiles by viscometry*, In: Chinese Journal of Chemistry, 2010, 28, 4, 656–662, https://doi.org/10.1002/cjoc.201090128
[22] Geba, M., Lisa, G., Ursescu, C.M., Olaru, A., Spiridon, I., Leon, A.L., Stanculescu, I., *Gamma irradiation of protein-based textiles for historical collections decontamination*, In: Journal of Thermal Analysis and Calorimetry, 2014, 118, 2, 977–985, https://doi.org/10.1007/s10973-014-3988-8
[23] Bitossi, G., Giorgi, R., Mauro, M., Salvadori, B., Dei, L., *Spectroscopic techniques in cultural heritage conservation: A survey*, In: Applied Spectroscopy Reviews, 2005, 40, 3, 187–228, https://doi.org/10.1081/ASR-200054370
[24] Kakoauei, M., Kakouei, M., Kumaran, S., *History, technology, and treatment of a painted silk folding screen belonging to the palace-museum of Golestan in Iran*, In: Fibres and Textiles in Eastern Europe, 2014 ,104, 2, 69–75
[25] Secareanu, L.O., Sandulache, I.M., Mitran, E.C., Lite, M.C., Iordache, O., Perdum, E., *Characterization of some textile artifacts from plopis wooden church – part of Unesco world heritage sites*, In: Annals of The University of Oradea Fascicle of Textiles, Leatherwork, 2021, 22, 1, 77–82
[26] Nascu, H. I., Jantschi, L., *Chimie Analitica si Instrumentala*, 2006

[27] Rezić, I., Ćurković, L., Ujević, M., *Simple methods for characterization of metals in historical textile threads*, In: Talanta, 2010, 82, 1, 237–244, https://doi.org/10.1016/j.talanta.2010.04.028
[28] Aleixo, M., Bailão, A., Gomes, A.E., Linhares, J., Andrés, M.S., Nascimento, S., *Chromatic reintegration in contemporary monochromatic unvarnished paintings: a case study based on artwork from Jorge Martins*, In: 5th edition of the International Meeting on Retouching of Cultural Heritage, 2019
[29] Ingamells, W., *Colour for textiles. A user's handbook*, 1993
[30] Dakal, T.C., Arora, P.K., *Evaluation of potential of molecular and physical techniques in studying biodeterioration*, In: Reviews in Environmental Science and Biotechnology, 2012, 11, 1, 71–104, https://doi.org/10.1007/s11157-012-9264-0
[31] Mocali, S., Benedetti, A., *Exploring research frontiers in microbiology: The challenge of metagenomics in soil microbiology*, In: Research in Microbiology, 2010, 161, 6, 497–505, https://doi.org/10.1016/j.resmic.2010.04.010
[32] Otlewska, A., Adamiak, J., Gutarowska, B., *Application of molecular techniques for the assessment of microorganism diversity on cultural heritage objects*, In: Acta Biochimica Polonica, 2014, 61, 2, 217–225, https://doi.org/10.18388/abp.2014_1889.
[33] Romanian Government, HG 1546 18/12/2003, Available at: https://legislatie.just.ro/Public/DetaliiDocument/49313 [Accessed onMay 2022]
[34] Gutarowska, B., Pietrzak, K., Machnowski, W., Milczarek, J.M., *Historical textiles – a review of microbial deterioration analysis and disinfection methods*, In: Textile Research Journal, 2017, 87, 2388–2406, https://doi.org/10.1177/0040517516669076
[35] Hugo, W.B., *A brief history of heat, chemical and radiation preservation and disinfection*, In: International Biodeterioration and Biodegradation, 1995, 36, 3–4, 197–217, https://doi.org/10.1016/0964-8305(95)00055-0
[36] Valentin, N., Lidstrom, M., Preusser, F., Valentin, N., Lidstrom, M., Preusser, F., *Studies in Conservation Microbial control by low oxygen and low relative humidity environment HUMIDITY ENVIRONMENT*, 2017, 3630
[37] Nittérus, M., *Ethanol as fungal sanitizer in paper conservation*, In: Restaurator, 2000, 21, 2, 101–115, https://doi.org/10.1515/REST.2000.101
[38] Pietrzak, K., Otlewska, A., Dybka, K., Danielewicz, D., Pangallo, D., Demnerová, K., Ďurovič, M., Kraková, L., Scholtz, V., Bučková, M., Puškárová, A., Kučerová, I., Škrdlantová, M., Drábková, K., Surma-Ślusarska, B., Gutarowska, B., *A modern approach to biodeterioration assessment and disinfection of historical book*, 2016
[39] Borrego, S., Valdés, O., Vivar, I., Lavin, P., Guiamet, P., Battistoni, P., Gómez de Saravia, S., Borges, P., *Essential Oils of Plants as Biocides against Microorganisms Isolated from Cuban and Argentine Documentary Heritage*, In: ISRN Microbiology, 2012, 1–7, https://doi.org/10.5402/2012/826786
[40] Carrillo-González, R., Martínez-Gómez, M. A., González-Chávez, M. del C. A., Mendoza Hernández, J. C., *Inhibition of microorganisms involved in deterioration of an archaeological site by silver nanoparticles produced by a green synthesis method*, In: Science of the Total Environment, 2015, 565, 872–881, https://doi.org/10.1016/j.scitotenv.2016.02.110
[41] Huang, Z., Maness, P. C., Blake, D. M., Wolfrum, E. J., Smolinski, S. L., Jacoby, W.*A., Bactericidal mode of titanium dioxide photocatalysis*, In: Journal of Photochemistry and Photobiology A: Chemistry, 2000, 130, 2–3, 163–170, https://doi.org/10.1016/S1010-6030(99)00205-1
[42] Sierra-Fernandez, A., De La Rosa-García, S.C., Gomez-Villalba, L.S., Gómez-Cornelio, S., Rabanal, M.E., Fort, R., Quintana, P., *Synthesis, Photocatalytic, and Antifungal Properties of MgO, ZnO and Zn/Mg Oxide Nanoparticles for the Protection of Calcareous Stone Heritage*, In: ACS Applied Materials and Interfaces, 2017, 9, 29, 24873–24886, https://doi.org/10.1021/acsami.7b06130
[43] Saoud, K.M., Ibala, I., Ladki, D.El, Ezzeldeen, O., Saeed, S., *Microwave assisted preparation of calcium hydroxide and barium hydroxide nanoparticles and their application for conservation of cultural heritage*, In: Lecture Notes in Computer Science (Including Subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics), 2014, 8740, 342–352, https://doi.org/10.1007/978-3-319-13695-0
[44] Hosseini, H., Shojaee-Aliabadi, S., Hosseini, S.M., Mirmoghtadaie, L., *Nanoantimicrobials in Food Industry*, In: Nanotechnology Applications in Food: Flavor, Stability, Nutrition and Safety. Elsevier Inc. 2017, https://doi.org/10.1016/B978-0-12-811942-6.00011-X
[45] Baglioni, P., Giorgi, R., Dei, L., *Soft condensed matter for the conservation of cultural heritage*, In: Comptes Rendus Chimie, 2009, 12, 1–2, 61–69, https://doi.org/10.1016/j.crci.2008.05.017.
[46] Giorgi, R., Bozzi, C., Dei, L., Gabbiani, C., Ninham, B.W., Baglioni, P., *Nanoparticles of $Mg(OH)_2$:Synthesis and Application to Paper Conservation*, In: Langmuir, 2005, 21, 18, 8495–8501, https://doi.org/10.1021/la050564m
[47] Giorgi, R., Ambrosi, M., Toccafondi, N., Baglioni, P., *Nanoparticles for cultural heritage conservation: Calcium and barium hydroxide nanoparticles for wall painting consolidation*, In: Chemistry – A European Journal, 2010, 16, 31, 9374–9382, https://doi.org/10.1002/chem.201001443.
[48] Gómez-Ortíz, N., Rosa-García, S., González-Gómez, W., Soria-Castro, M., Quintana, P., Oskam, G., Ortega-Morales, B., *Antifungal Coatings Based on $Ca(OH)_2$ Mixed with ZnO/TiO_2 Nanomaterials for Protection of Limestone Monuments*, In: ACS Applied Materials & Interfaces, 2013, 5, 5, 1556–1565, https://doi.org/10.1021/am302783h
[49] Ruffolo, S.A., la Russa, M., Malagodi, F.M., Oliviero Rossi, C., Palermo, A.M., Crisci, G.M., *ZnO and $ZnTiO_3$ Nanopowders for Antimicrobial Stone Coating*, In: Applied Physics A: Materials Science and Processing, 2010, 100, 3, 829–834, https://doi.org/10.1007/s00339-010-5658-4
[50] Sierra-Fernandez, A., de La Rosa-García, S.C., Gomez-Villalba, L.S., Gómez-Cornelio, S., Rabanal, M.E., Fort, R., Quintana, P., *Synthesis, Photocatalytic, and Antifungal Properties of MgO, ZnO and Zn/Mg Oxide Nanoparticles for the Protection of Calcareous Stone Heritage*, In: ACS Applied Materials and Interfaces, 2017 9, 29, 24873–24886, https://doi.org/10.1021/acsami.7b06130
[51] Terzi, E., Kartal, S.N., Yilgör, N., Rautkari, L., Yoshimura, T., *Role of various nano-particles in prevention of fungal decay, mold growth and termite attack in wood, and their effect on weathering properties and water repellency*, In: International Biodeterioration and Biodegradation, 2016, 107, 77–87, https://doi.org/10.1016/j.ibiod.2015.11.010
[52] Liao, C., Li, Y., Tjong, S., *Bactericidal and Cytotoxic Properties of Silver Nanoparticles*, In: International Journal of Molecular Sciences, 2019, 20, 2, 449, https://doi.org/10.3390/ijms20020449

[53] Becerra, J., Mateo, M., Ortiz, P., Nicolás, G., Zaderenko, A.P., *Evaluation of the applicability of nano-biocide treatments on limestones used in cultural heritage*, In: Journal of Cultural Heritage, 2019, 38, 126–135, https://doi.org/10.1016/j.culher.2019.02.010
[54] Pietrzak, K., Otlewska, A., Danielewicz, D., Dybka, K., Pangallo, D., Kraková, L., Puˇskárová, A., Mária Buˇcková., Scholtz, V., Durovic, M., Surma-Slusarska, B., Demnerová, K., Gutarowska B., *Disinfection of archival documents using thyme essential oil, silver nanoparticles misting and low temperature plasma*, In: Journal of Cultural Heritage, 2017, 24, 69–77, https://doi.org/10.1016/j.culher.2016.10.011
[55] Saada, N.S., Abdel-Maksoud, G., Abd El-Aziz, M.S., Youssef, A.M., *Green synthesis of silver nanoparticles, characterization, and use for sustainable preservation of historical parchment against microbial biodegradation*, In: Biocatalysis and Agricultural Biotechnology, 2021, 32, https://doi.org/10.1016/j.bcab.2021.101948
[56] Zhang, Y. Y., Xu, Q. B., Fu, F. Y., Liu, X. D., *Durable antimicrobial cotton textiles modified with inorganic nanoparticles*, In Cellulose – Springer Netherlands, 2016, 23, 5, 2791–2808, https://doi.org/10.1007/s10570-016-1012-0
[57] Becheri, A., Dürr, M., Io Nostro, P., Baglioni, P., *Synthesis and characterization of zinc oxide nanoparticles: Application to textiles as UV-absorbers*, In: Journal of Nanoparticle Research, 2008, 10, 4, 679–689, https://doi.org/10.1007/s11051-007-9318-3
[58] Baglioni, P., Chelazzi, D., Giorgi, R., *Deacidification of Paper, Canvas and Wood*, Chapter in: Nanotechnologies in the Conservation of Cultural Heritage, 2015, 117–144, ISBN 978-94-017-9302-5, https://doi.org/10.1007/978-94-017-9303-2
[59] Syafiuddin, A., *Toward a comprehensive understanding of textiles functionalized with silver nanoparticles*, In: Journal of the Chinese Chemical Society, 2019, 66, 8, 793–814, https://doi.org/10.1002/jccs.201800474
[60] Gutarowska, B., Skora, J., Zduniak, K., Rembisz, D., *Analysis of the sensitivity of microorganisms contaminating museums and archives to silver nanoparticles*, In: International Biodeterioration and Biodegradation, 2012, 68, 7–17, https://doi.org/10.1016/j.ibiod.2011.12.002
[61] Gutarowska, B., Rembisz, D., Zduniak, K., Skóra, J., Szynkowska, M., Gliścińska, E., Koziróg, A., *Optimization and application of the misting method with silver nanoparticles for disinfection of the historical objects*, In: International Biodeterioration and Biodegradation, 2012, 75, 167–175, https://doi.org/10.1016/j.ibiod.2012.10.002
[62] Pietrzak, K., Gutarowska, B., Machnowski, W., Mikołajczyk, U., *Antimicrobial properties of silver nanoparticles misting on cotton fabrics*, In: Textile Research Journal, 2015, 86, 8, 812–822, https://doi.org/10.1177/0040517515596933
[63] Pietrzak, K., Otlewska, A., Puchalski, M., Gutarowska, B., Guiamet, P., *Antimicrobial properties of silver nanoparticles against biofilm formation by Pseudomonas aeruginosa on archaeological textiles*, In: Applied Environmental Biotechnology, 2016, 1, 2, 1–9, https://doi.org/10.18063/aeb.2016.02.001.
[64] Ballottin, D., Fulaz, S., Cabrini, F., Tsukamoto, J., Durán, N., Alves, O.L., Tasic, L., *Antimicrobial textiles: Biogenic silver nanoparticles against Candida and Xanthomonas*, In: Materials Science and Engineering C, 2017, 75, 582–589, https://doi.org/10.1016/j.msec.2017.02.110
[65] Simončič, B., Klemenčič, D., *Preparation and performance of silver as an antimicrobial agent for textiles: A review*, In: Textile Research Journal, 2016, 86, 2, 210–223, https://doi.org/10.1177/0040517515586157
[66] Hebeish, A., El-Naggar, M.E., Fouda, M.M.G., Ramadan, M.A., Al-Deyab, S.S., El-Rafie, M.H., *Highly effective antibacterial textiles containing green synthesized silver nanoparticles,* In: Carbohydrate Polymers, 2011, 86, 2, 936–940, https://doi.org/10.1016/j.carbpol.2011.05.048
[67] Rautela, A., Rani, J., Debnath (Das), M., *Green synthesis of silver nanoparticles from Tectona grandis seeds extract: characterization and mechanism of antimicrobial action on different microorganisms*, In: Journal of Analytical Science and Technology, 2019, 10, 1, https://doi.org/10.1186/s40543-018-0163-z
[68] Tran, Q.H., Nguyen, V.Q., Le, A., *Corrigendum: Silver nanoparticles: synthesis, properties, toxicology, applications and perspectives*, In: Advances in Natural Sciences: Nanoscience and Nanotechnology, 2018, 9, 1–20, https://doi.org/10.1088/2043-6254/aad12b
[69] Riaz, S., Ashraf, M., Hussain, T., Hussain, M. T., Younus, A., *Fabrication of Robust Multifaceted Textiles by Application of Functionalized TiO2 Nanoparticles*, In: Colloids and Surfaces A: Physicochemical and Engineering Aspects, 2019, 581, https://doi.org/10.1016/j.colsurfa.2019.123799
[70] Shaheen, T.I., El-Naggar, M.E., Abdelgawad, A.M., Hebeish, A., *Durable antibacterial and UV protections of in situ synthesized zinc oxide nanoparticles onto cotton fabrics*, In: International Journal of Biological Macromolecules, 2016, 83, 426–432, https://doi.org/10.1016/j.ijbiomac.2015.11.003
[71] Mitran, E.-C., Sandulache, I.-M., Secareanu, L.-O., Lite, M.C., Iordache, O.G., Perdum, E., Radu, G.-L., *Assessing the presence of pesticides in modern and contemporary textile artefacts using advanced analysis techniques*, In: Industria Textila, 2021, 72, 2, 138–143, http://doi.org/10.35530/IT.072.02.1828

Authors:

MIHAELA-CRISTINA LITE[1,2], RODICA ROXANA CONSTANTINESCU[1], ELENA-CORNELIA TĂNĂSESCU[1,2], OVIDIU GEORGE IORDACHE[1], NICOLETA BADEA[2]

[1]National Research and Development Institute for Textiles and Leather,
Lucretiu Patrascanu, 16, 030508 Bucharest, Romanaia
e-mail: office@incdtp.ro

[2]Politehnica University of Bucharest, 1-7 Gheorghe Polizu Street, 011061, Bucharest, Romania
e-mail: secretariat@chimie.upb.ro

Corresponding author:

MIHAELA CRISTINA LITE
e-mail: cristina.lite@incdtp.ro

Analysing sustainability based relationship between debt and growth in South-Asian economies and their impact on textile industry: a case for developing economies

DOI: 10.35530/IT.073.06.202187

DURDANA QAISER GILLANI
MUHAMMAD ZAHID NAEEM
CRISTI SPULBAR
ABDULLAH EJAZ

RAMONA BIRAU
LUCIAN CLAUDIU ANGHEL
PETRE VALERIU NINULESCU
ANDREI CRISTIAN SPULBAR

ABSTRACT – REZUMAT

Analysing sustainability based relationship between debt and growth in South-Asian economies and their impact on textile industry: a case for developing economies

This research aims to quantify the linear and non-linear relationship between debt and economic growth in selected developing economies. Based on theoretical arguments and annual data considerations in modelling the debt and growth as a complex relationship across countries, our panel methodology is based on the fixed effect technique. Our core finding indicates that government debt lowers the GDP in selected developing economies. We also find that the urban population is a key factor that improves economic growth. Moreover, government expenditures on health and industrialization are helpful to enhance the growth of the economies. Our study also suggests increased exports, industrial development, and investment in education for growth. We also propose certain supporting strategies to reduce the adverse effects of debt-growth relation in the considered economies. Given developing economies' status, the prerequisite for broad, dynamic and rule-based debt policy is of paramount importance, ensuring the factual choices among numerous possibilities, addressing financial constraints and ensuring intergenerational welfare impact.

Keywords: *debt, industrialization, economic growth, developing economies*

Analiza relației sustenabile dintre datorii și creșterea economică în țările din Asia de Sud și impactul acestora asupra industriei textile: Un studiu de caz pentru economiile în curs de dezvoltare

Acest studiu de cercetare își propune să cuantifice relația liniară și neliniară dintre datorii și creșterea economică în cazul economiilor în curs de dezvoltare selectate. Pe baza argumentelor teoretice și a considerațiilor de date anuale în modelarea datoriei și a creșterii economice ca o relație complexă între țări, metodologia de cercetare de tip panel aplicată în acest studiu, se bazează pe tehnica cu efect fix. Constatarea noastră de bază indică faptul că datoria guvernamentală contribuie la scăderea PIB-ului în anumite economii în curs de dezvoltare. De asemenea, constatăm că populația urbană este un factor cheie care îmbunătățește creșterea economică. În plus, cheltuielile guvernamentale pentru sănătate și industrializare sunt utile pentru a spori creșterea economică. Studiul nostru sugerează, de asemenea, creșterea exporturilor, dezvoltarea industrială și investițiile în educație pentru a sprijini creșterea economică. De asemenea, propunem anumite strategii de sprijin pentru reducerea efectelor adverse ale relației de creștere a datoriilor în economiile luate în considerare. Având în vedere statutul economiilor în curs de dezvoltare, condiția prealabilă pentru o politică de îndatorare amplă, dinamică și bazată pe reguli este de o importanță capitală, asigurând alegerile faptice dintre numeroasele posibilități, abordând constrângerile financiare și asigurând impactul asupra bunăstării intergenerației.

Cuvinte cheie*: datorie, industrializare, creștere economică, economii în curs de dezvoltare, Produsul intern brut (PIB)*

INTRODUCTION

Debt is a double-edged sword. Used pragmatically and in fairness, it recovers welfare. However, if it is used improvidently and in excess, it has adverse effects on the economy. At the micro level, too much debt indicates bankruptcy and financial devastation. At the macro level, high debt recompenses the administration's ability to deliver indispensable services to the public.

The interface of debt and economic growth is multifaceted as it has effects on economic growth dynamics and the return growth rates affect the debt size. High rates of economic growth make enable borrowing and the burden of debt. The sustainability of debt is depending on the capability of improving revenue which tends to decrease in a recession. The defaulting of the private sector affects economic movements and tends to enhance debt when private debt is backed by flexible fiscal policy [1].

The link between public debt and economic growth has in recent times seemed emerged again as a strongly debated topic in the academic world and among policymakers. Preliminary from the influential involvement of Reinhart and Rogoff [2, 3] much of the

works has well-thought-out this link, in recognizing potential non-linearities and explaining their damaging and fundamental influences on growth [4]. The debt–growth nexus can be analysed within a standard neo-classical growth model. Certain notice of the concerned issue, studies done across countries are diligently associated with this work [5, 6].

Industrialization, the result of the industrial revolution that caused structural changes, has regularly increased production levels and employment, promoting extraordinary income growth. So, consistent industrial sector development can be significant for sustainable development. It is required now in a good way in the growth and development literature that the growth of manufacturing output and the growth of GDP are strongly related to each other [7].

The effect of industrialization on economic development has been extensively studied. Entirely past development successes and catch-up since 1870 have been helping raise and gather wealth by investing in their industries [8]. It resulted in amplified capacity and varieties of manufactured goods due to increased employment and better living standard. In the industrialization process, Kaldor [9] suggests the industrial sector as the engine of growth, as it results in the highest potential productivity growth in this sector. This empowers the economy with accurate plans, by transforming sluggish retrieval into an economic recovery.

Education and health are thought foundations for the development of a society. Dissimilar from income, these sectors wholly promote the economy's prosperity. In this moving era, humans are thou of out as the actual capital of the economy and efficiency and healthy actual capital can serve excellently with competition and efficiency. To provide better living standards, investing in humans is needed in economies. Developing economies having inadequate human capital and with deficit financing by foreign aid, can make use of this foreign aid to control their capital deficiency.

High quality of institutions has been contested as an economic growth impetus by incentivizing economic happenings like consumption and investment, improving efficiency, and making the allocation of resources more proficient [10].

Above mentioned studies on the topic suggest how some factors affect economic growth in different countries. The research aims to analyse how Government debt affects the growth of the economy. The hypothesis is that public debt adversely affects economic growth in selected developing economies. The analysis covers the period from 2002 to 2018. However, we check the influence of government debt(considering gross public debt, even though the net debt would seem like a better measure of government indebtedness [6], government health expenditures, urban population and industrialization on economic growth by using the random effect technique in some selected developing countries in this research. This study appears to contribute to the existing literature in many ways. Firstly, here we investigate how government debt which is an emerging issue for the development of the economy affects economic growth. Secondly, we incorporate domestic general government health expenditures, urban population and industrialization specifically in these selected economies. This research highlights the positive role of the urban population towards enhanced economic growth of these selected developing economies. Moreover, the study results are different from some of the previous studies due to variables, areas and applied methodology. Our study results highlight that, debt significantly affects the growth of selected developing economies.

Objectives of the study

This research investigates whether the relationship between public debt and economic growth is significantly negative or not. The study analyses the role of the urban population in some selected Asian countries. It examines the impact of government education expenditures and industrialization in India, Pakistan and Sri Lanka.

Organization of the study

The paper is organized as follows. After giving an introduction, the literature review is shown in the second section. The third section comprises a data source and the model specification along with the important variable discussion. The discussion of results and empirical analysis are presented in the fourth section. The concluding remarks are presented in the last section.

LITERATURE REVIEW

Much of the work has been done to seek out the link between debt and economic growth. However, an important review of some of the studies is presented here.

Many theoretic opinions provoke public debt and growth nexus in the long-run [11]. In standard overlapping generation models of growth, public debt makes lessens savings and accretion of capital, hence lowering economic growth [12–14]. In endogenous growth models, public debt generally affects long-run growth negatively [15, 16]. Additionally, high public debt bounds the proficiency of fruitful public spending on long-run growth [17], makes vagueness or potentials for future economic suppression [18] and could be linked with complex independent results [19] resulting in high rates of interest and private investment [20].

Non-linearities in the debt–growth nexus may rise too in case of high debt and as it could unswervingly affect investment, it will happen when investors have to pay tax on new projects for sharing debt burden [21, 22]; or else, as levels of debt levels increase regarding GDP, creditors would be demanded high rates of interest to make compensation of default risk and this influence would rise the cost of limiting investment and financing [23].

The debt-growth nexus is found to be negative but not statistically significant [24]. There is found a one-third effect of debt on growth due to accumulation of physical capital and a two-thirds effect on growth due to growth of factor productivity [25].
Debt and economic growth are associated even in the long-run, and they are positively related if the government obtains and uses the loans for the development of the economy sincerely instead of channelling the funds to get benefits personally [26]. Though debt affects the growth of the Nigerian economy positively in the short-run it depresses growth in the long-run [5].
Panizza and Presbitero [7] show a negative relationship between debt and growth in OECD countries. Moreover, Spulbar et al. [27] investigated the effect of tax revenue on GDP patterns for the European Union – 28 considering the period from 2005 to 2017.
Moreover, China is undoubtedly considered by dynamic changes. The critical economic incidents have a strong effect on this economy. Rahman [28] explains the causal relationship between health expenditures and education expenditures on GDP in Bangladesh from 1990 to 2009. It is concluded that health and education expenditures increase the growth of the country.
Kourtellos et al. [5] find that higher public debt tends to decrease growth for countries in the Low-Democracy regime by using a structural threshold regression method. Stylianou [29] finds no causality relationship between debt and growth in Greece. Anita et al. [30] indicate that debt decreases growth both in the short-run and long-run.
The debt-to-GDP ratio damages the growth of economies chiefly in high financial stress for European Monetary Union countries. It is also found that a high debt-to-GDP ratio hardly decreases growth in calm financial markets [31]. Teles and Mussolini [17] propose that the debt-to-GDP ratio influences fiscal policy negatively which as a result decrease growth. The results reveal a significant non-linear relationship between public debt and growth. Naeem et al. [32] also discussed the implications of CO_2 emission, global climate change and economic factors including household incomes and expenditures, which also have an impact on health. Mehdiabadi et al. [33] investigated the impact of industry 5.0 and also discussed global economic growth based on lower business costs.
Domestic debt is detrimental to the economy from the results of both short-run and long-run models. Contrarily, external debt is found to be beneficial in the short-run but has mixed effects found in the long-run. The debt service and inflation rate variables show a consistent negative relationship with GDP while the effect of the exchange rate is rather mixed. The exchange rate effect on the economy is based on the success or otherwise of government policy tools [34].
Isiksal [35] highlights that no economic growth can be achieved without industrialization in Nigeria. He finds a positive link between both variables. Ndiaya and Lv. [36] work on the role of institutions in economic growth in Senegal from 1960 to 2017. The study results find that foreign direct investment and industrialization increase economic growth. Moreover, the inflation rate and foreign exchange decrease economic growth. Nguyen et al. [37] find that institutional quality enhances economic growth for emerging economies growth over the 2002–2015 period by using SGMM methods.
Lim [38] shows the link between debt and growth from a vantage point that takes care of the totality of private and public debt by using data from 41 countries from 1952 to 2016. The vector autoregression model and GMM are used in the study. The result finds a negative link between the rate of total debt accumulation and economic growth, with a one standard deviation innovation in the former leading to a 0.2 percentage point contraction in the latter.
Pegkas, Staikouras, and Tsamadias [39] also find a negative long-run effect of public debt on growth by using data from 12 eurozone countries from 1995 to 2016. Moreover, the results show that there is long-run unidirectional causality running from investment, trade openness, and human capital to growth and bidirectional causality between public debt and growth.
The above mention studies show the relationship between debt and growth and other explanatory variables in different areas with different methodologies.

DATA AND METHODOLOGY

Data sources

We employ a panel dataset covering some selected developing economies such as India, Indonesia, Malaysia, Pakistan, Philippines, Sri Lanka, Thailand, Jordon and Namibia from 2013 to 2018. Data has been drawn from the source of the World Development Indicators database. The dependent variable is computed as LGDP. The other independent variables are Debt to GDP ratio (Central Government debt), Log urban population, Government expenditures on health (percentage of GDP) and Industrialization (manufacturing value added $ US). However, we know that growth is not exclusively the result of deb. Consequently, we incorporate numerous factors as control variables that might influence growth. For the analysis, we use the fixed effect technique to check the effect of explanatory variables on the dependent variable. We are using public debt as literature generally recognized a relationship between debt extended and low level of growth [40].

Model specification

The variables are gross domestic product (LGDP), log of urban population (LUBNP), Government expenditures on health (GHEXP) as a percentage of GDP) and Industrialization (manufacturing value added) financial.

$$LGDP_{it} = \beta_1 GDBT_{it} + \beta_2 LUBNP_{it} + \beta_3 GHEXP_{it} + \\ + \beta_4 INDS_{it} + u_{it} \quad (1)$$

The subscript *i* indicates each country and the subscript *t* describes each period in this empirical work. The term uit represents the error term.

RESULT AND EMPIRICAL ANALYSIS

This section analyses the role of Government debt and other explanatory variables such as debt (% of GDP), urban population, government health expenditures and industrialization on gross in some selected Asian countries.

Descriptive statistics

The descriptive analysis of variables is shown in the above table. Large variations are found in GDP as it ranges from 10.4123 to 16.0181. The average debt of the selected courtiers is 53.17% percent from 2002 to 2018. Likewise, variations are observed in industrialization (manufacturing value added) from 9.16000 to 2.5388 percent. On average, government health expenditures are 3.0141 percent of GDP in selected developing countries (table 1).

Unit root test

In table 2, we have checked the existence of unit root in panel data. For this we have used different tests such as Levin, Lin & Chu, I P, Shin W-stat, ADF – Fisher Chi-square and PP – Fisher Chi-square. Test statistics of four methods used for LGDP, DEBT and INDS at level form are not significant which indicates the data is non-stationary at level form. However, all these variables are significant at 1st difference. Moreover, the other variables like LUBNP and GHEXP are stationary at level.

Empirical results and interpretations

Table 3 reveals the fixed effects results and the dependent variable is log GDP. Hausman specification test (REM): this test is a common technique to make a comparison of fixed and random effects estimates of coefficients. To choose FEM or REM, we have used the Hausman test.

Probability of $chi_2 = 0.9907$. The p-value by Hausman indicates is in favour of random effects.

The study results highlight a nonlinear association between Government debt and gross domestic product. Economic growth might be reduced by increasing government debt.

Government debt affects the growth of the economy. A high debt burden creates a lot of problems for the economies. The findings show that the coefficient of DBT is negative and significant. One unit increase in Government debt decreases GDP by 0.0004 percent. High debt is a burden for the general public and the economy. It hampers the growth of the economy. People are unable to avail finance and cannot make sure their resource allocation towards education and health. These results is in line with most of the past analysis done by Presbitero [40], Kourtellos et al. [5], Teles and Mussolini [17], Mencinger [32], Vanlaer et al. [41] and Alshyab [42].

The result shows a positive coefficient of URBNP. One percent increase in urban population increases the GDP by 0.3328 percent in selected developing economies. When a well-educated and employed population play a positive role in employment,

Table 1

SUMMARY STATISTICS					
Variables	**Observation**	**Mean**	**Std. Dev**	**Min**	**Max**
GDP	54	12.8392	1.5282	10.4123	16.0181
GDBT	54	53.167	17.1014	23.7479	84.2100
LUBNP	54	7.4171	0.7612	5.9998	8.6630
GHEXP	54	2.5388	3.4889	0.6984	26.2149
INDS	54	10.5735	0.7438	9.1600	11.6862

Table 2

RESULTS OF PANEL UNIT METHODS					
Variables	**Probability**	**Levin, Lin & Chu t***	**IP & Shin W-stat**	**ADF – Fisher Chi-square**	**PP – Fisher Chi-square**
LGDP	At level At 1st difference	07388 0.0000	0.8984 0.0773	0.1725 0.1731	0.0003 0.0036
DEBT	At level At 1st difference	0.0011 0.0000	0.5394 0.0002	0.5705 0.0034	0.5872 0.0006
LUBNP	At level	0.0000	0.0000	0.0000	0.0000
GHEXP	At level	0.0000	0.0000	0.0395	0.0110
INDS	At level At 1st difference	0.0070 0.0000	0.9795 0.0000	0.9732 0.0000	0.3505 0.0000

Table 3

RANDOM EFFECT RESULTS	
Variables	**Coefficients Standard Errors T-statistics**
DEBT	–0.0004** 0.0002 (–1.65)
LUBNP	0.3328* 0.0845 (3.94)
GHEXP	0.0003 0.0003 (0.92)
INDS	0.8780* 0.0457 (19.20)
R-Square within R-Square between R-Square overall	0.97 0.59 0.59

improves investments, per capita income, growth and development.

The variable government health expenditure is found to be significantly positive (0.0003). These results show that spending on health tends to improve the GDP in selected developing countries during this time. This indicates that high human capital investments in these economies are connected with increasing growth. The results are in line with Rahman [28] which shows a positive link between health and education expenditures and the growth of the country.

Industrialization is most important for heavy industrial production, growth and development.

Industrialization increases gross domestic product. The result is statistically significant. The study result shows that a one percent increase in industrialization increases 0.8780 percent of GDP. The reason can be that industrialization enhances employment, income and economic growth. The result is consistent with Isiksal [35] and Ndiaya and Lv. [36].

CONCLUSION AND POLICY RECOMMENDATIONS

This research makes a significant contribution while discussing the relationship between public debt and long-run economic performance. The prevailing literature focuses on whether there exist nonlinear effects of public debt on growth. The findings show evidence for such nonlinearities.

The debt burden is a challenging issue in South Asian economies. The theories under discussion and work done empirically are incapable to find out the reasons for the influences of debt burden on economic growth. This study is a good contribution to examining the effect of government debt burden with industrialization on the gross domestic product by using 10 years of data in selected developing countries. Findings of the negative influence of government debt and gross domestic product are found by Presbitero [40], Kourtellos et al. [5], and Mencinger [32].

Government debt is a great hurdle for investment and human capital development and the growth of the economy. It decreases the chances of investment and saving. There is a dire need to control government debt in these selected developing economies. In these countries, there should be an inclusive set of policies to develop financial crisis know-how and intensity of this issue to lessen its burden on the economy. Moreover, institutional quality leads to improves growth and this is a good indicator of the growth and development of the economy. This institutional quality must be improved further.

The study concludes that more expenditure on health may increase human capital development and economic growth in developing economies so free-of-cost health facilities must provide to all segments of society. For this, institutions must play an important role. In addition, industrialization is contributing well towards growth. Moreover, more education of people must be ensured providing equal opportunities to males and females. In addition, Government must play a transparent and very effective role in lowering the debt burden by making regulations and reforms in the financial sector.

REFERENCES

[1] Cecchetti, S, Mohanty, M., Zampolli, F., *The future of public debt*, In: Gokarn, S. (ed), Challenges to central banking in the context of the financial crisis, New Delhi: AcademicFoundation, 2011, 183–217

[2] Reinhart, C., Rogoff, M., Kenneth, S., *Growth in a time of debt,* In: Am. Econ. Rev. Pap. Proc., 2010, 100, 2, 573–578

[3] Reinhart, C., Rogoff, M., Kenneth, S., *Debt and growth revisited,* MPRA Paper 24376. University Library of Munich, Germany, 2010

[4] Panizza, U., Presbitero, A.F., *Public debt and economic growth in advanced economies: A survey*, In: Swiss Journal of Economics and Statistics , 2013, 149, 175–204

[5] Kourtellos, A., Stengos, T., Tan, Chih M., *The effect of public debt on growth in multiple regimes*, In: J. Macroecon., 2013, 38, 35–43

[6] Panizza, U., Presbitero, A.F., *Public debt and economic growth in advanced economies: a survey,* In: Swiss J. Econ. Stat., 2013, 149, 2, 175–204

[7] Pacheo Lopez, P., Thirwall, A.P., *A New interpretation of Kaldor's Firs Growth Law for Open Developing Economies,* University of Kent, School of Economics Discussion Paper, 2013, KDPE 1312
[8] Szirmai, A., *Industrialization as an Engine of Growth in Developing Countries1950-2005*, In: Structural Change and Economic Dynamics, 2012, 23, 406–420
[9] Kaldor, N., *Strategic Factors in Economic Development*, Cornell University Press, Ithaca, NY, 1967
[10] Park, D., Kwanho, S., *Economic Growth, Financial Development and Income Inequality*, In: Asian Development Bank Economics Working paper series, 2015, 441
[11] Elmendorf, D.W., Mankiw, G.N., *Government debt*, In: Taylor, J.B., Woodford, M. (Eds.), Handbook of Macroeconomics, Elsevier, 1999, 25, 1615–1669
[12] Modigliani, F., *Long-run implications of alternative fiscal policies and the burden of the national debt*, In: Econ. J., 1961, 730–755
[13] Diamond, P.A., *National debt in a neoclassical growth model,* In: Am. Econ. Rev., 1965, 55, 5, 1126–1150
[14] Blanchard, O.J., *Debt, deficits, and finite horizons,* In: J. Polit. Econ., 1985, 93, 2, 223–247
[15] Barro, R.J., *Government spending in a simple model of endogenous growth*, In: J. Polit. Econ., 1990, 98, 5 pt 2, S103–S125
[16] Saint-Paul, G., *Fiscal policy in an endogenous growth model*, In: Q. J. Econ., 1992, 107, 4, 1243–1259
[17] Teles, V.K., Mussolini, C.C., *Public debt and the limits of fiscal policy to increase economic growth*, In: Eur. Econ. Rev., 2014, 66, 1–15
[18] Cochrane, J.H., *Inflation and Debt*, In: National Affairs, 2011, 53, National Affairs, Inc. and the American Enterprise Institute, Available at: https://www.nationalaffairs.com/publications/detail/inflation-and-debt. [Accessed on September 2021]
[19] Codogno, L., Favero, C., Missale, Al., *Yield spreads on EMU government bonds,* In: Econ. Policy, 2003, 18, 37, 503–532
[20] Laubach, T., *New evidence on the interest rate effects of budget deficits and debt*, In: J. Eur. Econ. Assoc., 2009, 7, 4, 858–885
[21] Krugman, P., *Financing vs. forgiving a debt overhang*, In: Journal of Development Economics, 1988, 29, 3, 253–268
[22] Aguiar, M., Amador, M., Gopinath, Gi., *Investment cycles and sovereign debt overhang*, In: Rev. Econ. Stud., 2009, 76, 1, 1–31
[23] Greenlaw, D., Hamilton, J., Hooper, P., Mishkin, F.S., *Crunch time: fiscal crises and the role of monetary policy,* In: Proceedings of the U.S. Monetary Policy Forum 2013, 2013
[24] Shuanglin, L., Kim, S., *Foreign debt and economic growth*, In: Economics of Transition, 2001, 9, 3, 635–655
[25] Pattillo, C., Poirson, H., Ricci, L., *What are the Channels through Which External Debt Affects Growth?*, 2004, IMF Working Paper 04/15, Washington, D.C.: IMF, Available at: http://www.imf.org/external/pubs/cat/longres.cfm?sk=17021.0 [Accessed on January 20, 2013]
[26] Egbetunde, T., *Public Debt and economic growth in Nigeria: Evidence from Granger Causality*, In: American Journal of Economics, 2012, 2, 6, 101–106
[27] Spulbar, C., Ehsanifar, M., Birau, R., Babaie, A., Doagă, D.I., *Advanced empirical research based on structural equation modeling (SEM) regarding the impact of tax revenue on GDP dynamics at EU-28 level*, In: Scientific Annals of Economics and Business, 2021, 68, 3, 285–307, https://doi.org/10.47743/saeb-2021-0017
[28] Rahman, F., Rahman, N., *Effectiveness of Foreign Aid and Social-Economic Variables on HDI: A Comparative Study between Bangladesh and India*, In: Journal of Business, 2014, 35, 3
[29] Stylianou, T., *Debt and economic growth: Is there any casual effect? An Empirical Analysis with Structural breaks and granger casualty for Greece*, In: Theoretical and applied Economics, 2014, xxi, 1, 590, 51–62
[30] Anita, C.C., Ana, A.B., Badurina, M.B.S., *Public debt and growth: Evidence from Central, Eastern and Southeastern European Countries*, In: Zb.rad.Ekon.fak.Rij., 2014, 32, 1, 35–51
[31] Proaño, C.R., Schoder, C., Semmler, W., *Financial stress, sovereign debt and economic activity in industrialized countries: Evidence from dynamic threshold regressions*, In: Journal of International Money and Finance, 2014, 45, 17–37, https://doi.org/10.1016/j.jimonfin.2014.02.005
[32] Naeem, M.Z., Arshad, S., Birau, R., Spulbar, C., Ejaz, A., Hayat, M.A., Popescu, J., *Investigating the impact of CO2 emission and economic factors on infants health: a case study for Pakistan*, In: Industria Textila, 2021, 72, 1, 39–49, http://doi.org/10.35530/IT.072.01.1784
[33] Mehdiabadi, A., Shahabi, V., Shamsinejad, S., Amiri, M., Spulbar, C., Birau, R., *Investigating Industry 5.0 and Its Impact on the Banking Industry: Requirements, Approaches and Communications*, In: Applied Sciences, 2022, 12, 10, 5126, https://doi.org/10.3390/ app12105126
[34] Ikudayise, A., Akin-Olagunju, U., Babatunde, A., Irhivben, B., Okoruwa.,V., *Nigerian debt portfolio and its implication on economic growth*, In: Journal of Economics and Sustainable Development, 2015, 6, 18, 87–99
[35] Isiksal, A.Z., Himeezie, O.J., *Impact of Industrialization in Nigeria*, In: European Scientific Journal, 2016, 12
[36] Ndiaya, C., Lv, K., *Role of Industrialization on Economic growth: The Experience of Senegal (1960–2017),* In: American Journal of Industrial and Business Management, 2018, 8, 2072–2085
[37] Nguyen, C.P., Dinh, T.S., Nguyen, T., *Institutional Quality and Economic Growth: The Case of Emerging Economies*, In: Theoretical Economics, 2018, 8, 11, 1943–1956, https://doi.org/10.4236/tel.2018.811127
[38] Lim, J.J., *Growth in the Shadow of Debt,* In: Journal of Banking and Finance, 2019, 103, 98–112

[39] Pegkas, P., Staikouras, C., Tsamadias, C., *On the Determinants of Economic Growth: Empirical Evidence from the Eurozone Countries,* In: International Area Studies Review, 2020, 23, 2, 210–229

[40] Presbitero, A.F., *Total Public Debt and Growth in Developing Countries*, In: European Journal of Development Research Forthcoming, 2012

Authors:

DURDANA QAISER GILLANI[1], MUHAMMAD ZAHID NAEEM[2], CRISTI SPULBAR[3], ABDULLAH EJAZ[4], RAMONA BIRAU[5], LUCIAN CLAUDIU ANGHEL[6], PETRE VALERIU NINULESCU[3], ANDREI CRISTIAN SPULBAR[3]

[1]The University of Lahore, Lahore, Pakistan
e-mail: durdana.qaiser@econ.uol.edu.pk

[2]University of Brunei Darussalam (UBD), Gadong BE1410, Brunei Darussalam
e-mail: drmznaeem@gmail.com

[3]Faculty of Economics and Business Administration, University of Craiova, Craiova, Romania
e-mail:cristi_spulbar@yahoo.com, petre.pregi@yahoo.it, andrei.spulbar@gmail.com

[4]Department of Anthropology, Economics and Political Science, MacEwan University, Canada
e-mail: ejazabdullah03@gmail.com

[5]University of Craiova, Doctoral School of Economic Sciences, Craiova, Romania

[6]Faculty of Management, National University of Political Studies and Public Administration, Bucharest, Romania
e-mail: lucian.anghel@facultateademanagement.ro

Corresponding author:

RAMONA BIRAU
e-mail: ramona.f.birau@gmail.com

Effects of impactors' shape on three-dimensional woven fabric composites at low-velocity impacts

DOI: 10.35530/IT.073.06.202193

ZULKIFLI MUHAMAD
CHIK AIMAN
ZAHID BILAL
YAHYA MOHAMAD

ABSTRACT – REZUMAT

Effects of impactors' shape on three-dimensional woven fabric composites at low-velocity impacts

This study investigated the fabric resistance of three-dimensional (3D) woven fibreglass composites generated by impactors of three shapes, i.e., hemispherical, conical, and ogival, on four types of composite structures. Composites were fabricated using the hand lay-up technique. Crimp and mechanical impact resistance tests were carried out in accordance with ASTM D2444 standards and ASTM D3883-04, respectively. The four-floating interlocked (4FLL) yielded the strongest fabric damage tolerance for all the three types of impactors' shapes with 6.3 kN for the hemispherical shape, 4 kN for the conically shaped, and 3.8 kN for the ogival shape. Additionally, the 4FLL generated a fabric crimp of 3.5% and 2.8% on both fabric directions. The post-impact damage showed that the ogival shape impactor penetrated samples of woven composites better than the conical and hemispherical shapes.

Keywords: *woven, composites, impact, impactors' shape, fibreglass*

Influența formei elementelor de impact asupra compozitelor țesute tridimensionale la impact cu viteză redusă

Acest studiu a investigat rezistența materialului compozitelor din fibră de sticlă țesute tridimensionale (3D) generate de elementele de impact cu trei forme, adică emisferice, conice și ogivale, pe patru tipuri de structuri compozite. Compozitele au fost fabricate folosind tehnica de întindere manuală. Testele de rezistență la ondulare și impact mecanic au fost efectuate în conformitate cu standardele ASTM D2444 și, respectiv, ASTM D3883-04. Țesătura de tip interlock cu 4 flotări (4FLL) a înregistrat cea mai ridicată toleranță la deteriorare pentru toate cele trei tipuri de forme de impact, cu 6,3 kN pentru forma emisferică, 4 kN pentru forma conică și 3,8 kN pentru forma ogivală. În plus, 4FLL a generat o ondulare a țesăturii de 3,5% și 2,8% pe ambele direcții. Daunele post-impact au arătat că elementul de impact cu formă ogivală a pătruns probele de compozite țesute mai bine decât cel cu formă conică și emisferică.

Cuvinte-cheie*: țesut, compozite, impact, forma elementelor de impact, fibra de sticlă*

INTRODUCTION

Woven composites are often created by combining technical textiles with dissimilar properties and adhering them together using polymer resin to create a superior product that can be utilised for a variety of technical applications [1]. The advancement of woven composite materials has been rapid due to superior features such as a high stiffness-ta high stiffness-to-weight ratioigue life. To date, both conventional two- (2D) and three-dimensional (3D) woven fabrics emerge as popular choices for various technical applications in sectors such as aerospace, shipping, and transportation.

In general, the 3D woven fabric is made by interlacing warp, weft, and z-yarn [2], with yarns assembled in the direction of the warp and weft. The yarn friction generated from this positioning is crucial in conferring the woven fabric agility against the smack of rupturing force [3]. 3D woven are made by interlacing yarns in lengthwise (X), crosswise (Y), and vertical (Z) [4]. The yarn's interweaving undulation movement has also caused another pertinent condition, i.e., the fabric crimp. Studies showed that the fabric crimp could significantly influence the mechanical strength, particularly on tensile and impact resistance performance, depending on the fraction of fabric crimp [5–7]. Through-thickness yarn plays a pivotal role in establishing the structurally intact three-dimensional fabric by binding non-crimp warp and weft yarn in the thickness direction [8]. Because 3D textiles are more resistant to delamination, the composite significance has progressed quickly [9, 10].

Meanwhile, minimising the damage against low-velocity impact has become one of the most crucial issues in fabricating the woven composite, especially in the application of aeroplane body parts. Low-velocity impacts against woven composite surfaces lead to matrix cracking, thus weakening the integrity of the structure. The damage is difficult to detect since it is not visible on the surface. If uncorrected, the structure's integrity will eventually fail and break apart, leading to catastrophic failure during its use.

Extensive studies had been conducted to optimise the reduction of impact damages on woven fabric

composites. Comparative studies showed that owing to the structure of the yarn interlacement', the 3D woven fabrics were able to maximise their impact resistance by eliminating the delamination. In this regard, the three-dimensional angle-interlocked is adequate for bulletproof protection, with delamination resistance higher than the laminated composite in the in-plane modulus [11]. Also, this composite showed higher resistance against impact owing to its ability to absorb a high capacity of energy by the z-direction fibres [12].

Meanwhile, the orthogonal weave attempts to move the warp at 90 degrees through fabric thickness for enhanced binding and organisational coherence structure [13]. This binder yarn increases modulus, resulting in greater shear and torsional strength and resistance to delamination [14]. Three-dimensional orthogonal composites, in particular, exhibited exceptional energy absorption for low momentum impact by spreading the damaging waves away from the impact zone more quickly [15]. Besides, this composite had a remarkable impact resistance since no delamination occurred when impacted with a conical cylindrical steel projectile owing to the presence of z-yarns in the direction of thickness [16].

The resistance of four different types of three-dimensional woven fabric fibreglass composites to a low-velocity drop-weight impact force was tested in this study. This study also determined the effects of impactors' shape on these three types of impactors (hemispherical, conical, and ogival). This study would significantly help optimise the yarn float length manipulation on 3D woven fabric–structure against impact resistance performance.

METHODOLOGY

Woven fabrics and composite fabrication

This study evaluated four types of 3D woven fibreglass fabrics: one-floating interlocked (1FAI), three-floating interlocked (3FALI), nine-floating interlocked (9FAI), and four-floating interlocked (4FLL), and figures 1, 2, 3, and 4 show their respective transversional view. The matrix of these fabrics comprised the

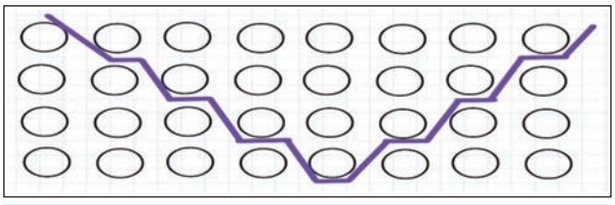


Fig. 1. The 1FAI

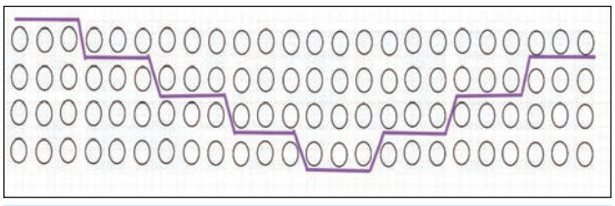


Fig. 2. The 3FALI

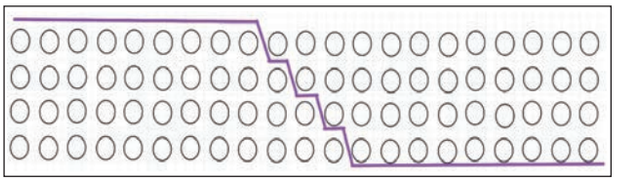


Fig. 3. The 9FAI

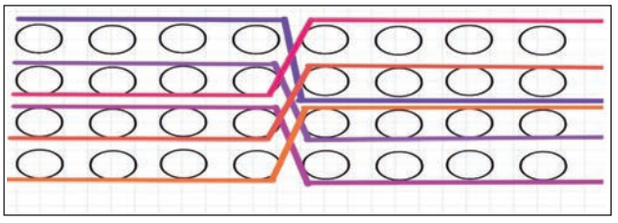


Fig. 4. The 4FLL

Morcrete BJC39 epoxy resin and hardener HY225. Table 1 summarises the properties of the epoxy resin. The fibreglass mingled well with the epoxy, producing composites with robust and high mechanical performance.

Table 1

CHARACTERISTICS OF THE EPOXY RESIN	
Epoxy: hardener ratio	3.5:1.25
Compression strength (MPa)	76
Curing hours	8 h
Curing temperature	Room temperature

Composites were fabricated using the hand lay-up approach. Each of the four woven textiles was cut into an 80 mm × 240 mm rectangle piece and placed in a mould. The resin, premixed with the hardener in a ratio of 3.7:1.3, was then applied to the fabrics and pressed along the fabrics with a roller. Together with the mould, the fabricated fabrics were cured in an oven with an initial temperature of 30°C. The temperature was continually increased by 20°C at every 30 min until it reached the maximum temperature of 100°C. The fabrics were then cured for another 3 h at the highest temperature. Altogether, 20 samples were prepared with five replicates for each type of fabric to minimise woven composite fabrication damage during processing while yielding average results.

Fabric crimp

The fabric crimp is the product of yarn undulation through the yarn-yarn interlacement on the weave structure (citation). The standard method of the American Society of Testing and Materials (ASTM) D3883-04 was used to estimate the crimp fraction of the yarn that was pulled out from the woven fabric sample. The length of the straightening yarn (L_1) was compared with the woven fabric length (L_2). Equation 1 depicts the calculation of the fraction of yarn crimp.

$$Yarn\ crimp\ (\%) = \frac{L_1 - L_2}{L_2} \times 100 \quad (1)$$

Impact testing

The impact of the fabric resistance was evaluated using an impact test machine (model: Instron Dynatup 9250 HV Tester) following the method of ASTM D2444. In this drop test, specimens were impacted by an impactor at low velocity until specimens ruptured or the limit of the extension was attained. All experiments were performed with a constant inceptive impact energy of 20 J via a mass of 3.29 kg at a distance of 0.6163 m between the impactor tup and specimen, and a velocity of 3.4901 m/s. The fabrics were tested with three types of impactors (12 mm diameter), i.e., conical, hemispherical, and ogival impactors (figure 5). All samples were cut into square pieces of 80 mm × 80 mm and fastened on the top of the round metal block to allow the impactor to pierce it. After the impactor perforated the textiles, the force imparted to the composites was calculated instantly.

Float Over Depth

The float over depth (FOD) is a ratio that measures warp length movement above weft yarns and then divided by how much it travels through fabric thickness, as shown by equation 2. The equation comprises where *f* is the measurement of float length while nl is the indication number of the layers that warp yarn travels through 3D fabric thickness:

$$Float\ over\ depth\ (FOD)\ ratio = \frac{f}{nl} \quad (2)$$

where *f* is float length and *nl* – the number of layers.

RESULTS AND DISCUSSION

The compilation results of the low-velocity drop impact test based on four different woven fabric samples and three different impactor shapes were presented in this section.

Fabric crimp

Figure 6 shows the crimp percentage of different 3D weave structures, 1FAI, 3FALI, 4FLL and 9FAI.

At the warp direction, the 1FAI woven fabric displayed the highest crimp percentage, i.e., 6% followed by 3FALI, 4FLL, and 9FAI, and the yarn float length showed a direct relationship with the reduction of crimp percentage in both warp and weft directions. Longer float resulted in lower crimp percentage as well as shearing behaviour. In general, the warp yarn in 3D fabrics produced higher crimps compared to

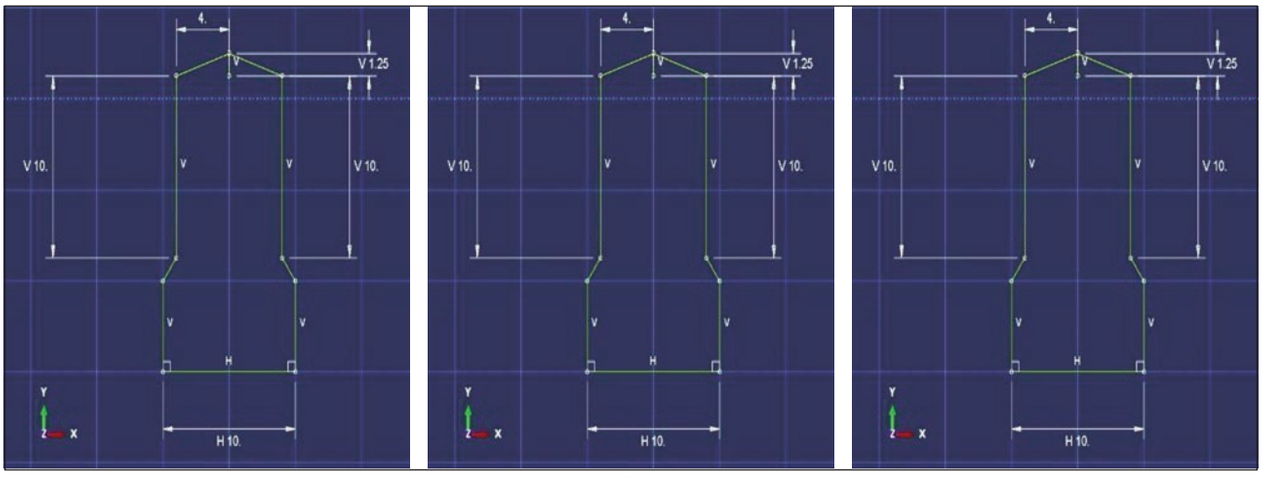


Fig. 5. Impactors shapes and dimensions in mm: *a* – ogival; *b* – hemispherical; *c* – conical

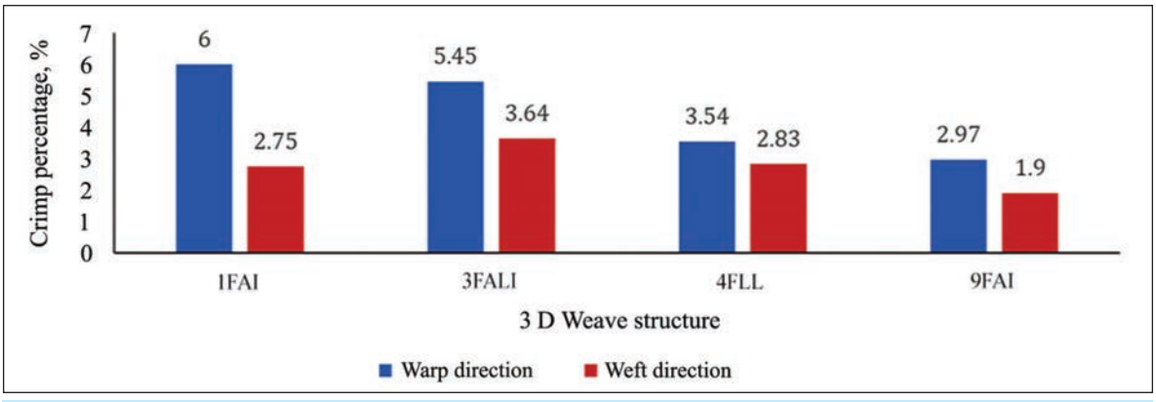


Fig. 6. Fabric crimp percentage

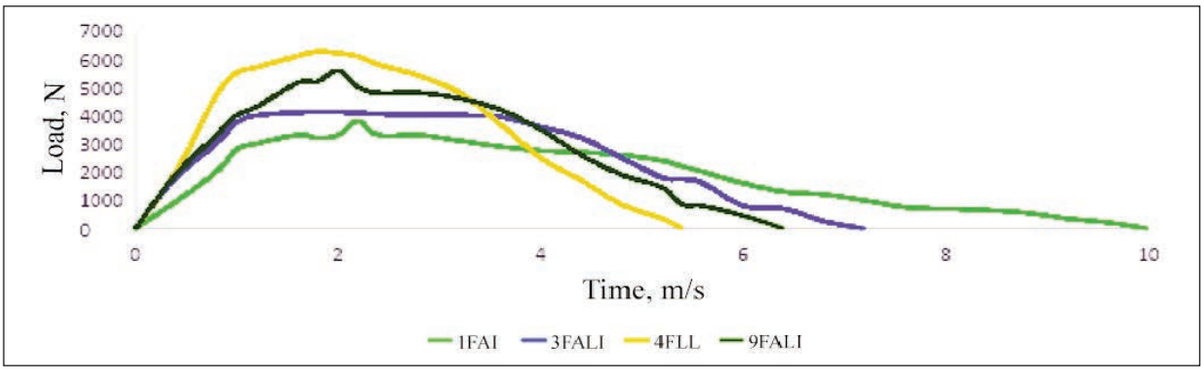


Fig. 7. Peak forces of the hemispherical impactor to rupture all composite samples

the weft yarn. This is because warp yarn had to move through the structures either layer to layer or through the structures.

Impact resistance based on the impactor shape

Figure 7 depicts the maximum force required by the hemispherical impactor to rupture all composite samples. The 4FLL fabric showed the greatest resistance towards the impact requiring an average force of 6250.0 N to rupture it and followed by 9FAI, 3FALI, and 1FAI fabrics requiring average forces of 5581.0, 4528.0, and 3800.0 N, respectively. The contact time for all composites attaining the peak force ranged between 1.8 and 2.2 m/s.

Figure 8 shows the peak force that the conical impactor needed to break all composite samples. The greatest peak force obtained by the 4FLL fabric was 4000.1 N, followed by the 9FAI, 3FALI, and 1FAI fabrics, with the maximum force typically reaching between 3.7 and 4.6 m/s, except for the 4FLL, which reached the peak force at 2.0 m/s. The conical impactor, with a smaller interacting surface area, could penetrate fewer layers of the composites compared to the hemispherical impactor, thus requiring a longer impacting time to rupture the fabrics.

Figure 9 shows the peak force that the ogival impactor needed to puncture all composite samples. Similar to the previous two impactors, the 4FLL fabric showed the highest resistance with an average force of 3750.7 N and followed by 9FAI, 3FALI, and 1FAI fabrics requiring an average force of 3411.0, 3342.6, and 2647.3 N, respectively. The contact time for all composites attaining the peak force ranged between 3.6 and 4.6 m/s.

Overall, the 4FLL composite consistently gave the most robust fabric resistance with the highest peak force, followed by 9FAI, 3FALI, and 1FAI fabrics. In general, the hemispherical impactor tup, with a generally larger surface area, required a higher force at the shortest contact time (5.6 m/s) to break the fabric, while the ogival impactor, with the smallest surface area, penetrated easier (less force but a longer contact time, i.e., 7.6 m/s) as more pressure was exerted on the composites. The findings of this study were consistent with the modelling results reported in another study [17, 18], i.e., the ogival impactor required the smallest peak force to puncture the fabrics. However, the ogival impactor generated more friction between the impactor and composite, thus increasing the contact time.

The hemispherical impactor yielded a broader damaged area without penetrating the composite but with matrix cracking. In contrast, the ogival impactor penetrated the composite with matrix cracking encircling the pierced hole due to the fibre breakage. Penetration was observed in the impact of the conical impactor but with a smaller damaged area than the ogival impactor but larger than the hemispherical impactor. In general, damages on the rear surface area were dependent on the shape of the impactor.

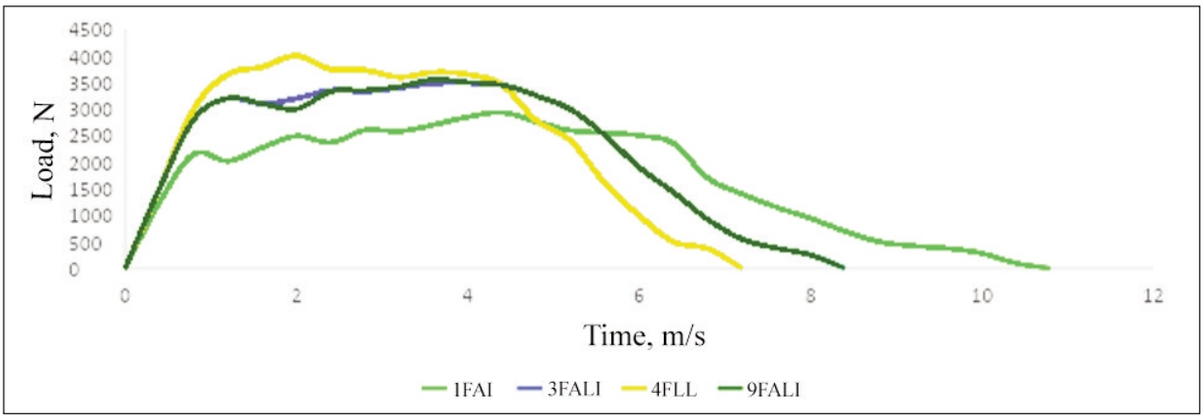


Fig. 8. Peak forces of the conical impactor to penetrate all composite samples

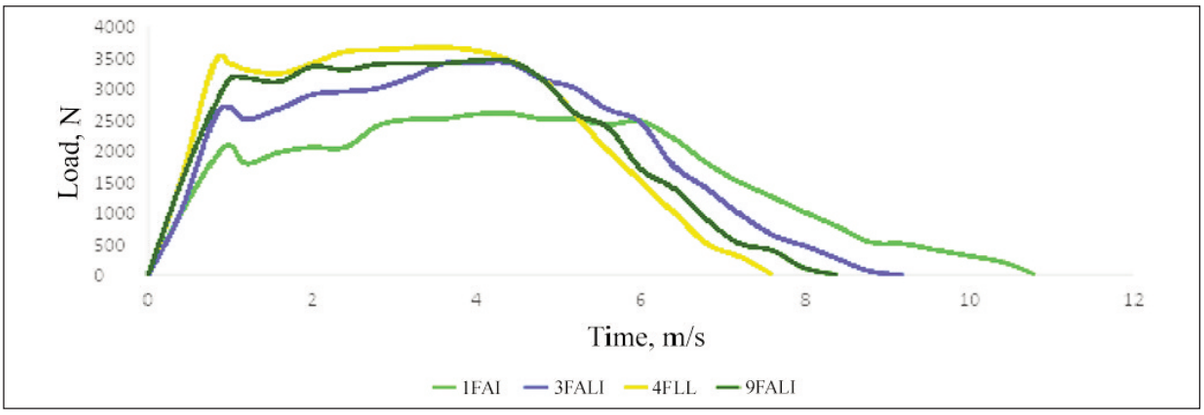


Fig. 9. Peak forces of the ogival impactor to pierce all composite samples

Table 2

FLOAT OVER DEPTH RATIO ACCORDING TO DIFFERENT IMPACTOR SHAPES AND WEAVE STRUCTURE				
Fabric	**FOD ratio**	**Conical Impactor (N)**	**Ogival Impactor (N)**	**Hemispherical Impactor (N)**
1FAI	0.25	2850.0	2647.3	3800.0
3FALI	3	3478.9	3342.6	4528.0
4FLL	4	4000.1	3750.7	6250.0
9FAI	2.25	3490	3411.0	5581.0

Float over depth ratio

Further analysis was carried out to investigate the role of floats and layers in chosen 3D woven fabric structures during the impact and damage process. Table 1 showed that fabric 4FLL reported the highest results for conical, ogival, and hemispherical impact values as well as float over depth (FOD) ratio. The longer yarn float with minimal interlacing depth resulted in higher impact performance. The float-over-depth ratio for each type of fabric is presented in following table 2.

CONCLUSION

The impact damage of four different types of 3D woven textiles was investigated in this study. The 4FLL composite yielded the most robust resistance against impact followed by 9FAI, 3FALI, and 1FAI fabrics. The longer warp length above weft with lower depth was able to provide greater resistance during impact. This was shown by 4FLL capability to respond for higher impact within a 2 seconds time frame and delayed maximum impact force (N) for hemispherical and conical impactors. Meanwhile, the ogival impactor, with a smaller surface area, required a slightly lower force and a shorter time frame within 1 second to break the composite compared to blunter impactors, such as the conical and hemispherical impactors. Future investigations on post-damage woven composite characteristics could be studied using physical and computer simulations to determine the suitability of technical applications based on the type of weave structure against different impactor shapes.

ACKNOWLEDGEMENT

The work is supported entirely by a grant from Universiti Teknologi MARA (UiTM) under the 600-IRMI 5/3/LESTARI (044/2019).

REFERENCES

[1] Ansar, M., Xinwei, W., Chouwei, Z., *Modeling strategies of 3D woven composites: A review*, In: Composite Structures, 2011, 93, 8, 1947–1963, https://doi.org/10.1016/j.compstruct.2011.03.010

[2] Unal, P.G., *3D Woven Fabrics,* InTech, 2012, 91–120

[3] Yahya, M.F., Salleh, J., Ahmad, W.Y., Ghani, S.A., *Finite element analysis of impactor shapes effects on puncture damage of plain woven fabric,* In: Colloquium: IEEE Colloquium on Humanities, Science and Engineering (CHUSER), 2012, 729–734

[4] Behera, B. K., Dash, B. P., *An experimental investigation into the mechanical behaviour of 3D woven fabrics for structural composites*, In: Fibers and Polymers, 2014, 15, 9, 1950–1955, https://doi.org/10.1007/s12221-014-1950-9

[5] Nasrun, F.M., Yahya, M.F., Ghani, S.A., Ahmad, M.R., *Effect of weft density and yarn crimps towards tensile strength of 3D angle interlock woven fabric,* In: Conference: AIP Conference Proceedings, 2016, AIP Publishing LLC

[6] Bilisik, K., *Two-dimensional (2D) fabrics and three-dimensional (3D) preforms for ballistic and stabbing protection: A review,* In: Textile Research Journal, 2017, 87, 18, 2275–2304

[7] Das, S., Jagan, S., Shaw, A., Pal, A., *Determination of inter-yarn friction and its effect on ballistic response of para-aramid woven fabric under low velocity impact*, In: Composite Structures, 2015, 120, 129–140

[8] Isart, N., El Said, B., Ivanov, D.S., Hallett, S.R., Mayugo, J.A., Blanco, N., *Internal geometric modelling of 3D woven composites: A comparison between different approaches*, In: Composite Structures, 2015, 132, 1219–1230, https://doi.org/10.1016/j.compstruct.2015.07.007

[9] Miao, H., Wu, Z., Ying, Z., Hu, X., *The numerical and experimental investigation on low-velocity impact response of composite panels: Effect of fabric architecture*, In: Composite Structures, 2019, 227(June), 111343, https://doi.org/10.1016/j.compstruct. 2019.111343

[10] Hübner, M., Fazeli, M., Gereke, T., Cherif, C., *Geometrical design and forming analysis of three-dimensional woven node structures,* In: Textile Research Journal, 2018, 88, 2, 213–224, https://doi.org/10.1177/0040517516677231

[11] Li, Z., Sun, B., Gu, B., *FEM simulation of 3D angle-interlock woven composite under ballistic impact from unit cell approach*, In: Computational Materials Science, 2010, 49, 1, 171–183

[12] Hu, X., Ying, Z., Cheng, X., Wu, Z., *Effect of Z-binder tension and internal micro-structure on damage behavior of 3D orthogonal woven composite,* In: Journal of Industrial Textiles, 2018, https://doi.org/10.1177/1528083718791328

[13] Ahmed, S., Zheng, X., Wu, T., *Elastic and strength analysis of hybrid 3D woven orthogonal composites: Numerical and analytical modelling,* In: Journal of Reinforced Plastics and Composites, 2019, https://doi.org/10.1177/0731684419844331

[14] Midani, M., Seyam, A.F., Saleh, M.N., Pankow, M., *The effect of the through-thickness yarn component on the in- and out-of-plane properties of composites from 3D orthogonal woven preforms*, In: Journal of the Textile Institute, 2019, 110, 3, 317–327, https://doi.org/10.1080/00405000.2018.1481722

[15] Yahya, M.F, Ghani, S.A, Zahid, B., *Uniaxial Tensile Simulation of 3D Orthogonal Woven Fabric*, In: International Journal of Engineering & Technology, 2018, 7, 3.15, 197, https://doi.org/10.14419/ijet.v7i3.15.17529

[16] Jiang, L., Hu, H., *Finite element modeling of multilayer orthogonal auxetic composites under the low-velocity impact,* In: Materials, 2017, 10, 8, https://doi.org/10.3390/ma10080908

[17] Yahya, M.F., Ghani, S. A., Salleh, J., *Effect of impactor shapes and yarn frictional effects on plain woven fabric puncture simulation*, In: Textile Research Journal, 2014, 84, 10, 1095–1105

[18] Kazemianfar, B., Esmaeeli, M., Nami, M.R., *Response of 3D woven composites under low velocity impact with different impactor geometries,* In: Aerospace Science and Technology, 2020, 102, 105849, https://doi.org/10.1016/j.ast.2020.105849

Authors:

ZULKIFLI MUHAMAD[1], CHIK AIMAN[1], ZAHID BILAL[2], YAHYA MOHAMAD[1]

[1]Universiti Teknologi MARA (UiTM) Shah Alam, Faculty of Applied Sciences, Textile Research Group, 40450 Shah Alam, Selangor Darul Ehsan, Malaysia

[2]NED University of Engineering & Technology, Textile Engineering Department, Main University Road, Block 1, Gulshan-e-Iqbal, Karachi, Pakistan

Corresponding author:

YAHYA MOHAMAD
e-mail: mfy@uitm.edu.my

Development and characterization of socks with improved anti-odour, thermo-regulating and handle properties

DOI: 10.35530/IT.073.06.20221

JAMSHAID HAFSA
NADEEM MUHAMMAD
ABDUL WAQAR RAJPUT

DAD ALLAH
HUSSAIN UZAIR

ABSTRACT – REZUMAT

Development and characterization of socks with improved anti-odour, thermo-regulating and handle properties

Due to awareness of the potential threats of spreading diseases, the demand for antimicrobial fabrics in the world market has grown significantly and, is, expected to increase the share of medical textiles in the future world market. The purpose of this study is to develop antibacterial socks with the application of silver particles and to study thermo-physiological properties as well as the evaluation of tactile sensory perceptions of treated socks against untreated socks. Socks, which are a necessary item of clothing, need to be comfortable and affordable. The materials used for this study are cotton and polyester fibre with three different cross-sectional shapes i.e., common Polyester (round shape), Coolmax (Channeled polyester) and Thermolite (Hollow polyester). Blend ratios with percentages of 80/20 Cotton/Polyester, 80/20 Cotton/Coolmax and 80/20 Cotton/Thermolite were used as main yarns in plain crew socks while elastane yarn is used in the same percentage in all developed socks. A comparison between the samples treated with silver particles and the corresponding control samples concerning the selected properties was done. The presence of particles on the treated fibre was confirmed through an SEM study. Testing of untreated and treated fabrics for antibacterial study and odour test was carried out and found significant. The thermo-physiological properties such as air permeability, relative water vapour permeability % and thermal resistance were also studied and found better results as compared to untreated samples. Later tactile sensorial comfort i.e., fabric hand value was compared which is improved for treated samples which makes the wearer comfortable hand feeling. These data present a great interest to socks manufacturers who can make better choices to manufacture, cost-effective anti-odour socks.

Keywords: *socks, antibacterial, cotton, thermo-physiological comfort, polyester (PET)*

Dezvoltarea și caracterizarea șosetelor cu proprietăți îmbunătățite anti-miros, termoreglare și tușeu

Datorită conștientizării potențialelor amenințări ale răspândirii bolilor, cererea de materiale textile antimicrobiene pe piața mondială a crescut semnificativ și, se așteaptă să crească ponderea textilelor medicale pe viitoarea piață mondială. Scopul acestui studiu este de a dezvolta șosete antibacteriene cu aplicarea de particule de argint și de a studia proprietățile termofiziologice, precum și evaluarea percepțiilor senzoriale tactile ale șosetelor tratate față de șosete netratate. Șosetele, care sunt un articol de îmbrăcăminte necesar, trebuie să fie confortabile și accesibile. Materialele utilizate pentru acest studiu sunt bumbacul și poliesterul cu trei forme diferite de secțiune transversală, adică poliester comun (formă rotundă), Coolmax (poliester cu canale) și Thermolite (poliester cu lumen). Rapoartele de amestec cu procente de 80/20 Bumbac/Poliester, 80/20 Bumbac/Coolmax și 80/20 Bumbac/Thermolit au fost utilizate ca fire principale în șosetele simple, în timp ce firele de elastan sunt utilizate în același procent în toate șosetele dezvoltate. S-a făcut o comparație între probele tratate cu particule de argint și probele de control corespunzătoare cu referire la proprietățile selectate. Prezența particulelor pe fibra tratată a fost confirmată prin studiul SEM. Testarea materialelor textile netratate și tratate pentru studiul antibacterian și testul de miros a fost efectuată și s-a constatat că este semnificativă. Proprietățile termofiziologice, cum ar fi permeabilitatea la aer, permeabilitatea relativă la vapori de apă și rezistența termică au fost, de asemenea, studiate și s-au înregistrat rezultate superioare în comparație cu probele netratate. Ulterior, a fost comparat confortul senzorial tactil, adică valoarea tușeului materialului, care este îmbunătățită pentru mostrele tratate care oferă senzația de tușeu moale pentru utilizator. Aceste date prezintă un mare interes pentru producătorii de șosete, care pot face alegeri mai bune pentru fabricarea șosetelor anti-miros rentabile.

Cuvinte-cheie*: șosete, antibacterian, bumbac, confort termofiziologic, poliester (PET)*

INTRODUCTION

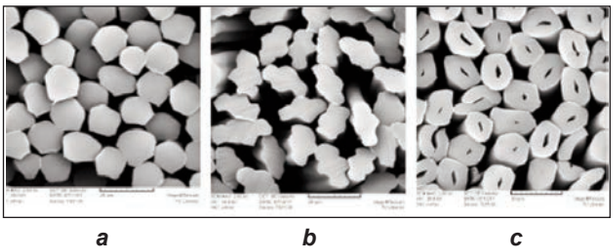
Human Beings always want to find ways for achieving comfort, as it is their basic requirement. Comfort can be classified into three types which are sensorial/tactile comfort, physiological comfort and thermo-psychological comfort. Fabric hand is described as "the tactile sensations or impressions which arise when fabrics are touched, squeezed, rubbed, or otherwise handled" [1, 2]. Thermo-physiological comfort defines the heat and moisture interaction between the human body and the clothing. Socks are designed for various purposes like protecting feet,

fashion etc. In either case, as socks are in direct contact with the human body, they need to possess comfort properties. The effects of fibre properties and fabric construction on comfort properties are studied by various researchers. Cimilli et al. investigated the comfort properties of socks produced with viscose, cotton, bamboo, modal, micro-modal, soybean and chitosan and concluded that chiton and soybean have high thermal resistance values as compared to others while cotton has the highest wicking properties [3]. Similarly, other researchers studied the effect of different materials on the comfort properties of socks [4–7]. M. Morris et al. also studied the relationship between fibre materials and fabric properties on the comfort of socks. Sock softness and dryness are such factors that are parallel with the concept of comfort [8]. Clothing can be contaminated with microorganisms due to warm temperatures and humid conditions. This type of environment is best suited for the growth of bacteria which can lead to unpleasant odours. Studies on the nature of body odour began in the 1960s with the discovery that axillary odour could be produced by the interaction of odourless apocrine secretions with inoculation by gram-positive bacteria found on human skin surface [9].

During physical activity, the textile fabrics affect sweating and odour formation. Poor material selection according to the requirements is one of the reasons for odour formation. Sweat secretion, the bacteria population and a moist environment are the three major components contributing to odour production by the skin [10]. As textile materials are organic materials and they are favourable substrates for microbial growth thus sweat produced by human skin, feeds the bacteria. In extreme conditions, microorganisms can cause serious problems like fabric rotting, unpleasant odours and health concerns like infections and diseases. Socks are pieces of clothing for enclosing the foot and are worn inside the shoes. The foot is among the heaviest producers of sweat in the body, which can produce over a pint of perspiration per day [11]. As 99% of the sweat is water and it forms a perfect medium for bacterial growth, which causes foot odour [12]. Researchers' interest has been increasing day by day in the development of textile fabric having antibacterial elements. Different types of substances like oxidizing agents, coagulants, and metallic or quaternary ammonium compounds are used for antibacterial properties but many of them are considered harmful and toxic [13, 14]. It is considered that silver has a wide range of activity for viruses, fungi and bacteria. In the literature, it was reported that it has good antibacterial properties against various types of bacterial strains [15–18]. Silver has been used as an antimicrobial agent since ancient times. For newborn babies' eyes to prevent blindness, Crede in 1881 used a dilute solution of $AgNO_3$ [19]. Its application has been exploited in wound dressings, creams, surgical prostheses, dental implants and coating on medical devices [20]. Researchers focused to achieve antibacterial properties by using different concentrations of silver solution and application of the solutions on fabric surfaces. The use of silver for coating by electroless plating was done on nylon fibre but the coating has the disadvantage that the silver may be removed from the material by washing and the antimicrobial efficiency of the product will be decreased/finished [21]. In another invention, powdered metal alloy as an antimicrobial agent was used in an extruded polymer fibre [22]. Silver nanoparticles and colloidal silver have been used to impart antimicrobial properties in polymer fibres but they may migrate into the subject or can leach out [23–25]. In another invention, silver was used as a precursor of polymer for fibre formation, but this had the limitation of high cost and different cross-sections of fibre cannot be used [26]. It is required that antimicrobial effect can be attained by a minimum amount within the textile as a whole to produce cost-effective textiles. In the present study, this problem is considered. Such different studies of using silver were found in the literature but no studies found its application by the novel idea of deposition of silver particles on fibre in one step reaction procedure and without the involvement of any toxic chemicals. Additionally, it was also investigated, in the present work, its effect on thermo-physiological, fabric hand and hygiene/antibacterial properties against gram-positive (*Staphylococcus aureus*) bacteria.

MATERIALS AND METHODS

Cotton fibre which is cellulose fibre and the most widely used natural fibre was purchased from the local market. Common polyester fibre (PET) of the circular profile is a synthetic fibre that is widely used in clothing. Coolmax has 20% more surface area and is a modified polyester fibre with a multi-channel cross-section Thermolite is also modified polyester and it is a hollow polyester fibre and has coral gaps in the structure. Cross-sectional images of different PET fibres are shown in figure 1.



a ***b*** ***c***

Fig. 1. Cross-sectional images of PET fibre:
a – PET circular; *b* – Coolmax; *c* – Thermolite

Mechanism of deposition of silver particles in the fibre

Inorganic antimicrobial agents, particularly silver is considered very effective. Silver nitrate $AgNO_3$ offers several merits and is the least expensive salt of silver. It is relatively stable to light. It also dissolves in

numerous solvents, including water and its melting point is 209.7°C [21]. Silver nitrate ($AgNO_3$) solution of 600 ppm is prepared in distilled water with the quantity of 0.003552 mg/l and was used to treat the fabric with liquor ratio 1:10. When polyester fibre is heated at higher or above glass transition (Tg) temperature, so polymer chains become mobile or vibrate, increasing spaces and free volume. This creates an opportunity for the silver particles to penetrate the fibre-free volume which is trapped inside. When the temperature cools down, the fibre comes back to its original position and silver particles penetrate the fibre. So, all different shapes of polyester are treated at 130°C in the TUSJII Dyeing machine (high-pressure dyeing machine) for 20 min.

Characterization of silver particles

The morphology of silver particles deposited on the PET fibre surface was investigated by scanning under an electron microscope of Nova Nano SEM. The microstructure of blended silver-coated PET fabrics was observed on a scanning electron microscope at an accelerated voltage of 5 kV.

Preparation of socks

As different types of yarns are used for socks, the most important of them are main yarn and plaiting yarn. The yarn used on the face side of the fabric is called main yarn and the yarn used on the back side is called plaiting yarn. Due to the common availability and cost-effectiveness of cotton blended with different cross-sectional shapes polyester was selected as the main yarn. Through conducting pretests, a minimum of 20% polyester content was found to be suitable for bacterial efficiency.

In this study crew socks were produced from 20/1 Ne (29.5 tex) by blending 80:20 cotton fibre and treated polyester (PET), Coolmax (CM) and Thermolite (TL) fibres in the same machine settings in LONATI GL 544 (12 E,144 needles and 4“ diameter), labelled as S4, S5 and S6 respectively. Besides treated samples, cotton with untreated polyester, Coolmax and Thermolite fibre with the same above blend ratio was also produced to compare the properties having the same yarn count and on the same machine parameters. These samples are labelled as S1, S2 and S3 respectively.

All these yarns are used as the main yarn in socks. Main yarns are produced on a sample spinning machine LAYCOCK TEXTILE ENGLAND. This is miniature textile machinery which provides a quick approach for the evaluation of fibres and their blends. Yarns developed from all fibres had nominally the same structure, yarn count, and torsion value. Nylon-covered elastane was used in socks, in this study, as a plaiting yarn. 20 Elastane/Creora 70/24/1 i.e. 20D elastane as a core yarn, 70 Denier nylon as a covering yarn, and (24 is the number of filaments of nylon) is used as plaiting yarn. 11% of elastane in plaiting is constant in all samples. All the samples were produced by maintaining a constant stitch length of 0.57 ± 0.01cm. Knitted socks were put under some basic finishing treatments, and appropriate scouring and bleaching processes were applied to cotton/PET, cotton/CM, and Cotton/TL samples. Scour and bleach process is performed by using 2% sodium bicarbonate and 2% hydrogen peroxide by keeping the liquor ratio 1:20 on the weight of socks at 90 centigrade temperature for 45 minutes.

Characterization

Mechanical testing of yarn

Uster Tensorapid tester was used to test all the treated and untreated yarns as per standard ASTM D 2256. An average of 10 samples were taken.

Thermo-physiological comfort properties testing

Air permeability is defined as the rate of air flow passing perpendicularly through a known area. All the samples were tested on SDL-ATLAS, M021 A, air Permeability tester as per standard ISO-9237. The air pressure differential between the two surfaces of materials was maintained at 100 Pa. The mean and SD of 10 repeats were calculated for each sock’s samples.

The thermal resistance of all samples was tested by sweating-guarded hot plate SDL-ATLAS, M-2598 by the test method ISO 11092. The mean and standard deviation was calculated for 3 readings of each sample.

All the samples were tested for water vapour permeability on the PERMETEST instrument as per standard EN ISO 11092. The mean and Standard deviation of up to five measurements was noted. All the testing was done at standard conditions i.e. 21°C temperature and 65% R.H.

The PhabrOmeter system (Nu Cybertek) was used to quantify human tactile sensory perception.

PhabrOmeter determines the instrumental relative hand by standard AATCC, Test Method 202-2014, Relative Hand Value of Textiles, using the mechanical properties measured on a selected reference fabric and a comparable candidate fabric. The instrument finds relative hand value (RHV) by considering stiffness, smoothness, softness, drape and wrinkle recovery rate. It is a fabric sensory quality evaluation system that comes with intelligent software that analyses the complex, fabric force-displacement curve directly via pattern recognition theory and multivariate data analysis. The attributes tested for the present work were resilience/stiffness, softness, smoothness, and Relative hand value (RHV). The evaluation for before and after treatment of samples was done based on testing [27].

Antimicrobial properties testing/microbial inhibition

Antimicrobial properties were measured according to test method AATCC 147-1998. The bacterial strains of Gram-positive, *Staphylococcus aureus, (*ATCC 29213 strain) which had been incubated overnight, were spread on a sterile agar plate. Test specimens of each of the samples were placed onto inoculated agar plates at 37°C for 24 h. For comparison, the untreated samples were also tested for reference.

The agar plates were examined for inhibition of microbial growth underneath the samples and inhibition zone along the edges of the specimen.

Odour test

The odour test is conducted concerning SNV 19651 [28]. Before doing the test the 6 male participants were requested to wear the socks for normal working hours (8 hours) in the same working place and requested not to use any cosmetics or any other antibacterial product [29]. After the wearing trail time, the samples were separated and put into airtight bags. These samples were used for the analysis of the odour test. The control and treated samples were placed on top of 300 ml sodium carbonate solution and kept in a closed container for 15 hours. After this 6 people were requested to judge the odour intensity and rate it accordingly to the intensity scale (Grade 1: odourless, Grade 2: weak odour, Grade 3: tolerable odour, Grade 4: annoying odour and Grade 5: intolerable odour).

Statistical analysis

The mean of subjective analysis of odour intensity was calculated and ANOVA was carried out to analyse the effect of fabric structure on odour intensity. The analysis of variance was performed to study the effect of bacterial counts on the structure and participants. The correlation analysis was performed to analyse the interdependence between the factors. Both analyses were performed by using the data analysis feature in Microsoft Excel software.

RESULTS & DISCUSSION

SEM microstructure

The SEM was employed to observe the deposition of silver particles into the fibre. The SEM images shown in figure 2 depict the silver particles on the fibre, which is an indication of the efficacy of the deposition technique. As % the age of silver particles used is very less, it has deposited in some places.

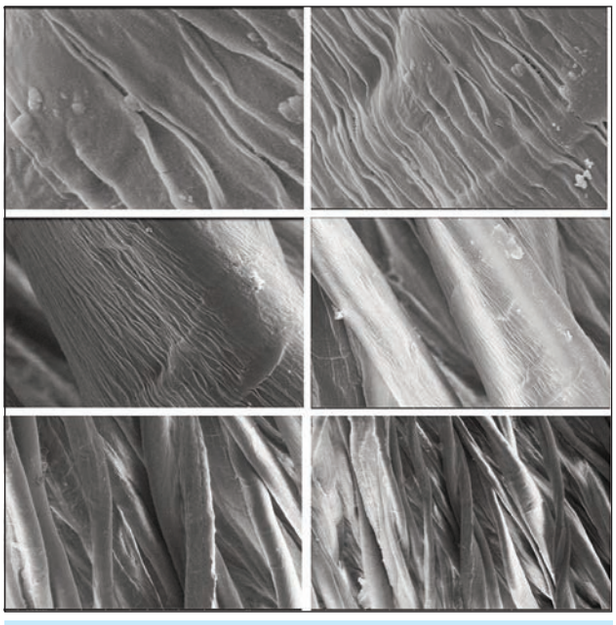


Fig. 2. SEM images of silver particle-treated antimicrobial fabric

Mechanical properties of yarn

Yarn is the basic requirement for knitting and the strength of the yarn is the basic criterion for setting knitting tension. The knitting process is highly dependent on the mechanical properties of the yarn. A summary of the properties of treated and untreated yarns used in this study is given in table 1. Samples are labelled as S1-S3 for untreated and S4-S6 for treated.

Table 1

SUMMARY OF PROPERTIES OF YARN

Sample #	Blend ratio	Breaking strength (cN/tex)	Elongation (%)
S1	C/PET	15.68	5.07
S2	C/CM	13.47	5.95
S3	C/TL	13.27	6.11
S4	C/PET	14.15	4.9
S5	C/CM	12.0	5.03
S6	C/TL	11.85	5.15

It is observed that mechanical properties are adversely affected after treatment i.e., breaking strength and elongation % of treated yarns, got decreased as shown in table 1. The results show that the deposition of silver particles affects the mechanical performance of the fibre. Ultimately, the reduction of breaking strength of treated yarn was in the range of 10 % in comparison with untreated yarn. It may be due to the heating of fibre at a high temperature and may lead to a reduction of the degree of orientation in the crystalline region of fibre during the deposition of silver particles which affects its load-bearing capacity [30, 31].

Further, it can be seen that yarn having solid circular cross-sectional fibres, has better breaking strength than channel and hollow core. Yarn made from circular cross-section fibre encourages better packing with adjacent fibres and hence leads to better inter-fibre cohesion and higher rigidness of fibres leads to the lowest elongation % [32]. The elongation % age of yarn made from circular cross-section has the lowest value due to better packing. While in hollow cross section due to higher crimp has the highest elongation %.

Thermo-physiological testing

Air permeability

The sweat could be discharged by diffusion, desorption, absorption, condensation, and air exchange rate /air passage through the fabric. The air permeability phenomenon affects sweat evaporation. It can be seen in figure 3 that treated samples have higher air permeability than the untreated ones. Air permeability of treated samples S4, S5 and S6 were found 149 mm/sec, 180 mm/sec, and 190 mm/sec respectively, while the air permeability for untreated samples S1,

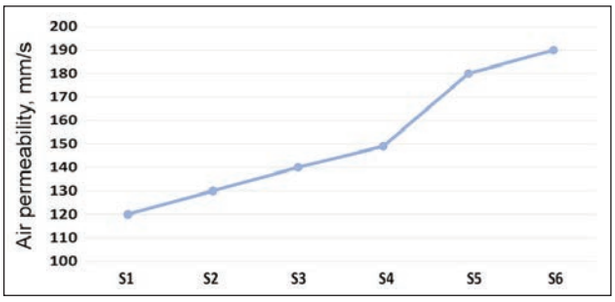


Fig. 3. Air permeability of untreated and treated socks

S2, and S3 was 120 mm/sec, 130 mm/sec and 140 mm/sec respectively. This indicates that the heating process during deposition statistically affects air permeability. Due to chain movement, the size of pores increases, and air permeability also increases [33]. It seems possible that the porosity of fabric increases. It was observed that there is not much significant difference between the air permeability values of socks knitted by different cross-sectional fibres which pointed out that the structure of fibre didn't affect much air permeability, rather fabric parameters are a more decisive parameter. Yarn made from circular cross-section fibre has the highest air permeability. Fabric knitted with circular cross-sectional fibre was observed to be more permeable to air due to the large size of their inter yarn pores [34]. The reason for this result may be because of the effect of surface area in the fabric. From the previous studies, it is also evident that the higher specific surface area of the modified cross-sectional shape offered more drag to airflow across the fabric [35].

Thermal resistance

The thermal properties of fabric determine thermal comfort sensation by measuring the heat flow through the fabric. The heat transfer from the human to the surroundings decreases as the thermal resistance of the fabric increases which increases the temperature in the microclimate. From figure 4 it can be seen that the thermal resistance of treated samples was slightly increased due to an increase in total pore volume which leads to an increase in air pockets. Air has lower thermal conductivity i.e. 0.025 $Wm^{-1}K^{-1}$ as compared to any textile fibre. The number of dead air pockets influences the overall thermal resistance of fabrics.

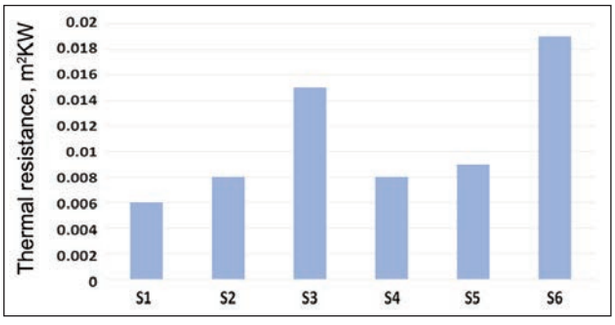


Fig. 4. Thermal resistance of untreated and treated socks

From figure 4, the results indicate that the yarns made from a blend of cotton and normal PET, Channeled PET and hollow PET provide higher thermal resistance properties that are similar to each other. It was expected that the hollow PET blended yarns would provide higher thermal resistance due to entrapped air within the fibre structure.

Relative water vapour permeability %

RWVP % defines the transfer of sweat from the body to the environment through the fabric. Fabric relative water vapour permeability % property is the replacement of fabric–air interface with fabric–water interface. A more porous structure means more resistance to water permeability. From figure 5, it can be seen that socks samples having silver deposition has a lower value than untreated which shows that during deposition, the molecular chain of different polyester fibres aligned in a new direction. The water vapour resistance showed only a minor difference, indicating that the comfort properties were conserved.

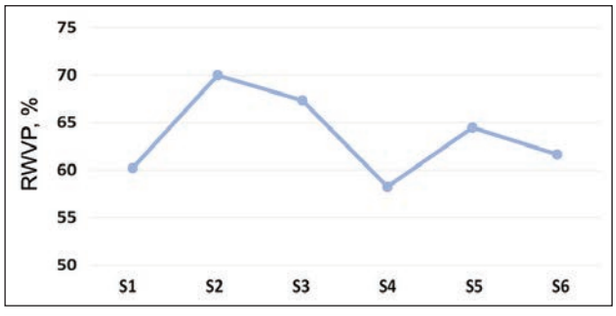


Fig. 5. Relative water vapour permeability % of untreated and treated socks

Natural fibres such as cotton don't have good moisture management properties due to their natural curly fibre structure. Changing the fibre shapes, which affect its surface area, is a reasonable way to improve the capillary force of hydrophobic PET fibre and to improve its wicking ability. As socks made of C/CM have the highest water vapour permeability % value due to channelled PET fibre which improves as reported in the literature that fabrics made of non-circular fibre exhibit higher mass flow rate than that of circular fibre. This situation can be explained by the principle of applied water vapour permeability test which is matched with the convection mass transfer law. In convection mass flow, the mass flow rate is directly proportional to the surface area along the direction of the flow. Thus, a higher (20%) fibre surface area of channelled structure leads to higher water vapour permeability characteristics as compared to conventional round polyester fibres [36]. The presence of channels on the fibre surface offers a less tortuous path for the liquid to travel. Hollow fibre can provide greater bulk and provide improved heat and moisture management properties as compared to normal polyester fibre. Due to higher surface area, samples made from these fibres have good RWVP % properties as compared to those made from conventional polyester fibres of round cross-sections.

Table 2

QUANTIFIED DATA OF FABRIC HAND VALUE OBTAINED FROM PHABROMETER				
Sample #	**Resilience/Stiffness**	**Softness**	**Smoothness**	**RHV**
S1	37.43	80.8	65.15	0
S2	36.64	81.58	65.21	0
S3	32.63	81.93	64.65	0
S4	38	83.93	64.8	5.3
S5	38.5	80.5	64.96	1.32
S6	38.5	80.5	64.96	2.62

Sensorial comfort properties testing

A fabric handle is getting increasing attention in the textile and clothing industry. Sensory tactile perception without objective evaluation is very difficult to quantify and interpret hand attributes such as stiffness, softness, and smoothness. Stiffness indicates the bending of fabric which gives an objective evaluation of whether the fabric is flexible or rigid. Softness indicates the compressibility of fabric and smoothness indicates how fabric behaves when sliding a fingertip across a fabric surface i.e., resistance faced. From table 2, it is quite clear that there is not much difference between untreated and treated samples for different attributes. All the samples were as mentioned in table 2 compared for RHV, which is improved for treated samples which makes the wearer comfortable hand feeling.

Antimicrobial properties

The antimicrobial activity of treated and untreated samples was tested against *S. Aura* in figure 6, *b* shows the zone of inhibition around the sample swatch. The micrographs of the zone of inhibition indicate that all treated samples have a clear zone and are quite effective against *S. Aura.* Whereas the untreated fabric figure 6, *a* showed no antimicrobial activity, bacterial growth can be seen in the plate containing the untreated samples (under the test specimen). The results indicate that the treated fabric reduces the bacterial population next to the skin fabric which in turn reduces the odour formation.

Effect of antimicrobial treatment on odour intensity

The subjective study was performed for control and treated samples as explained in the experimental part. The evaluation is done, specifying that almost the same trend appeared for all treated blended PET fabric. There is a significant reduction observed in all blended PET treated fabrics ($p<0.05$). For treated fabric odour intensity is in the range of grades 1 and 2 while for untreated it is in the range of grades 4 and 5.

CONCLUSIONS

In the present work blend of cotton with different cross-sectional shapes of polyester before and after silver deposition was studied. The yarn strength, thermo-physiological comfort properties, sensorial comfort properties, antibacterial properties and odour

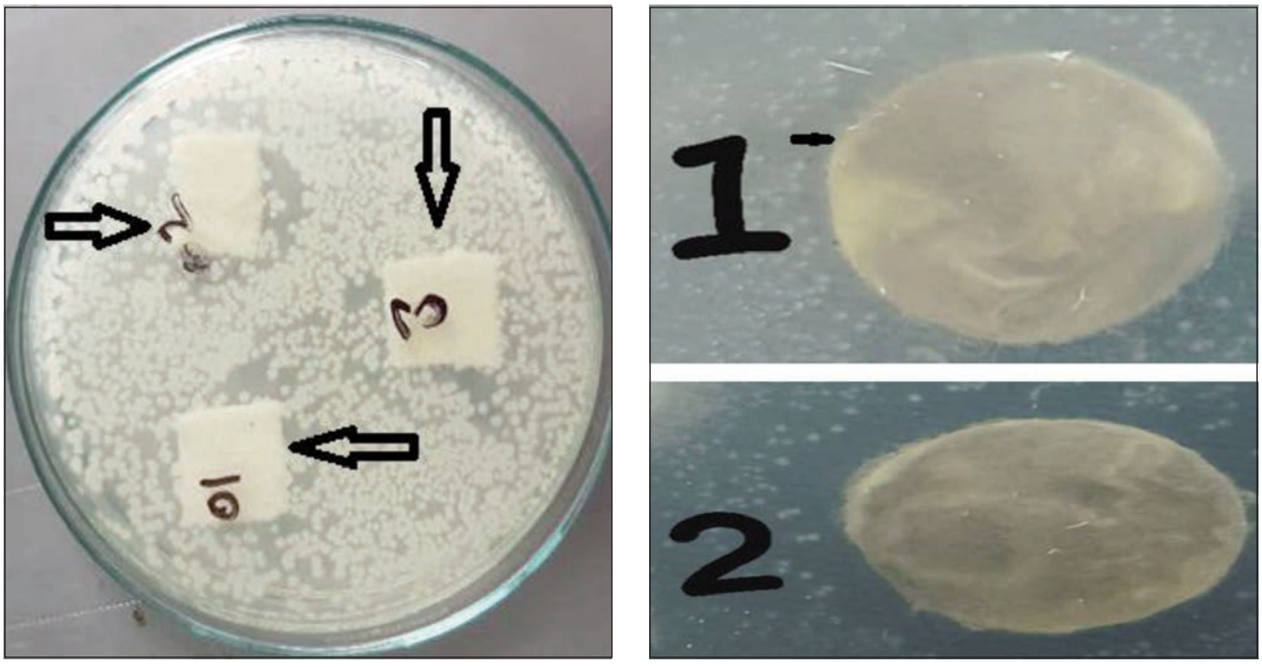


Fig. 6. Zone of inhibition against the odour-forming bacterial strain: *a* – untreated samples; *b* – treated samples

properties of developed socks were investigated. The advantage of the process that is described in this paper is a simple, efficient and one-step process. The SEM images show the deposition of silver particles without any significant damage to the structure of the fibre. Thermo physiological properties were discussed. Overall, all properties are conserved in treated samples. The performance of treated socks was investigated and the excellent killing effect of bacteria was demonstrated. A subjective assessment of odour was also performed, and good grading is assessed. The deposition mechanism can be used for other applications of apparel products at low cost and commonly available material.

ACKNOWLEDGEMENT

The work was supported/funded by the project: "Development of Comfortable Compression Socks for Treatment of Varicose Veins or Chronic Venous Disease in Legs" under the HEC project Establishment of Technology Development Fund (TDF) (No.TDF03-149).

REFERENCES

[1] Oglakcioglu, N., Celik, P., Ute, T.B., Marmarali, A., Kadoglu, H., *Thermal comfort properties of angora rabbit/cotton fibre blended knitted fabrics*, In: Text. Res. J., 2009, 79, 888–894

[2] Atalie, D., Ferede, A., K.r Rotich, G., *Effect of weft yarn twist level on mechanical and sensorial comfort of 100% woven cotton fabrics*, In: Fashion. Text., 2019, 6, 1–12

[3] Cimilli, S., Nergis, B.U., Candan, C., *A comparative study of some comfort-related properties of socks of different fibre types*, In: Text. Res. J., 2009, 80, 948–957

[4] Čiukas, R., Abramavičiute, J., Kerpauskas, P., *Investigation of the thermal properties of socks knitted from yarns with peculiar properties. Part II: thermal resistance of socks knitted from natural and stretch yarns*, In: Fibre. Text. East. Eur., 2011, 19, 64–68

[5] Hasha, M.M., Hasan, K.M.F., Khandaker, M.F.R., Karmaker, K.C., Deng, Z., *Functional properties improvement of socks items using different types of yarn*, In: Int. J. Text. Sci., 2017, 6, 34–42

[6] Atasağun, H.G., Öner, E., Okur, A., *A comprehensive study on the general performance properties of Viloft-blended knitted fabrics*, In: J. Text. I., 2015, 106, 523–535

[7] Fan, J., *Physiological comfort of fabrics and garments, in engineering apparel fabrics and garments,* In: Fan J. and Hunter L. Eds., FL, USA: Woodhead Publishing, 2009, 1, 201–250

[8] Spencer, D.J., *Knitting technology*, Woodhead Publishing Limited and Technomic Publishing Company Inc, Cambridge, United Kingdom, 2001, 446–545

[9] Maqsood, M., Seide, G., *Development of bio based socks from sustainable polymer and statistical modeling of their thermo-physiological properties*, In: J. Clean. Prod., 2018, 197, 170–177

[10] Morris, M., Prato, H., White, N., *Relationship of fibre content and fabric properties to the comfort of socks*, In: Cloth. Text. Res, J., 1984, 3, 14–19

[11] Shehadesh, J.S., Kilgman, A.M., *The effect of topical antibacterial agents is the bacterial flora of the axilla*, In: J. Invest. Dermatol., 1963, 40, 61–71

[12] Rennie, P.J., Gower, D.B., Holland, K.T., *In vitro and in vivo studies of human axillary odour and the cutaneous micro flora*, In: Br. J. Dermatol.,1991, 24, 596– 602

[13] Richie, D., *Athletic socks*. In: M. Werd, and E. Knight, (Eds.), Athletic footwear and orthoses in sports medicine, Springer, New York, 2010, 69–78

[14] Euler, R., *Creating "comfort" socks for the U.S. consumer*, In: Knitting. Times, 1985, 54, 47–50

[15] Gao, Y., Cranston, R., *Recent advances in antimicrobial treatments of textiles*, In: Text. Res. J., 2008, 78, 60–72

[16] Ramachandran, T., Rajendrakumar, K., Rajendran, R., *Antimicrobial textiles – an overview*, In: IE (I) Journal-TX, 2004, 84, 42–47

[17] Durán, N., Marcato, D.P., Souza, G., Alves, O., *Antibacterial effect of silver nanoparticles produced by fungal process on textile fabrics and their effluent treatment*, In: J. Biomed. Nanotech., 2007, 3, 203–208

[18] Tarimala, S., Kothari, N., Abidi, N., Hequet, E., Fralick, J., Dai, L.L., *New approach to antibacterial treatment of cotton fabric with silver nanoparticle–doped silica using sol–gel process*, In: J. App. Polym. Sci., 2006, 101, 2938–2943

[19] Mahltig, B., Fiedler, D., Simon, P., *Silver-containing sol-gel coatings on textiles: antimicrobial effect as a function of curing treatment*, In: J. Text. I., 2011, 102, 739–745

[20] Lee, H.J., Yeo, S.Y., Jeong, S.H., *Antibacterial effect of nanosized silver colloidal solution on textile fabrics*, In: J. Mater. Sci., 2003, 38, 2199–2204

[21] Sulaiman, G.M., Mohammed, W.H., Marzoog, T.R., *Green synthesis, antimicrobial and cytotoxic effects of silver nanoparticles using Eucalyptus chapmaniana leaves extract*, In: Asian. Pac. J. Tropic. Biomed., 2012, 3, 58–63

[22] USP20100166832A1, *Silver coated nylon fibres and associated methods of manufacture and use*, 2010

[23] USP20140374941, *Enhancing and preserving anti-microbial performance in fibres with pigments*, 2014

[24] Ghosh, S., Yadav, S., Reynolds, N., *Antibacterial properties of cotton fabric treated with silver nanoparticles*, In: J. Text. I., 2010, 101, 917–924

[25] Foltynowicz, Z., Gwiazdowska, D., Rodewald, D., *Antimicrobial properties of socks protected with silver nanoparticles*, In: Fibre. Text. East. Eur., 2013, 5, 91–96

[26] Petica, A., Gavriliu, S., Lungu, M., *Colloidal silver solutions with antimicrobial properties*, In: Mater. Sci. Eng: B., 2008, 152, 22–27

[27] Mahar, T., Wang, H., *Measuring fabric handle to define luxury: an overview of handle specification in next-to-skin knitted fabrics from Merino wool*, In: Animal Prod. Sci., 2010, 50, 1082–1088

[28] SNV 195651, *Textiles-determination of smell development from outfit and gear (Sensory testing) Ausgabe*, Textilien; Bestimmung der Geruchsentwicklung von Ausrüstungen (Sinnenprüfung), Schweizerische Normen-Vereinigung, 1968, Available at: www.snv.ch [Accessed on January 20, 2021]

[29] McQueen, R.H., Laing, R.M., Delahunty, C.M., *Retention of axillary odour on apparel fabrics*, In: J. Text. I., 2008, 99, 515–523

[30] Sibel, S., Ozcan, O., Ismail, K., *The effects of heat-setting on the properties of polyester/viscose blended yarns*, In: Fibre. Text. East. Eur., 2007, 15, 50–53

[31] Gupta, V.B., Kumar, S., *The effect of heat setting on the structure and mechanical properties of poly ethylene terephthalate fibre, IV. Tensile properties are other than modulus and their dependence on structure*, In: J. Appl. Polym. Sci., 1981, 26, 1897–1905

[32] Roy, M.D., Sinha, S.K., *Performance of wicking through yarn and fabric made from polyester fibres of different cross-sections*, In: Int. J. Text. Sci., 2014, 3, 44–50

[33] Ertekin, G., Marmarali, A., *The effect of heat-setting conditions on the performance characteristics of warp knitted spacer fabrics*, In: J. Eng. Fibre. Fabric., 2016, 11, 64–71

[34] Das, B., Das, A., Kothari, V.K., *Effect of fibe'r diameter and cross-sectional shape on moisture transmission through fabrics*, In: Fibre. Polym., 2008, 9, 225–231

[35] Petrulis, D., *Fundamental study of the effect of the fibre wall thickness and inner diameter on the structure of polyamide and polypropylene hollow fibres*, In: J. Appl. Polym. Sci., 2004, 92, 2017–2022

[36] Coolmax by Invista, Available at: http://www.coolmax.invista.com/g_en/home.aspx [Accessed on January 21, 2021]

Authors:

JAMSHAID HAFSA[1], NADEEM MUHAMMAD[1], ABDUL WAQAR RAJPUT[2], DAD ALLAH[3], HUSSAIN UZAIR[1]

[1]Protective Textile Research Group, Faculty of Engineering & Technology, National Textile University, Pakistan

[2]Technical Textile Research Group, BZU College of Textile Engineering, Multan, Pakistan

[3]Pakistan Institute of Fashion Design, Lahore, Pakistan

Corresponding author:

ABDUL WAQAR RAJPUT
e-mail: waqar.rajput@bzu.edu.pk

Archaeological and digital restoration of straight-front robe of Mawangdui Han Dynasty Tomb based on 3D reverse engineering and man-machine interactive technologies

DOI: 10.35530/IT.073.06.202192

HANHAN WU
KAIXUAN LIU
YANBO JI
CHUN ZHU
ZHAO LÜ

ABSTRACT – REZUMAT

Archaeological and digital restoration of straight-front robe of Mawangdui Han Dynasty Tomb based on 3D reverse engineering and man-machine interactive technologies

Based on 3D reverse engineering and man-machine interactive technologies, this paper completed the pattern development of a straight-front robe of the Mawangdui Han Dynasty tomb and restored the straight-front robe by virtual simulation technology. Firstly, the garment contour was extracted from the straight-front robe image of the Mawangdui Han Dynasty tomb, and then the garment model was established in the 3D virtual environment. According to the style characteristics of the straight-front robe, the structural curves were drawn on the adjusted 3D robe surface, and the different curved surfaces formed by these curves were expanded to obtain 2D garment patterns. Finally, the unfolded patterns were stitched on the virtual human body to realize the digital restoration of the straight-front robe of the Mawangdui Han Dynasty tomb.
Compared with the current methods of garment restoration, the method proposed in this paper not only reduces the technical requirements of pattern-making for archaeologists but also for unearthed cultural relic garments, the final pattern can be obtained without consulting a lot of data and repetitive modification of pattern, to improve efficiency and save manpower. Our proposed technology provides a new practical method for costume archaeology and restoration.

Keywords: *reverse engineering, Han dynasty, straight-front robe, Mawangdui Tomb, virtual simulation, pattern-making, human-computer interaction*

Restaurarea arheologică și digitală a veșmântului de înmormântare frontal al mormântului dinastiei Han Mawangdui, bazată pe inginerie inversă 3D și tehnologii interactive om-mașină

Bazată pe inginerie inversă 3D și tehnologii interactive om-mașină, această lucrare a finalizat dezvoltarea tiparelor unui veșmânt de înmormântare frontal al mormântului dinastiei Han Mawangdui și a restaurat veșmântul prin tehnologia de simulare virtuală. În primul rând, conturul îmbrăcămintei a fost extras din imaginea veșmântului de înmormântare frontal al mormântului dinastiei Han Mawangdui, iar apoi modelul îmbrăcămintei a fost stabilit în mediul virtual 3D. În conformitate cu stilul veșmântului de înmormântare frontal, curbele structurale au fost desenate pe suprafața ajustată a veșmântului 3D, iar diferitele suprafețe curbate au fost extinse pentru a obține tiparele 2D. În cele din urmă, tiparele desfășurate au fost asamblate pe corpul uman virtual pentru a realiza restaurarea digitală a veșmântului de înmormântare frontal al mormântului dinastiei Han Mawangdui.
În comparație cu metodele actuale de restaurare a articolelor de îmbrăcăminte, metoda propusă în această lucrare nu numai că reduce cerințele tehnice ale modelării pentru arheologi, ci și cele impuse relicvelor culturale dezgropate, modelul final putând fi obținut fără consultarea multor date și modificarea repetitivă a tiparelor, astfel încât să îmbunătățească eficiența și să economisească forța de muncă. Tehnologia noastră propusă oferă o nouă metodă practică pentru arheologia și restaurarea costumelor.

Cuvinte-cheie*: inginerie inversă, dinastia Han, veșmânt frontal, mormântul Mawangdui, simulare virtuală, construcția tiparelor, interacțiune om-calculator*

INTRODUCTION

Mawangdui Han Dynasty tomb is the family cemetery of Li Cang, the prime minister and Marquis of Changsha in the early Western Han Dynasty (202 BC-8 AD). Among the three Han Dynasty tombs, Tomb No. 2 is Li Cang, the Prime Minister of Changsha in the early Han Dynasty; Tomb 1 is Li Cang's wife, and Tomb No. 3 is Li Cang's son [1]. More than 3000 precious cultural relics are unearthed from the three Han Dynasty Tombs of Mawangdui [2], most of which are well preserved. Among them, more than 500 pieces of various lacquerware are exquisitely made with gorgeous patterns and new lustre [3]. In addition, a large number of silk fabrics were unearthed from Tomb No. 1, which were well protected. There are many varieties, such as tough silk, figured woven silk material, silk with sparse texture, gauze and brocade [4]. There is a plain gauze garment, which is 1.28 meters long and has long sleeves. It weighs only 49 grams and has

excellent weaving skills [4]. Han Dynasty is the heyday of the textile industry in the history of Chinese arts and crafts. The cultural relics unearthed from the Mawangdui Han Dynasty Tomb carry the unique aesthetic connotation of Han Dynasty costumes, reflecting the two characteristics of functional beauty and formal beauty. The tomb contains a large number of costume cultural relics and records about costumes. It is the largest number, the most complete variety and the most complete preserved costume cultural relics in China. These costume relics and related records complement each other with different kinds of wooden servants and figures in silk paintings in the tombs, which constitute a relatively complete set of costume materials in the early Han Dynasty, and truly and intuitively represent the splendid costume culture of the Han Dynasty, which is of the highest value in the field of Costume research. The research on the development and restoration of the straight-front robe pattern of the Mawangdui Han Dynasty tomb is a supplement to the research on Chinese traditional costume culture.

The most important step in costume Archaeology and restoration is to make a costume pattern. Garment pattern is an important intermediate link in garment design and production. It is the basis for cutting or sewing [5]. Garment pattern-making methods are mainly divided into traditional manual drawing and computer-aided design [6]. Manual pattern-making is drawing garment structure lines on kraft paper and then cutting along these structure lines to obtain the pieces of paper for cloth cutting. The automatic generation of computer patterns uses computer drawing software to establish the pattern library, we can find similar patterns in the pattern library and modify them to get the target pattern. This method is more likely to find similar patterns, and finally, get the final pattern by enlarging and reducing the key points of the pattern [7]. Both of these methods have three shortcomings: time-consuming, low production efficiency, and inability to meet individual needs.

In the process of Archaeology and restoration, archaeologists need to consult a large number of documents, constantly measure the objects, and repeatedly modify the pattern, to get a reasonable pattern. It largely depends on the personal experience of archaeologists, and repeated folding of cultural relics may cause physical damage. Emerging technologies, such as ergonomics, virtual simulation and reverse engineering, provide new methods for garment pattern-making. Many scholars try to use these new technologies to develop clothing patterns quickly and simply. These methods provide a new idea for the archaeological restoration of ancient costumes. For example, Xuyuan Tao et al. [8] directly conceived the virtual clothing on the human body model in the virtual space, taking into account the comfort margin between the human body and the clothing, which saves the production process of two-dimensional garment patterns. Wang et al. [9] proposed a garment pattern-making method based on fuzzy logic and artificial neural network knowledge to generate garment patterns quickly. Kaixuan Liu et al. [10–12] proposed parametric pattern-making and flat design methods based on human body size, which can generate garment patterns quickly by inputting some constraint parameter values. Haisang Liu et al. [13] established a warp knitted garment size prediction model by analysing the relationship between the size characteristics of warp knitted jacquard pattern and knitting process, and realized the automatic generation of garment pattern by using JavaScript and WebGL technology. Guangzhou Zhu et al. [14] established the Mass-Spring model by using regular mesh method to mesh the quadrilateral pattern and connecting the diagonal lines of the quadrilateral to get the triangular mesh. On this basis, the paper pattern design was completed by using the integral method. Haixia Li et al. [15] applied three-dimensional virtual reality technology to establish a three-dimensional model of human body, and then carried out the design, and then designed and optimized the pattern of Yoga suit. Yeonhee Jeong et al. [16] constructed a three-dimensional garment surface with triangular meshes. On the premise of keeping the original three-dimensional surface area unchanged, these triangular meshes were pieced together to obtain two-dimensional garment patterns. Jin Wang et al. [17] constructed an electronic human body model based on the digital information of human body features. By smoothing the human body surface, they obtained the deployable garment prototype surface attached to the human body surface, and then expanded the prototype surface to obtain the garment prototype patterns. Sun min Kim et al. [18–20] obtained human body data by non-contact three-dimensional scanner to construct a human body model, which was approximately expanded to automatically generate clothing pattern. Kaixuan Liu et al. [21] proposed a three-dimensional interactive garment pattern-making technology. Pattern makers can efficiently develop garment patterns in the way of “what you see is what you get” by their proposed technology in the way of “what you see is what you get”. This technology was successfully applied to the pattern-making of riding clothes [22].

Based on the methods of previous studies, this paper proposed a method of ancient costume pattern-making and digital restoration based on 3D reverse engineering and man-machine interactive technologies, which was used to restore the straight-front robe of Mawangdui Han Dynasty tomb. Compared with the previous clothing Archaeology and restoration methods, 3D interactive clothing pattern-making technology doesn’t require archaeologists to have pattern-making knowledge, which solves the problem of high requirements for operators in the process of traditional clothing archaeology, renovation and restoration. With the support of our proposed method, archaeologists can quickly recover the pattern of costume relics without manual pattern-making, and realize the costume relics according to the pattern.

METHODOLOGY

General scheme

The restoration process of straight-front robe of Mawangdui Han Dynasty tomb based on 3D reverse engineering and man-machine interactive technologies can be divided into seven steps: 2D garment outline pattern extraction, 3D garment model establishment, 3D garment model adjustment, 3D garment surface construction, 3D garment surface flattening, 2D garment pattern adjustment, 3D virtual simulation. The implementation process is shown in figure 1.

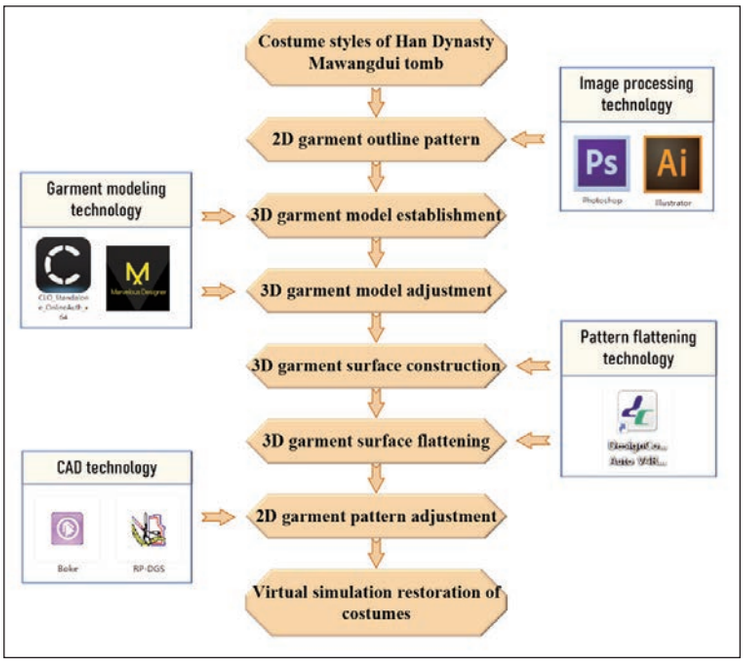


Fig. 1. General scheme

The pattern development process of the straight-front robe of Mawangdui Han Dynasty tomb adopts 3D interactive garment pattern-making technology, which mainly includes 2D to 3D garment modeling, 3D to 2D pattern flattening and 2D to 3D virtual simulation process. First of all, we extracted the contour pattern of the straight-front robe, and then established a 3D garment model in the virtual environment. The purpose of this process is to transform the 2D garment contour pattern into a 3D garment model. Secondly, we drew structural curves on the adjusted 3D garment surface according to the straight-front robe garment style, which divided the 3D garment surface into different adjacent surfaces. We unfolded the different 3D garment surface, adjusted the lines of the unfolded plane, and finally got the garment pattern of the straight-front robe. Finally, the feasibility of this method was verified by virtual fitting technology, and the virtual simulation restoration garment of the straight-front robe was obtained.

Object analysis

The costumes of Han Dynasty mainly include Shenyi, Robes, Danyi, Ru, and so on. Shenyi is still used as court clothes in the Han Dynasty, and its shape is still the Zhou Dynasty (1046 BC – 256 BC) model of cross collar, the right lapel, curving-front robe and top and bottom, but the sleeves are obviously longer and wider than those of the Zhou Dynasty. Shenyi style robe of Han Dynasty (202 BC – 220 AD) follows the old system of Qin Dynasty (1636 AD – 1912 AD). On the basis of the cross shaped plane structure of the upper and lower garments, it adds a lot of techniques of straight cutting and oblique splicing, and projects a prosperous imperial atmosphere. The clothes unearthed from Mawangdui Han Dynasty tomb No.1 are basically well preserved. There are 11 robes, including 8 curving-front robe and 3 straight-front robe, all of which are in the style of cross collar and right lapel. The data information of relevant robes is shown in table 1 [23].

There are mainly two types of robes, namely “curving-front robe” and “straight-front robe”. The skirt of curving-front robe extends in a triangular shape to one side. When wearing a curving-front robe, the triangle part of the skirt is wrapped around the back from the armpit, and then tied with a rope to cover the back. The curving-front robe is mainly used for formal dress. The “Zhuhong Luoqi cotton robe” unearthed from the Mawangdui Tomb No.1 is the Han Dynasty formal dress of curving-front robe style (figure 2, *a*). The straight-front robe is slightly different from the curving-front robe. Its shape is that the lapels intersect to the back of the left chest and fall vertically until the hem. When wearing, the inner lapel is covered under the left armpit, the outer lapel is around the right side, and the bottom is slightly curved.

Table 1

THE SIZE DATA OF CURVING-FRONT ROBE AND STRAIGHT-FRONT ROBE UNEARTHED OF MAWANGDUI HAN DYNASTY TOMB NO.1 [23]

Items	Length (cm)	Long sleeve length (cm)	Sleeve width (cm)	Cuff width (cm)	Waist width (cm)	Hem width (cm)	Collar edge width (cm)	Sleeve edge width (cm)	Swing edge width (cm)
Curving-front robe	130~155	232~250	30~39	24~28	52~63	58~80	20~28	26~35	28~31
Straight-front robe	130~132	228~250	38~41	25~30	48~54	57~66	10~20	29~44	37~38

Fig. 2. Zhuhong Luoqi cotton robe and printed crimson silk robe [24]

Straight-front robe is a kind of casual clothes, which cannot be worn on important occasions.

The "Printed crimson silk robe" unearthed from the Tomb No.1 of Mawangdui is a straight-front robe silk robe (figure 2, *b*).

The upper part of straight-front robe with the printed crimson silk cotton is spliced with four pieces, and the lower part of the straight-front robe is spliced with three pieces. Both the upper and lower parts of the robe are cut straight. Outer placket and inner placket are spliced form a certain amount of overlap. With the wide collar and swing edge, the inner and outer placket can be covered to a slightly backward position. The robe is made of printed crimson yarn and plain yarn. The pattern on the garment surface consists of branches and leaves, buds, stamens and flower spikes. The branches are printed in Yangwen version, which is called "Yinhua", while the rest are painted manually, namely "Fucai".

Garment size determination

The pattern development of straight-front robe of Mawangdui Han Dynasty tomb is based on 3D reverse engineering and man-machine interactive technologies in this paper. We take the printed crimson silk robe of Mawangdui No.1 Han Dynasty tomb as an example of pattern-making and restoration. The length of the straight-front robe is 130 cm, and the length of the through sleeve is 236 cm [23]. As shown in figure 3, the front placket of the straight-front robe intersects left and right, the upper part of the robe is four pieces of stitching, and the lower part of the robe is three pieces of stitching. The upper and lower parts of the robe are cut straight, and the back is sewed together. The upper part of the straight-front robe is cut straight, and the lower part, collar edge, sleeve edge and swing edge are cut obliquely.

Among them, the oblique cutting of sleeve edge is the most characteristic in the use of fabric. The sleeve edge of straight-front robe is "obliquely rolled into a tube shape with half a piece of white yarn straight strip, and folded inward into two layers, so the cuff is seamless" (figure 4). The structure of the inclined cut and inclined roll gives the cuffs good scalability. From the perspective of the wide cuff size (the width of the cuff is 25–30 cm), the scalability of the cuffs exceeds the practical purposes such as warmth preservation, convenient to wear and take off, and convenient for activities. On the one hand, the phenomenon above reflects the economic richness, on the other hand, it indicates the social status of the wearer. This kind of structure in the use of fabric performance technology has reached the peak which cannot be achieved in the future. The edge of the slant cut is slanted at the side seam, so that the hem is slightly stretched, which not only increases the beauty of the train skirt, but also makes the road convenient.

2D garment contour pattern extraction

The acquisition of 2D garment contour pattern is the basis of 3D garment modeling. According to the

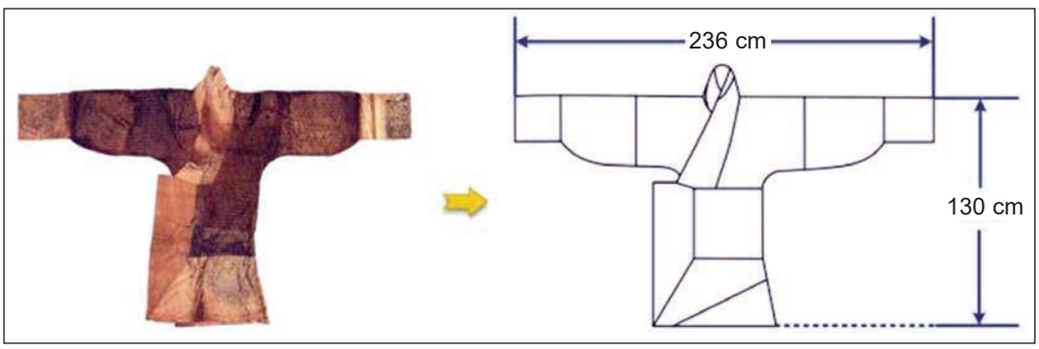


Fig. 3. The straight-front robe's size at Mawangdui Han Dynasty Tomb

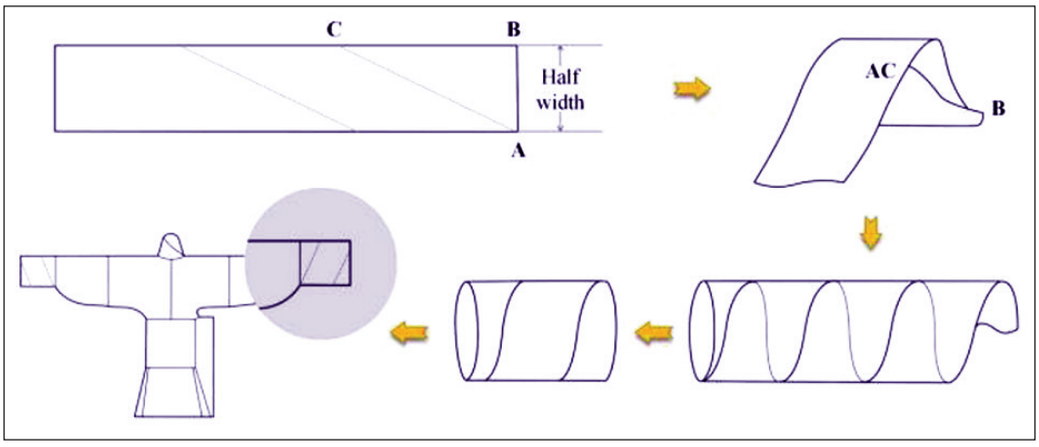


Fig. 4. The oblique cutting diagram of Mawangdui straight-front robe's sleeve edge [23]

straight-front robe pattern in the Mawangdui tomb, the line drawing of garment was directly extracted in CAD drawing software (figure 5, *a*), and then the front and rear contour paper of garment was drawn combined with the determined length of garment and sleeve length (figure 5, *b*). This process is only for obtaining the contour pattern of the robe and does not require accurate pattern size, so there is no requirement for the operator's garment pattern-making skills.

3D garment model establishment

After getting the 2D garment pattern, we needed to build the 3D garment model on the mannequin. At present, the existing modeling methods are mainly start from the perspective of 3D scanning human

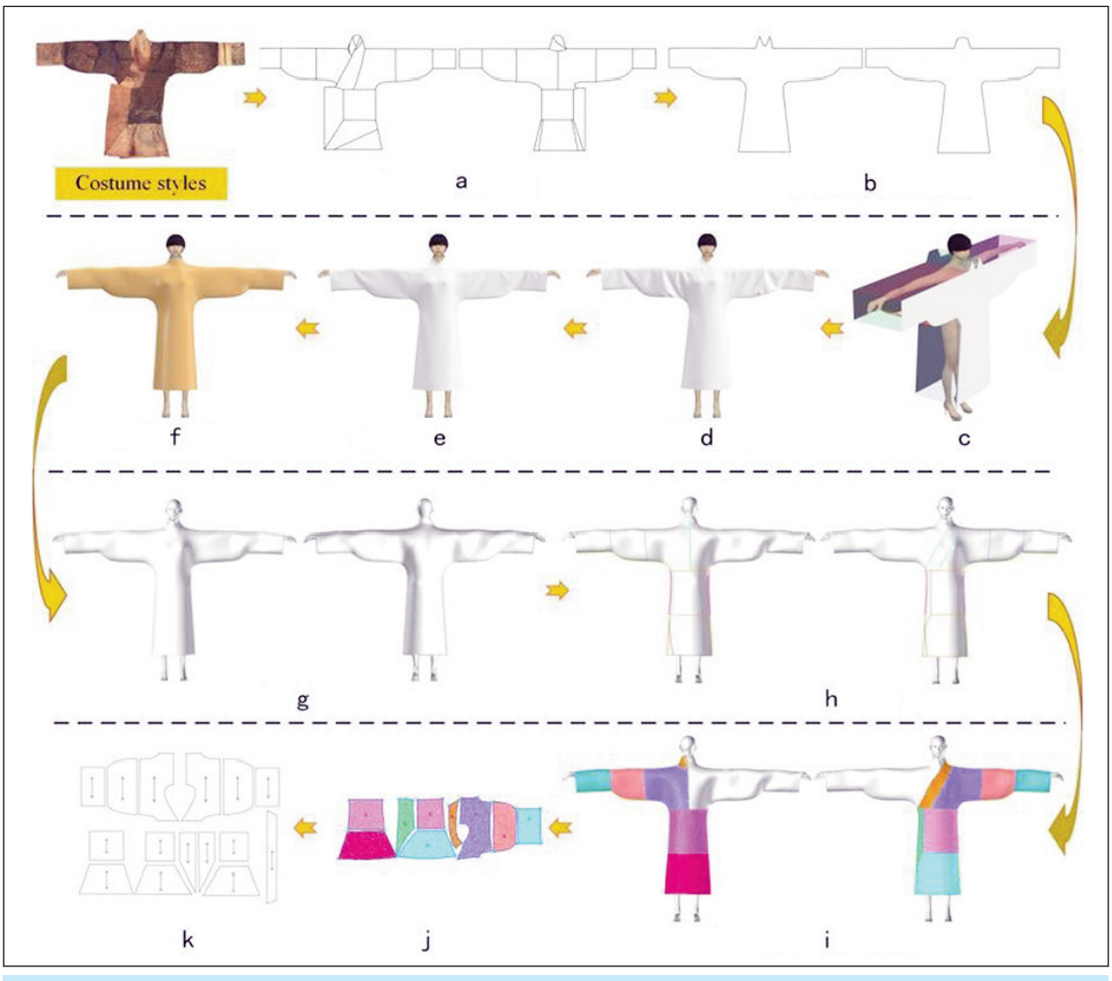


Fig. 5. Interactive pattern-making of the straight-front robe of Mawangdui Han Dynasty Tomb: *a* – line drawing; *b* – contour extraction; *c* – arrangement; *d* – try-on; *e* – adjustment; *f* – hardening; *g* – freeze; *h* – draw curves; *i* – generating surfaces; *j* – 3D→2D unfolding; *k* – pattern post-processing

body. At present, the main modeling method is to use 3D human body scanning to build 3D human body model based on feature information, and then expand the surface of 3D garment model to get 2D pattern [25]. In addition, there are many methods for garment modeling, such as garment modeling based on 2D sketch [21, 26, 27], garment modeling based on 3D sketch [8, 28–37] and garment modeling based on image [38, 39]. According to the structural characteristics of Mawangdui Han Dynasty tomb straight-front robe garment, this paper adopted the method of combining geometric modeling and image modeling. The development of Mawangdui Han Dynasty tomb straight-front robe pattern was based on the real image, so its 3D model was directly stitched by 2D garment pattern in the virtual environment using virtual try on technology (figure 5, *c* and *d*).

3D garment model adjustment

In the above two steps, we extracted the two-dimensional outline patterns of the straight-front robe of Mawangdui Han Dynasty tomb, and then the outline patterns were virtual stitched to get the three-dimensional clothing model. Because the two-dimensional contour pattern is not a real garment pattern, the garment model cannot fully meet the simulation requirements. Moreover, there may be some problems in the model, such as the model's surface is not smooth enough, and the details are creased or wrinkled. The existence of these creases and folds affects the accuracy of the structural curve drawn on the model's surface.

In order to avoid the above uncertainty, we adjusted the three-dimensional model of the straight-front robe of Mawangdui Han Dynasty tomb properly, and then unfolded the surface without changing the area and edge of any triangle mesh, so as to make the clothing model surface flatter and smoother (figure 5, *e*). Finally, we froze the stretched garment to maintain its shape (eliminating virtual gravity) (figure 5, *f*). In the process of 3D garment adjustment, we only need to ensure that the visual effect of 3D garment can meet the restoration requirements, and there are not too many restrictions on the shape and size of 2D garment outline pattern.

3D garment surface construction

The 3D garment model of the straight-front robe of Mawangdui Han Dynasty tomb was created based on the garment image. The 2D pattern obtained from the 3D garment model is more realistic. According to the analysis of the straight-front robe style, we used surface flattening technology to draw the structure curve on the surface of the 3D robe model after stretching and freezing (figure 5, *g* and *h*). Because the human body shape is irregular surface, we need to adjust and modify the curve repeatedly in order to get the most accurate pattern. These structural curves divided the 3D garment's surface into different small surfaces (figure 5, *i*).

3D garment surface flattening

There are three kinds of 2D flattening techniques for 3D garment modeling, which are geometric unfolding, mechanical unfolding and geometric unfolding combined with mechanics correction method. In this paper, the geometric expansion method was used to expand the different 3D garment areas subdivided in the previous section into 2D garment patterns using 3D surface unfolding technology (figure 5, *j*). In this process, we should minimize the changes of triangle mesh edge on 3D garment surface and the corresponding changes of 2D pattern in combination with the previous steps.

2D garment pattern adjustment

Generally speaking, the expanded boundary triangles of 2D garment patterns are irregular, so we need to Delaunay triangulation again. The process must maintain the pattern's boundaries and also maintained characteristic areas such as "holes" that may exist in the pattern. The vertex of the re-triangulated mesh only contains the information of the 2D plane domain, so it needs to be mapped to the 3D space domain in order to obtain the exact position of the mesh in the 3D space and complete the stitching of garment. According to the principle of topological invariance, the 3D positions of the vertices can be obtained by using the relationship between the barycentric coordinates of the triangle and the coordinates of the vertices [40]. In addition, we needed to smooth the edge of the straight-front robe patterns using pattern-making CAD (figure 5, *k*).

RESULT

3D virtual simulation restoration

Using 3D interactive pattern making technology, we have completed the pattern development of the straight-front robe of Mawangdui Han Dynasty tomb. In order to verify the feasibility of this method, we needed to check and modify the adjusted pattern, and sewed the 2D pattern back to the virtual human body in the 3D virtual environment. First, we imported the 2D garment pattern into the 3D virtual simulation software, the pattern in the form of plane can be seen in the 2D and 3D visualization interface. Through the arranged points that have been set, the pattern can be accurately matched and attached to the corresponding body parts. Next, we performed virtual stitching in the way of actual garment stitching. Before stitching, the number of pattern layers was set according to the garment style. In this way, we tried to avoid the phenomenon of disordered stitching due to overlapping and cross-stitching during stitching. Moreover, the pattern must be placed in the 3D window according to the requirements of being close to the human body and meeting the suture position. Then, we set the pattern, technology, color, thickness, elasticity, hardness and other properties of the fabric in the physical window. Finally, the virtual garment was tried on and displayed, and the virtual simulation of the straight-front robe of Mawangdui Han

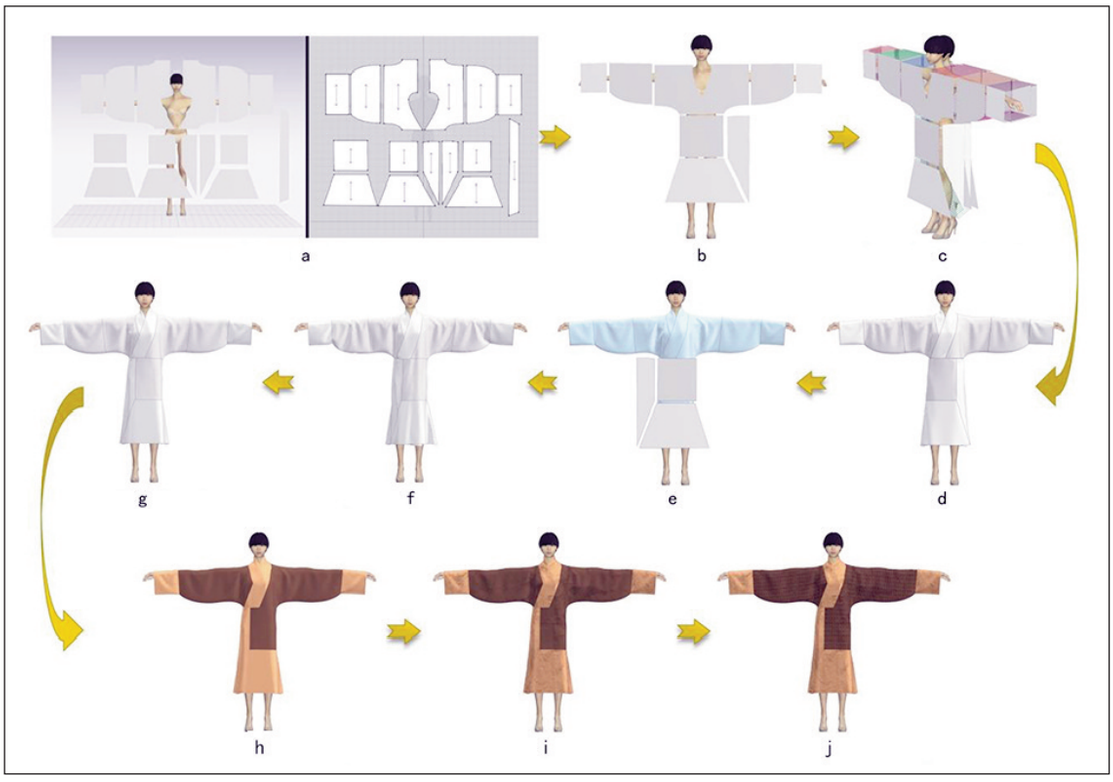


Fig. 6. The virtual simulation restoration of the straight-front robe of Mawangdui Han Dynasty tomb: *a* – pattern import; *b* – pattern arrangement I; *c* – sewing thread setting; *d* – virtual suture I; *e* – pattern arrangement II; *f* – virtual suture II; *g* – adjustment; *j* – pattern attribute settings; *l* – texture attribute settings; *h* – colour attribute settings

Dynasty tomb was adjusted to meet the restoration requirements (figure 6).

We compared the real straight-front robe with the simulated straight-front robe. As shown in figure 7, the upper left corner of the figure is the real photo of the unearthed straight-front robe, the upper right corner is the simulation picture of the tiled straight-front robe, the lower left corner is the front view of the 3D simulation restoration of the straight-front robe, and the lower right corner is the back view of the 3D simulation restoration of the straight-front robe. Through the comparison, we find that the restoration technology we proposed reflects a higher fidelity, and it can be used as a new attempt and method for costume Archaeology and restoration.

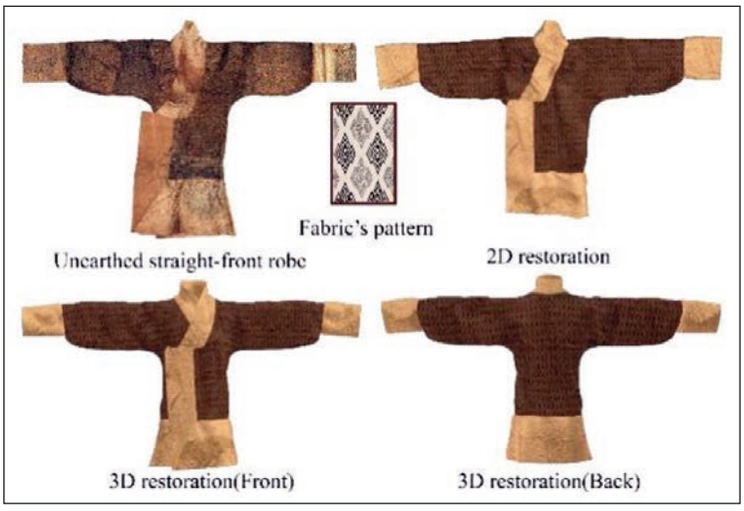


Fig. 7. Real unearthed straight-front robe and its simulated restoration picture

Evaluation of garment virtual restoration effect

After completing the virtual restoration of straight-front robe of Mawangdui Han Dynasty tomb, we use the hierarchical fuzzy comprehensive method to evaluate the effect of virtual restoration garment. Firstly, we determine the evaluation index of garment restoration effect $U = (u_1, u_2, u_3, u_4)$ = (overall shape, color pattern, fabric performance, detail structure). According to the restoration effect, a five-level evaluation standard $C = (c_1, c_2, c_3, c_4)$ = (very poor, poor, average, good, very good) is adopted. Then, we use the priority chart method to determine the weight of each item in the evaluation item set, and the evaluation group is composed of 8 teachers majoring in garment digital technology. They compare two of the four indicators respectively according to their professional experience. The weight of each index calculated according to the score is $A = (\alpha_1, \alpha_2, \alpha_3, \alpha_4) = (0.44, 0.16, 0.09, 0.31)$. The importance of each index can be obtained according to the degree of membership: overall shape > detail structure >

color pattern > fabric performance. We evaluate the recognition degree of virtual garment in the form of questionnaire. The respondents are college students who have a relevant understanding of virtual garment. According to the statistical results, we get the comprehensive evaluation matrix E:

$$E = \begin{bmatrix} 0 & 0 & 0.04 & 0.46 & 0.50 \\ 0 & 0 & 0.13 & 0.41 & 0.46 \\ 0 & 0 & 0.47 & 0.27 & 0.26 \\ 0 & 0 & 0.47 & 0.44 & 0.09 \end{bmatrix}$$

Finally, the comprehensive effect evaluation B can be obtained by synthesizing E with the corresponding evaluation item weight. The comprehensive evaluation results show that 24% of the evaluators think the restoration effect is “general”, 42% think the restoration effect is “good”, and 34% think the restoration effect is “very good”. According to the principle of maximum subordination, the restoration effect of character costumes in straight-front robe of Mawangdui Han Dynasty tomb is “good”.

DISCUSSION

At present, the research on the costumes at Mawangdui Han Dynasty tomb mainly focuses on the surface cultural characteristics such as shape, color, pattern, etc. The research from the perspective of garment structure is not detailed enough, and there is no complete garment pattern be formed. From the perspective of traditional costume restoration, it is mainly realized by means of reality restoration. Due to the limitation of technical conditions, it is difficult to preserve the real objects obtained from reality restoration, which is not conducive to the spread of culture. Drawing on the concept of 3D reverse engineering, this paper used 3D interactive garment pattern-making technology without professional knowledge to complete the pattern development of straight-front robe of Mawangdui Han Dynasty tomb. This paper introduced the automatic generation of garment pattern through 2D to 3D garment modeling and 3D to 2D pattern flattening. Finally, the garment was dynamically adjusted in 2D and 3D garment visualization space, and the virtual simulation of the straight-front robe of Mawangdui Han Dynasty tomb was obtained. Our proposed method highlights the advantages of improving efficiency, saving manpower, and lower professional requirements for operators. It shows that it is a feasible and effective way to develop the pattern of unearthed costume relics by using 3D reverse engineering and man-machine interactive technologies.

The smooth and coherent garment style characteristics of Mawangdui Han Dynasty tomb reflect the high unity of aesthetic and functional. Taking the straight-front robe of Mawangdui Han Dynasty Tombs as an example, the paper pattern development makes up for the lack of complete records of Mawangdui Han Dynasty Tombs garment pattern, further improves and enriches the research content in this field, and provides a useful exploration for the study of Han Dynasty garment modeling structure. At the same time, it provides a direction for deepening and expanding the research of this major, and also provides a reference for the follow-up research of this kind of garment, which has certain practical and guiding significance. However, the human-computer interactive garment pattern-making technology based on 3D reverse engineering is not perfect. Due to the thickness of garment fabric itself, the pattern contour extracted from garment image may have slight deviation from the actual garment, which is a problem we need to solve in the future.

CONCLUSION

In this paper, reverse engineering, virtual simulation, human-computer interaction and other technologies are used to complete the digital restoration of straight-front robe of Mawangdui Han Dynasty Tomb. Compared with the existing technical methods of costume restoration, this method has obvious advantages. First of all, it reduces the technical requirements for operators in the traditional pattern making process when obtaining the garment pattern. Secondly, the pattern can be made without consulting a large number of materials and repetitive modification, which solves the problem of time-consuming and laborious, low efficiency and damage to unearthed cultural relics. Our proposed method provides a feasible new method for costume archaeology and digital restoration. It can be recommended for reconstruction of partly destroyed historical textiles. The restored garment does not need to be preserved on the spot, which eliminates the constraints of time and geographical conditions on the transmission of ancient garment culture. It also provides a new way to inherit and develop clothing culture. The combination of technology and traditional costume archaeology is one of the directions of future archaeology.

ACKNOWLEDGMENTS

The work was financially supported by the Humanities and Social Sciences Project of the Ministry of Education, China (No. 22YJAZH064), the Later Funded Project of Philosophy and Social Science Research of the Ministry of Education, China (No. 22JHQ008), the National Endowment for the Arts, China (No. 2018-A-05-(263)-0928), the Social Science Fund Project of Shaanxi Province, China (No. 2018K32) and the Youth Innovation Team of Shaanxi Universities, China.

REFERENCES

[1] Maeshiro, L.R., *Investigation of the Han Tombs No. 1, 2, and 3 at Mawangdui, Changsha, Hunan*, University of Hawai'i at Manoa, 1981

[2] Chen, D., et al., *Autopsy and forensic study on a rare human corpse preserved over two thousand years: The Mawangdui ancient cadaver,* In: Biopreservation and Biobanking, 2019, 17, 2, 105–112

[3] Li, X., *China's museums,*Cambridge University Press, 2011
[4] Bond, B.A., *Silk Maps: The story of MI9's excursion into the world of cartography 1939–1945,* In: Cartographic Journal, 1984, 21, 2, 141–144
[5] Wang, Z., et al., *Estimating Human Body Dimensions Using RBF Artificial Neural Networks Technology and Its Application in Activewear Pattern Making,* In: Applied Sciences, 2019, 9, 6, 1140–1153
[6] Gu, B., Liu, G., Xu, B., *Individualizing women's suit patterns using body measurements from two-dimensional images,* In: Textile Research Journal, 2017, 87, 6, 669–681
[7] Au, C.K., Ma, Y.-S., *Garment pattern definition, development and application with associative feature approach,* In: Computers in Industry, 2010, 61, 6, 524–531
[8] Tao, X., Bruniaux, P., *Toward advanced three-dimensional modeling of garment prototype from draping technique,* In: International Journal of Clothing Science and Technology, 2013, 25, 4, 266–283
[9] Wang, Z., et al., *A knowledge-supported approach for garment pattern design using fuzzy logic and artificial neural networks,* In: Multimedia Tools and Applications, 2020
[10] Liu, K., et al., *Parametric design of garment pattern based on body dimensions,* In: International Journal of Industrial Ergonomics, 2019, 72, 212–221
[11] Liu, K., et al., *Associate Design of Fashion Sketch and Pattern,* In: IEEE Access, 2019, 7, 48830–48837
[12] Liu, K., et al., *Parametric design of garment flat based on body dimension,* In: International Journal of Industrial Ergonomics, 2018, 65, 46–59
[13] Liu, H., et al., *The size prediction and auto-generation of garment template,* In: International Journal of Clothing Science and Technology, 2021, 33, 1, 74–92
[14] Zhu, G., Song, W., *Patterns simulation in the 3D virtual stitching and try-on system,* In: International Journal of Clothing Science and Technology, 2020, 32, 6, 909–920
[15] Li, H., Wang, Y., *Structural optimization of yoga top based on 3D virtual-reality technology,* In: The Journal of the Textile Institute, 2020, 111, 6, 916–923
[16] Jeong, Y., Hong, K., Kim, S.-J., *3D pattern construction and its application to tight-fitting garments for comfortable pressure sensation,* In: Fibers and Polymers, 2006, 7, 2, 195–202
[17] Wang, J., et al., *Interactive 3D garment design with constrained contour curves and style curves,* In: Computer-Aided Design, 2009, 41, 9, 614–625
[18] Kim, S.M., Kang, T.J., *Garment pattern generation from body scan data,* In: Computer-Aided Design, 2002, 35, 7, 611–618
[19] Kuzmichev, V.E., Tislenko, I.V., Adolphe, D.C., *Virtual design of knitted compression garments based on bodyscanning technology and the three-dimensional-to-two-dimensional approach,* In: Textile Research Journal, 2019, 89, 12, 2456–2475
[20] Hu, Z., et al., *An interactive co-evolutionary CAD system for garment pattern design,* In: Computer-Aided Design, 2008, 40, 12, 1094–1104
[21] Liu, K., et al., *3D Interactive garment pattern-making technology,* In: Computer-Aided Design, 2018, 104, 113–124
[22] Liu, K., et al., *Development of upper cycling clothes using 3D-to-2D flattening technology and evaluation of dynamic wear comfort from the aspect of clothing pressure,* In: International Journal of Clothing Science and Technology, 2016, 28, 6, 736–749
[23] Liu, R., Chen, J., *Research on the structure of Chinese national costume.Han nationality (in Chinese),* China Textile Press, 2013
[24] Museum, H., *Cultural relics of Han Tombs in Mawangdui*, 2015, Available from: http://61.187.53.122/list.aspx?id=19&lang=zh-CN&page=4 [Accessed on September 2021]
[25] Kang, Y., Kim, S., *Three-dimensional garment pattern design using progressive mesh cutting algorithm,* In: International Journal of Clothing Science and Technology, 2019, 31, 3, 339–349
[26] Decaudin, P., et al., *Virtual garments: A fully geometric approach for clothing design,* In: Computer Graphics Forum, 2006, 25, 3, 625–634
[27] Robson, C., et al., *Context-aware garment modeling from sketches,* In: Computers & Graphics, 2011, 35, 3, 604–613
[28] Rodel, H., et al., *Links between design, pattern development and fabric behaviours for clothes and technical textiles,* In: International Journal of Clothing Science and Technology, 2001, 13, 3–4
[29] Wang, C.C.L., Wang, Y., Yuen, M.M.F., *Feature based 3D garment design through 2D sketches,* In: Computer-Aided Design, 2003, 35, 7, 659–672
[30] Petrak, S., Rogale, D., Mandekic-Botteri, V., *Systematic representation and application of a 3D computer-aided garment construction method: Part I: 3D garment basic cut construction on a virtual body model,* In: International Journal of Clothing Science and Technology, 2006, 18, 3, 179–187
[31] Jin, W., et al., *Customer participating 3D garment design for mass personalization,* In: Textile Research Journal, 2010, 81, 2, 187–204
[32] Huang, H.Q., et al., *Block pattern generation: From parameterizing human bodies to fit feature-aligned and flattenable 3D garments,* In: Computers in Industry, 2012, 63, 7, 680–691
[33] Thomassey, S., Bruniaux, P., *A template of ease allowance for garments based on a 3D reverse methodology,* In: International Journal of Industrial Ergonomics, 2013, 43, 5, 406–416

[34] Yasseen, Z., et al., *Sketch-based garment design with quad meshes,* In: Computer-Aided Design, 2013, 45, 2, 562–567
[35] Ei Chaw, H., Krzywinski, S., Roedel, H., *Garment prototyping based on scalable virtual female bodies,* In: International Journal of Clothing Science and Technology, 2013, 25, 3, 184–197
[36] Bruniaux, P., Cichocka, A., Frydrych, I., *3D Digital Methods of Clothing Creation for Disabled People,* In: Fibres & Textiles in Eastern Europe, 2016, 119, 5, 125–131
[37] Cichocka, A., Bruniaux, P., Frydrych, I., *3D Garment Modelling–Conception of its Structure in 3D,* In: Fibres & Textiles in Eastern Europe, 2016, 24, 4, 121–128
[38] Cho, C.-S., et al., *An implementation of a garment-fitting simulation system using laser scanned 3D body data,* In: Computers in Industry, 2010, 61, 6, 550–558
[39] Zhou, B., et al., *Garment Modeling from a Single Image,* In: Computer Graphics Forum, 2013, 32, 7, 85–91
[40] Kim, K., Fujii, C., Takatera, M., *Adaptivity of pattern making methods to garments for varying body dimensions,* In: International Journal of Clothing Science and Technology, 2019, 31, 8, 475–486

Authors:

HANHAN WU[1,2], KAIXUAN LIU[1], YANBO JI[1], CHUN ZHU[1,3], ZHAO LÜ[1]

[1]School of Fashion and Art Design, Xi'an Polytechnic University, Xi'an 710048, China
e-mail: 190696850@qq.com, 1183369029@qq.com

[2]Fashion Institute, Shaanxi Fashion Engineering University, Xi'an 712046, China
e-mail: 475790485@qq.com

[3]College of Fashion and Design, Donghua University, Shanghai 200051, China
e-mail: 466071020@qq.com

Corresponding author:

KAIXUAN LIU
e-mail: L40260611@hotmail.com

Rationalisation methods for managing the production processes of textile products from the regulated field

DOI: 10.35530/IT.073.06.2021108

IONUT DULGHERIU
MANUELA AVADANEI
SAVIN-DORIN IONESI

IRINA IONESCU
EMIL-CONSTANTIN LOGHIN

ABSTRACT – REZUMAT

Rationalisation methods for managing the production processes of textile products from the regulated field

One of the essential features of the unified European market is the free movement of many industrial products, thanks to the harmonisation of the laws of the European Union countries. The rigour of safety regulations has led to a constant increase in the supply and volume of personal protective equipment. The EU legislation defines "essential requirements" for personal protective equipment but does not do the same for technical specifications. From this point of view, products can be divided into non-regulated and regulated products. Protective products and toys are manufactured in the regulated sector in the textile sector and require formal certification under European Community directives. Products intended for military use (in the regulated area) are subject to special, sometimes top-secret rules. Fashionable clothing belongs to the non-regulated area and does not require formal certification. The protective equipment must ensure compliance with EU regulations, such as absolute individual protection against specific risks; durable protective functions; psychological comfort while wearing it; ease of maintenance.
The production of textile garments in the regulated sector requires flawless execution with the help of qualified personnel, who have created the physical conditions for the optimal execution of the operations to achieve a constant level of quality. A factor that determines the constant quality level is efficient production management. Production management in the textile industry refers to structuring processes, setting time rules and ensuring efficient working conditions for the people performing the work (rational design of the workplace makes it possible to achieve greater efficiency and meet occupational safety requirements). Once the requirements are clearly defined from the customer's point of view, their translation into technical measures is a task for the manufacturing company. With this in mind, the main objective of this paper is to provide an example of streamlining the management of production to facilitate the manufacturing process of a product in a regulated sector that is compliant with European regulations. The case study has been carried out for the manufacturing process of a pistol bag.

Keywords: *personal protective equipment, production management, execution time, Methods time Measurement, garment industry*

Eficientizarea metodelor de management al producției pentru produse din domeniul reglementat

Una dintre caracteristicile esențiale ale pieței europene unificate este libera circulație a multor produse industriale, grație armonizării legilor țărilor Uniunii Europene. Rigoarea reglementărilor de siguranță a dus la o creștere constantă a ofertei și a volumului de echipamente individuale de protecție. Legislația UE definește „cerințe esențiale" pentru echipamentul individual de protecție, dar nu procedează la fel pentru specificațiile tehnice.
Din acest punct de vedere, produsele textile pot fi împărțite în produse care se încadrează în domeniul nereglementat și reglementat. Produsele de protecție și jucăriile sunt produse care se încadrează în domeniul reglementat din sectorul textil și necesită o certificare oficială în conformitate cu directivele Comunității Europene. Produsele textile cu destinație militară (în zona reglementată) sunt supuse unor reguli speciale, uneori extrem de secrete. Produsele de îmbrăcăminte de modă aparțin zonei nereglementate și nu necesită certificare formală. Echipamentele individuale de protecție trebuie să respecte normele și reglementările UE, în ceea ce privește protecția individuală absolută împotriva riscurilor specifice; funcții de protecție durabile; confort psihologic în utilizării produsului; ușurința întreținerii.
Producția de confecții textile în sectorul reglementat necesită condiții speciale de fabricație, un personal executant cu un nivel ridicat de calificare, care să execute operațiile în conformitate cu specificațiile tehnice ale acestuia. Managementul producției în industria textilă se referă la structurarea proceselor, stabilirea normelor de timp și asigurarea unor condiții corespunzătoare de muncă pentru executanți (proiectarea rațională a locului de muncă asigură o eficiență ridicată a activității prestate și permite îndeplinirea cerințelor de securitate specifice). Pe baza cerințelor definite de către client, departamentul tehnic al firmei producătoare elaborează documentația tehnică de fabricație a produsului contractat. Obiectivul principal al lucrării este de a prezenta un studiu de caz, de eficientizare a managementului producției pentru a facilita procesul de fabricație al unui produs în domeniul reglementat, compatibil cu reglementările europene. Studiul de caz a fost realizat pentru o operație necesară execuției unei genți port-pistol.

Cuvinte-cheie*: echipament individual de protecție, managementul producției, timp de execuție, Metode de măsurare a timpului, industria confecțiilor*

INTRODUCTION

From the manufacturer's point of view, innovative technologies, efficient production management methods, and process flows contribute towards obtaining regulated products compatible with the European customers' standards. In this sense, direct, visible signals to consumers are necessary [1–4].

According to the European Community Directive No. 89/656/EEC, companies that manufacture products in the regulated areas of the European market must: establish harmonised European standards applicable to their products:

- draw up technical regulations applicable to the products manufactured by the company and that are compatible with European regulations;
- determine the conformity assessment procedure to be applied;
- ensure that the products comply with the standards and with all the essential requirements of the applicable directives;
- affix the marking CE on the products and/or on the packaging or accompanying documents, as provided. To affix the CE marking, there are European directives and/or regulations that detail the requirements that the products must meet.

Although national and international standards and norms hold products to a certain standard, they are the "invisible" part of consumers. It should be noted that successful companies are distinguished from others by efficient production management methods and process flows [5–7].

In the apparel industry, labour cost is essential, accounting for over 70%. The labour of operators and the level of knowledge and production process management quality determine the difference in profit figures. Many manufacturers have problems with the lack of understanding of the technological process and the blockages in the various stages of the manufacturing process.

The timing rules required to perform specific operations are based on the time measurement method (MTM), which uses the times for basic human movements to define the time for a job to be performed at a given level of performance. In 1883, Frederick Winslow Taylor introduced the chronometer to measure the time required to complete a complicated task accurately. He developed the scientific study of productivity and found out how to coordinate different tasks to avoid wasting time and improve the quality of work [8]. Later, the method of time measurement (MTM) system was defined by Maynard et al. [8] in "Methods Time Measurement" (1940): "the MTM system is a method of breaking down any work process or manual operation into the basic movements required to perform it and assigning to each movement a predetermined normative time that depends on the nature of the movement and the conditions under which it is performed".

This method provides a logical record and critical analysis of how an operation is performed and how it can be improved. In time study, various techniques are used to determine the time required to perform effective physical and mental work to accomplish a specific task [9]. Various repetitive tasks that require physical and mental effort and material flow can be improved through time studies [9]. Among other data, business management relies on time study because it is a tool that provides information about the efficiency and sustainability of the company [9].

In garment companies, the manufacturing process is divided into successive stages. In what concerns products with regulated destinations, a good knowledge of the variability of manufacturing processes requires an analysis whose purpose is to characterise their state and, if necessary, to make operational corrections (to ensure the prescribed accuracy). The characterisation of their normal operating state involves taking real measures to ensure the performance of the ones that actively influence the entire manufacturing process for this type of product [10, 11].

This paper presents a model for streamlining production management to increase the efficiency of manufacturing a product in the regulated sector so that it complies with European regulations. The case study has been developed to assemble the back with support straps (a pistol bag).

DESCRIPTION OF THE WORK METHOD STAGES

To illustrate the application of these measures, the authors have studied the issue of finding solutions to reduce the execution time of an operation or the assembly phase of the back component with support strips and pieces comprising a pocket gun opening [12]. The front and the back are bound by sewing their contours at a 0.2 cm distance and attaching a piece of Velcro that will later fasten the product (figure 1).

In the company where this case study has been made, all the production process steps are carried out by a single worker. This has the following consequences:

- different execution steps and variable phase sequences;
- products with a high degree of variability in terms of quantity and quality.

Fig. 1. The pistol bag

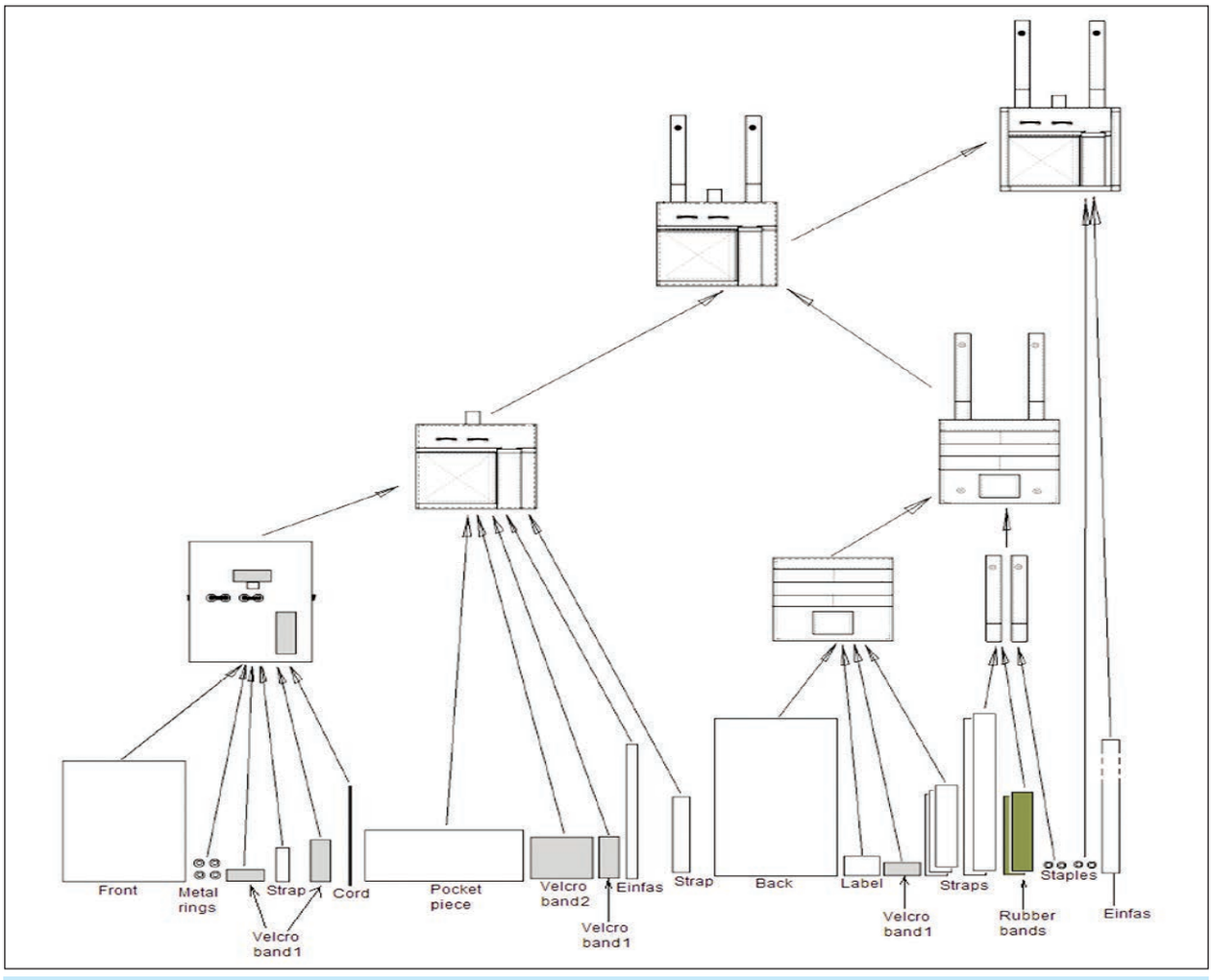


Fig. 2. The hierarchical structure of the pistol bag

To obtain products that meet the European requirements for military items, the following steps have been carried out:

– technological design in the hypothesis of phase work and
– technological redesign of some operations.

The technological design process consists of the realisation of the structure and the elaboration of the technological processes [13] along with the identification of the phases, the types of equipment and the timing of each phase (figure 2).

The tracking of the sewing process in the existing production system, which is necessary to measure the time during the preparation of the process, showed high variability in the duration of the execution of the phases by different workers (the time measurement is based on an average of the time per phase obtained for 4 workers, where the workers are not dependent on the previous and subsequent sewing phase as in the execution of serial products).

The following deductions are:

- the process analysis shows complex handling caused by the rigid structure of the material and the variable number of layers used to make the products, which affects the process and consequently the working times of the same phase;
- was found that the breaking of needles occurs with varying frequency depending on the skill in handling the material (the product has several reinforcements at the beginning and end of the seam).

These findings led to the idea of improving the manufacturing system from a technological point of view [14–17].

This assembly phase of the back component with support straps was chosen because it is essential from a functional point of view since the integrity of the product content depends on the correctness (the attachment of the front of the product to the back is done by edging with a very narrow strip of 1.8 cm supporting all four layers) with an internal reserve of only 3–4 mm.

Moreover, the central component of the product is merged with the rest of it through the edging process, the quality of which is directly influenced by the stage in which the front side and the PVC backside are attached.

The steps that are necessary to improve the workflow from a technological point of view are [18–21]:

a. systematic work description;
b. identification of the structure of the movements specific to the execution of the operation;
c. analysis of the original work method;

d. estimated the time necessary for the execution of the operation according to the original method using the Methods-Time Measurement (MTM) method. MTM analyses an industrial work or manual activity or method into the required basic movements or human movements and assigns a predetermined time standard to each movement: reaching, moving, extending, turning, applying pressure, grasping, positioning, releasing, eye times, body, leg, and foot movements.
e. identification of sources of improvement and proposal of solutions;
f. quantification of the results obtained by applying the proposed solutions.

The improvement method is used to change the working procedures and implicitly redesign the workplace.

The following are the detailed steps:

a. Define the task: "attaching the face and back with support bands" as a working system using the seven necessary elements to identify the characteristics of the factors that may affect the activity performed in this operation.

Table 1 shows the elements that systematically define the analysed work operation.

The activity is summarised in figure 3, *a–f*.

b. The identification of the movements' structure specific to the operation's execution is shown in table 2.

c. Analysis of the initial method of work

The worker uses the sewing piece. The workstation configuration in the original version is shown in figure 4.

The work method for sewing the front and back pieces of the back with the support strips consists of the following steps:

Table 1

ELEMENTS THAT SYSTEMICALLY DEFINE THE ANALYSED OPERATION	
Element	**Description**
WORKING TASK	Aligning the back component of the basic material with the back, sewing the logo, sewing the edges of the doubled back 0.2 cm apart, with the introduction of the 9 cm support strip, sewing a 9 mm narrow strip around, along with the introduction of a 42 mm support tape, sewing in the middle of the 9 cm support tape (3 pieces), cutting the thread, restoring the package.
INPUT	Package containing 50 front components made of base material for the back and a package containing 50 pieces of back components made of the back base material. 9 cm pieces and 42 cm support tape, logo
WORKER	53 years old female worker, 23 years of experience
OUTPUT	Package containing 50 pieces of back components sewn-on edge, sewn logo, 9cm support tape (432 cm length), processed with threads
WORKING MACHINES	JUKI sewing machine (with shuttle) without thread cutter, scissors, power connection (tape) – right, storage box with sewn parts on the left side
ENVIRONMENT	Normal

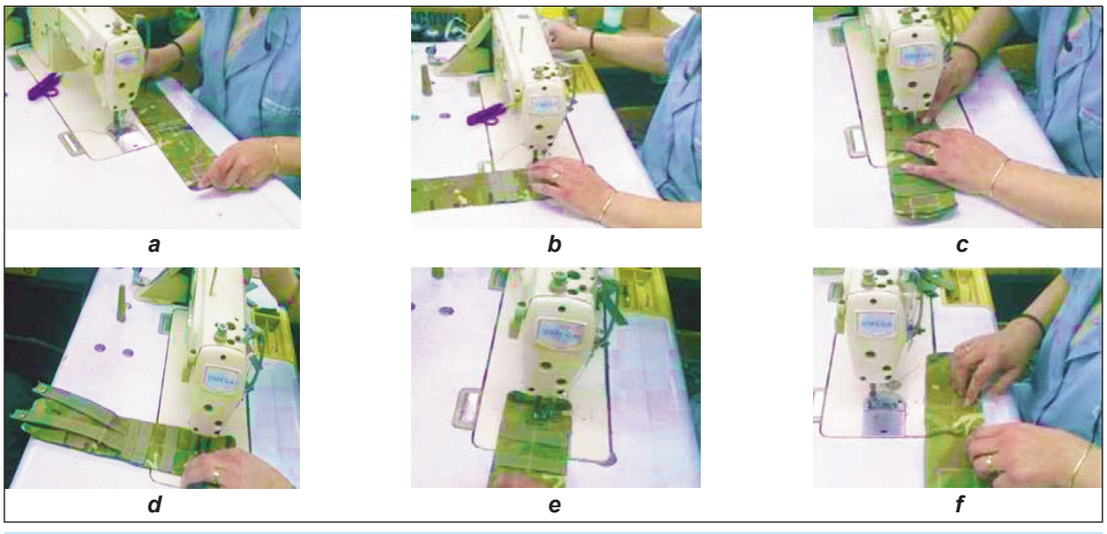


Fig. 3. Analysed work operation: *a* – attaching the front component to the back component; *b* – sewing around the area where the components have been attached with support tape (9 cm); *c* – sewing the two sides of the narrow band together with the 42 cm straps; *d* – sewing the 9 cm wide supporting tape in the middle three times; *e* – sewing the label; *f* – cutting the threads

Table 2

SPECIFIC MOVEMENTS IN THE EXECUTION OF THE ANALYSED OPERATION	
Movement structure	**Description**
1st move	Extend the right hand towards the sewing machine countertop, grab the back rear component, bring the piece and place it on the sewing machine countertop
2nd move	Extend the right hand to the belt, grab the front side of the back component, bring it and release it, and align the ensemble
3rd move	Position the ensemble under the foot at the sign, and arrange the edge pieces
4th move	Extend the right hand and take the narrow support band, bring it into position at the mark, guide the material, extend the right hand and take the 9 cm, support band, bring it into position at the mark, guide the material, extend the right hand and take the 9 cm, support band, bring it into position at the mark, guide the material, extend the right hand and take the 9 cm, support band, bring it into position at the mark, guide the material
5th move	Reposition the material, guide the material, reposition the material, guide the material, reposition the material, guide the material, reposition the material, guide the material, reposition the material, guide the material, reposition the material, guide the material, arrange the ensemble edges, guide the material, reposition the material, guide the material, reposition the material, guide the material, arrange the material, guide the material, reposition the material, guide the material, reposition the material, guide the material, reposition the material, stretch out the left hand, take the scissors, bring the scissors, cut the threads, stretch out the left hand, put the scissors on the left side of the sewing machine countertop, bring the left hand into the sewing area
6th move	Turn the body with the right hand extended, grasp the 42 cm support band (2 pieces), bring it close, release one band, and then the second band, position it on the shield, drive the material, extend the left hand, grasp the second support band 42 cm, bring the left hand close and transfer it to the right hand, position the shield, guide the material, extend the right hand to the reinforcement lever, reinforce, bring the right hand close, guide the material, stretch the right hand, reinforce, bring the right hand, reposition the piece, guide the material, reach for the steering wheel, reposition the landmark, guide the material, reposition the material, guide the material, bring the right hand, guide the material, reach: for the steering wheel, reposition the material, guide the hand, reposition the material, guide the material, reposition the material, guide the material, reposition the material, guide the material, reposition the material, guide the material, reposition the material
7th move	Extend the right hand, seize the logo, bring it, position it on the shield, drive the material, reposition it, drive the material, reposition it, drive the material, reposition it, drive the material, reposition it, drive the material, extend the right hand, seize the scissors, bring them with the transfer to the left hand, cut the threads, extend the left hand with the body back and leave the back mark in the storage box

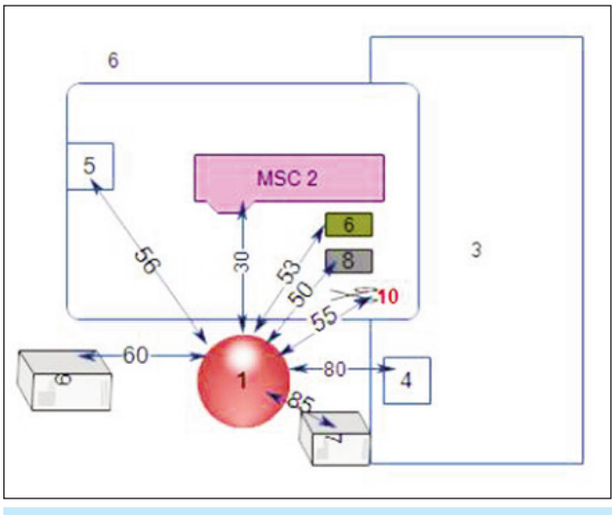


Fig. 4. Initial setup of order: *1* – worker; *2* – simple sewing machine; *3* – band; *4* – back component made of base material; *5* – back cover of the back component made of a base material; *6* – 9 cm support band; *7* – box with support band; *8* – logo; *9* – landmark storage box; *10* – scissors

A. Work preparation

1. Place the back cover of the base material on the right side of the tape.
2. Place the package with the rear pieces of the back of the base material on the left side of the sewing machine countertop.
3. Place the box with the sewn and stitched 42 cm long support tape on the right side of the chair.
4. Place the 9 cm, long support band, on the right side of the sewing machine countertop under the reinforcement lever.
5. Place the logo on the right side, on the sewing machine countertop.
6. Place the scissors on the sewing machine countertop.
7. Place the box for storing the sewn back components on the left side, next to the worker's seat.

B. Procedure

1. Grab the rear part of the back from the base material with the left hand. Place it on the sewing machine countertop in the sewing area.

2. Grab the front part of the back piece from the base material with the left hand. Place it on the rear of the back piece.
3. Check the edges of the components. Place them under the presser foot on the tag.
4. Pick up the 9 cm support tape, mark and sew the edge.
5. Sew the 42 cm support tape and the 9 cm support tape together in the centre with reinforcement.
6. Sew the logo, finish and remove.

d. Estimating the time that is necessary to perform the operation by employing the original procedure using the MTM method.

The necessary time for the processes shown in table 2 is estimated using the MTM method, with a sequence of operation modes shown in table 3.
The unit for Methods-Time Measurement (MTM) is TMU (time measurement unit): 1 TMU = 36 milliseconds (1 TMU = 0.036 seconds) [13–17].
According to the original working method, the time needed to perform the operation is 2.983 minutes.

e. Identify sources of improvement and propose solutions

After the detailed analysis of the existing situation, the following steps can be taken [15–18]:
A. Modifying the work method,
B. Improving the positioning of the front and rear parts on the tabletop.
The results obtained are given below.
A. Changing the work method is done by:
1. Placing the front and back parts of the back at a distance as small as possible;
2. Positioning the package of overlapping front and the back sides of the back components on the top of the sewing machine countertop as close as possible to the sewing area, inside the machine arm;
3. Sewing the chain stitched logo on the newly-formed rear assembly;
4. Sewing the 9 cm support strip with chain stitch;
5. Sewing on the middle of the 9 cm wide support band with chain stitch;
6. Sewing the 42 cm support strip with chain stitch;
7. Keeping the sewn back as close as possible to the worker;
8. Replacing the simple machine without a thread cutter with the simple machine with a thread cutter.

B. Improving the positioning of the front and rear parts on the work surface of the sewing machine countertop.
The following changes have been proposed:
1. The positions of the front and back parts that are going to be attached shall be as close as possible to the sewing area, resulting in an automatic movement when the front and back parts are placed in there (by overlapping and aligning the assembly before sewing).
2. Executing the front and back of the back piece simultaneously and positioning it under the presser foot without replacing the front and back sides of the back component one over the other.
3. Placing the back sewn with the logo or support tape as close as possible to the sewing area to avoid returning the worker's head.

f. Quantifying the results obtained by applying the proposed solutions

As in the analysis of the baseline situation, the following will be carried out to estimate the results of the proposed solutions:
A. Reconfiguring of the workstation where the analysed operation is performed, and
B. Estimating the operational time after the implementation of the proposed solutions.
A. Reconfiguring of the workstation where the analysed operation is performed.
The reconfiguration of the analysed order is shown in figure 5.
B. Estimating the operational time after the implementation of the proposed solutions.
The estimated data are presented sequentially in table 4.
According to the previously described working method, the operating time achieved in performing the operation is 2.15 minutes.

Table 3

ESTIMATION OF THE OPERATIONAL EFFORT FOR THE EXISTING WORKING PROCEDURE BY THE MTM METHOD (FOR FIVE PIECES)

No.	Description	MTM (5 pieces)	TMU	T (min)
1	Extend the right hand to the sewing machine countertop, grab the backside of the back component basic material, bring the back component and position it on the sewing machine countertop	(R56A G1A M56B P1SE) × 5	203.5	0.1221
2	Stretch the right hand out to the band, grab the front side of the back component basic material, brings the components and releases, and arrange the head-straight assembly	(R80AG1A M80B RL1 G4C) × 5	301.5	0.1809
3	Position the set of overlapping front and back sides of the back component base material under the foot at the mark, arrange the edge of the sides	(P2NSD G4C) × 5	197.5	0.1185
.....	.....	.....	.....	.....
		TOTAL	4972	2.983

Table 4

ESTIMATION OF THE OPERATING TIME FOR THE PROPOSED WORKING METHOD ACCORDING TO THE MTM METHOD (FOR FIVE PIECES)

No.	Description	MTM	TMU	T (min)
1	Stretch out the right hand and left hand at the same time, bring to the sewing machine countertop, grab the front sides of the back pieces package of the base material with markings on the top, bring and put on the knee, back sides of the base material with markings below the knee area	R30A G1 M30B (R2A G1A M2C RL1) × 5	44.8	0.0268
2	Stretch the hands out and places the bundle of overlapping parts on the sewing machine countertop and arrange the head straight, release the bundle, stretch the right hand, grab the scissors, grab the overlapped back pieces package, arrange the head straight, put it inside the sewing machine arm, grab the emblem with the left hand	R15B P1SSE RL1 R30A G1B M30B G1B P1SSE M15B P2NSD R5A G1A M15B	97.5	0.057
.....	.....	.....	.....	.....
13	Repack the components, bring the package onto the sewing machine countertop, and bring the 42 cm support band inside the sewing machine arm (12–14 pieces)	G1B P1SSE M15B R79A G1B M79B	68	0.0408
14	Position the backmarker under the presser foot, grab the support band, bring, position to the signs, drive the material, pull the backmarker, cut the threads, redo the package	(P2NSD G1B M15B P2NSD M9B R10B P2SSD M4C) × 5	542.5	0.322
15	Release in the storage box	LR1 × 5	10	0.006
		TOTAL	3595.1	2.15

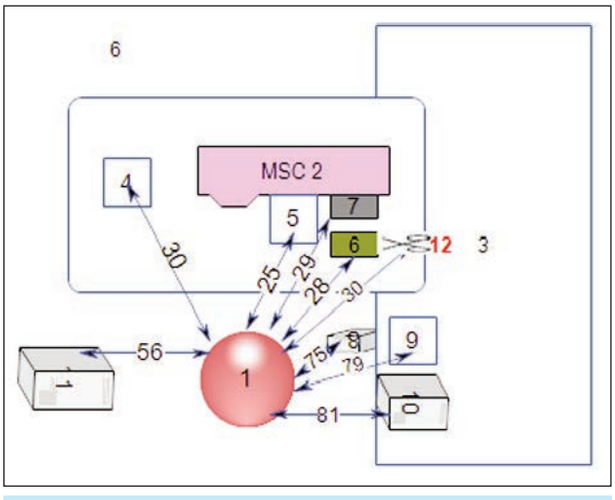


Fig. 5. Reconfiguration of the analysed tasks: *1* – worker; *2* – simple sewing machine; *3* – ribbon; *4* – sewn back a packet with the logo; *5* – overlapped back and front packet; *6* – emblem; *7* – support ribbon; *8* – box with 9 cm long support ribbon; *9* – sewn back a packet with an arrow support ribbon; *10* – box

RESULTS INTERPRETATIONS AND CONCLUSIONS

- Comparing the time obtained with the workers' working method (which had a time of 4972TMU) and the proposed solution, one saves 1376.9 TMU per 5 pieces (0.826 min). Changing the working method described above removes the hands' movements necessary to grab and put down the scissors. This reduces the time that one needs to carry out the sewing stage. By using the improved method, the time can be reduced by 50%. Thus, time is no longer wasted searching for the scissors, and the worker no longer turns their head after taking the scissors and does not force their eyes; the rhythm is constant and even progressive.
- By the changes proposed for the new method, the feeding of the front of the back with the rear of the back on the superimposed knees, and the formation of the head-straight package, their bringing out of the girdle, turning one's body, and stretching one's hands are no longer necessary.
- It shortens the way and the time if, when sewing the emblem, the worker takes over the front and rear parts of the back inside the sewing machine at the same time.
- Stretching one's hands, turning one's head, and straining one's eyes at the stage while picking up the wide supporting band from the right side of the machine's work area is no longer necessary. This is replaced in the improved method by grasping several 20–25 pieces in the right hand and releasing them three at a time. The stretching movements of the right hand to the belt are no longer necessary, and when the worker picks up the 42 cm support tape, they are positioned in the sewing machine arm in a reasonable number.
- By replacing the simple sewing machine without a thread cutter with a simple sewing machine with a thread cutter, one can eliminate the use of scissors, increasing the number of manufactured products per day by 50%.

- If one repositions the package containing the front sides and the backsides as close as possible to the sewing area, their feeding phase will be more efficient.
- Implementing the proposed working method will undoubtedly lead to an increase in the quality level of the next operation, the application of the narrow band on the contour.

Standardisation is one of the pillars of using MTM to define jobs that imply labour. MTM analyses entered into the database with improved definitions of jobs can be shared among users as potential best practices, ensuring a common language and replicability of methods. Such a contribution could facilitate the replication of successful companies on a global scale and contribute to employment and public recognition.

A collaborative platform can be developed where skilled technicians can continuously improve remanufacturing processes based on a standardised data set.

The research community can identify optimisation methods for specific products or processes and derive precise requirements for developing new manufacturing technologies.

REFERENCES

[1] Decision no. 1.597 of December 18, 2002, for the approval of the methodological norms for the application of the Government Emergency Ordinance no. 95/2002 on the defence industry, 2002, Available at: http://www.cdep.ro/pls/legis/legis_pck.htp_act_text?idt=39894 [Accessed on November 2022]

[2] Abrudan I., Cândea, D., *Ingineria şi Managementul Sistemelor de Producţie*, ISBN 973-35-I588-4, Ed. Dacia, Cluj Napoca, 2002

[3] Ahmad, A., Javed, I., Abrar, U., Ahmad, A., Jaffri, N.R., Hussain, A., *Investigation of ergonomic working conditions of sewing and cutting machine operators of clothing industry*, In: Industria Textila, 2021, 72, 3, 309–314, http://doi.org/10.35530/IT.072.03.1723

[4] Choi, B.-W., Nagy, D., *Global Solutions to Challenges in Manufacturing*, Ceong-Moon-Gac Publishers Korea, ISBN 978-89-92592-34-5, 2007

[5] Nicolaiov, P., Florea, A., Loghin, C., *Metode inovative de organizare a operaţiilor de lucru în sectorul confecţii textile (cap. 1–6)*, Editura Certex, București, ISBN-978-973-1716-61-9, 2010, 116

[6] Nicolaiov, P., Loghin, C., Ionescu, I., *The technological reconfiguration, an instrument for increasing the sewing work productivity*, In: Proceedings of the International Conference MANAGEMENT OF TECHNOLOGICAL CHANGES, ISBN 978-960-8475-04-5, 2005, 1, 99–104

[7] Chourabi, Z., Babay, A., Khedher, F., Cheikhrouhou, M., *A new objective function for the assembly line balancing optimization in terms of workers' global competence*, In: Industria Textila, 2020, 71, 4, 398–407, http://doi.org/10.35530/IT.071.04.1545

[8] Avadanei, M., Dulgheriu, I., Cezar, D.R., *Virtual prototyping design of bulletprof vest*, In: Industria Textila, 2012, 63, 6, 290–295

[9] Chisosa, D.F., Chipambwa, W., *An exploration of how work study techniques can optimise production in Zimbabwe's clothing industry*, In: Journal of Textile and Apparel Technology and Management, 2018, 10, 3

[10] Loghin, C., Nicolaiov, P., *Optimizarea sistemelor de lucru în confecții*, Ed. Performantica, Iaşi, ISBN 973-730-166-8, 2005, 260

[11] Loghin, C., Nicolaiov, P., Ionescu, I., *Work Method – Decisional Tool for Technological Changes*, In: Proceedings of the International Conference MANAGEMENT OF TECHNOLOGICAL CHANGES, ISBN 978-960-8475-05-2, 2005, 2, 53–58

[12] Dulgheriu, I., Avadanei, M., Cozmanciuc, C., *Research concerning the heat-sealed treatment parameters influence on the main characteristics of a doubled ensemble,* In: Tekstil ve Konfeksiyon, 2014, 24, 4, 380–385

[13] Nicolaiov, P., Loghin, C., *Managementul tehnologic in fabricatia confectiilor textile,* Ed. Performantica, Iaşi, ISBN 973-730-161-7, 2005, 207

[14] Loghin, C., Nicolaiov, P., *Configurarea locurilor de munca în confectii. Studii de caz.,* Ed. Performantica, Iaşi, ISBN 973-7994-65-5, 2004, 140

[15] Loghin, C., Nicolaiov, P., *Optimizarea sistemelor de lucru in confectii,* Ed. Performantica, Iaşi, ISBN 973-730-166-8, 2005, 260

[16] Loghin, C., Nicolaiov, P., Ionescu, I., *Work method – decisional tool for technological change*, In: Proceedings of the 4-th International Conference on the Management of Technological Changes, Chania, Greece, August 19-20, 2005, Book 2

[17] Nicolaiov, P., Loghin, C., *The Optimisation of Sewing Workplaces Design,* In: Revista Romana de Textile-Pielarie, 2001, 2, 139–144

[18] Refa course, *Organizarea proceselor şi sistemelor de lucru*, Iaşi, 2001

[19] Refa course, *Managementul datelor de proces*, Iaşi, 2001

[20] Nicolaiov, P., Loghin, C., Rusu, C., *Flexibility in Technological Process Design – Requirements and Instruments*, In: The 2-nd International Textile, Clothing & Design Conference „Magic World of Textiles", Dubrovnik, Croatia, 2004

[21] Zahid, B., Jamshaid, H., Rajput, A.W., Chen, X., *Impact properties of continuously textile reinforced double fabric layered riot-police-helmet-shells*, In: Industria Textila, 2021, 72, 5, 485–490, http://doi.org/10.35530/IT.072.05.1820

Authors:

IONUT DULGHERIU, MANUELA AVADANEI, SAVIN-DORIN IONESI,
IRINA IONESCU, EMIL-CONSTANTIN LOGHIN

"Gheorghe Asachi" Techical University of Iasi, Faculty of Industrial Design & Business Management,
29 Bld D Mangeron, Iasi 700050, Romania

Corresponding author:

MANUELA AVADANEI
e-mail:mavad@tex.tuiasi.ro

The impact of hazards control practices on injuries and accidents in textile industry

DOI: 10.35530/IT.073.06.202255

MUHAMMAD AWAIS-E-YAZDAN
CRISTI SPULBAR
RAMONA BIRAU
LORENA DUDUIALA POPESCU

ABSTRACT – REZUMAT

The impact of hazards control practices on injuries and accidents in textile industry

Workplace injuries and accidents have an adverse effect on the lives of textile workers. The research study investigates the moderating effect of ethical climate on the relationship between safety management practices and safety behaviour. A simple random sampling technique was employed to collect data from 12 textile companies. A total of 384 textile workers participated in this study. Results revealed that management commitment, safety training, workers involvement, safety communication & feedback and safety promotion policies have a significant and positive influence on safety behaviour. While safety rules and procedure are failed to predict safety behaviour. Moreover, ethical climate positively moderate the relationship among management commitment, safety training, workers' involvement, safety communication & feedback and safety behaviour. Whereas, the ethical climate failed to moderate safety rules and procedure, safety promotion policies and safety behaviour. It is recommended that Textile companies must provide an ethical work climate in which the best SMP may help to reduce workplace injuries and accidents.

Keywords: *safety behaviour, ethical climate, Safety Management Practices (SMP), textile companies*

Impactul practicilor de control al pericolelor asupra cazurilor de vătămări corporale și accidente din industria textilă

Vătămările corporale și accidentele la locul de muncă au un efect negativ asupra vieţiilucrătorilor din domeniul textil. Studiul de cercetare investighează efectul moderator al climatului etic asupra relației dintre practicile de management al siguranței și comportamentul de siguranță. Tehnica de eșantionare aleatorie simplă a fost folosită pentru a colecta date de la 12 companii din sectorul textil. La acest studio de cercetare au participat 384 de lucrători din domeniul textil. Rezultatele empirice au demonstrat că angajamentul managementului, instruirea în materie de siguranță, implicarea lucrătorilor, comunicarea și feedback-ul privind siguranța și politicile de promovare a siguranței au o influență semnificativă și pozitivă asupra comportamentului de siguranță, în timp ce regulile și procedura de siguranță nu au reușit să prezică comportamentul de siguranță. În plus, climatul etic influentează pozitiv relația dintre angajamentul managementului, instruirea în materie de siguranță, implicarea lucrătorilor, comunicarea și feedback-ul privind siguranța și comportamentul de siguranță. Totuşi, climatul etic nu a reușit să influenţeze regulile și procedurile de siguranță, politicile de promovare a siguranței și comportamentul de siguranță. Se recomandă ca companiile din industria textilă să ofere un climat de lucru etic în care cele mai bune pratici de management al siguranței să poată contribui la reducerea cazurilor privind vătămările corporale și accidentele la locul de muncă.

Cuvinte-cheie: *comportament de siguranță, climat etic, Practici de management al siguranței (SMP), companii din sectorul textil*

INTRODUCTION

There are the latest technologies and legislations to control occupational injuries and accidents. Besides this, there are still huge numbers of workplace accidents. It is the responsibility of the organizations to provide a risk and accidents free environment to their workers [1]. Every year millions of workers were injured and died due to work-related injuries and accidents. Similarly, millions of working hours were also wasted due to absenteeism from work. An occupational accident is defined as "an unexpected condition arising during the course of work which can cause injury or disease which sometimes leads to death".

Narrowing to the textile industry is one of the oldest industries of mankind. The textile industry is old as human civilization and it produces fundamental human needs such as food. It is the largest manufacturing industry in Pakistan. In Asia, Pakistan is number eight to export textile products. The textile industry has great significance as it contributes 8.5% of the total GDP of Pakistan and it gives employment to 45% of the country's labour force. Moreover, the textile industry should focus on workplace safety and health but unfortunately, the condition of Pakistani textiles relating to health and safety is worst. By comparing occupational injuries and accidents of years 2017/2018 to 2020/2021 it is clear that in these years

the textile industry has increased occupational injuries and accidents [2].

Table 1

COMPARISON OF OCCUPATIONAL INJURIES PERCENTAGE IN TEXTILE INDUSTRY OF PAKISTAN AND OTHER INDUSTRIES [3]

Items	2017–2018	2020–2021
Textile (Manufacturing)	16.91%	19.11%
Transport, storage & communication	7.71%	9.96%
Electricity Gas & water	0.44%	0.36%
Mining & Quarrying	0.27%	0.48%

Table 1 shows the statistics of different types of occupational injuries in the Pakistani textile industry and other industries from 2017–2018 to 2020–2021. The table reveals that the textile industry has a high percentage of occupational injuries as compared to other industries.

The introduction of the latest machinery in the textile industry produces hazardous incidents and an unhealthy environment. The officials failed to establish the rules relating to occupational safety and health in textiles, and the promotion of occupation hazards is inadequate. The workers in the textile industry are unaware of how to work safely, as there are inappropriate safety management practices (SMP) in the textile industry. The workers did not know how to behave safely and lack of safety behaviour is the cause of workplace injuries and accidents. The present study measured the safety behaviour of textile workers by safety compliance and safety participation based on task and contextual performance [4]. Safety compliance is related to the set rules by an organization whereas, safety participation is a voluntary action performed by the workers [4]. The authors choose these dimensions of safety behaviour as these are widely used and accepted by past researchers [5, 6]. The major reasons for injuries and accidents in textile industries are the lack of safety training, poor management, inappropriate rules, and inadequate safety promotion policies. Therefore, this research is conducted to understand safety behaviour according to human error. The workers' safety behaviour can be influenced by SMP [6, 7]. SMP are the policies and procedures which are implemented by the organization to improve the safety behaviour of the workers [5, 8]. Similarly, it is argued that SMP helps to understand and reduce human errors in the workplace. The six SMP (management commitment; safety training, workers involvement; safety rules & procedure and safety promotion policies), when applied completely, can influence safety behaviour in the workplace [9].

We incorporate workers' ethical climate as a moderating variable on the relationship between SMP and safety behaviour to obtain better results. The ethical climate is the viewpoint of the workers relating to the work environment and organizational procedures [10]. According to the limited knowledge of researchers, this is the first study to incorporate ethical climate as moderating variable in the relationship between SMP and safety behaviour. The theoretical framework of the present study is shown in figure 1. The framework describes how SMP can influence safety behaviour by moderating the role of ethical climate concerning lower injuries and accidents in textile industries. Similarly, an ethical climate portrays the rules and procedures already maintained by the organization [11], which could positively influence the workplace safety environment. Pakistan is a developing country and the condition of the Textile industry relating to hazards is worst. There is a dearth of SMP in the textile industry and if the situation remains the same the industry will face very bad consequences. The workers working in Pakistani textile are uncertain and their situation at work is worst. The statistics have shown the highest number of occupational injuries and accidents among them. Therefore, the present study is an addition to very few studies in the Pakistan textile industry to incorporate SMP and safety behaviour with the moderating role of ethical climate.

LITERATURE REVIEW AND HYPOTHESIS DEVELOPMENT

Safety behaviour

Miscellaneous studies debate safety behaviour and measured it as the dependent variable with a variety of safety-related outcomes, along with accidents rates [12, 13], injuries [14, 15–17], safety involvement or commitment [18, 19] and safety compliance and safety participation [20–23]. Compliance is an important component to define safety behaviour. Safety compliance is a "core behaviour that workers need to perform to retain workplace safety. Such behaviour contains maintaining the standards of work procedures and wearing personal protective equipment" [24]. Furthermore, safety compliance is defined as the efforts taken by employees to maintain workplace safety by following the organization's rules and procedures [21]. This kind of behaviour encompasses adherence to safety standards which would be beneficial in the Textile industry to avoid accidents.

At present the textile industry of Pakistan has no specific rules and standards so, there must be some basic safety rules and procedures for this industry, the workers should know about the manners of the workplace. Companies must follow basic safety precautions to avoid any incident. Therefore, safety compliance taken as a dimension of safety behaviour is beneficial. The next concept is safety participation which refers to a behaviour that secondarily takes part in employee personal safety and stimulates the growth of the workplace that reinforces safety.

Safety participation explains as a behaviour that does not affect the personal safety of employees directly but can help educate the people on an environment that supports safety [22, 24]. This type of behaviour comprises helping colleagues regarding safety

issues, organizing safety meetings and taking part in voluntary safety activities. Safety participation includes voluntary safety actions like attending safety meetings and assisting fellow workers in safety-related issues. This kind of behaviour is essential where there is a risk of an accident. Voluntary participation is essential from workers when there is a unique nature (textile) of industry, where the rate of accidents is high as compared to other industries. Hence, safety participation is beneficial for measuring safety behaviour.

A study by Pedersen and Kines [23] on safety motivation and safety performance (safety compliance and safety participation). Based on a theoretical model seven occupational safety motivation questionnaire items were developed with three forms of motivation for safety compliance/participation as follows: normative, social, and calculated motivations. The study revealed that there is a significant positive relationship between safety motivation and safety performance. In a similar study, Lu and Yang [20] investigated the relationship between safety leadership (safety motivation, safety policy, and safety concern) and safety performance (safety compliance and safety participation).

The study revealed that safety motivation and safety concerns positively affected safety compliance and safety participation. Singer et al. [25] examined the relationship between safety climate and safety performance. The study showed a significant link between organization safety climate and safety performance in hospitals. In a similar related study Siu et al. [26] examine the relationship between safety climate, psychological strains and safety performance. The results revealed that psychological strains partially mediated the relationship between safety climate and safety performance and there is a direct significant association between safety climate and safety performance. The two dimensions of safety behaviour (safety compliance & safety participation) have received a lot of recognition and empirically tested in safety management research that they can reduce the number of accidents in the workplace.

Management commitment

Management commitment plays a vital role in the organization to improve workplace attitudes and behaviour [27, 28]. Management commitment to safety is a degree to which upper-level management recognizes safety as a fundamental principle of an organization [29]. In addition, management commitment refers to the efforts by the upper level of management to assure that every feature of operations including, selection, procedure, equipment, training and work scheme are properly analysed and re-organize if needed [30]. Similarly, the commitment of an organization's top-level management plays a vital role in provoking organizational safe culture [29, 31, 32]. Yule et al. [33] examined the role of management and safety climate in stopping risk-taking at the workplace. The result revealed a positive relationship between management commitment and worker risk-taking. In another study, conducted by Cox et al. [34] in UK plant reactors, the behavioural approaches to safety management were examined. The study revealed a positive relationship between management commitment and behavioural safety at all levels of the organization. Donald and Canter [35] conducted a study, they believe that number of safety climate scales including management commitment were correlated among employees of UK power plants. Similarly, Diaz and Cabrera [36] carried out a study on safety climate and attitude as evaluation measures of organizational safety. The findings concluded that company safety policies (including management commitment) were significant factors that influence organizational safety. Committed management indulges in safety-related outcomes and it can improve the safety behaviour of the Textile workers thus the following hypothesis is formulated:

H1: Management commitment is significantly and positively related to safety behaviour.

Safety training

Training prepares workers with the help of essential knowledge and skills and it also creates a positive attitude and behaviour of workers to work safely [37]. Similarly, training helps reduce hazards in the workplace and it enhances the abilities of employees to mark uncertainties [38]. Safety training is explained as it is knowledge, and understanding of safety given to the workers to work safely at the workplace without any danger to their welfare [39]. Thus, everyone at the workplace should be trained and able to control any hazard at the workplace. Wadsworth and Smith [40] organized research to determine the relationship between safety cultures, safety behaviour and occupational safety and health. The study resulted that training related to safety is the fundamental factor to enhance safety behaviour in the workplace. In another study, Zacharatos et al. [41] examined the association between high-performance work systems and occupational safety. The study revealed that appropriate training can upgrade the level of safety in the workplace. The results also indicated a significant association between high performance and safety training. Mohammad et al. [42] conducted a study on safety management in the construction sector of Jordon. The study revealed that training for workers is paramount to enhancing safety performance. Furthermore, the study indicated the component which leads to zero accident rates is safety training. In a similar vein, another study was conducted on safety performance in the construction sector of Palestine. The study followed qualitative and quantitative methods to identify safety performance among subcontractors. The resulting exhibit is that safety training is significantly related to the rate of injuries. Hayes et al. [43] assessed the concept of safety in the work environment. In addition, the study showed that the employees who are well trained had an effective perception regarding the workplace safety environment than those who are not. Similar results have

been attained by O'Dea and Flin [44], who conducted a study in the offshore oil and gas sector. They found that workers who are trained had an excessive perception regarding safety climate than those workers who are not properly trained. It is believed that safety performance can lower the injury rate and can positively influence workplace safety. Therefore, we proposed the following hypothesis.
H2: Safety training is significantly and positively related to safety behaviour.

Workers involvement

Workers' involvement is described as the willingness of workers to acquire responsibility to create a work environment free from accidents [45]. Workers' involvement is a technique that demands energetic and action-oriented behaviour and continuous progress towards safety responsive environment. Similarly, the ability to which workers are indulging in the decision-making process, be responsible for their acts and empower to take safety improvement initiatives at the workplace. Vredenburgh [46] stated that employees who are very close to work are the workers who are well-experienced and can make suggestions for the improvement of safety. Organizations that make specific teams to attain safety revealed the best result as compared to those that did not [47]. Similarly, the degree to which management motivate workers' involvement to assign them daily routine work, influence safety at the workplace [48]. Cheyne et al. [49] examined workers' attitudes in manufacturing companies. The result showed that workers' involvement was a significant predictor of safety-related activities. In addition, Vredenburgh [45] stated that workers' participation is a key element in the prohibition of injuries. On a similar note, Costella et al. [50] indicated that workers' participation is important in achieving a safer workplace without occupational accidents. Moreover, Rooney [51] conducted a study to check the influence of workers' involvement and employee ownership on safety and health in the workplace. The study revealed that worker involvement is significantly related to a lower injury rate. Lee [52] assessed the safety culture in UK nuclear fuels. The study covered numerous other aspects like training, job satisfaction, safety rules and procedures and workers' involvement. The result showed that workers' involvement is a conclusive element in safety management. Workers' involvement can improve and upgrade the safety behaviour of the workers thus the following hypothesis are designed.
H3: Workers' involvement is significantly and positively related to safety behaviour.

Safety communication and feedback

Communication plays a main role in the success of any individual or organization to complete their work and achieve their goals. The role of feedback is critical in defining employee performance because the behaviour of workers depends on new appearances, such as updated information on hazards and threats. Vinodkumar and Bhasi [5] revealed that regular communication related to safety among supervisors, management and employees is an efficient management practice for the advancement of safety in the workplace. Similarly, Lee [52] listed communication attributes of low-accident units, and the study disclosed communication as a major contributor to the success of safety outcomes. Meanwhile, Havold and Nesset [53] defined communication as the degree to which workers realize that organization deliver an effective information exchange concerning internal safety business. Bentley and Haslam [54] examined safety practices used by managers of high and low accident rates in postal delivery offices. The study stated that there is a positive association between safety communication and lower accident rates. In addition, Mohamed [55] analysed the safety climate in construction. The results indicated the importance of communication in attaining a positive safety climate and safer work behaviour in construction. Similarly, DeJoy, Schaffer, and Wilson [56] evaluated the determinants and the role of safety climate. The study revealed a significant relationship between safety policies and communication as a feature of safety climate. Safety communication & feedback could understand and influence the concept of safety behaviour therefore the following hypothesis is formulated.
H4: Safety communication & feedback is significantly and positively related to safety behaviour

Safety rules and procedures

According to Vinodkumar and Bhasi [5], rules and procedures are maintained by the organizations towards its implementation to enhance the safety behaviour of the workers at the workplace. In the existing literature, safety rules and procedures play a significant role in safety-related outcomes. For example, a study conducted by Mearns, Whitaker and Flin [7] investigated the relationship between safety climate, SMP and safety performance in an offshore environment. The findings revealed that safety rules and procedures significantly relate to safety performance. Another study by Vinodkumar and Bhasi [5] examined the mediating role of safety knowledge and motivation on the relationship between SMPs and safety behaviour. The result showed that safety rules and procedures are the factors that have a significant correlation with injuries and accident rates. Leggat, Bartram & Stanton [57] aimed to discover the gap between practices and policy in healthcare reforms. The study showed that high-performance work systems characterized by procedures and policies contributed to safety performance. Dejoy et al. [56] revealed that safety policies and procedures were significantly related to safety at the workplace. Similarly, Diaz and Caberra [36] reported that safety policies and procedures are the contributors to the safety climate.
Concluding, well-maintained rules and procedures guarantee of safer work environment for the workers. Therefore, we proposed the following hypothesis

H5: Safety rules & procedures are significantly and positively related to safety behaviour.

Safety promotion policies

Safety promotion policies such as rewards, incentives and recreational activities motivate employees to complete their tasks safely at the workplace. Similarly, safety promotion policies can stimulate employees to contribute to the hazard control program and motivate employees to take self-protection action towards safety. Previous researchers have found that incentive programs effectively reduce accidents more than traditional measures, for instance, personnel selection, training, disciplinary actions and engineering improvements [58].

According to Ostrom, Wilhelmsen and Kaplan [59] organizations with good safety culture reward workers who are aware of safety problems and those who have awareness of finding ways to assess and remove workplace hazards. McAfee and Winn [60] review 24 studies and revealed that giving feedback and providing incentives promote employees' welfare and reduce workplace injuries and accidents further explain that all 24 studies found that giving feedback and providing incentives helped improve the safe environment. Likewise, Haynes, Pine and Fitch [61] also assessed that feedback and incentives reduce workplace accident rates. Vinodkumar and Bhasi [5] admitted safety promotion policies as one of the safety management practices and revealed them as a positive factor for incentives, rewards, promotion and creating awareness among workers for arranging safety programs. Similarly, safety promotion policies have a significant impact on the safety behaviour of the workers thus we come up with the following hypothesis.

H6: Safety promotion policies are significantly and positively related to safety behaviour.

Ethical Climate: Moderator

Ethical climate refers to the perception of the workers regarding organization standards and ethical behaviour [10]. Incorporating an ethical climate as a moderator is significant. Numerous moderating effects have been investigated in the relationship between SMP and safety behaviour but we introduced ethical climate as a moderator. We believe that an ethical climate can positively affect these relationships in Textile settings, as the ethical workplace motivates the workers to work safely and protect themselves and the organization from deadly hazards. Luria and Yagil [62] stated that a productive ethical climate has a positive relationship with a firm's performance. Ethical climate can be described as a significant component of a safe workplace where individuals can work safely. It also allows individuals to control and solve ethical issues within organizations [63]. In addition, an ethical climate helps in the decision-making process of the employees to make the work environment safe and secure [64]. There is a clear link between the role of interacting supportive ethical environment and the safe behaviour of the workers. Likewise, it is argued that organizations which portray weak ethical and professional standards found a higher ratio of unethical behaviour in the workplace. Whereas, organizations which practice strong laws and ethical procedures observed a rare ratio of unethical behaviour in the workplace. Therefore, Leaders, supervisors and managers are responsible for making an ethical atmosphere to make the work environment safe. Committed management, trained and involved workers which communicate and follow workplace rules with an ethical atmosphere can reduce workplace injuries and accidents. With this argument, we come up with the following hypothesis.

H7: Ethical climate moderates the relationship between management commitment and safety behaviour.

H8: Ethical climate moderates the relationship between safety training and safety behaviour.

H9: Ethical climate moderates the relationship between workers' involvement and safety behaviour.

H10: Ethical climate moderates the relationship between safety communication & feedback and safety behaviour.

H11: Ethical climate moderates the relationship between safety rules & procedures and safety behaviour.

H12: Ethical climate moderates the relationship between safety promotion policies and safety behaviour.

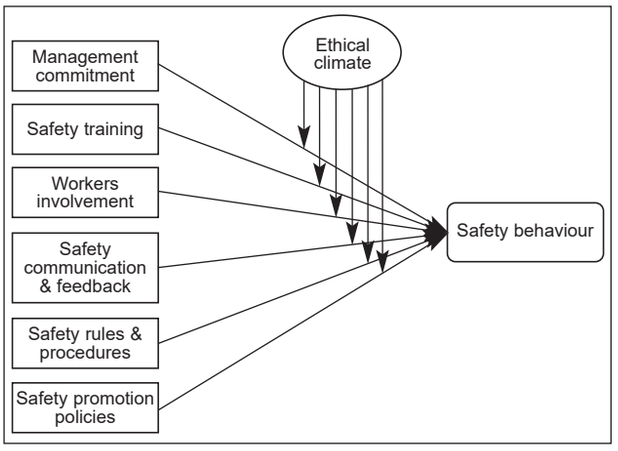


Fig. 1. Research framework

MATERIAL & METHODS

Data collection

Data was collected with the help of a simple random sampling technique from 12 Textile companies. Data was collected from Faisalabad city, as most of the textile industries are in Faisalabad. Faisalabad is also called Manchester of Pakistan because both cities are famous for the textile industry. A total of 536 questionnaires were distributed among respondents. Out of 536 questionnaires, 384 were used for data collection. The remaining questionnaires were discarded because some of them were incomplete and torn. The response rate was 72%. The questionnaire

Table 2

STUDY'S ITEMS & ITS SOURCES			
Constructs	**Items**	**A**	**Source**
Management commitment	9 items	0.876	Vinodkumar & Bhasi [5]
Safety training	6 items	0.812	Vinodkumar & Bhasi [5]
Workers involvement	5 items	0.819	Vinodkumar & Bhasi [5]
Safety communication & feedback	5 items	0.814	Vinodkumar & Bhasi [5]
Safety rules & procedures	5 items	0.866	Vinodkumar & Bhasi [5]
Safety promotion policies	5 items	0.891	Vinodkumar & Bhasi [5]
Safety compliance	7 items	0.854	Vinodkumar & Bhasi [5]
Safety participation	5 items	0.863	Vinodkumar & Bhasi [5]
Ethical climate	10 items	0.841	Victor & Cullen [10]

for SMP and safety behaviour (safety compliance & safety participation) ranging from (1) strongly disagree to (5) strongly agree was adapted from the study of Vinodkumar and Bhasi [5]. Similarly, the measurement for ethical climate ranging from (1) strongly disagree to (5) strongly agree was adapted from the study of Victor and Cullen [10]. All items were measured using 5 point Likert scale.

Table 2 shows the main sources of the constructs and the items which were adapted in this study. It also shows the recommended Cronbach's alpha of the constructs.

Table 3 depicts that 56.25% of the participants were male and 43.75% were female. Most of the respondents, 37.5% belong to the 31 to 40 years of group. In addition, 26.04% belong to the 41 to 50 years of group and 22.13% were related to 20 to 30 years of age. Similarly, 7.18% were associated with 51 to 60 years of groups. Lastly, 4.42% were under 20 years and only 2.08% were above 60 years. Regarding marital status, 77.86% were married while 22.13% were unmarried. As far as education is concerned majority, 39.06% of the respondents have a matriculation education. Following, 24.47% have intermediate qualification and 14.58% have bachelors. Likewise, 9.11% and 7.29% have Secondary and primary education respectively. Whereas, only 5.46% have a master's degree. Concerning working departments, the majority 28.38% of the respondents were working in the processing unit. Whereas, 26.04% were working in the weaving unit. Moreover, 24.47% of the participants were working in stitching and 21.09% belonged to the spinning unit. Concerning working experience, the majority 45.83% of the respondents belong to the 1 to 5 years of age group. In addition, 31.25% have 6 to 10 years of experience. Similarly, 15.62% have above 10 years of experience and only 7.29% have less than a year of experience. Concerning living areas, the majority 62.5% belong to the rural area while 37.5% were related to urban areas.

Table 3

DEMOGRAPHIC PROFILE OF THE RESPONDENTS		
Elements	**Frequency**	**Percentage (%)**
Gender		
Male	216	56.25
Female	168	43.75
Age		
Under 20 years	17	4.42
20 to 30 years	85	22.13
31 to 40 years	144	37.5
41 to 50 years	100	26.04
51 to 60 years	30	7.18
Above 60 years	8	2.08
Marital Status		
Married	299	77.86
Un-Married	85	22.13
Education Level		
Primary School Certificate	28	7.29
Secondary School Certificate	35	9.11
Matriculation	150	39.06
Intermediate	94	24.47
Bachelors	56	14.58
Masters	21	5.46
Working Units		
Stitching	94	24.47
Processing	109	28.38
Weaving	100	26.04
Spinning	81	21.09
Working Experience		
Less than 1 year	28	7.29
1 to 5 years	176	45.83
6 to 10 years	120	31.25
Above 10 years	60	15.62
Living Area		
Urban	144	37.5
Rural	240	62.5

Validity and correlation analysis

Table 4 presented the mean and standard deviation of the constructs. A textile worker shows their agreement

Table 4

MEAN AND STANDARD DEVIATION		
Variables	**Mean**	**Standard deviation**
Management commitment	4.12	0.82
Safety training	3.86	0.78
Workers involvement	3.74	0.85
Safety communication & feedback	4.34	0.76
Safety rules & procedures	4.15	0.89
Safety promotion policies	3.84	1.14
Safety compliance	4.44	0.86
Safety participation	4.33	0.84
Ethical climate	3.12	1.04

relating to SMP, ethical climate and safety behaviour model. Thus, it is recommended that Textile companies must follow SMP and provide an ethical working atmosphere to reduce workplace injuries and accidents. The Pearson correlation method was incorporated to measure correlation among constructs. Hair et al. [65] stated that the recommended values of the correlation coefficient must be under 0.7 to avoid any multi-collinearity issue. Therefore, the correlation among all constructs was under the recommended threshold and provide satisfactory measurement.

For convergent validity table 5 depicts the values of AVE. Each value of AVE is higher than 0.5 which represents the appropriate level of convergent validity and goodness of fit of the model.

CONCLUSIONS AND DISCUSSION

Our study hypothesized that management commitment is positively related to safety behaviour. The result in table 5 depicted that management commitment is positively related to safety behaviour. It means that when top management is committed to safety-related activities employees voluntarily behave safely to maintain the decorum of the workplace. Similarly, one logical explanation of this significant relationship could be that the management of the Pakistani textile industry is genuine and pure to exhibit safety activities at the workplace. Likewise, the next hypothesis of the present study is that safety training is positively associated with safety behaviour. The result of table 6 indicated that it is a strong and positive relationship between safety training and

Table 5

CONVERGENT AND DISCRIMINANT VALIDITY									
Variables	**AVE**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Management commitment	0.56	**0.74**							
Safety training	0.64	0.32	**0.8**						
Workers involvement	0.58	0.48	0.54	**0.76**					
Safety communication & feedback	0.62	0.59	0.63	0.56	**0.78**				
Safety Rules & Procedures	0.59	0.60	0.45	0.54	0.02	**0.76**			
Safety Promotion Policies	0.68	0.58	0.22	0.64	0.14	0.29	**0.82**		
Safety Behaviour	0.70	0.28	0.39	0.52	0.41	0.56	0.14	**0.83**	
Ethical Climate	0.73	0.49	0.44	0.22	0.56	0.41	0.55	0.16	**0.85**

Note: the boldface shows the square root of the average variance extracted (AVE).

Table 6

RESULTS OF REGRESSION & PATH COEFFICIENT				
H+	**Relationships**	**Coefficient**	**P-Value**	**Decision**
1	Management commitment → Safety behaviour	0.359	0.000	Supported
2	Safety training → Safety behaviour	0.621	0.012	Supported
3	Workers involvement → Safety behaviour	0.238	0.003	Supported
4	Safety communication & Feedback → Safety behaviour	0.563	0.025	Supported
5	Safety rules & procedures → Safety behaviour	0.324	0.201	**Not Supported**
6	Safety promotion policies → Safety behaviour	0.566	0.000	Supported
7	Management commitment*Ethical climate → Safety behaviour	0.489	0.016	Supported
8	Safety training*Ethical climate → Safety behaviour	0.293	0.031	Supported
9	Workers involvement*Ethical climate → Safety behaviour	0.495	0.000	Supported
10	Safety communication & feedback *Ethical climate → Safety behaviour	0.326	0.019	Supported
11	Safety rules & procedures *Ethical climate → Safety behaviour	0.248	0.359	**Not Supported**
12	Safety promotion policies *Ethical climate → Safety behaviour	0.299	0.148	**Not Supported**

safety behaviour. A probable justification for this finding could be the adequate training resources of the Pakistani textile industry. The data is collected from the companies situated in Faisalabad city and Faisalabad is famous for its Textile work so it means the companies have a sufficient budget for spending on training activities. In addition, we hypothesized that workers' involvement is positively related to safety behaviour. Our result indicated that there is a strong and positive relationship between workers' involvement and safety behaviour.

A plausible explanation of this positive result could be the involvement of workers in the decision-making process. The management of the Pakistani textile industry indulges workers in safety-related meetings to empower workers. Empowering workers in safety activities provides better improvement in the workplace. Moreover, our study hypothesized that there is a significant and positive relationship between safety communication and feedback and safety behaviour. The result of this study indicated that safety communication and feedback have a positive and strong relationship with safety behaviour. The finding could be the result of an open communication among top management and workers which influence workplace safety and health. Effective communication could specify the issues and help them to solve them as soon as possible. In addition, the study also hypothesized that safety promotion policies have a positive relationship with safety behaviour. Our results provide a strong and positive association between this relationship. The result could be attributed to a strong reward and recognition approach which motivate Textile employees to behave safely. However, the reward could be in any form it could be an appreciation or it could be some monitory benefit.

Monitory benefits are very helpful for the workers as it is considered as a bonus for them which brings joy to their faces. At last, the present study hypothesized that there is a positive relationship between safety rules and procedures and safety behaviour. The result indicated that there is no relationship between safety rules and procedures and safety behaviour. The non-significant result could be due to weak rules and procedures relating to Textile companies. In Pakistan, there is no independent authority which is responsible for occupational safety and health rules. Likewise, in developed nations, they have proper authorities which make and implement workplace rules and procedures for specific industries. Pakistan is far behind in establishing safety rules according to the need of the industries. As far as moderating effects are concerned the present study provides a strong and positive moderating effect with management commitment and safety behaviour, safety training and safety behaviour, workers' involvement and safety behaviour and safety communication& feedback and safety behaviour. In simple words, when management is committed to providing adequate safety training and there is open communication in which every worker takes part in an ethical environment then the workers behave safely. In an ethical work environment, the management is committed to providing appropriate facilities and in turn, the worker follows the safety protocol at the workplace. Similarly, ethical climate positively influences the relationship between safety training and safety behaviour. It means that the Textile companies provide an ethical environment in which workers are getting trained to avoid any unpleasant incident.

In addition, in an ethical work climate, the workers are involved in every decision of their company so their involvement brings a positive impact on their safety behaviour. The ethical climate also positively moderates the relationship between safety communication & feedback and safety behaviour. The result could be attributed to the fact that in an ethical climate open communication medium among workers and top management is mandatory which influences the safety behaviour of the workers. The presence of an ethical climate is the main pillar of a safe work environment. On the other hand ethical climate failed to moderate the relationship between safety rules and procedures and safety promotion policies. A possible explanation for these findings could be the absence of an ethical climate in the organization.

Organizations which have set rules & standards have a positive impact on workplace safety. As mentioned earlier, in Pakistan there is a scarcity of safety-related legislation which could be one reason for the insignificant result. The absence of an ethical climate diverts the worker's minds to fulfil their daily safety-related task. Lack of work ethics could not promote workplace safety activities which failed to produce the desired results. Therefore, it is mandatory to have an ethical work environment with appropriate rules and procedures which can maintain workplace safety.

LIMITATIONS, IMPLICATIONS AND FUTURE DIRECTIONS

The present provides some useful insights relating to SMP, ethical climate and safety behaviour. However, this study has some limitations. The cross-sectional design was employed for data collection. In future, it is suggested that longitudinal design would apply to obtain better results. Similarly, in our study, the data was collected from Faisalabad city only. Therefore, in future, the data must be collected from other cities to increase the generalizability of the results. Moreover, our study was conducted under a quantitative approach. Future studies must follow mixed methods to decrease the doubts in results. Our study contributes additional evidence to the literature on SMP, ethical climate and safety behaviour. The present study verified the results conducted in developing countries as most of the studies were conducted in developed countries.

Crucial practical implications of this study are that the industries which are facing workplace injuries and accidents may be interested in this study. The results of this study may be fruitful for underdeveloped nations as they must follow the workplace safety rules of developed nations. Similarly, the present

study provides insights to the government and bureaucrats to develop a regulatory authority to minimize workplace injuries and accidents. It is recommended for future research that more SMP must be included to check it impact on safety behaviour. Our study checked ethical climate as a moderating variable. Future studies must include other variables (e.g. work environment) to test the moderating effect.

REFERENCES

[1] Awais-E-Yazdan, M., Hassan, Z., Ejaz, A., Spulbar, C., Birau, R., Mitu, N.E., *Investigating the nexus between safety training, safety rules and procedures, safety performance and protection against hazards in Pakistani construction companies considering its impact on textile industry*, In: Industria Textila, 2022, 73, 1, 48–53, http://doi.org/10.35530/IT.073.01.202154

[2] Pakistan Bureau of Statistics, *Labour Force Survey (2006-2007),* Government of Pakistan Statistics Division, 2017-2018

[3] Pakistan Bureau of Statistics, *Labour Force Survey (2020-2021),* Government of Pakistan Statistics Division, 2020–2021, Available at: https://www.pbs.gov.pk/sites/default/files/labour_force/publications/lfs2020_21/tables/Table_28.pdf [Accessed on February 2022]

[4] Neal, A., Griffin, M.A., *Safety climate and safety behaviour*, In: Australian Journal of Management, 2002, 27, 1_suppl, 67–75

[5] Vinodkumar, M.N., Bhasi, M., *Safety management practices and safety behaviour: Assessing the mediating role of safety knowledge and motivation*, In: Accident Analysis & Prevention, 2010, 42, 6, 2082–2093

[6] Keffane, S., Delhomme, P., *Assessing the mediating role of communication in safety management and performance for road safety practices: French organizations model*, In: Proceedings Book, 2013, 26

[7] Mearns, K., Whitaker, S.M., Flin, R., *Safety climate, safety management practice and safety performance in offshore environments*, In: Safety Science, 2003, 41, 8, 641–680

[8] Vredenburgh, A.G., *Organizational safety: which management practices are most effective in reducing employee injury rates?,* In: Journal of Safety Research, 2002, 33, 2, 259–276

[9] Subramaniam, C., Mohd. Shamsudin, F., MohdZin, M.L., Sri Ramalu, S., Hassan, Z., *Safety management practices and safety compliance in small medium enterprises: Mediating role of safety participation*, In: Asia-Pacific Journal of Business Administration, 2016, 8, 3, 226–244

[10] Victor, B., Cullen, J.B., *The organizational bases of ethical work climates,* In: Administrative Science Quarterly, 1988, 101–125

[11] Awais-e-Yazdan, M., Hassan, Z., The impact of HRM practices on turnover intention with the mediation effect of ethical climate: an empirical evidence from higher educational sector of Pakistan, In: PalArch's Journal of Archaeology of Egypt/Egyptology, 2020, 17, 11, 12–28

[12] Mearns, K., Whitaker, S.M., Flin, R., *Safety climate, safety management practice and safety performance in offshore environments*, In: Safety Science, 2003, 41, 8, 641–680

[13] Siu, O.L., Phillips, D.R., Leung, T.W., *Safety climate and safety performance among construction workers in Hong Kong: The role of psychological strains as mediators*, In: Accident Analysis & Prevention, 2004, 36, 3, 359–366

[14] Awais-E-Yazdan, M., Ilyas, M.A., Aziz, M.Q., Waqas, M., *Dataset on the safety behaviour among Pakistani healthcare workers during COVID-19*, In: Data in brief, 2022, 41

[15] Fabiano, B., Currò, F., Pastorino, R., *A study of the relationship between occupational injuries and firm size and type in the Italian industry,* In: Safety Science, 2004, 42, 7, 587–600

[16] Murray, M., Fitzpatrick, D., O'Connell, C., *Fishermens blues: factors related to accidents and safety among Newfoundland fishermen*, In: Work and Stress, 1997, 11, 3, 292–297

[17] Zohar, D., *The effects of leadership dimensions, safety climate, and assigned priorities on minor injuries in work groups*, In: Journal of Organizational Behaviour, 2002, 23, 1, 75–92

[18] Dedobbeleer, N., Béland, F., *Is risk perception one of the dimensions of safety climate*, In: Occupational Injury: Risk Prevention and Intervention, 1998, 73–81

[19] Oliver, A., Cheyne, A., Tomás, J.M., Cox, S., *The effects of organizational and individual factors on occupational accidents*, In: Journal of Occupational and Organizational Psychology, 2002, 75, 4, 473–488

[20] Lu, C.S., Yang, C.S., *Safety leadership and safety behaviour in container terminal operations*, In: Safety Science, 2010, 48, 2, 123–134

[21] Neal, A., Griffin, M.A., *A study of the lagged relationships among safety climate, safety motivation, safety behaviour, and accidents at the individual and group levels,* In: Journal of Applied Psychology, 2006, 91, 4, 946

[22] Neal, A., Griffin, M.A., Hart, P.M., *The impact of organizational climate on safety climate and individual behaviour,* In: Safety Science, 2000, 34, 1–3, 99–109

[23] Pedersen, L.M., Kines, P., *Why do workers work safely? Development of safety motivation questionnaire scales*, In: Safety Science Monitor, 2011, 15, 1, 1–10

[24] Neal, A., Griffin, M.A., *Safety climate and safety behaviour*, In: Australian Journal of Management, 2002, 27, 1_suppl, 67–75

[25] Singer, S., Lin, S., Falwell, A., Gaba, D., Baker, L., *Relationship of safety climate and safety performance in hospitals*, In: Health services research, 2009, 44, 2p1, 399–421

[26] Siu, O.L., Phillips, D.R., Leung, T.W., *Safety climate and safety performance among construction workers in Hong Kong: The role of psychological strains as mediators*, In: Accident Analysis & Prevention, 2004, 36, 3, 359–366
[27] Angle, H.L., Perry, J.L., *An empirical assessment of organizational commitment and organizational effectiveness*, In: Administrative Science Quarterly, 1981, 1–14
[28] Koch, J.L., Steers, R.M., *Job attachment, satisfaction, and turnover among public sector employees*, In: Journal of Vocational Behaviour, 1978, 12, 1, 119–128
[29] Fleming, M.T., Flin, R.H., Mearns, K., Gordon, R.P., *The offshore supervisor's role in safety management: Law enforcer or risk manager*, In: SPE Health, Safety and Environment in Oil and Gas Exploration and Production Conference, Society of Petroleum Engineers, 1996, January
[30] Wiegmann, D.A., Zhang, H., Thaden, T-V., Sharma, G., Mitchell, A., *Safety culture: A review* (No. ARL-02-3/FAA-02-2), Savoy, Illinois: University of Illinois at Urbana-Champaign, 2002
[31] Flin, R., Mearns, K., O'Connor, P., Bryden, R., *Measuring safety climate: identifying the common features*, In: Safety Science, 2000, 34, 1–3, 177–192
[32] Zohar, D., *A group-level model of safety climate: testing the effect of group climate on microaccidents in manufacturing jobs*, In: Journal of Applied Psychology, 2000, 85, 4, 587
[33] Yule, S., Flin, R., Murdy, A., *The role of management and safety climate in preventing risk-taking at work*, In: International Journal of Risk Assessment and Management, 2006, 7, 2, 137–151
[34] Cox, S., Jones, B., Rycraft, H., *Behavioural approaches to safety management within UK reactor plants*, In: Safety Science, 2004, 42, 9, 825–839
[35] Donald, I., Canter, D., *Employee attitudes and safety in the chemical industry*, In: Journal of Loss Prevention in the Process Industries, 1994, 7, 3, 203–208
[36] Díaz, R.I., Cabrera, D.D., *Safety climate and attitude as evaluation measures of organizational safety*, In: Accident Analysis & Prevention, 1997, 29, 5, 643–650
[37] Kvalheim, S.A., Dahl, Ø., *Safety compliance and safety climate: A repeated cross-sectional study in the oil and gas industry*, In: Journal of Safety Research, 2016, 59, 33–41
[38] Díaz-Cabrera, D., Hernandez-Fernaud, E., Isla-Díaz, R., *An evaluation of a new instrument to measure organisational safety culture values and practices*, In: Accident Analysis & Prevention, 2007, 39, 6, 1202–1211
[39] Abdullah, N.A.C., Spickett, J.T., Rumchev, K.B., Dhaliwal, S.S., *Assessing employees' perception on health and safety management in public hospital,* In: International Review of Business Research Papers, 2009, 5, 4, 54–72
[40] Wadsworth, E., Smith, A., *Safety culture, advice and performance*, In: Policy and Practice in Health and Safety, 2009, 7, 1, 5–31
[41] Zacharatos, A., Barling, J., Iverson, R.D., *High-performance work systems and occupational safety,* In: Journal of Applied Psychology, 2005, 90, 1, 77
[42] Mohammad, S., Al-Smadi, B.M., Hyari, K. H., Rababeh, S.M., *Safety management in the Jordanian construction industry*, In: Jordan Journal of Civil Engineering, 2010, 4, 1, 47–54
[43] Hayes, B.E., Perander, J., Smecko, T., Trask, J., *Measuring perceptions of workplace safety: Development and validation of the work safety scale*, In: Journal of Safety Research, 1998, 29, 3, 145–161
[44] O'Dea, A., Flin, R., *Site managers and safety leadership in the offshore oil and gas industry,* In: Safety Science, 2001, 37, 1, 39–57
[45] Geldart, S., Shannon, H.S., Lohfeld, L., *Have companies improved their health and safety approaches over the last decade? A longitudinal study*, In: American Journal of Industrial Medicine, 2005, 47, 3, 227–236
[46] Vredenburgh, A.G., *Organizational safety: which management practices are most effective in reducing employee injury rates?*, In: Journal of Safety Research, 2002, 33, 2, 259–276
[47] Roy, M., *Self-directed work teams and safety: a winning combination?,* In: Safety Science, 2003, 41, 4, 359–376
[48] Niskanen, T., *Safety climate in the road administration*, In: Safety Science, 1994, 17, 4, 237–255
[49] Cheyne, A., Oliver, A., Tomás, J.M., Cox, S., *The architecture of employee attitudes to safety in the manufacturing sector,* In: Personnel Review, 2002, 31, 6, 649–670
[50] Costella, M.F., Saurin, T.A., de Macedo Guimarães, L.B., *A method for assessing health and safety management systems from the resilience engineering perspective*, In: Safety Science, 2009, 47, 8, 1056–1067
[51] Rooney, P.M., *Employee ownership and worker participation: effects on health and safety*, In: Economics Letters, 1992, 39, 3, 323–328
[52] Lee, T., *Assessment of safety culture at a nuclear reprocessing plant*, In: Work & Stress, 1998, 12, 3, 217–237
[53] Håvold, J.I., Nesset, E., *From safety culture to safety orientation: Validation and simplification of a safety orientation scale using a sample of seafarers working for Norwegian ship owners*. Safety Science, 2009, 47, 3, 305–326
[54] Bentley, T.A., Haslam, R.A., *A comparison of safety practices used by managers of high and low accident rate postal delivery offices*, In: Safety Science, 2001, 37, 1, 19–37
[55] Mohamed, S., *Safety climate in construction site environments*, In: Journal of Construction Engineering and Management, 2002, 128, 5, 375–384
[56] DeJoy, D.M., Schaffer, B.S., Wilson, M.G., Vandenberg, R.J., Butts, M.M., *Creating safer workplaces: assessing the determinants and role of safety climate*, In: Journal of Safety Research, 2004, 35, 1, 81–90

[57] Leggat, S.G., Bartram, T., Stanton, P., *High performance work systems: the gap between policy and practice in health care reform,* In: Journal of Health Organization and Management, 2011
[58] Simonet, S., Wilde, G.J.S., *Risk: Perception, acceptance and homeostasis*, In: Applied Psychology: an international review, 1997, 46, 3, 235–252
[59] Ostrom, L., Wilhelmsen, C., Kaplan, B., *Assessing safety culture*, In: Nuclear Safety, 1993, 34, 2, 163–172
[60] McAfee, R.B., Winn, A.R., *The use of incentives/feedback to enhance work place safety: A critique of the literature*, In: Journal of Safety Research, 1989, 20, 1, 7–19
[61] Haynes, R.S., Pine, R.C., Fitch, H.G., *Reducing accident rates with organizational behaviour modification,* In: Academy of Management Journal, 1982, 25, 2, 407–416
[62] Luria, G., Yagil, D., *Procedural justice, ethical climate and service outcomes in restaurants*, In: International Journal of Hospitality Management, 2008, 27, 2, 276–283
[63] Cullen, J.B., Parboteeah, K.P., Victor, B., *The effects of ethical climates on organizational commitment: A two-study analysis*, In: Journal of Business Ethics, 2003, 46, 2, 127–141
[64] Kapp, E.A., Parboteeah, K.P., *Ethical climate & safety performance design better programs, improve compliance and foster participation*, In: Professional Safety, 2008, 53, 07
[65] Hair, J.F., Black, W.C., Babin, B.J., Anderson, R.E., Tatham, R.L., *Multivariate data analysis 6th Edition. Pearson Prentice Hall. New Jersey. humans: Critique and reformulation*, In: Journal of Abnormal Psychology, 2006, 87, 49–74

Authors:

MUHAMMAD AWAIS-E-YAZDAN[1], CRISTI SPULBAR[2], RAMONA BIRAU[3], LORENA DUDUIALA POPESCU[4]

[1]College of Business, Universiti Utara Malaysia, Malaysia (UUM)
06010 Sintok, Kedah DarulAman Malaysia
e-mail: awais.yazdan@gmail.com

[2]Department of Finance, Banking and Economic Analysis,
Faculty of Economics and Business Administration, University of Craiova, Craiova, Romania
e-mail: cristi_spulbar@yahoo.com

[3]University of Craiova, Doctoral School of Economic Sciences, Craiova, Romania

[4]Faculty of Economic Science, University "Constantin Brancusi", Tg-Jiu, Romania
e-mail: lorena_ucb@yahoo.com

Corresponding author:

RAMONA BIRAU
e-mail: ramona.f.birau@gmail.com

Mechanical suture–modern alternatives for suturing

DOI: 10.35530/IT.073.06.202289

ALEXANDRU-FLORIN SĂVULESCU
CRISTIAN CÎRLAN
FLORIN-CRISTIAN BLĂJUȚ
MĂDĂLINA-IONELA IORDACHE-PETRESCU
MIHAI IORDACHE
ALEXANDRA-BIANCA PETRESCU
RADU BOTEANU
LUCIAN POPA
DENISA SURDU

ABSTRACT – REZUMAT

Mechanical suture–modern alternatives for suturing

The increase in the incidence of gastric and colorectal cancer in developed or developing countries led to the need to improve oncological surgery. Oncological surgery of the digestive tract translates in most cases into resection and anastomosis. Using a mechanical suturing device is no longer considered something revolutionary. However, the technology behind new instruments that helps surgeons perform operations changed over time.
The main purpose of perfecting these devices is to execute a safer suture or anastomosis and shorten the intraoperative time. In this study, we made a short review of the principles behind intestinal and skin staplers, and the advantages and disadvantages of these tools as an alternative to manual suturing using textile materials. We also described the use of cyanoacrylate as an adhesive and sealant.

Keywords: *mechanical staplers, cyanoacrylate, intestinal anastomoses, skin staplers, technology, intracorporeal suturing device*

Sutura mecanică – alternative moderne pentru sutură

Creșterea incidenței cancerului gastric și colorectal în țările dezvoltate sau în curs de dezvoltare a condus la necesitatea îmbunătățirii chirurgiei oncologice. Chirurgia oncologică a tractului digestiv se traduce în majoritatea cazurilor prin rezecție și anastomoză. Folosirea unui dispozitiv mecanic de sutură nu mai este considerată ceva revoluționar. Cu toate acestea, tehnologia din spatele noilor instrumente, care ajută chirurgii la efectuarea intervențiilor s-a schimbat în timp.
Scopul principal al perfecționării acestor aparate este executarea unei suturi sau anastomoze mai sigure și scurtarea timpului intraoperator. În acest studiu, s-a realizat o scurtă trecere în revistă a principiilor din spatele staplerelor intestinale și cutanate, a avantajelor și dezavantajelor acestor instrumente ca alternativă la sutura manuală cu materiale textile. Am descris, de asemenea, utilizarea cianoacrilatului ca adeziv și sigilant al plăgilor.

Cuvinte cheie: *staplere mecanice, cianoacrilat, anastomoze intestinale, staplere cutanate, tehnologie, dispozitiv de sutură intracorporeală*

INTRODUCTION

This article aims to present an overview of modern suturing methods. For this purpose, PubMed, ResearchGate and public search engines were searched for representative articles. Search terms were “skin stapler”, “cyanoacrylate”, “intestinal anastomoses”, and “intracorporeal stitching”. The period covered was between 1980 and August 2022.

Intestinal staplers

Surgical staplers work by compressing tissue, connecting two pieces of tissue with staggered rows of B-shaped surgical staples and, in some models, cutting away excess tissue to create a clean closure of the surgical wound. Common materials for surgical staples include stainless steel and titanium [1].
The technique of surgical stapling was pioneered by Hungarian surgeon Humer Hultl. Hultl's prototype stapler of 1908 required two hours to assemble and load. The technology was refined in the 1950s in the Soviet Union, allowing for the first commercially produced reusable stapling devices for the creation of bowel and vascular anastomoses to be developed. In 1977 Johnson and Johnson's Ethicon brand entered the market and today they are widely used, along with competitors from the Far East. USSC was bought by Tyco Healthcare in 1998, which became Covidien on June 29, 2007. Since its introduction, the surgical stapler has provided a means to efficiently create safe and effective visceral and vascular anastomoses. The surgical stapler design continues to evolve while still maintaining the basic principles that were implemented in the original design [2]. Of course, there can be a sum of malfunctions when using intestinal staplers, part of which interest the staple formation. The presence of unacceptable

forms can compromise the integrity and strength of the staple line resulting in an increased rate of leaks and bleeding (figure 1) [3].

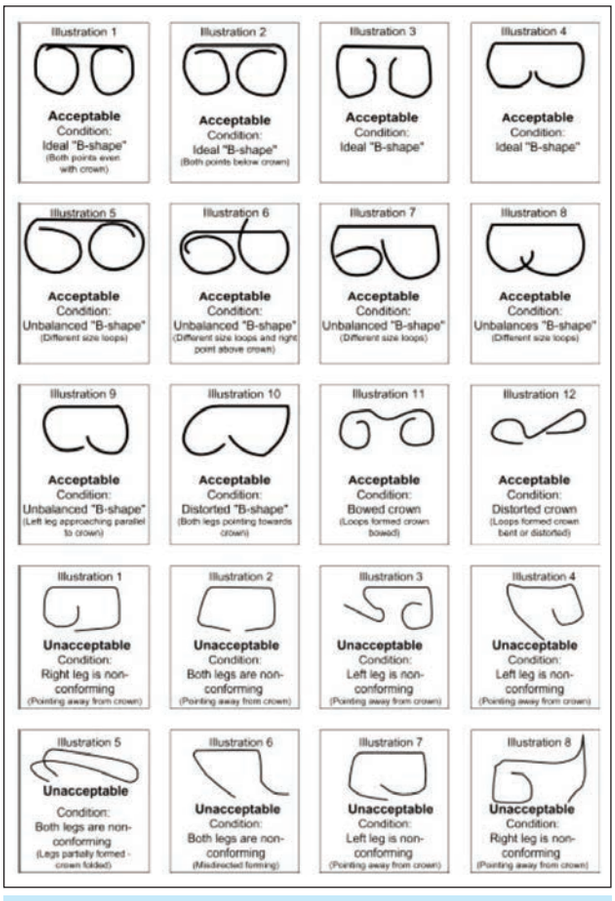


Fig. 1. Acceptable and unacceptable forms of the staple line [3]

Principles of intestinal staplers

There are various designs for different types of surgeries, with most categorized as either linear or circular. Most modern staplers bend each staple into a B-shape staple form, which helps to secure the tissue in place. However, malformed staples can occur because staple leg bending depends on several tissue/stapler characteristics including tissue thickness, tissue viscosity, staple height, and other staple properties (thickness, bending characteristics, type of metal, etc.). Staples are designed to form consistently unlike manual suture with textile materials which rely heavily on surgeon's experience, so staples that are not forming as intended should be investigated [4].

Staples in surgical staplers are made available in various sizes and heights so that the surgeon can choose the one that provides appropriate hemostasis/tissue apposition without significant ischemia or tissue destruction [5].

If the closed staple height is too low, then it may inadequately appose the tissues and result in leakage, bleeding, and/or dehiscence. Conversely, if the staple height selected is to high, then ischemia, serosal shearing, or "cheese wiring" may result, potentially leading to leakage or frank necrosis [4].

The unique properties of the different types of tissues in the body have a major impact on the choice of a stapler and staple height. Different tissues in the body vary in thickness, and dimensions may change based on sex, age, organ/system/anatomical structure, location within an organ, preoperative therapies, intraoperative medications, and disease state [4].

Optimal stapling of any tissue requires an adequate tissue compression time (to decrease the fluid amount within he tissue) to allow elongation of the tissue being compressed, the smooth firing of the instrument, and consistent staple line formation; this need must be balanced against the risk of increased tissue tearing and excessive tensile strength [5].

Most of both linear and circular classical surgical staplers used for better timing during the interventions have an automatic variant. One of the criteria for safe anastomosis is to wait some seconds between closing the stapler on the tissue and shooting the cartridge for the water from the tissue to disperse and to reduce the edema under compression. Automatic staplers are adapted to the tissue thickness, hydration level and consistency to adjust firing speed based on force feedback when clamped and during firing.

Advantages, disadvantages and indications of intestinal stapler

Using surgical staplers reduces operating times by increasing the speed by which the anastomosis is completed. The tissue is less traumatized because it is manipulated less. Another advantage is that anastomoses can be performed, safely and reliably, in difficult-to-reach areas (e.g., low anterior rectal resection). Tissue heals just as well as in the case of a sutured anastomosis with textile materials. The learning curve for performing stapled anastomoses is low. Staplers that are equipped with their blade reduce the risk of contaminating the peritoneal cavity with gut bacteria, by cutting between the stapled ends of the bowls.

The primary disadvantage is represented by the higher cost of the surgery. Some staplers or cartridges do not come equipped with a knife, thus necessitating the use of a scalpel, increasing the risk of injury. The stapler or cartridge can malfunction resulting in the firing mechanism not activating the knife, requiring the use of a scalpel; the staples did not bite enough tissue or were not placed at all, increasing the risk of bowl contents spilling into the peritoneal cavity when the stapler is fired. Another disadvantage is represented by the risk of the stapler's jaws becoming locked together, traumatizing the tissue in the effort to unlock them.

Most commonly performed anastomoses using staplers are represented by side-to-side gastrojejunal anastomosis, end-to-end esojejunal anastomosis, side-to-side entero-entero anastomosis, end-to-side or side-to-side ileocolic anastomosis, side-to-side colocolic anastomosis, side-to-end or end-to-end colorectal anastomosis [6].

Skin staplers

Skin stapling is an alternative to conventional suture with textile materials. Any scalpel wounds or excisional wounds can be closed with the sterile disposable instruments now available. The main advantage is speed. Wound closure with the stapler can be performed in one-fifth to one-half the time required for conventional suturing using textile strings. The stapler is ideal for closing wounds in areas with thick skin and high tissue tension [7].

A study showed that closing the skin with staples in laparoscopic cholecystectomy is three times faster. Furthermore, the anaesthetic time was reduced, thus increasing the efficacy of anesthetic gases [8].

Principles and technique of skin staplers. Comparison with classical sutures with textile materials

Depending on the type of surgery that is performed, the length and the anatomical site of the wound, the closure of the skin is made using different methods and materials.

Sutures using textile materials are most commonly used for skin closure of surgical wounds. The material from which the suture can be either natural or synthetic, absorbable or non-absorbable, single filament or braided. Sutures are flexible, have strength, and are non-toxic and these characteristics offer them a great advantage. Although the sutures are used most often, they can cause ischemia of the tissues and in this way hinder regular and rapid healing [9]. One of the advantages is having a low inflammatory reaction in the tissues. Staples have great results in the fixation, the rapidity of the application and better cosmetic look [10].

For the healing to occur in good conditions, the skill and technique of the surgeon are also important, as well as the closure materials.

Stapling is associated with lower tissue reaction and a lower risk of infection when compared to textile stitches. This produces a higher resistance to infection in contaminated wounds, given the non-introduction of exogenous material, and consequent impairment of local immune response [11]. Also, the staples reduce the local inflammatory response, width of the wound, time to wound closure, and residual cross marks. Although the sutures are the most common technique of closure, they can increase the risk of wound infection.

Complications of surgical wounds that can occur are dehiscence or infection and have a considerable impact on the recovery of the patient [12]. Both methods for skin closure, staples or sutures hold the skin edges together while healing is occurring. Staples are considered to be superior in this case because they are quicker and easier to place than sutures with textile materials, but they can create an increased tension along the incision, so they have a higher dehiscence rate than sutures [13].

Regarding the duration of the two types of procedures, staples have a way more rapid speed of closure. In skin closure, the staplers used are disposable and loaded with 5–35 staples, depending on the manufacturer. They are lightweight and have handles that are easy to grip and control [14].

Cyanoacrylate

Cyanoacrylate has been used in several fields of different surgical specialities as an adhesive or a sealant. It can be used for the closure of mucous and cutaneous lacerations. One of its advantages is that it has an excellent immunological response. Regarding aesthetic concerns, cyanoacrylate has been applied with satisfactory results, when compared with common sutures with textile materials. It presents better coaptation of edges of cutaneous and mucosal lesions, smaller residual scars, and biocompatibility. However, it is limited to areas of little tissue tension [15].

Some of the most frequent indications for the use of cyanoacrylate include esophageal fistula, myocardial surgery, bilateral mammoplasty, skin wound closure, bone and cartilage grafting, corneal surgeries, varicose vein occlusion, and embolization of arteriovenous malformations [16–18].

There are several in vivo studies that compare the effects of cyanoacrylate versus sutures. Cooper and Paige a study involving 18 adult and pediatric patients with cleft lips and reported excellent results with no allergic or infectious reactions and no dehiscence using cyanoacrylate [19]. Vastani and Maria compared the use of cyanoacrylate and textile sutures in alveoloplasty in 30 patients and found that inflammation after suturing was greater than after cyanoacrylate [20].

There are multiple types of surgical adhesives and sealants, of which we can take note cyanoacrylates, albumin and glutaraldehyde, poly(ethylene glycol) (PEG), polyurethane, and fibrin [21].

Cyanoacrylates were first used in a surgical setting in 1959 and since then many composites have been studied and used. Cyanoacrylates are part of a class of monomers made up of alkyl esters of 2-cyanoacrylic acid; most studied composites are methyl, ethyl, n-butyl, isobutyl, isohexyl and octyl cyanoacrylates. However, only n-butyl and octyl composites are actually used at present. There are advantages and disadvantages regarding the length of the alkyl chains: while shorter chains (n-butyl) provide a stronger bond, longer chains (octyl) provide more flexibility and thus, a higher breaking point. Longer chain-cyanoacrylates are preferred lately due to their superior bursting strength [21]. For example, a study conducted by Charles et al. showed a bursting strength of incisional wounds about 3 times greater in patients who benefited from closure with Dermabond (an octyl-2-cyanoacrylate) compared to the ones treated with Histoacryl (n-butyl-cyanoacrylate) [22].

Cyanoacrylates are mostly used nowadays in skin closure after surgery or traumatic lesions, providing a good tissue approximation and sealing postoperative wounds from the environment, some of them acting like a microbial barrier. To succeed in approximating

the tissue edges, these must be priorly brought together by sutures in the subcutaneous plane. Compared to the common textile suture closing of the skin, at 3–4 weeks and 3 months follow-ups there have not been reported differences between the two techniques as far as wound complications or the cosmetic result are concerned. However, patient satisfaction was greater in patients who benefited from adhesive-closed wounds [21].
Regarding the future uses of cyanoacrylates composites, possibilities are open because of the strong development of new composites with even better results on the outer tissues of the human body. In addition, there are some who strive to develop compounds that can be used inside the human body and aid or even totally replace microsurgery involved in some urological, vascular, gynecological, and general surgical procedures. However, even though this method is already used successfully in experimental animals, the surgical community is still mostly reluctant to use these compounds in humans [23].

Intracorporeal suturing devices (definition, main components compatible threads)

As laparoscopic surgery and minimally invasive approaches were described for increasingly complex pathologies, the need intracorporeal suturing and knotting grew. At first, surgeons tried performing sutures and knots the same way they did while using an open approach [24] but the need for a faster, easier method led the surgical community to a breakthrough comparable to that of the emergence of the sewing machine for the clothing industry.
Intracorporeal suturing devices, such as SewRight 5 SR (LSI Solutions), DuraKnot (Ethicon), Overstitch (Apollo Endosurgery Inc.), EndoSew (Karl Storz Endoscopes) and Endostitch (Covidien) revolutionised minimally invasive surgery, giving surgeons the opportunity to positively affect pacient health in a less aggressive manner [25].
Intracorporeal stitching devices are instruments used in laparoscopic surgery for the approximation of tissue and placement of interrupted or running stitches in soft tissues. It passes a single or double-pointed needle with a textile thread firmly attached back and forth between two needle holders to avoid the need for manually grasping and otherwise manipulating the needle. The device generally includes a body portion defining a suture tray and a loading unit portion attached to the body portion.
The Endo Stitch (Covidien, Mansfield, MA) is a 10-mm single-use suturing device that allows the placement of multiple suture types during laparoscopic surgery and simplifies the process of laparoscopic knot tying. The SILS Stitch (Covidien, Mansfield, MA) is based on the same technology as the Endo Stitch with the added advantage of articulation up to 75 degrees and rotation up to 360 degrees [26].
The suture compatible with these devices come in the form of loading units, containing one or more strands of sutures attached to a needle, including Surgidac™, Polysorb™, Bralon™, and Softsilk™ – available in two suture thread lengths – 7" for intracorporeal knot tying and 48" for extracorporeal knot tying.
Automatic suturing devices have simplified the intracorporeal suturing process and allow even less-experienced surgeons to efficiently perform laparoscopic suturing and knot tying [26]. Reconstructive laparoscopic procedures requiring multiple suture placement may be completed in a shorter period using this instrument [27].
These devices enable surgeons to operate in tight spaces during advanced laparoscopic procedures, and to reach tissues in their natural anatomical position rather than pulling or manipulating tissue into the suturing device [26].

DISCUSSION AND FURTHER PERSPECTIVES

Every technique has its limitations, but hand-sutured anastomoses with textile materials occupy the first place due to the necessity of large incision to access organs and the prolonged time for completing an anastomosis [28]. Another important aspect is the shorter time taken for a stapled anastomosis compared to a manual suture [29]. Of course, the surgeon's need to be in control of his gestures at every moment can cause some reluctance to use mechanical devices, but we believe that the widespread use of staplers is just the beginning of the paradigm shift related to mechanical anastomoses and sutures.
As mechanical suturing devices are being developed for decades worldwide, in the past few years, biomedical companies are struggling to bring out to market ultimate intracorporeal suturing devices to support surgeons in one of the most challenging steps of minimally invasive surgery. In this way, a novel device (Su2ura Approximation) used to insert anchors threaded with textile stitches to allow a single action placement of a suture has been in a comparative experimental study with Endo-stitch for safety measurements and performances [30].
A retrospective case series on dogs showed similar results regarding the technique approach in 2017 between an endoscopic needle driver (END) vs a SILS Stitch articulated endoscopic suturing device (AESD) [31]. Further studies on humans are expected.
To facilitate intracorporeal anastomosis in all cases of laparoscopic colectomy, not only those in which the colon is exteriorized, a device by which purse-string suturing can be performed intracorporeally was invented in 2017 by a Japanese team. The 6 cm device can be introduced through a 12 mm trocar inside the peritoneal cavity [32].

CONCLUSION

As recent years have shown, a medical system must work quickly, accurately and safely. These conditions apply to all specialities, including surgery. Part of the merits of medical evolution is attributed to technological development. There is still a relatively important percentage of surgeons who are skeptical or critical of the use of mechanical suture devices, but the

results in the literature are comparable both for staplers and for classic suture techniques using textile materials. Future generations of surgeons will probably use more precise, sophisticated and safer devices to replace hand-sewing and maybe even the instruments that are consider now “modern”.

REFERENCES

[1] Moran, B.J., *Stapling instruments for intestinal anastomosis in colorectal surgery*, In: British Journal of Surgery, 1996, 83, 7, 902–909

[2] Gaidry, A.D., Tremblay, L., Nakayama, D., Ignacio, R.C.Jr., *The History of Surgical Staplers: A Combination of Hungarian, Russian, and American Innovation*, In: Am. Surg., 2019, 85, 6, 563-566. PMID: 31267894

[3] Akiyoshi, T., Ueno, M., Fukunaga, Y., et al., *Incidence of and risk factors for anastomotic leakage after laparoscopic anterior resection with intracorporeal rectal transection and double-stapling technique anastomosis for rectal cancer*, In: Am. J. Surg., 2011, 202, 3, 259–264

[4] Chekan, E., Whelan, R.L., *Surgical stapling device-tissue interactions: what surgeons need to know to improve patient outcomes*, In: Med. Devices (Auckl), 2014, 12, 7, 305–318, PMID: 25246812, PMCID: PMC4168870, https://doi.org/10.2147/MDER.S67338

[5] Collopy, B.T., *Colorectal anastomotic leak rates are measures of technical skill in surgery,* In: ANZ. J. Surg., 2001, 71, 9, 508–510

[6] Ray, M.D., *Gateway to Success in Surgery*, Jaypee Brothers Medical Publishers, First edition, 1 January 2012

[7] Stegmaier, O.C., *Use of skin stapler in dermatologic surgery*, In: J. Am. Acad. Dermatol., 1982, 6, 3, 305-309, PMID: 7068959, https://doi.org/10.1016/s0190-9622(82)70020-9

[8] Huda, F., Gajula, B., Singh, S., Kumar, S., Lokavarapu, M.J., Sowmya, D., *Staples Versus Sutures for Skin Closure in Standard Four Port Laparoscopic Cholecystectomy: A Prospective Cohort Study*, In: Cureus., 2021, 13, 3, e13725, https://doi.org/10.7759/cureus.1372

[9] Hochberg, J., Meyer, K.M., Marion, M.D., *Suture choice and other methods of skin closure,* In: Surg. Clin. North. Am., 2009

[10] Edlich, R.F., et al., *Revolutionary advances in the management of traumatic wounds in the emergency department during the last 40 years: part II*, In: The Journal of emergency medicine, 2010, 38, 2, 201

[11] Johnson, A., et al., *Automatic disposable stapling devices for wound closure,* In: Annals of Emergency Medicine, 1981, 10, 12

[12] Smith, T.O., et al., *Sutures versus staples for skin closure in orthopaedic surgery: meta-analysis*, In: BMJ (Clinical research ed.), 2010, 340, c1199

[13] Coupland, R.M., *Sutures versus staples in skin flap operations,* In: Annals of the Royal College of Surgeons of England, 1986

[14] Robinson, K.E., *Materials for Wound Closure*, 2021, Available at: https://emedicine.medscape.com/article/1127693-overview?reg=1#a5 [Accesed on August 6, 2022]

[15] Lins, R.D., Gomes, R.C., Santos, K.S., Silva, P.V., Silva, R.T., Ramos, I.A., Use of cyanoacrylate in the coaptation of edges of surgical wounds, In: An. Bras. Dermatol., 2012, 87, 6, 871–876, PMID: 23197206, PMCID: PMC3699926, https://doi.org/10.1590/s0365-05962012000600008.

[16] Rezende, M.L.R.D., Cunha, P.D.O., Damante, C.A., Santana, A.C.P., Greghi, S.L.A., Zangrando, M.S.R., *Cyanoacrylate adhesive as an alternative tool for membrane fixation in guided tissue regeneration*, In: The Journal of Contemporary Dental Practice, 2015, 16, 6, 512–518, https://doi.org/10.5005/jp-journals-10024-1714

[17] Perez, M., Fernandez, I., Marquez, D., Bretana, R.M., *Use of N-butyl-2-cyanoacrylate in oral surgery: biological and clinical evaluation,* In: Artificial Organs, 2000, 24, 3, 241–243

[18] Bélgica Vásquez, P., Schencke, C., Rodríguez, C., Veuthey, C., del Sol, M., *Comparison between ethyl-cyanoacrylate and conventional suture for the closure of skin incisions in rabbit (Oryctolagus cuniculus)*, In: International Journal of Morphology, 2012, 30, 3, 797–802, https://doi.org/10.4067/S0717-95022012000300004

[19] Cooper, J.M., Paige, K.T., *Primary and revision cleft lip repairs using octyl-2-cyanoacrylate*, In: The Journal of Craniofacial Surgery, 2006, 17, 2, 340–343, https://doi.org/10.1097/00001665-200603000-00023

[20] Vastani, A., Maria, A., *Healing of intraoral wounds closed using silk sutures and isoamyl 2-cyanoacrylate glue: A comparative clinical and histologic study,* In: Journal of Oral and Maxillofacial Surgery, 2013, 71, 2, 241–248, https://doi.org/10.1016/j.joms.2012.08.032

[21] Sanders, L, Nagatomi, J., *Clinical applications of surgical adhesives and sealants*, In: Crit. Rev. Biomed. Eng., In: 2014, 42, 3–4, 271–292, PMID: 25597240, PMCID: PMC7997729,https://doi.org/10.1615/critrevbiomedeng.2014011676

[22] Charles, D., Williams, K.3rd, Perry, L.C., Fisher, J., Rees, R.S., *An improved method of in vivo wound disruption and measurement*, In: J. Surg. Res., 1992, 52, 3, 214–218, PMID: 1538596, https://doi.org/10.1016/0022-4804(92)90076-c

[23] Bot, G.M., Bot, K.G., Ogunranti, J.O., Onah, J.A., Sule, A.Z., Hassan, I., Dung, E.D., *The use of cyanoacrylate in surgical anastomosis: an alternative to microsurgery*, In: J. Surg. Tech. Case Rep., 2010, 2, 1, 44–48, PMID: 22091332, PMCID: PMC3214492, https://doi.org/10.4103/2006-8808.63727

[24] Wang, X., Li, Y., Cai, Y., Meng, L., Cai, H., Liu, X., Peng, B., *Laparoscopic suture training curricula and techniques*, In: Ann. Transl, Med., 2018, 6, 11, 215, PMID: 30023378, PMCID: PMC6035970, https://doi.org/10.21037/atm.2018.05.17

[25] Schmid, R., Löhmann, C., Martinschek, A., *The Value of Endoscopic Intracorporeal Suturing Devices for the Reconstruction of Urinary Diversions*, In: JOJ uro & nephron., 2018, 5, 2, 555657, https://doi.org/10.19080/JOJUN.2018.05.555657

[26] Hart, S., *The benefits of automated suturing devices in gynecologic endoscopic surgeries: the Endo Stitch and SILS Stitch*, In: Surg Technol Int., 2012, 22, 159–164, PMID: 23225593

[27] Adams, J.B., Schulam, P.G., Moore, R.G., Partin, A.W., Kavoussi, L.R., *New laparoscopic suturing device: initial clinical experience*, In: Urology, 1995, 46, 2, 242–245, PMID: 7624994, https://doi.org/10.1016/s0090-4295(99)80200-3

[28] Steger, J., Jell, A., Ficht, S., Ostler, D., Eblenkamp, M., Mela, P., Wilhelm, D., *Systematic Review and Meta-Analysis on Colorectal Anastomotic Techniques*, In: Ther. Clin. Risk. Manag., 2022, 18, 523–539, PMID: 35548666, PMCID: PMC9081039, https://doi.org/10.2147/TCRM.S335102

[29] Liu, B.W., Liu, Y., Liu, J.R., Feng, Z.X., *Comparison of hand-sewn and stapled anastomoses in surgeries of gastrointestinal tumors based on clinical practice of China*, In: World J. Surg. Oncol., 2014, 12, 292, PMID: 25240386, PMCID: PMC4194420, https://doi.org/10.1186/1477-7819-12-292

[30] Ramot, Y., *Safety and Performance Evaluation of Su2ura Approximation, a New Suturing Device*, In: Ramot, P.-Y., Rousselle, S., Steiner, M., Lavie, Y., Ezov, N., Nyska, A., SAGE Journals, 2021

[31] Coleman, K.A., *Comparison of laparoscopic gastropexy performed via intracorporeal suturing with knotless unidirectional barbed suture using a needle driver versus a reticulated endoscopic suturing device: 30 cases,* Wiley Online Library, 2017, Available at: https://onlinelibrary.wiley.com/doi/abs/10.1111/vsu.12722 [Accessed on August 7, 2022]

[32] Kijima, K., *A new device to facilitate intracorporeal purse-string suturing during endoscopic surgery*, SAGES, 2017, Available at: https://www.sages.org/meetings/annual-meeting/abstracts-archive/a-new-device-to-facilitate-intracorporeal-purse-string-suturing-during-endoscopic-surgery/ [Accessed on August 7, 2022]

Authors:

ALEXANDRU-FLORIN SĂVULESCU[1,2], CRISTIAN CÎRLAN[1,2], FLORIN-CRISTIAN BLĂJUȚ[1], MĂDĂLINA-IONELA IORDACHE-PETRESCU[1], MIHAI IORDACHE[1], ALEXANDRA-BIANCA PETRESCU[1], RADU BOTEANU[1], LUCIAN POPA[1], DENISA SURDU[1]

[1]Central Military Emergency University Hospital "Carol Davila", General Surgery Department,
Calea Plevnei 134, 010825, Bucharest, Romania
e-mail: chirurgie2@scumc.ro

[2]University "Titu Maiorescu", Faculty of Medicine and Pharmacy,
Gheorghe Petrașcu 67A, 031593, Bucharest, Romania
e-mail: medicina.generala@univ.utm.ro

Corresponding author:

ALEXANDRU-FLORIN SĂVULESCU
e-mail: savfl@yahoo.com

Research on user donation and information sharing in textile crowdfunding

DOI: 10.35530/IT.073.06.202195

XUEKE PEI
ZHENGWEI HUANG
YANNI YANG
OTHMAN BESTOON

ABSTRACT – REZUMAT

Research on user donation and information sharing in textile crowdfunding

Exploring the mechanism of user donation and information sharing behaviour in textile crowdfunding under the social network environment provides the theoretical basis for researching the behaviour of users and suggestions for the operation and management of textile crowdfunding platform. Based on the grounded theory, it appeared that there were only a few studies examining the empirical relation between the two constructs, particularly in textile crowdfunding. The study investigated 35 users with semi-structured interviews. Nvivo11 qualitative analysis software was used to encode and analyse the interview data. The attribution theory was used to construct the model of influencing factors of textile crowdfunding user donation and information-sharing behaviour and the theoretical saturation test of the coded result. This study divided the influencing factors of textile crowdfunding user donation and information-sharing behaviour into trait attribution and situation attribution and extracted eight main categories that affect user participation behaviour. Emotional factors, interpersonal relationships, and perceived risks are the key factors affecting participants' donation and information sharing. In addition, the study found that compared with the behaviour of donating for textile crowdfunding projects, the willingness of user information sharing behaviour was low.

Keywords: *textile crowdfunding, grounded theory, donation behaviour, information sharing behaviour*

Cercetare privind donațiile utilizatorilor și schimbul de informații în crowdfunding-ul textil

Explorarea mecanismului de donație al utilizatorilor și al comportamentului de schimb de informații în crowdfunding-ul textil pe rețelele sociale oferă o bază teoretică pentru cercetarea comportamentului utilizatorilor și sugestii pentru funcționarea și gestionarea platformei de crowdfunding textil. Pe baza teoriei fundamentate, s-a dovedit că au existat puține studii care examinează relația empirică dintre cele două aspecte, în special în crowdfunding-ul textil. Studiul a investigat 35 de utilizatori cu interviuri semi-structurate. Software-ul de analiză calitativă Nvivo11 a fost folosit pentru a codifica și analiza datele interviului. Teoria atribuirii a fost utilizată pentru a construi modelul factorilor de influență ai comportamentului de donație și schimb de informații al utilizatorilor de crowdfunding textil și testul teoretic de saturație al rezultatului codificat. Acest studiu a împărțit factorii de influență ai donației utilizatorilor de crowdfunding textil și comportamentul de schimb de informații în atribuirea trăsăturilor și a situației și a extras opt categorii principale, care afectează comportamentul de participare al utilizatorilor. Factorii emoționali, relațiile interpersonale și riscurile percepute sunt elemente cheie care afectează donațiile participanților și schimbul de informații. În plus, studiul a constatat că față de comportamentul de donare pentru proiectele de finanțare publică din domeniul textil, disponibilitatea comportamentului de schimb de informații al utilizatorilor a fost scăzută.

Cuvinte-cheie*: crowdfunding textil, teorie fundamentată, comportament de donație, comportament de schimb de informații*

INTRODUCTION

Thanks to the prosperity of the Internet economy, the number of crowdfunding websites and the scale of financing in China have shown rapid growth. The crowdfunding methods include reward crowdfunding, donation crowdfunding, equity crowdfunding, and debt crowdfunding. Textile crowdfunding discussed in this article is donation-based crowdfunding, which refers to the behaviour of help seekers to raise funds from individuals to pay for textile-related expenses [1, 2]. Textile crowdfunding participants can not only support patients through donations through the crowdfunding platform but also share relevant information on social media, calling on more people to help patients. Compared with traditional fundraising methods, textile crowdfunding initiated by social networks has lower thresholds and lower costs, and the information dissemination process involves a wider scope and faster speed, without being limited by time and space, which helps to increase public participation Degree, the success rate of the project has also improved significantly [3].

Textile crowdfunding platforms have been on the rise since 2014, such as water drops and easy raises. As of August 2018, Water Drop Fund has helped more than 630,000 households raise a total of 7.2 billion yuan, and more than 210 million people participated in donations [4]. Crowdfunding textile, as a new Internet economic service model, helps ordinary families solve the problem of expensive textile treatment. The success of textile crowdfunding projects

depends to a large extent on the spread of users on social textile platforms, such as Weibo and WeChat, which have attracted widespread attention from textile crowdfunding projects. Social media users have different attitudes towards textile crowdfunding donations and information sharing, and the reasons for user participation are different. This study explores user donation and information-sharing behaviours in crowdfunding textiles, which helps to deepen the understanding of textile crowdfunding participation behaviours.

Existing related research on crowdfunding financing provides a good basis for exploring the behaviour of textile crowdfunding users in this research, but the user behaviour mechanism in textile crowdfunding needs to be further analysed [5–7]. This study conducts an exploratory analysis of textile crowdfunding in a social network environment, explores the reasons for promoting user participation in donations and information sharing, and based on grounded theory, conducts semi-structured interviews with 35 users, and uses Nvivo11 qualitative analysis software to analyse interview data Perform coding and test the coding results, establish a model of influencing factors for textile crowdfunding users 'participation behaviour, explore participants' perceptions of donations and information sharing and their influencing factors, and provide targeted recommendations for the operation and management of textile crowdfunding platforms. Make more people participate in crowdfunding textiles, and promote textile crowdfunding to play a greater role in China's public welfare.

The main objective of this study is to present the most common and uncommon approaches regarding the main paths of user donation and information sharing. This study covers the guidance towards finding the most reliable scientific publications on each approach for User Donation and Information Sharing. In addition, this study also summarizes current knowledge on these topics and suggests necessary future investigations. In other words, this study aims to identify novel trends for the researchers to focus on in future studies. Some parameters were used to measure the occurrence of these studies in international publications using the search engines of various databases and search options

It after an extensive review, the results show that there are many studies on the global scope of user donation and information sharing [1, 2, 7]. The novelty of this study regarding the scope of both user donation and information sharing is very scarce, and most of them have not made a systematic review. Both user donation and information sharing in Textile crowdfunding have been used for the same goal except the fact that user donation can be used for extending some scopes related to social science. This means that a global review can be made only by considering both user donation and information sharing to complete the bigger image of the mentioned scopes.

LITERATURE REVIEW

Research on crowdfunding textile

In the context of the rapid development of the Internet economy, domestic and foreign scholars have gradually deepened their research on public welfare crowdfunding from the perspectives of psychology, sociology, and consumer behaviour. From the perspective of textile crowdfunding project information, Briers [8] research found that the higher the number of crowdfunding goals, it often indicates that the more recipients are in more embarrassing and embarrassing situations, which can better stimulate the compassion of donors and increase the impact of refusal to donate. Guilt. Kuppuswamy [9] examined the characteristics of information content, fundraising time, and enthusiasm for updating when users choose a crowdfunding project, which will affect the success of the project. Ahlers [10] found that the success of crowdfunding projects depends on the information the project displays to the audience and the provision of detailed risk information. Zhong Zhijin [11] analysed the influencing factors of public fundraising ability and information transparency in social media and put forward the development advantages and problems of the social media platform for public fundraising. Li Jingli [12] believes that in the context of the Internet, language, picture symbols, and audience interaction on the rescue platform have a significant impact on the fundraising of rescuers. From an individual perspective, Bekkers [13] provides a basic theoretical framework for the research of public welfare crowdfunding, verifying that reputation, self-image, and psychological benefits are important factors affecting the results of public welfare crowdfunding. Agrawal [14] analysed the geographical distribution characteristics of crowdfunding participants and found that a large number of locals would participate in the short period after the information was released, while the participants who were far away decided to participate relatively late.

Castillo [15] believes that the donation behaviour of individuals can serve as a model for their peers in social networks, and will also bring some social pressure, and more people know that crowdfunding information will increase the possibility of donation. Zhang Yinfeng [3] focused on investigating the public's attitude towards public welfare activities based on platforms such as Weibo and WeChat. Li Jing [16] pointed out that the responding behaviour of the respondent’s textile crowdfunding information was oriented towards the degree of relationship. Participants decided whether to forward according to the rules of human exchange, and their self-presentation was the main obstacle to forwarding. Starting from the factors of altruistic behaviour, combined with the actual dissemination of micro-public information, Liu Jihong [17] refined several communication techniques and precautions to improve the effectiveness of communication.

Factors influencing user participation

To explore the influencing factors of user participation behaviour in social media such as Weibo and WeChat, many researchers have carried out research on the aspects of trait attribution and context attribution. From the perspective of trait attribution, it mainly involves individual factors, interpersonal factors, emotional factors and perceived risk. Prencipe [18] believes that the motivation for donation is often not based on material benefits, but is a decision-making behaviour that arises from emotional factors, and the return is often spiritual. Gerber [19] found that individuals' demands for prestige and respect, or desire for satisfaction and slow release of guilt would promote the occurrence of donation behaviour. Dingxianfeng [20] found that individuals showed a clear preference for donations from their hometowns. Zheng [21] believes that social network relationships and social responsibility have an important impact on user participation behaviour. Chiu [22] finds that trust and identity are also valued as interpersonal or contextual factors for information sharing. Xu Chenfei [23] believes that personal characteristics and Perceived risk is also key factor influencing user participation in crowdfunding textile.

Scenario attributions that affect users' participation in textile crowdfunding donations and information sharing mainly involve information content characteristics, features of rescue objects, organizational factors, and self-presentation. Allison's [24] research found that the text content of textile crowdfunding information (such as language, symbols, pictures, and videos) has a significant impact on the success rate of the project; Bi [25] based on the ELM model research found that the number of video and commentary on the project was significant to the project Success has a positive impact. Colombo [26] believes that the initial donation amount of textile crowdfunding projects will accelerate its success. Mollick's [27] empirical research shows that project quality, the amount of crowdfunding and the supporters of the project are closely related to the success of crowdfunding. Burtch [28] believes that project transparency has a significant impact on project success. Kuppuswamy [9] believes that the crowdfunding behaviour of participants are affected by the time limit of the project, the amount of financing and the form of return. Ordanini's [29] case study of three popular crowdfunding platforms in the United States shows that the interaction with project sponsors through crowdfunding platforms is an important factor for crowdfunding investors' investment enthusiasm. Zhong Zhijin [11] believes that the more times the crowdfunding information is forwarded, the higher its fundraising rate.

In the social media environment, users 'attitudes towards textile crowdfunding vary widely, and there are many factors affecting their participation behaviours.

To analyse this issue, this study focuses on user participation donations and information-sharing behaviours. Using attribution theory, users' donations and Causal interpretation or derivation of information-sharing behaviours [30], explanation of the reasons for the behaviour of individuals or organizations, and construction of a model of influencing factors for textile crowdfunding user donations and information-sharing behaviours.

STUDY DESIGN AND DATA ANALYSIS

Research methods

Grounded theory is a scientific method for constructing and developing the theory through systematic data collection and analysis. It is suitable for inductive generalization of original data in the context of immature research topics and then establishing a theory. Created by Glaser and Strauss [31]. This article chooses a rooted theoretical approach for two main reasons: On the one hand, the research on the influencing factors and operating mechanisms of textile crowdfunding projects at home and abroad is still in its infancy, and there are many issues worth further analysis, which is suitable for exploration through qualitative research methods. Sexual research; on the other hand, the current application of textile crowdfunding is a cutting-edge research direction, and there are few related references, so the most direct is to obtain data from interviews for qualitative analysis. Therefore, this article will collect and organize user interview data based on the research of textile crowdfunding participation behaviour in social media, and use the software Nvivo11 to perform open coding, main coding and selective coding [32], and Perform theoretical saturation test, establish a model of influencing factors of textile crowdfunding user donation and information sharing behaviour, and based on this, put forward decision-making suggestions for the management of textile crowdfunding platform.

Sample collection

This paper uses semi-structured interviews as a qualitative research method to obtain richer and more realistic data. To ensure the validity of the data, we interviewed individuals who had been exposed to textile crowdfunding information. In-depth one-on-one interviews with the interviewees to analyse as much as possible the respondents' donation and sharing willingness, emotions, and potential motivations for crowdfunding textiles. During the interview, we obtained the consent of the interviewees to record the interviews. After the interviews, the recordings were sorted out and the interview records and memos were completed. In the end, 35 complete interview records were obtained. We randomly selected 27 interview records for coding analysis and model construction. The other 8 interview records were mainly used for the theoretical saturation test.

From June to August 2018, 35 users who participated in textile crowdfunding on social media were interviewed and recorded by face-to-face or voice calls. The interview duration for each participant was

between 20 and 35 minutes. Participants ranged in age from 18 to 46, with 20 women and 15 men. The interviewees had many occupations, including company clerks, media practitioners, insurance sales staff, public institution personnel, scientific research personnel, elementary and middle school teachers, housewives and college students. Semi-structured interviews focus on the following issues:

(1) Have you participated in a textile crowdfunding project?
(2) Can you introduce an experience of participating in textile crowdfunding on social media?
(3) Under what circumstances do you not share donations for textile crowdfunding projects on social media? When to donate and share information?
(4) Under what circumstances do you not donate and share textile crowdfunding projects on social media? Under what circumstances do you donate to share information?

Although this article focuses on the research of social media "crowdfunding textile" user donation and influencing factors, the interview process will still roughly understand the individual's perception of the crowdfunding platform, which will help better reveal the individual's perception of the textile crowdfunding to raise awareness and awareness of the project. In addition to the above-mentioned leading questions, the researchers also interviewed the number of donations and information transfers by participants. Finally, integrate these text materials and voice materials to make the data truly and accurately reflect the donation and information-sharing behaviour of social media textile crowdfunding users.

Coding analysis and theory establishment

Open coding

Open coding is reading and analysing the original data word by word and sentence by sentence, to find out the recognizable phenomena from the original data, put the initial tags, and then gather the related tags together to form a concept, and further refine the category, thereby The obtained disaggregated data information is condensed into several categories. In the open coding phase, first of all, the interview recordings are sorted out, sorted and sorted out, and the content related to donation and information sharing is extracted and coded. At this stage, 68 concepts were formed and 21 categories were refined. The detailed contents are shown in table 1.

Spindle coding

Spindle coding is based on the concepts and categories compiled in the open coding stage, and the main categories are summarized to make the categories tighter. At this stage, it is necessary to dig out the main category from the existing categories so that it can link to other categories. This study categorizes different categories at the conceptual level and their logical relationships and summarizes 8 main categories: personality characteristics, interpersonal relationships, emotional factors, perceived risks, information content characteristics, rescue object characteristics, organization Factors, and self-presentation, each main category and its corresponding open coding category are shown in table 2.

Selective coding

Selective coding is to excavate the core category from the main category, analyse the relationship between the core category and the main category and other categories, and supplement the incompletely developed categories to complete the process. The purpose is to use the existing categories and connections to concise and concise content. Explain everything. Through open coding, main axis coding and related analysis, the core problem category of this research is reduced to the core category of "influencing factors of user donation and sharing behaviour in crowdfunding textile". Because users have different understandings of reasons for participating in crowdfunding textiles, people will have different emotional reactions and show different expectations and behavioural tendencies [33]. According to individual attribution, attribution can be divided into trait attribution and situational attribution. Trait attribution is the attribute of behaviour that is attributed to the individual. Scenario attribution is considered to be caused by external factors [34]. Textile crowd-

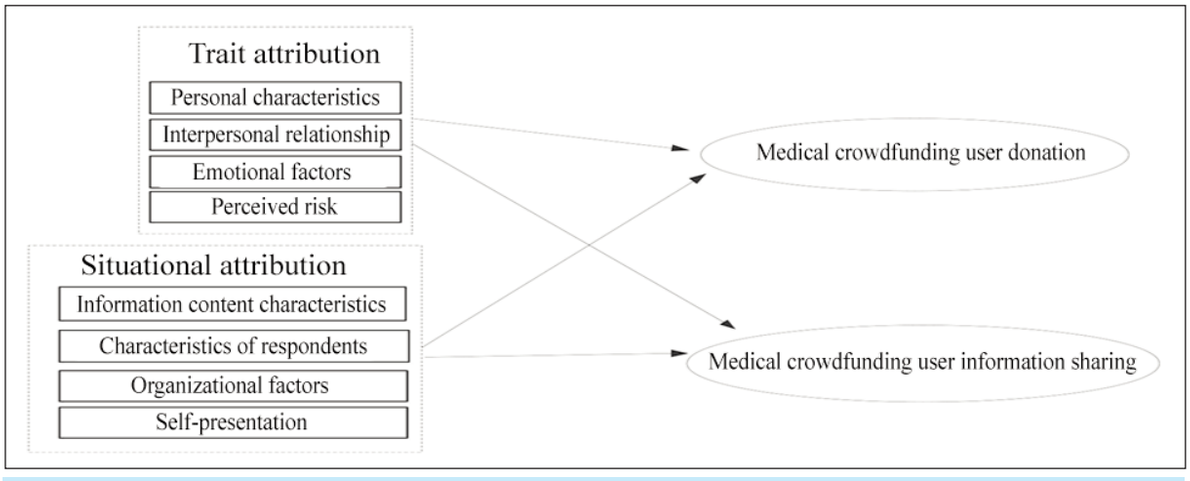


Fig. 1. Models of influencing factors for textile crowdfunding user donation and information sharing behaviour

Table 1

DEVELOPMENT CODING FORMATION CATEGORY		
No.	**Category**	**Concept**
1	Personality Traits	Be kind (4); Helpers need help (7)
2	Social responsibility	Hope to help others (10); no obligation (3); has nothing to do with yourself (3)
3	Behavioural habits	Too many messages, and it is impossible to donate each one (5); Those who do not understand do not easily donate (3); Do not usually see (3); More people donate (5); Not sure if someone will help (5); Do not like to send friends (4)
4	Past experience	No false information found (8); Have been deceived by yourself or those around you (3); Have seen false information in the media (5)
5	Empathy	Compassion (8); Compassion (9)
6	Self-efficacy	Help others and feel happy (9); Self-satisfaction (6)
7	Guilt feels	Don't help, feel guilty (3); Suffer pitiful (9)
8	Geographical distance	In one place(6) ; In the surrounding area(3); In the village(4)
9	Degree of relationship	Friends or relatives (15); Unfamiliar (7); Not Knowing (6)
10	Human relationship	Feelings have helped me before (4); Frequent contacts (5); Other people may need help in the future (6); Do not want to owe other people's feelings (9); Do not bother others (5)
11	Authenticity	Believe that what your friends have initiated is true (8); Not sure whether it is true or credible (7); Worry about deception and fraud (4); Exaggerate the facts (4)
12	Transparency	I do not know how the money goes to patients (9); Lack of detailed information on the use of money (8); Worry about personal information leakage (3)
13	Text content	Written language (5); Pictures and videos (4); Emoji (5)
14	Project progress	Fundraising Amount (3); Fundraising Progress (8); Number of Information Updates (6)
15	User participation	Number of user comments (13); Number of donors (11); Number of sharing (7)
16	Disease risk	Severity of disease (5); Type of disease (8)
17	Resident status	Student (4); Excellent (7); Ordinary (5)
18	Sense of organizational support	Initiated by the leader(6) ; Unit organization (6); Seeing donations from those around you (3); Strong participation atmosphere (5);
19	Sources of information	People you care about (4); Very authoritative (6); People you respect and trust (6); Authoritative media reports (5); Wide attention (8)
20	Perceived image	Leaving a good image that is helpful (3); Worrying that you will not be recognized and your image will be damaged (5); Others have donated because of the face (3)
21	Negative evaluation	Worries about frequent reposting will be considered by others as a charity show (5); worried about putting pressure on others (6); information shared may be untrue and inaccurate, and worried about being negatively evaluated (6)

Table 2

MAIN CATEGORIES OF MAIN SHAFT CODING		
No.	**Main category**	**Category**
1	Personal characteristics	Personality traits; Social responsibility; Behavioural habits; Past experience
2	Emotional factors	Empathy; Self-efficacy; Guilt Feels; Geographic distance
3	Interpersonal relationship	Human feelings; Degree of relationship
4	Perceived risk	Authenticity; Transparency
5	Information content characteristics	Text content; Project progress; User participation
6	Characteristics of respondents	Risk of Disease; Identity of Rescuers
7	Organizational factors	Organizational support; Source of information
8	Self-presentation	Perceived image; Negative evaluation

funding participation behaviour is based on a self-presentation and self-disclosure behaviour method on social media platforms [35]. According to the source of the factors affected by user participation behaviour, this article divides the factors affecting textile crowdfunding user participation behaviour Trait and situational attribution. Based on the attribution theory, the concepts, categories, and main categories are integrated into a whole, forming a theoretical framework for user donation and information sharing in social media textile crowdfunding, as shown in figure 1.

Theoretical saturation test

In this study, the theoretical saturation test was performed on the interview records of the remaining eight subjects. The results show that the categories in the model have developed very richly. For the eight main categories that influence user donation and sharing behaviour (personality characteristics, interpersonal relationships, emotional factors, perceived risks, information content characteristics, rescue object characteristics, organizational factors, self (Presentation), no new important categories were found, and no new constituent factors were found within the eight main categories. It can be considered that the above theoretical framework is theoretically saturated.

DISCUSSION OF RESULTS

This study divides the influencing factors of Textile crowdfunding user donation and information-sharing behaviour into trait attribution and situation attribution and extracts 8 main categories that affect user participation behaviour, and emotional factors, interpersonal relationships, and perceived risks are the key factors affecting participants' donation and information sharing. In addition, the study found that compared with the behaviour of donating for Textile crowdfunding projects, the willingness of user information sharing behaviour is low.

The interview results show that users mainly contact textile crowdfunding projects through social media platforms such as WeChat and Weibo. The behaviours of user participation are mainly two ways of online donation and information sharing on social media. Users are much less willing to share information than donate to crowdfunding textile projects. Of the 35 interviewees, 32 people participated in the donation, of which only 21 people donated and performed information sharing. The reason is that information sharing is an open behaviour, and users are worried about information sharing on social platforms. It will bring oppression to others or cause a negative evaluation of their image, so users are more cautious when they share information. In addition, this study found that emotional factors, interpersonal relationships, and perceived risk are the key factors that affect participant donation and information sharing. Based on the attribution theory, the influencing factors of user donation and information-sharing behaviour are divided into trait attribution and situation attribution.

Trait attribution

Trait attribution refers to the subjective feelings and judgments of social media users based on personal personality traits when accessing textile crowdfunding information. A total of 4 main trait attribution variables are extracted: personality traits (personal traits, social responsibility, behavioural habits), Past experience); emotional factors (empathy, self-efficacy, guilt, geographical distance); interpersonal relationships (personal relationships, degree of relationship); perceived risks (authenticity, transparency). Trait attribution has an impact on user donation and information-sharing behaviours. An interpersonal relationship is a key factor that users consider when making donations and information sharing.

The individual characteristics of users play a major role in their participation in crowdfunding textiles. Donations and information sharing are individual user behaviours. The user's personality traits, social responsibility, behavioural habits, and past experience affect their textile crowdfunding participation. The personality traits and behaviour habits of each user are different, and their attitudes towards textile crowdfunding donations and information sharing are very different. Some participants stated that the reason they made donations was entire that they were concerned for the condition of certain social groups and did not attempt to give back for free. And those with a strong sense of social responsibility believe that they have a responsibility and obligation to help those in need. Past donations and information-sharing experiences on textile crowdfunding projects often affect users' current judgments. Satisfied past users are more likely to participate in crowdfunding textiles.

Emotional factors in the process of user donation and information sharing for textile crowdfunding projects are the direct factors that prompt users to donate, which are mainly reflected in empathy, self-efficacy, guilt, and geographical distance. The text content of textile crowdfunding information released by patients can arouse the empathy and empathy of users, allow users to have empathy and promote user donations and information sharing. Or users who want to get praise, improve self-satisfaction or even reduce guilt can promote user donation behaviour. In addition, geographical distance will shorten the emotional distance between the two parties, and users are more willing to help people who are in the same place or close to themselves.

Interpersonal relationships are a key factor to consider when donating and sharing information. Before making a donation decision, participants evaluate the relationship with the patient. Almost all interviewers mentioned that the extent of the relationship is the most important factor for their donation consideration. The closeness of the relationship will promote donation and information-sharing behaviour occur. Some participants believe that donation and retransmission of textile crowdfunding projects are all human relationships. Human-based forwarding is self-interested, not altruistic. User donations are intended to reward the help received in the past and look forward to the help of others in the future. Human exchange should also follow the principle of reciprocity. The survey found that participants will not forward textile crowdfunding projects too much, so as not to owe too much human favour.

Crowdfunding textile, as an online funding model, also has risks. Perceived risk is an important factor that hinders users from participating in donations and

information sharing. It mainly reflects the two aspects of doubts about the authenticity of textile crowdfunding information content and the transparency of the use of funds. The phenomenon that textile crowdfunding information is difficult to distinguish and exaggerate the facts in social media occurs from time to time, leading to a decrease in users' trust in textile crowdfunding information. The textile crowdfunding platform has not continued to pay attention to the use of donations. Participants cannot see the use of their donations. This will affect the attitudes and behaviours of some potential participants, at least by showing the use of donations in front of them. This will increase users' trust in crowdfunding projects.

Situational attribution

In the discussion of the influencing factors of user donation and information-sharing behaviour, in addition to trait attribution, users are also affected by context attribution. In this study, these context attributions are summarized into four aspects: information content characteristics (text Content, project progress, user participation); characteristics of rescue targets (disease risk, rescuer status); organizational factors (organizational support, information source); self-presentation (perceived image, negative evaluation). Contextual attribution has an impact on user donation and information sharing, and self-presentation is a key factor that users consider when sharing information.

Information content characteristics will affect user willingness to donate and share information, which is mainly reflected in three aspects: text content, project progress, and user participation. Each project is equipped with pictures and text descriptions such as bed photos, ID cards, and hospital diagnosis certificates to prove the authenticity and reliability of the project and deepen the user's understanding of the project information. The size of the fundraising amount conveys to the user the fundraising target and difficulty of the rescued object, which is directly related to the success or failure of the fundraising purpose. The more followers a project has, the more supporters it will have in the process of project funding, and the more likely the project is to succeed. Users post their views and related questions in the project comment area. Projects with more comments have more opportunities to be seen by more people. This information can provide a reference and basis for users' participation in decision-making.

The characteristics of the rescue target will affect the user's willingness to donate and share information, which is mainly reflected in the two aspects of disease risk and rescuer identity. Judgment of disease risk will affect the user's perception of the value of the donation. When the rescue target is seriously ill and the textile expenses are unaffordable, users are more willing to participate in donations and information sharing. Participants are also concerned about the identity of the recipients. For example, if the recipient is a student, it is easier to get social attention and support. In addition, we also found that users are more willing to help someone who is hard-working and enterprising rather than lazy and not working hard.

Organizational factors affect user donation and willingness to share information, which is mainly manifested in the two aspects of organizational support and information source. The users of the textile crowdfunding project initiated by the unit organization or the leader are more enthusiastic. Seeing that colleagues and friends around them donate or forward information, psychological users who are out of the group and follow the crowd will also participate. Participants said that the close relationship can dispel participants doubts about the textile crowdfunding information and the authenticity of the patients, especially the messages released by people whom they usually respect and trust. Users are more likely to participate in donations and information sharing. News media has a certain influence as a social public platform, and its dissemination can improve the authenticity and attention of project information, weaken users' perception of project uncertainty, and increase user participation.

Self-presentation is a key factor that users consider when sharing information, and it also affects their willingness to donate, which is mainly reflected in perceived images and negative evaluations. Much of the textile crowdfunding information is difficult to distinguish. Users will consider the impact of sharing such news on a social media platform with themselves and others. Perceiving negative and low-quality information will damage their image and others. You don't necessarily want to see this information or donate because of emotional pressure. Some participants indicated that they are not accustomed to sending a circle of friends. Considering that helping participants is voluntary, there is no need to share in the circle of friends for others to donate. It will give others a sense of oppression and may be considered a charity show. In addition, some participants have different opinions. They believe that information sharing does not require time and money costs, and there is no requirement for media application technology. Sharing the news of textile crowdfunding in the circle of friends can not only express their ideas, but also let more people see the information, and then call for more people to participate in crowdfunding textiles.

CONCLUSION

Exploring the individual participants 'perceptions of user donation and information sharing in textile crowdfunding in the online social media environment and their influencing factors will help to better analyse the motivation of users' participation in behaviour and further provide a reference for the management and operation of textile crowdfunding projects.

First, strengthen the management of the textile crowdfunding platform and promote the standardized development of the industry. The textile crowdfunding

platform should strictly control the quality of the project information content, pay attention to the authenticity and comprehensiveness of the information presented on the website, and strictly require helpers to indicate the project title, project content, fundraising amount and time required when initiating the project. Contains content and highlights precautions to improve information quality from the source. In addition, the textile crowdfunding platform must regularly update the displayed information content characteristics, including project status, completion progress, and rescuer treatment conditions. For the phenomenon of fraudulent donations and fraudulent donations in social networks, the crowdfunding platform should establish its credit evaluation system based on the helper's family situation, textile expenses, fundraising amount, and use of fundraising, concerning user social network authentication. Use the credit evaluation algorithm to determine the credit level of each rescuer, and display it on the homepage of the website. A blacklist system is adopted for rescuers who have seriously violated the rules and shared among crowdfunding platforms.

Second, give full play to the power of social media and expand the influence of the platform. Textile crowdfunding platforms usually use social media channels such as Weibo and WeChat to promote textile crowdfunding information, but there are certain limitations in the way of relying on helpers and participants' connections to promote. The textile crowdfunding platform can widely carry out textile crowdfunding-related cultural propaganda, spread the concept of modern crowdfunding textiles, and create a cultural atmosphere to participate in crowdfunding textiles, allow people to get out of misunderstandings, eliminate public concerns, and truly understand the significance of crowdfunding textiles. Then form a strong sense of participation and social atmosphere.

Third, improve the quality of information released by help seekers and enhance users' psychological perception. In the process of contacting crowdfunding textiles, helpers and users cannot communicate face-to-face but communicate information through online textile crowdfunding platforms. Therefore, in the process of information writing, helpers should try to shorten the psychological distance with the user as much as possible, and use text content that can resonate and empathize with the participants, so that the user has a sense of identity and belonging. Stimulate the feeling of helping others inside, making users more willing to help.

This article focuses on the issue of user donation and information-sharing behaviour research. It conducts theoretical exploration and analysis based on the existing literature and research. Future research can be discussed from the following two aspects. On the one hand, whether users' participation in textile crowdfunding behaviour is affected. The impact of gender, age, occupation, and education level; on the other hand, for the model proposed in this study, the causality and correlation between variables can be discussed and analysed through a wide range of data surveys.

ACKNOWLEDGEMENTS

This paper was written under a grant from the National Natural Science Foundation of China (No. 18CTQ033).

REFERENCES

[1] Sisler, J., *Crowdfunding for medical expenses*, In: Canadian Medical Association Journal, 2012, 184, 2, 123

[2] Kim, J.G., Kong, H.K., Karahalios, K, et al., *The power of collective endorsements: Credibility factors in medical crowdfunding campaigns*, CHI '16: Proceedings of the 2016 CHI Conference on Human Factors in Computing Systems, 2016

[3] Zhang, Y., Hou, J., *Analysis on the Status Quo and Trend of Micro-public Welfare Development in China*, In: China Youth Research, 2014, 10, 41–47

[4] Water Drop Fundraising Platform[EB/OL], Available at: https://www.shuidichou.com [Accessed on August 6, 2018]

[5] Belleflamme, P., Lambert, T., Schwienbacher, A., *Crowdfunding: Tapping the right crowd,* In: Core Discussion Papers, 2011, 29, 5, 585–609

[6] Wheat, R.E., Wang, Y., Byrnes, J.E., *Raising money for scientific research through crowdfunding,* In: Trends in Ecology & Evolution, 2013, 28, 2, 71–72

[7] Davies, R., *Three provocations for civic crowdfunding*, In: Information Communication & Society, 2015, 18, 3, 342–355

[8] Barbara, B., Mario, P., Luk, W., *Adding exchange to charity: a reference price explanation*, In: Journal of Economic Psychology, 2007, 28, 1, 15–30

[9] Kuppuswamy, V., Bayus, B.L., *Crowdfunding creative ideas: The dynamics of project backers in kickstarter,* In: Social Science Electronic Publishing, 2013

[10] Ahlers, G.K.C., Cumming, D., Günther, C., *Signaling in equity crowdfunding*, In: Entrepreneurship Theory and Practice, 2015, 39, 4, 955-980

[11] Othman, B., Weijun, H., Huang, Z., Rashid, N., Xi, J., Yuan, F., *The effect of service marketing mix elements and customer retention towards clothing store brands in China*, In: Industria Textila, 2021, 72, 4, 388–397, http://doi.org/10.35530/IT.072.04.1777

[12] Li, J., *A Discourse Study of Network Assistance Texts – An Analysis of Three Cases of "Easy Raising" and "Wei Ai Channel"*, In: Journalism, 2016, 11, 47–53

[13] Bekkers, R., Wiepking, P., *A literature review of empirical studies of philanthropy*, In: Nonprofit & Voluntary Sector Quarterly, 2010, 40, 5, 924–973

[14] Agrawal, A., Catalini, C., Goldfarb, A., *Crowdfunding: Geography, Social Networks, and the Timing of Investment Decisions*, In: Journal of Economics & Management Strategy, 2015, 24, 2, 253–274
[15] Castillo, M., Petrie, R., Wardell, C., *Fundraising through online social networks: A field experiment on peer-to-peer solicitation*, In: Journal of Public Economics, 2014, 114, 6, 29–35
[16] Li, J., Yang, X., *Research on "Medical Crowdfunding" Information Sharing Behaviour in Social Media: Forwarding or Not Forwarding?*, In: Journalism and Communication Studies, 2018, 2, 64–79
[17] Liu, J., *The Fit of Altruistic Networks and Social Networks Improving the Effect of Micro-public Information Dissemination*, In: News, 2011, 08, 85–91
[18] Prencipe, A., Zelazo, P.D., *Development of affective decision making for self and other: Evidence for the integration of first- and third-person perspectives*, In: Psychological Science, 2005, 16, 7, 501–505
[19] Gerber, E.M., Hui, J., *Crowdfunding: Motivations and deterrents for participation*, In: ACM Transactions on Computer-Human Interaction, 2016, 20, 6, 34–32
[20] Ding, X., Yi, X., *Charitable Donation in Mass Disaster-Mediating Effect of Empathy*, In: Chinese Journal of Clinical Psychology, 2011,19, 03, 363–366
[21] Zheng, H., Li, D., Wu, J., *The role of multidimensional social capital in crowdfunding: A comparative study in China and US*, In: Information & Management, 2014, 51, 4, 488–496
[22] Othman, B., Weijun, H., Huang, Z., Xi, J., Ramsey, T., *Effect of service quality on service value and customer retention for clothing store brands in China*, In: Tekstilec, 2020, 63, 4, 242–255
[23] Xu, C., Chen, K., *Research on Influencing Factors of User Participation in Crowdfunding Websites Taking "Crowdfunding Network" as an Example*, In: Information Magazine, 2015, 11, 175–182
[24] Allison, T.H., Davis, B.C., Short, J.C., *Crowdfunding in a prosocial microlending environment: Examining the role of intrinsic versus extrinsic cues*, In: Entrepreneurship Theory & Practice, 2015, 39, 1, 53–73
[25] Bi, S., Liu, Z., Usman, K., *The influence of online information on investing decisions of reward-based crowdfunding*, In: Journal of Business Research, 2017, 71, 10–18
[26] Colombo, M.G., Franzoni, C., Rossi, L.C., *Internal social capital and the attraction of early contributions in crowdfunding*, In: Entrepreneurship Theory and Practice, 2015, 39, 1, 75–100
[27] Mollick, E., *The dynamics of crowdfunding: An exploratory study*, In: Social Science Electronic Publishing, 2014, 29, 1, 1–16
[28] Burtch, G., Ghose, A., Wattal, S., *An empirical examination of the antecedents and consequences of contribution patterns in crowd-funded markets,* In: Social Science Electronic Publishing, 2011, 24, 3, 499–519
[29] Ordanini, A., Miceli, L., Pizzetti, M., *Crowd□funding: transforming customers into investors through innovative service platforms*, In: Journal of Service Management, 2013, 22, 4, 443–470
[30] Kelley, H.H., Michela, J.L., *Attribution theory and research*, In: Annual Review of Psychology, 1980, 31, 1, 457–501
[31] Glaser, B., Strauss, A.L., *The Discovery of grounded theory: Strategies for qualitative research*, In: Nursing Research, 1968, 17, 4, 377–380
[32] Zhengwei, H., Xueke, Pe., Jing, X., Bestoon, O., Sher, A., *The Influence of Consumers ' Perception on Perceived Value and Purchase Intention with respect to Regional Products Based on a C-A-B Model*, In: Tekstilec, 2019, 62, 3, 219–228
[33] Weiner, B., *An attributional theory of motivation and emotion,* Springer US, 1986, 167–183
[34] Heider, F., *The psychology of interpersonal relations*, In: American Sociological Review, 1983, 23, 6, 170
[35] Kim, H.S., *What drives you to check in on facebook? Motivations, privacy concerns, and mobile phone involvement for location-based information sharing*, In: Computers in Human Behaviour, 2016, 54, 3, 397–406

Authors:

XUEKE PEI[1], ZHENGWEI HUANG[1], YANNI YANG[2], OTHMAN BESTOON[3,4]

[1]College of Economics & Management, China Three Gorges University, Yichang, 443000, China

[2]School of Literature and Media, China Three Gorges University, Yichang, 44300, China

[3]Department of Business Administration, Koya Technical Institute, Erbil Polytechnic University, Erbil, Iraq

[4]Department of Business Administration, College of Administration and Economics, Nawroz University, Duhok, Iraq

Corresponding author:

YANNI YANG
e-mail: 814348293@qq.com

Hybrid composites based on textile hard waste: use as sunshades

DOI: 10.35530/IT.073.06.202158

SHERAZ HUSSAIN SIDDIQUE
MUHAMMAD OWAIS RAZA SIDDIQUI
MUHAMMAD ALI
DANMEI SUN

ABSTRACT – REZUMAT

Hybrid composites based on textile hard waste: use as sunshades

Hybrid composites have gained exceptional interest from researchers and industry sectors in the last couple of decades with an aim to improve existing and/or develop new composites to cater for a wide variety of applications. In this research, hybrid composites utilizing glass fibre combined with textile hard waste were fabricated. A control sample and 7 hybrid composite samples including glass-polyester hard waste, glass-mercerized cotton hard waste and glass-cotton hard waste were developed as part of this study. Density, tensile strength and thermal conductivity of all developed samples and that of a commercial composite (purchased from the market) were measured. The results revealed that the control sample developed at the lab scale showed similar or higher values of density, tensile properties and thermal conductivity. Hybrid composites based on unmercerized and mercerized cotton showed very low tensile properties and similar conductivity, so they are not suitable for sunshade application. On the other hand, a composite made from polyester provided with highest tensile properties amongst all the hybrid composites but was still quite lower than a commercial sample. Polyester hybrid composite has enhanced thermal insulation properties suggesting that it has the potential to replace the existing composite, but a compromise needs to be made between the physical and thermal properties of the sunshade.

Keywords: *hybrid composites, textile reinforcement, thermal conductivity, tensile strength, tensile modulus*

Compozite hibride pe bază de deșeuri textile dure: utilizare ca parasolare

Compozitele hibride au câștigat un interes excepțional din partea cercetătorilor și a sectoarelor industriale în ultimele două decenii, cu scopul de a îmbunătăți compozitele existente și/sau de a dezvolta noi compozite pentru o mare varietate de aplicații. În această cercetare, au fost fabricate compozite hibride care utilizează fibră de sticlă combinată cu deșeuri textile dure. În cadrul acestui studiu au fost dezvoltate o probă martor și 7 probe compozite hibride, inclusiv deșeuri dure din sticlă-poliester, deșeuri dure din bumbac mercerizat cu sticlă și deșeuri dure din sticlă-bumbac. Au fost determinate densitatea, rezistența la tracțiune și conductivitatea termică a tuturor probelor dezvoltate și a unui compozit comercial (achiziționat de pe piață). Rezultatele au arătat că proba martor dezvoltată la scară de laborator a prezentat valori similare sau superioare ale densității, rezistenței la tracțiune și conductivității termice. Compozitele hibride pe bază de bumbac nemercerizat și mercerizat au prezentat o rezistență la tracțiune foarte scăzută și o conductivitate similară, deci nu sunt potrivite pentru a fi aplicate la realizarea parasolarelor. Pe de altă parte, compozitul realizat din poliester a avut cea mai bună rezistență la tracțiune dintre toate compozitele hibride, dar au fost mai scăzută în comparație cu proba comercială. Compozitul hibrid din poliester are proprietăți de izolare termică îmbunătățite, ceea ce sugerează că are potențialul de a înlocui compozitul existent, dar trebuie făcut un compromis între proprietățile fizice și termice ale parasolarului.

Cuvinte-cheie*: compozite hibride, armătură textilă, conductivitate termică, rezistență la tracțiune, modul de tracțiune*

INTRODUCTION

Hybrid composites are getting important consideration in recent years because they possess reasonable physical and mechanical properties for some applications and they are more cost-effective [1, 2]. Hybrid composites are manufactured by mixing two or more different fibres in the reinforcement. The composites are also considered hybrid if two different resins are blended or some filler material is added to the resin [3, 4]. It is a common practice in the industry to manufacture composites using glass, carbon and Kevlar fibres as reinforcement [5, 6]. However, to overcome some inherent disadvantages of these fibres being used as reinforcement, these fibres are blended in the reinforcement to manufacture hybrid composites [4, 7]. Hybrid composites are also being manufactured by blending lingo-cellulosic fibres with glass fibres as reinforcement. These composites are getting attention from the researchers because the used natural fibres are bio-degradable, renewable and less expensive as compared to glass fibres [8–11].

The textile industry generates a lot of waste; this waste is also being used by some researchers to manufacture hybrid composite materials [12, 13]. Recycling waste produced by the textile industry is always a challenge. Composites manufactured using the aforementioned fibres and their hybrid configurations have been utilized in a variety of applications in different industries including automobile, building and

packaging [14–17]. Sunshades are one key application area where cost reduction in addition to improved mechanical and thermal properties is the primary consideration.

Several researchers have reported improved thermal and mechanical properties of hybrid composites that were made by utilizing a blend of natural and synthetic fibres [18–21]. Idicula suggested that the thermal properties of glass composites were enhanced when a mixture of glass fibre with natural fibre was utilized [18]. Osugi's research focused on the thermal conductivity of composite when Manila hemp was used as reinforcing fibre. In the research composites, samples were fabricated at different fibre content levels. Results suggested that thermal insulation was greatly improved when higher fibre content levels were used [19]. Karthik developed composites using banana and glass fibre with epoxy. Different length of banana fibres was used to evaluate the effect of fibre length on the mechanical behaviour of fibres. It was concluded that tensile properties improved when fibre length increases up to a certain level but then started decreasing gradually [20]. Atiqah investigated the thermal behaviour of sugar palm/glass fibre thermoplastic hybrid composites. Samples were made at different weight fractions of sugar palm/glass fibre. The results of the study emphasized that thermal properties were enhanced in the case of hybrid configuration [21].

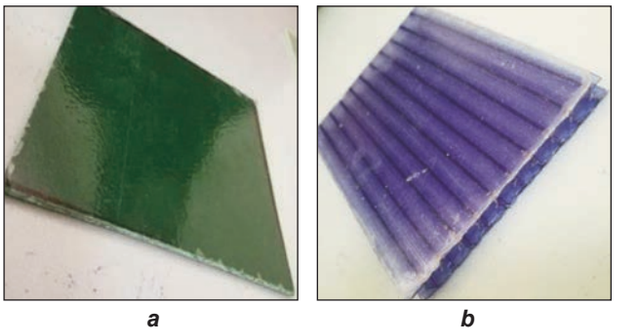
The sunshades could be used in the gardens to provide protection from heat and UV rays. The buildings are designed to become energy efficient based on the ratios of windows and walls. If sunshades are provided at the windows, they will increase the energy efficiency of the building [22, 23]. In general, the sunshades will provide coolness and protection from the radiation of the sun and help to design buildings with better ventilations. However, they will have a disadvantage for additional installation cost and they could also be a possible fire hazard, the shades will also affect the light transmission from the sun to the building rooms [24, 25]

The above-mentioned literature study suggests that a lot of work has been carried out on hybrid composites made using a combination of natural and synthetic fibres, but very few studies have been carried out to evaluate the performance and characterization of hybrid composites made using a combination of textile hard waste along with glass fibre [26, 27]. In this research work, the hard waste produced from the yarn manufacturing industry has been utilized to manufacture hybrid composite material. The composite material based on the textile hard waste will be tested for its mechanical and thermal properties, it is hoped that this material could be used to replace the existing sunshade in the market.

MATERIALS AND METHODS

Materials

Based on the thickness the commercially available sun shades are divided into four categories i.e. 1 mm, 1.5 mm, 4 mm and 2.5 mm. The commercial sample of 1.5 mm was chosen for comparison because these are commonly used as garden sunshades. These sunshades are also shown as an example in figure 1.



a *b*

Fig. 1. Types of sunshades: *a* – 1.5 mm; *b* – 2.5 mm

For this research work, Glass fibre mats having the GSM 300 g/m^2 were purchased from the local supplier i.e. Al Khair Industries, Karachi, while the hard waste was obtained from Soorty Enterprises, Karachi. Two types of hard waste were used i.e. cotton and polyester. The hard waste was obtained from the cone winding section of the spinning mill. The hard waste was also used as reinforcement to manufacture hybrid composites.

Some of the cotton hard waste was treated with Caustic Soda to make a category of mercerized cotton hard waste. It is a common practice in the composite industry to treat cellulosic fibres with NaOH so that the interaction i.e. adhesion between the resin and the fibres is improved [28, 29]. Cotton hard waste was immersed in the solution of caustic soda (27 Baume) for 60 seconds at 20°C. The cotton hard waste sample is hot-washed and cold-washed simultaneously. Finally, it was dried in an oven at 100°C for 30 minutes.

Unsaturated polyester thermoset resin, Malikens GP was used as a matrix, MEEK 50 Methyl ethyl ketone peroxide was used as a hardener and Cobalt octoate was used as an accelerator to accelerate the reaction and harden the polyester quickly. These chemicals were purchased from Al Khair Industries Private Limited, Karachi, Pakistan.

Composites development

The characterization results of the developed samples were compared against a commercially available glass fibre-reinforced composite of thickness 1.5 mm. To find out the percentage of reinforcement i.e. glass fibre in the selected commercially available composite, the ISO 1172 method was used [30].

The sample obtained from the market was considered a standard sample, this sample was replicated by using a 30% glass fibre mat and 70% polyester resin was considered as a control sample. Different combinations for manufacturing hybrid composites were considered for this research work and are shown in table 1.

Table 1

DIFFERENT TYPES OF COMPOSITE SAMPLES MANUFACTURED			
S. No.	**Type of composite**	**Abbreviation**	**Thickness (mm)**
1	Glass fibre composite sample purchased from market	Standard (M)	1.5
2	Glass fibre composite sample manufactured in the lab (30% glass fibre mat and 70% polyester resin)	Controlled (C)	1.55
3	Cotton hard waste and glass fibre hybrid composite (10% C and 10% G)	GC 10-10	4.28
4	Cotton hard waste and glass fibre hybrid composite (15% C and 15% G)	GC 15-15	2.37
5	Mercerized cotton and glass fibre hybrid composite (10% MC and 10% G)	GMC 10-10	3.13
6	Mercerized cotton and glass fibre hybrid composite (15% MC and 15% G)	GMC 15-15	3.75
7	Polyester and glass fibre hybrid composites (10% P and 10% G)	GP 10-10	2.86
8	Polyester and glass fibre hybrid composites (15% P and 15% G)	GP 15-15	2.47

The hand layup technique is commonly used to manufacture composite material. In this study, this technique was utilized. It involved using of a glass plate as a tool; some wax was spread on the glass plate to avoid sticking of sample on the plate. We wanted to manufacture a composite sample of A4 size i.e. 10 by 7 inches, therefore A4 size plastic sheet was placed on the glass plate. Some resin was spread on the sheet. The glass fibre mat was placed on the A4 sheet, the hard waste was spread and the reinforcement was covered by another glass fibre mat. A resin coat was spread on the top of the glass fibre mat; it was covered by an A4-size plastic sheet. A roller was used to ensure the proper spreading of resin in the composite sample. The A4 plastic sheet was covered with a glass plate. A marble piece of 5 kg was placed on the top glass plate to provide enough pressure. The resin was allowed to cure for 24 hours and finally, the composite sample was obtained. The composite sample was placed in an oven for post-curing at 100°C for two hours. The schematic process for making composite samples is shown in figure 2.

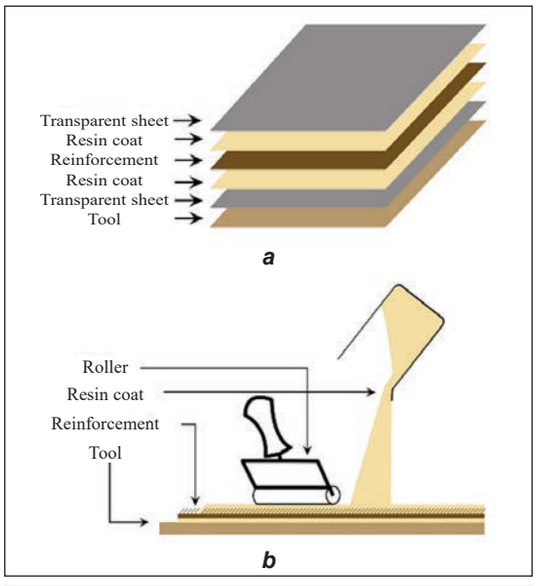


Fig. 2. Schematic process for making composite samples: *a* – layering of different layers and resin during composite manufacturing; *b* – hand layup (reinforcement means; glass fibre mats or the combination of glass fibre mat and hard waste)

Determination of density

The density of composite samples was determined using Archimedes' principle, using the standard method ISO 1183 [31]. Five specimens of 2 by 2 inches were used for each category to measure the density of composites.

Testing of Tensile Properties

The tensile tests were performed at 2mm/min by using a universal tensile testing machine (Zewick/Roell Z005 with 5 KN load cell) using ISO-527-4,1997 standard [32]. The gage length was fixed at 150 mm. Tensile strength, strain and modulus were determined for all types of composites mentioned in table 1. Five specimens of 10 × 1 in^2 were selected for each category.

Evaluation of Thermal conductivity

In the context of the present study, it was considered important to calculate the thermal conductivity of the composite material to be used as a sunshade. For this purpose, two plate method was used (ASTM 1530 2016) [33]. A circular specimen with a diameter of 50 mm is positioned such that it separates the two metal plates (hot plate and cold plate respectively). Heat travels from the hot plate to the cold because of the longitudinal temperature difference. Once the steady-state condition is attained, temperature sensors mounted on the metal plates measure temperature at both ends of the composite specimen. An additional measurement of heat flux is obtained with the help of a heat flux sensor. Thermal conductivity is then calculated by using these three measurements. The test was carried out for all types of composite materials.

RESULTS AND DISCUSSION

From figure 3, it is evident that the density of the control sample manufactured in the lab was very close to the standard sample. The density of hybrid composites with mercerized cotton hard waste as

reinforcement was the lowest. This was perhaps due to the action of the caustic soda which might have removed the waxes on the fibre surface thus slightly reducing the density. The density of hybrid composites in all categories was lower than the composites reinforced with only the glass fibre strand mats. This was because glass fibre has higher density as compared to cotton and polyester. In the case of hybrid composites, the difference in the densities was not significant; therefore this matter was not investigated further.

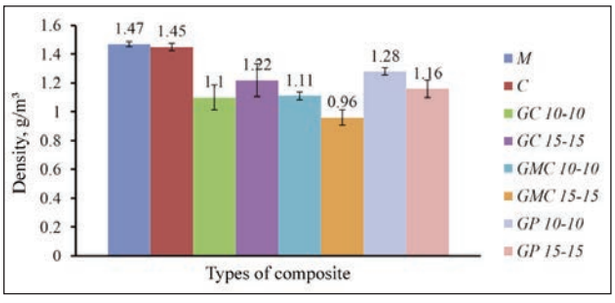


Fig. 3. Density of the composite samples

The force-strain curves for the Market sample as well as the samples manufactured in our lab were obtained from the software of the testing machines (figure 4).

From figure 4, it was observed that the samples obtained from the market are brittle in nature, and the standard samples manufactured in the lab with 30% glass fibre content are also brittle in nature. By adding the hard waste along with the glass fibres i.e. the hybrid composites show brittleness as well.

The tensile properties of different types of composites were determined by using the method explained in the last section. The results are shown in figures 5, 6 and 7.

From figure 5, it can be observed that the tensile strength of the controlled sample was slightly higher than the standard sample. Hybrid composite samples with mercerized cotton have shown the minimum strength, this might be because of the lower interaction of resin and cotton hard waste. It is a common belief that caustic soda is used to remove waxes, hemicellulose and other vegetable substances from lingo-cellulosic fibres to improve the interaction of resin and the fibres, by making the surface of fibres rough [11]. In the case of cotton hard waste used during this research work did not contain any impurities, so when the hard waste was treated with caustic soda, it resulted in swelling of fibres, thus causing shrinkage of small pieces of yarn, the caustic soda also makes the smooth surface of cotton fibre, resulting in less interaction of yarn pieces with the resin and minimum strength. The strength of hybrid

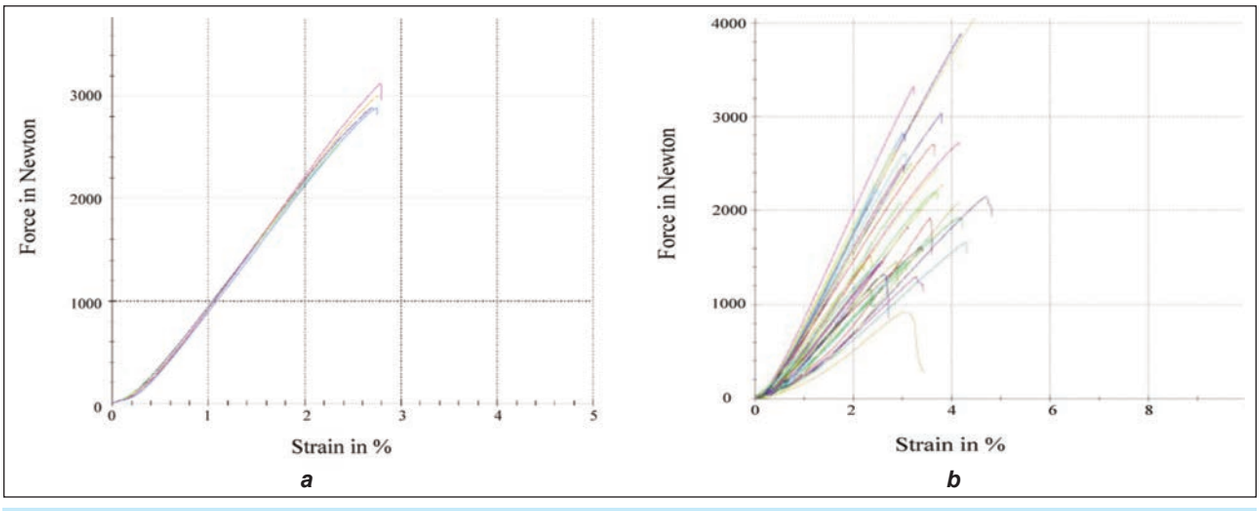


Fig. 4. Force-strain curves for: *a* – market samples; *b* – standard and hybrid composite samples

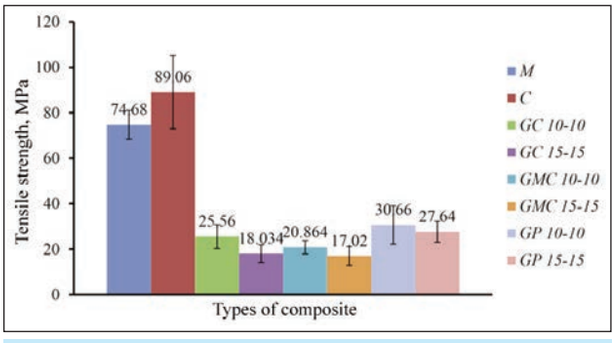


Fig. 5. Tensile strength of the composite samples

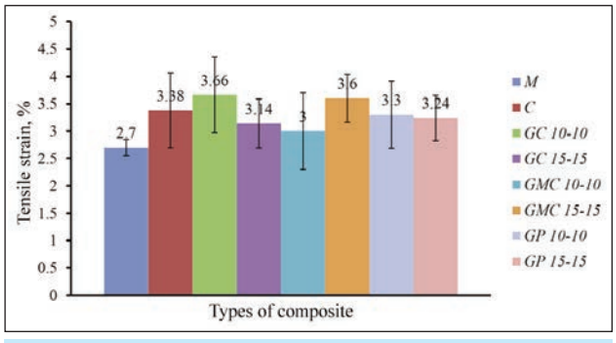


Fig. 6. Tensile strain of the composite samples

polyester composites is slightly higher than the composites manufactured with cotton hard waste. This is perhaps because polyester has high strength as compared to cotton.
Figure 6 shows that the tensile strain of the controlled sample is slightly higher than the commercial sample obtained from the market. In the commercial sample, the fibres might not be distributed properly, when we manufacture the control sample in our lab, the fibre distribution in the resin was proper showing more resistance to the load, resulting in higher elongation. For hybrid samples, the even distribution of fibres and hard waste also resulted in higher strain values.

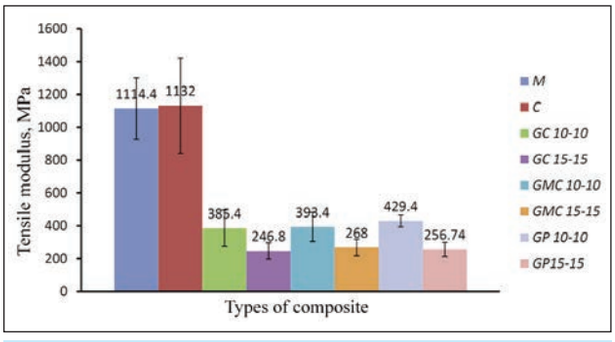


Fig. 7. Tensile modulus of the composite samples

There is not much difference in the tensile modulus of standard and controlled samples, presented in figure 7. Hybrid composites have lower modulus as compared to composites manufactured only from glass fibre mats as reinforcement. All the hybrid composites have shown a mixed trend, so this phenomenon was not discussed further.
The tensile properties i.e. tensile strength of the controlled sample was 19.25% higher, and the tensile stain for the controlled sample was 25% higher than the market sample. This was perhaps because of the hand layup method adopted in the lab resulted in the proper distribution of fibres in the resin. However the tensile modulus of the commercial and controlled samples is similar, so we were able to successfully replicate the samples in the lab.
In the case of hybrid composites, the samples manufactured with 10% polyester and 10% glass have shown better results. For example: the tensile strength of 10% polyester and 10% glass composite was 19.95% higher as compared to 10% cotton and 10% glass composites; it was also 10.93% higher as compared to 15% polyester and 15% glass hybrid composites.
When these samples were compared with the commercial samples the tensile strength was 58.94% lower, and when they were compared with controlled samples, the strength was 65.57% lower. If we consider sun shade as a non-structural product, then this hybrid composite material has the chance to replace the commercial sunshade.
The thermal conductivity of different types of composites was assessed by using the two-plate method explained in the last section (figures 8).

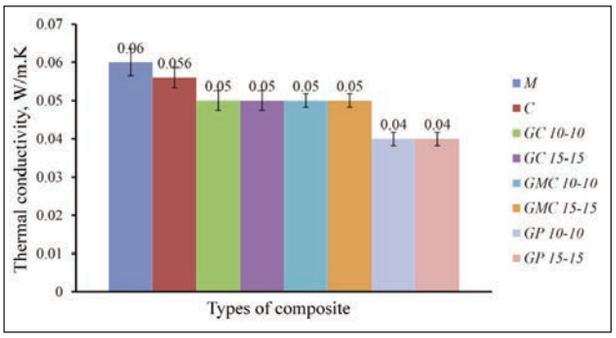


Fig. 8. Thermal conductivity of the composite samples

From figure 8, it can be observed that the thermal conductivity of composites reinforced with glass fibre strand mats is the highest. This means it will allow more heat to pass the shade thus it has a less insulating effect.
Hybrid composites reinforced with glass and polyester hard waste resulted in lower thermal conductivity as compared to glass fibre composites. Because the presence of hard waste as reinforcement resulted in more gaps within the fibre networks in the composite material. In the case of polyester hard waste, thermal conductivity is further reduced, this might be because most of the heat is trapped in the layer of polyester hard waste, and a very small quantity of heat passed the layer of glass fibres and resin.
The combination of glass fibre mats (10%) and polyester hard waste (10%) in the reinforcement has a great potential to replace commercial sunshades having 30% glass fibre mats as reinforcement. These samples developed as a result of this research work have reasonable strength (30.66 MPa) and modulus (429.4 MPa), lower density (1.28) i.e., the samples will be lighter in weight and lower thermal conductivity (0.04) as compared to the commercial market sample. The tensile properties of polyester hybrid composites are much lower as compared to glass mat composites, but the application of sunshades could come in the category of non-structural application, so the tensile properties will be considered less important.

CONCLUSIONS

From the above discussion, the following conclusions can be made: the commercial samples of sunshades can be replicated by our successfully developed composites at a lab scale that have slightly higher tensile properties, similar density and slightly lower thermal conductivity. The hybrid composites based on un-mercerized and mercerized cotton had shown lower tensile properties and similar thermal conductivity, so these composite materials are not considered to be used as sunshades. The hybrid composites based on polyester fibre as reinforcement had lower tensile properties, but they have lower thermal conductivity as compared to glass fibre composites. The hybrid composites based on polyester hard waste have the potential to be used as sunshades if

we consider this application as a non-structural one. However, in future research, these composite materials will be tested further to prove their performance in actual environmental conditions for the sunshades.

ACKNOWLEDGMENT

The authors would like to acknowledge the financial and moral support provided by NED University of Engineering & Technology, Karachi, during the course of this study.

REFERENCES

[1] Hamouda, T., Hassanin, A.H., Saba, N, et al., *Evaluation of mechanical and physical properties of hybrid composites from food packaging and textiles wastes*, In: J. Polym. Environ., 2019, 27, 3, 489–497

[2] Chuang, Y.C., Bao, L., Lou, C.W., et al., *Hybrid-fibre-reinforced composite boards made of recycled aramid fibres: Preparation and puncture properties*, In: Fibre Polym., 2019, 20, 2, 398–405

[3] Bunea, M., Cîrciumaru, A., Buciumeanu, M., et al., *Low velocity impact response of fabric reinforced hybrid composites with stratified filled epoxy matrix*, In: Compos. Sci. Technol., 2019, 169, 242–248

[4] Swolfs, Y., Verpoest, I., Gorbatikh, L., *Recent advances in fibre-hybrid composites: materials selection, opportunities and applications*, In: Int. Mater. Rev., 2019, 64, 4, 181–215

[5] Yousfani, S.H., Gong, R.H., Porat, I., *Effect of Process Variables on the Tensile Properties of Fibreglass Nonwoven Composites,* In: Polym. Polym. Compos., 2016, 24, 1, 65–70

[6] Li, F., Scarpa, F., Lan, X., et al., *Bending shape recovery of unidirectional carbon fibre reinforced epoxy-based shape memory polymer composites*, In: Compos. Part A-Appl. S., 2019, 116, 169–179

[7] Singh, S.B., Chawla, H., *Hybrid effect of functionally graded hybrid composites of glass–carbon fibres*, In: Mech. Adv. Mater. Struc., 2019, 26, 14, 1195–1208

[8] Nurazzi, N.M., Khalina, A., Sapuan, S.M., et al., *Thermal properties of treated sugar palm yarn/glass fibre reinforced unsaturated polyester hybrid composites,* In: J. Mater. Res., 2020, 9, 2, 1606–1618

[9] Giridharan, R., *Preparation and property evaluation of Glass/Ramie fibres reinforced epoxy hybrid composites*, In: Compos. Part B-Eng., 2019, 167, 342–345

[10] Ismail, A.S., Jawaid, M., Sultan, M.T.H., et al., *Physical and Mechanical Properties of Woven Kenaf/Bamboo Fibre Mat Reinforced Epoxy Hybrid Composites*, In: Bio. Res., 2019, 14, 1, 1390–1404

[11] Mochane, M.J., Mokhena, T.C., Mokhothu, T.H., et al., *Recent progress on natural fibre hybrid composites for advanced applications: A review,* In: Express Polym. Lett., 2019, 13, 2, 159–198

[12] Mishra, R., Behera, B., Militky, J., *Recycling of textile waste into green composites: performance characterization*, Polym. Composite, 2014, 35, 10, 1960–1967

[13] Ramamoorthy, S.K., Persson, A., Skrifvars, M., *Reusing textile waste as reinforcements in composites*, In: J. Appl. Polym. Sci., 2014, 131, 17

[14] Saba, N., Jawaid, M., Alothman, O.Y., et al., *A review on dynamic mechanical properties of natural fibre reinforced polymer composites*, In: Constr. Build Mater., 2016, 106, 149–159.

[15] Senthilkumar, K., Saba, N., Rajini, N., et al., *Mechanical properties evaluation of sisal fibre reinforced polymer composites: a review*, In: Constr. Build Mater., 2018, 174, 713–729

[16] Xue, B., Xie, L., Bao, Y., et al., *Multilayered epoxy/glass fibre felt composites with excellently acoustical and thermal insulation properties*, In: J. Appl. Polym. Sci., 2019, 136, 3, 46935

[17] Wang, G., Zhang, D., Wan, G., et al., *Glass fibre reinforced PLA composite with enhanced mechanical properties, thermal behaviour, and foaming ability*, In: Polymer, 2019, 181, 121803

[18] Idicula, M., Boudenne, A., Umadevi, L., et al., *Thermophysical properties of natural fibre reinforced polyester composites*, In: Compos. Sci. Technol., 2006, 66, 15, 2719–2725

[19] Osugi, R., Takagi, H., Liu, K., et al., *Thermal conductivity behaviour of natural fibre-reinforced composite*, In: Asian Pacific Conference for Materials and Mechanics, Yokohama, Japan 13 November 2009, 13–16

[20] Karthick, R., Adithya, K., Hariharaprasath, C., et al., *Evaluation of mechanical behaviour of banana fibre reinforced hybrid epoxy composites*, In: Mater. Today-Proc., 2018, 5, 5, 12814–12820

[21] Atiqah, A., Jawaid, M., Sapuan, S.M., et al., *Thermal properties of sugar palm/glass fibre reinforced thermoplastic polyurethane hybrid composites,* In: Compos. Struct., 2018, 202, 954–958

[22] Xue, P., Qian, L., Jingchao, X., et al., *Optimization of window-to-wall ratio with sunshades in China low latitude region considering daylighting and energy saving requirements*, In: Appl. Energy, 2019, 233–234, 62–70

[23] Li, B., Guo, W., Liu, X., et al., *Sustainable Passive Design for Building Performance of Healthy Built Environment in the Lingnan Area*, In: Sustainability, 2021, 13, 16, 1–23

[24] Wei, T., Chen, Y., *Green building design based on BIM and value engineering*, In: J. Ambient Intell. Human Comput., 2020, 11, 3699–3706

[25] Tufail, M.R., Jamshaid, H., Mishra, R., et al., *Characterization of Hybrid Composites with Polyester Waste Fibres, Olive Root Fibres and Coir Pith Micro-Particles Using Mixture Design Analysis for Structural Applications*, In: Polymers, 2021, 13, 14, 1–24

[26] Kumar, A., *Utilization of textile waste in manufacturing of composite materials*, Master's Thesis, LUT University, Lappeenranta, Finland, 2019

[27] Sivakumar, V., Mohan, R., *Sustainable Solid Waste Management in Leather and Textile Industry: Leather & Textile Waste Fibre-Polymer Composite and Nanocomposite – Overview and Review*, In: Textile & Leather Review, 2020, 3, 2, 54–63

[28] de Macedo, J.R.N., Carmona, V.N., Derval, S.R., *Differences of Alkali and Thermal Treatment on Cotton Residues Applicable to Green Composites*, In: Mater. Sci. Eng. Adv. Res., 2016, 1, 4, 13–18

[29] Bisanda, E.T.N., *The effect of alkali treatment on the adhesion characteristics of sisal fibres*, In: Appl. Compos. Mater., 2000, 7, 5–6, 331–339

[30] ISO 1172:1999. Textile-glass-reinforced plastics – Prepregs, moulding compounds and laminates – Determination of the textile-glass and mineral-filler content – Calcination methods. Geneva: International Organization for Standardization

[31] ISO 1183-1:2019. Plastics – Methods of determining density of non-cellular plastics Part 1: Immersion method, liquid pycnometer method and titration method. Geneva: International Organization for Standardization

[32] ISO 527-4:1997. Plastics – Determination of tensile properties – Part 4: Test conditions for isotropic and orthotropic fibre-reinforced plastic composites. Geneva: International Standard Organization

[33] ASTM E1530:2019. Standard Test Method for Evaluating the Resistance to Thermal Transmission by the Guarded Heat Flow Meter Technique. West Conshohocken, PA: ASTM International

Authors:

SHERAZ HUSSAIN SIDDIQUE[1], MUHAMMAD OWAIS RAZA SIDDIQUI[1], MUHAMMAD ALI[1], DANMEI SUN[2]

[1]NED University of Engineering & Technology, Department of Textile Engineering,
University Road, 75270, Karachi, Pakistan

[2]Heriot-Watt University, School of Textiles & Design, TD1 3HF, Galashiels, UK
e-mail: d.sun@hw.ac.uk

Corresponding author:

MUHAMMAD ALI
e-mail: alimughal@neduet.edu.pk

Design & implementation of the production line in garment industry

DOI: 10.35530/IT.073.06.1745

D. VASANTH KUMAR
G. MADHAN MOHAN
K. M. MOHANASUNDARAM

ABSTRACT – REZUMAT

Design & implementation of the production line in garment industry

The traditional strategy in garment businesses is confronting a considerable measure of issues, for example, longer Production lead time, high work, supply sought after, high texture waste, longer production time and ailing in the utilization of assets. ABC clothing company is experiencing the previously mentioned issues. Enhancing efficiency through quantitative research strategies and distinctive lean assembling devices, for example, the institutionalization of the work process, line adjusting, and 5S were utilized to distinguish the issues and to address the arrangements. By understanding the real issue, the use of these lean assembling devices and their advantages were inspected. Earlier it was around 210 items for each day once in the day of actualizing the lean tools it was around 280 every day. The efficiency has increased by 25%. In like manner, the adjusting balancing loss was decreased by 35%. The implication of this investigation can give the entire practical answer to the usage of lean tools, minimization of waste and viable use of the asset in a piece of the garment industry for enhancing efficiency.

Keywords: *productivity, lean manufacturing, line balancing, 5S, efficiency*

Proiectarea și implementarea liniei de producție în industria de îmbrăcăminte

Strategia tradițională în afacerile cu îmbrăcăminte se confruntă cu o serie de probleme, de exemplu, timp îndelungat între emiterea comenzilor și executarea acestora, durata mare de lucru, cerere mare de aprovizionare, cantitate mare de deșeuri, timp de producție mai lung și dificultăți în utilizarea activelor. Compania textilă ABC este una dintre unitățile producătoare de articole de îmbrăcăminte care se confruntă cu problemele menționate anterior. Creșterea eficienței prin strategii de cercetare cantitativă și dispozitive distinctive de asamblare de tip lean, de exemplu, instituționalizarea procesului de lucru, ajustarea liniilor de producție și 5S au fost utilizate pentru a distinge problemele și pentru a aborda soluțiile. Prin înțelegerea problemei reale, au fost analizate aceste dispozitive de asamblare de tip lean și avantajele acestora. Anterior, producția zilnică era de aproximativ 210 de articole, iar în ziua implementării acestor instrumente s-a ajus la o producție zilnică de aproximativ 280 articole. Eficiența a crescut cu 25%. În mod similar, pierderea echilibrului de ajustare a fost redusă cu 35%. Implicația acestei investigații poate oferi răspunsul practic la utilizarea instrumentelor de tip lean, la reducerea deșeurilor și a activelor viabile utilizate în industria de îmbrăcăminte, pentru creșterea eficienței.

Cuvinte-cheie*: productivitate, producție de tip lean, echilibrarea liniilor de producție, 5S, eficiență*

INTRODUCTION

The garment industry is one of the businesses that have the potential in building up an economy. History delineates that this industrial area has been a base for some effective modern improvements and hence Indian government has characterized an approach where one of the policies distinguished is quick development through the generation of high-esteem agricultural items and expanded help to send out situated assembling segments of textile and garment [1]. The garment industry in creating nations are lack of skilled workforce and additionally money to execute new advancements for enhancing efficiency and adaptability. Along these lines, ventures have been running generally for a considerable length of time and are inflexible to change. They don't have much certainty and will towards advancement over old procedures; henceforth coming about low efficiency and disappointment of clients [2]. Having a similar circumstance part of this issue is looking for ABC textile mills, India. The most ideal approach to adapt to every one of these difficulties is the presentation and routine of lean Manufacturing tools [3]. Lean is a term to depict a framework that produces what the client needs, when they need it, with the least waste, based on the Toyota production system [4]. Lean thinking spotlights on esteem included lean and comprise of best practices, tools and strategies from all through the industry with the points of eliminating waste and expanding the flow and productivity of the general system to accomplish definitive consumer satisfaction [5]. Lean Manufacturing is a manufacturing philosophy that abbreviates the time between the customer order and the item assembly/shipment by taking outsourcing waste. Another method for taking lean is that it plans to accomplish a similar yield with less input-less time, less space, less human exertion, less machinery, less material, and fewer expenses [6]. There are quantities of LM tools when utilized as

a part of appropriate ways will give the best outcomes [3].

Problem definition

Garment takes after a traditional creation framework. In this industry, the procedure stream format of an article of garment production which has between reliance between the cuttings and sewing segments is not legitimately format. Likewise in the sewing segment, the generation line is inadequately adjusted. Sewing tasks (concerning cutting and completing) need high skill and in addition quality work, as a result, related to repairing items sewed with wrong specifications [3]. Some other issues confronted which affect directly the garment industry is fabricating which straightforwardly influences profitability, for example, no standard circumstances exist for different creation tasks and target setting depends on mystery or encounter, pointless development, low generation limit and poor asset usage, for example, space, work, machine and time. Besides, keeping in mind the end goal to accomplish a constant efficiency increase and aggressive in the market, it is smarter to have the business with a smart production framework.

Research methodology

Research related to assembly line balancing problems and various lean tools. The underlying advance in this examination was methodically auditing the related literature such as various tools and strategies of the Lean Manufacturing framework, including the institutionalization of the work process, line balancing, and 5S. Likewise, rank positional weight (RPW) has been utilized for line balancing. Following this, the current creation arrangement of garments was considered utilizing qualitative research approaches [7] for gathering and examining the information. Primary information was gathered through physical observation and by utilizing a stopwatch time study on the shop floor. On account of the secondary information source, it was acquired through a literature review, internet sources identified with lean assembling and industry-specialized reports. In this study availability sampling techniques were utilized. Availability sampling techniques depend on the accessible possibility of the subject amid the study.

Objective

The objective of assembly line balancing is to divide the total work content of the job as evenly as possible between the stations and maximize the use of scarce resources. It helps to find out the production parameters and hence production planning and scheduling. In general, line balancing means minimising idle time or balancing loss, minimising the number of workstations, and distributing balancing loss evenly between stations while not violating any constraints [8]. In the apparel industry, these constraints are resource constraints, precedence constraints, and time constraints.

In practice, a perfect balance could not normally be achieved as shown in figure 1, where the workstation times are balanced and equal to the desired cycle time. In reality there exist an imbalance, which results from imperfect line balance. In practice periods of idleness caused by the difference between cycle times and workstation times is hard to find because a worker will normally be inclined to perform his or her work operations within the time available. It has been estimated that the balancing loss is normally between 5 and 20 percent in the garment industry.

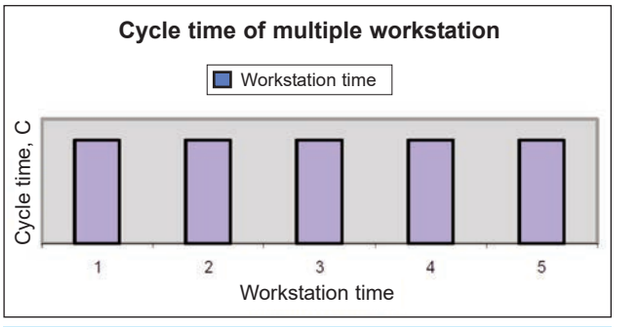


Fig. 1. Line balancing

LINE BALANCING PROCEDURE

Line balancing could be achieved by using many methods [9]. Some of them are linear programming, dynamic programming, heuristic methods, and computer programming. A heuristic method is one based on trials with logical ground rules or policies to guide the assignment of job elements to workstations [10]. Among other heuristic methods the Ranked Positional Weights (RPW) procedure (developed by Helgerson and Birnei) is a rapid, but approximate, method, which has been shown to provide acceptable good solutions quicker than many of the alternative methods; it is capable of dealing with both precedence and equipment constraints.

Balancing problems arise from the nature of work performed in garment factories [11]. The work is mostly manual and performed mostly by semi-skilled or unskilled workers. Their performance is unpredictable, which makes it difficult to determine the standard time of elements. Where the standard time of an element is the time required to operate for that particular element considering 100% performance for average workers and 15% personal allowance. A variety of orders also makes balancing harder in the garment industry. An order for garments may be one of two types [12]. In the first case, a single product is manufactured in large volumes for an individual client. In the second model, more than one product is manufactured for the client at the same time. This multi-model problem requires more planning and iteration [13]. Overall, the line-balancing problem in a garment factory becomes a complex activity due to the wide product variety. Unpredictable performance of mostly unskilled workers, very tight production schedules, supply chain problems and offline production is not always possible.

A production line should be so designed to achieve several goals. These goals are to improve productivity in terms of throughput and better utilization of scarce resources, to reduce material flow path and conflict, to provide a definite space for each production line, to create a conducive environment for the workers in each production line, and to increase the social interaction between workers and supervisors [12]. To meet these goals following issues need to be addressed. They are the number of production lines, the number of workstations and the number of workers per line, the floor space for each production line, and the adaptability of different models in a single line [13]. In designing the production line three aspects are considered in this research. They are balancing the production line and layout.

DATA COLLECTION

Using the RPW method a balanced production line has been designed. The parameters of the balanced line are calculated in the following manner. The time required to complete the work allocated to each station is known as the service time. The time available at each station for the performance of the work is known as the cycle time, the cycle time normally being longer than the service time.

Thus Cycle time = Service time + Idle time or loss (1)

The cycle time (C) and the minimum number of workstations (n min) can be calculated as follows,

$$C = T/N \quad \text{and} \quad n_{min} \geq N\sum t/T \tag{2}$$

where N is number of items to be produced, t – element time and T – time to produce N.

The average workstation time (c) is simply the total work content ($\sum t$) divided by the actual number of stations (n).

$$c = \sum t/n \tag{3}$$

Balancing loss percent is calculated as:

$$\text{Balancing loss} = \{(C - c)/C\} \times 100 = \{n(C) - \sum t\} \times 100/n(C) \tag{4}$$

The detailed steps of line balancing are shown below. RPW method takes standard time for each element as input and can come up with precedence diagram and other design parameters.

Step 1: Break down the whole assembly task into reasonable elements.

Step 2: Take several numbers of readings (Performance time) for each element. The average of these will give a selected time for each element.

Step 3: Determine the rating of each operator performing of each element based on normal Performance equal to 100%.

Step 4: Determine the Standard time for each element using Standard time = Normal time × 100/(100 – allowance in percent), where Normal time = Selected time × Rating in percent /100.

Step 5: An allowance of 15% for Personal time is usually considered for the assembly operation.

Step 6: Determine for each element the immediately preceding element(s).

Step 7: For each task determine positional weight. Positional weight of each task = element times of the task itself + time of all tasks that must follow it.

Step 8: Arrange the positional weight in descending order and construct a precedence diagram.

Step 9: Determine cycle time (C), where C = Available time per shift/production rate per shift.

Step 10: Select each workstation by summing the time of the highest positional weights such that the time should not exceed the cycle time & will not violate technological sequence.

Step 11: If an element violates either of the above restrictions passes over it and take the next acceptable element. When a station cycle time is filled. Move on to the next station.

Step 12: Sum up times for all operations to get total time $\sum t_i$.

Step 13: Theoretical number of workstations, $n = \sum t_i/C$ (should be integer number).

Step 14: Maximum efficiency, $E_{max} = \sum t_i/nC$, actual efficiency, $E = \sum t_i/mC$. Where, m = actual number of workstations.

Step 15: Note what elements constitute each workstation task. Thus an approximate layout will be obtained.

Step 16: Since the RPW technique does not necessarily give an optimum balance (i.e. $E < E_{max}$), attempt should be taken to get better efficiency by minor rearranging elements in a better configuration (if possible).

Girls top was selected for analysis using the RPW method. For each operation, a time study was conducted to determine all elements and the performance rating of the labour is assumed as 100%. Allowance was provided by 15% to the normal time for arriving standard time of the process. The corresponding standard time of various operations is shown in table 1. Other allowances are not considered for the calculation of the standard time.

DISCUSSION

Actual Number of Workstations in the existing system is 7, with one operator for each station. Takt time is calculated to improve the balancing of the process. The takt time is the average time between two successive units and can be evaluated as:

Takt time

$$T = \frac{\textit{Total Avaliable time per shift}}{\textit{Demand per shift}} \tag{5}$$

$$T = \frac{25200}{210}$$

$$T = 120 \text{ Sec}$$

The efficiency of the exiting line is calculated to evaluate the current performance of the system

$$\eta = \frac{\textit{Total Minutes produced}}{\textit{Total Minutes avaliable}} \tag{6}$$

Table 1

STANDARD TIME FOR GIRLS TOP											
Process number	**Operation**	**Observed time in sec**						**Performance rating**	**Normal time in sec**	**Allowance**	**Standard time in sec**
		1	2	3	4	5	AVG				
1	One side shoulder attach	60	63	58	65	65	62.2	100%	62.20	15.55	78
2	Label attachment	180	178	178	180	180	179.2	100%	179.20	44.80	234
3	Neck binding	120	123	120	118	115	119.2	100%	119.20	29.80	117
4	Back neck tape overlock	180	175	200	195	185	187	100%	187.00	46.75	149
5	The second shoulder attach	90	96	98	95	90	93.8	100%	93.80	23.45	224
6	Sleeve hem lower	120	125	130	118	120	122.6	100%	122.60	30.65	153
7	Sleeve attachment	240	243	228	230	248	237.8	100%	237.80	59.45	297
8	Side seam overlock	360	380	396	348	336	364	100%	364.00	91.00	455
9	Bottom hem (full length)	180	178	187	186	175	181.2	100%	181.20	45.30	227
10	Peak (in sleeve and rib)	180	169	178	180	189	179.2	100%	179.20	44.80	224
Total time required / Piece (sec)											2158

$$\eta = \frac{Output \times Standard\ Time}{Avalaible\ time \times Number\ of\ Operator} \times 100$$

$$\eta = \frac{42 \times 2158}{25200 \times 7} \times 100$$

$$\eta = 51.38\ \%$$

Balancing loss

$$B_L = 100 - \text{Efficiency} \quad (7)$$

$$B_L = 100 - 51.38 = 462\%$$

Cycle time

C = available time per shift / production rate per shift (8)

$$C = 25200/42 = 600 \text{ sec}$$

Based on the various operation carried out in manufacturing girls top precedence is calculated as shown in table 2. The operation starts with a shoulder attach and ends in a peak. The total number of operations in the girls top is limited to 10.

The precedence diagram was constructed as shown in figure 2 to identify the process flow of the girl' top. Once the precedence diagram is constructed the critical path in manufacturing the product is calculated, the various path in the girls top manufacturing are as follows:

Path 1: 1-5-8-9-10 = 78 +224 + 455 +227 + 224 = = 1208 sec

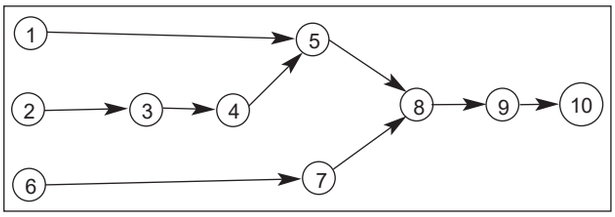


Fig. 2. Precedence diagram

Table 2

PRECEDENCE TABLE			
Process number	**Operation**	**Standard time in sec**	**Predecessor**
1	One side shoulder attach	78	-
2	Label attachment	234	-
3	Neck binding	117	2
4	Back neck tape overlock	149	3
5	Second shoulder attach	224	1.4
6	Sleeve hem lower	153	-
7	Sleeve attachment	297	6
8	Side seam overlock	455	5.7
9	Bottom hem (full length)	227	8
10	Peak (in sleeve and rib)	224	9

Path 2: 2-3-4-5-8-9-10 = 234 +117+149 + 224 + = 455 +227 + 224 = 1630 sec

Path 3: 6-7-8-9-10 = 153 + 297 + 455 +227 + 224 = = 1356 sec

Path 2 is a critical path with a duration of 1630 seconds.

For this particular product, Girls Top total time required for a single unit = 2158 seconds. Existing production = 6 units/hr, therefore Cycle time = 3600/6 = 600 seconds. We proposed a target with the cycle time, C = 460 seconds (Production demand is 1250 units). Therefore Per hour production will be =

3600/460 = 8 units, and number of workstations = 2158/460 = 4.69. The theoretical minimum number of workstations will be n = 5, Bottleneck time = 455 sec, Total task time = T = 2158 sec, Maximum production rate = 3600/460 = 8 units per hour, Cycle time C = 460 sec.

Theoretical number of work station $N = T/C$ = 2158/460 = 4.69 = 5 Station

Takt time

$$T = \frac{Total\ Avaliable\ time\ per\ shift}{Demand\ per\ shift} \quad (9)$$

$$T = \frac{25200}{280}$$

$$T = 90\ Sec$$

The efficiency of the proposed line is calculated to evaluate the current performance of the system

$$\eta = \frac{Total\ Minutes\ produced}{Total\ Minutes\ avaliable} \quad (10)$$

$$\eta = \frac{Output \times Standard\ Time}{Avalaible\ time \times Number\ of\ Operator} \times 100$$

$$\eta = \frac{56 \times 2158}{25200 \times 7} \times 100$$

$$\eta = 650\ \%$$

Balancing loss

$$B_L = 100 - Efficiency \quad (11)$$

$$B_L = 100 - 650 = 31.5\%$$

The ranked weight value of an operation is calculated by adding all operation time considered with the time of another precedence in the series. After all of the ranked positional weights of the operations are determined, they are arranged in decreasing order as shown in table 3.

Table 3

RANKED POSITIONAL WEIGHT METHOD			
Process Number	**RPW**	**Standard time in sec**	**Predecessor**
1	2158	78	-
2	2080	234	-
6	1846	153	-
3	1693	117	2
4	1576	149	3
5	1427	224	1.4
7	1203	297	6
8	906	455	5.7
9	451	227	8
10	224	224	9

Then tasks are assigned to each workstation starting from the task with the highest-ranked positional weight as shown in table 4. Before this the operation having the subsequent highest-ranked value should be selected from the other working operations to assign to the workstation; the precedence constraints are to be noted such that no operation is to be idle, and the operation time and unused workstation time should be controlled. The assignment procedure is continued until one of the conditions below is obtained:

1. If all the processes are assigned to the workstations,
2. If no operations are having either precedence or unassigned time constraints.

Table 4

ASSIGN TASK TO WORKSTATION			
Work station	**Process**	**Standard time in sec**	**Total time for station (sec)**
1	1	78	429
	2	234	
	3	117	
2	6	153	450
	7	297	
3	4	149	373
	5	224	
4	8	455	455
5	9	227	451
	10	224	

The possible improvements are identified in the product upon implementing the proposed line. The significant changes developed after line balancing is a reduction in Takt time, cycle time, balancing loss, workstation and increases in production efficiency as shown in table 5.

Table 5

COMPARISON OF BEFORE AND AFTER LINE BALANCING		
Description	**Before**	**After**
Takt Time	120 sec	90 sec
Cycle Time	600 sec	460 sec
Work station	7	5
Balancing Loss	462%	31.5%
Production/ Day	210	280
Line Efficiency	51.38%	65%

CONCLUSION

The manufacturing system in a garment factory is mostly manual and can be iterated many times over the life of the production of a model. Unfortunately, this manual process is not honed to the degree possible, oftentimes only because of a lack of understanding of line-balancing terminology and techniques. In this work a guideline has been presented to show how efficiently the production line can be

balanced in a garment factory, using a balancing for the production line.

1. The significant achievement is a 2% reduction in Takt time, a 23% reduction in cycle time, a 35% reduction in balancing loss and a 28% reduction in the number of workstations in lead time.
2. The production line efficiency has been increased by 25%.

REFERENCES

[1] Sorri, R., *Performance Measurement and Improvement of Ethiopian Garment Industries*, Masters Thesis of Science in Mechanical Engineering (Industrial Engineering Stream), School of Graduate Studies of Addis Ababa University, 2010

[2] Ramanan, G.V., Rajendran, C., *Scheduling in kanban-controlled flowshops to minimise the makespan of containers*, In: Int. J. Adv. Manuf. Technol., 2003, 21, 348–354

[3] Paneru, N., *Implementation of Lean Manufacturing Tools in Garment Manufacturing Process Focusing Sewing Section of Men's Shirt,* In: Oulu Univ. Appl. Sci., 2011, 80

[4] Monden, Y., *TOYOTA Production System An Integrated Approach to Just-In-Time*, 1988

[5] Chakraborttya, R., Paul, S., *Study and implementation of lean manufacturing in a garment manufacturing company: Bangladesh perspective*, In: J. Optim. Ind. Eng., 2011, 7, 11–22

[6] Nahmias, S., *Production and Operations Analysis*, McGraw Hill, New York, 2001

[7] Kothari, C.R., *Research Methodology: Methods and Techniques*, Delhi: New Age International, Delhi, India, 2012

[8] Sarder, M.D., Ali, M.Y., *Design of a Production Line- It's Balancing and Layouting for a Garment Factory*, 1996

[9] Miltenburg, G.J., Wijngaard, J., *U-line line balancing problem*, In: Manage. Sci., 1994, 40, 1378–1388

[10] Eryuruk, S.H., Kalaoglu, F., Baskak, M., *Assembly line balancing in a clothing company*, In: Fibres Text. East. Eur., 2008, 16, 93–98

[11] Milas, G.H., *Assembly Line Balancing, Let's Remove the Mystery*, 1990

[12] Barnes, R.M., *Motion and Time Study Design and Measurement of Work*, 7th ed. John Wiley & Sons Inc. Singapore, 1980

[13] Kriengkorakot, N., Pianthong, N., *The Assembly Line Balancing Problem: Review articles,* In: KKU Eng. J., 2007, 34, 133–140

Authors:

D. VASANTH KUMAR[1], G. MADHAN MOHAN[2], K.M. MOHANASUNDARAM[3]

[1]Department of Mechanical Engineering, Dr. N.G.P. Institute of Technology, Coimbatore 641048, Tamil Nadu, India

[2]Department of Production Engineering, PSG College of Technology, Peelamedu, Coimbatore 641004, Tamil Nadu, India
e-mail: gmadhanmohan@yahoo.co.in

[3]Department of Mechanical Engineering, SVS College of Engineering, Arasampalayam, Coimbatore 642109, Tamil Nadu, India
e-mail: kmmsundaram@gmail.com

Corresponding author:

D. VASANTH KUMAR
e-mail: vasanthmech09@gmail.com

Online purchase of textile products during Covid-19 crisis and the role of brand recognition – an empirical study

DOI: 10.35530/IT.073.06.202146

DHEENADHAYALAN ARUMUGAM ADALARASU BALRAJ

ABSTRACT – REZUMAT

Online purchase of textile products during Covid-19 crisis and the role of brand recognition – an empirical study

Textiles and clothing have been considered major industries ever since Indian civilization was born. The demand for clothing and textile products had always been high among Indian consumers. Covid-19 and the lockdown restrictions imposed on account of it have forced them towards making a purchase of textile products online rather than the conventional physical stores. The relationship between online brand recognition in the textile sector and the purchase intention of textile products by consumers through online mode has been empirically estimated in this research. Online brand recognition has been measured using five constructs. The demographic factors of consumers namely age, gender and educational qualifications have been taken as moderators and the influence of these factors on the purchase intention has also been examined. Data collected from 457 respondents were collected through a closed-end questionnaire designed with standard instruments. The outcomes showed that online brand recognition created an impact on the online purchase decision of consumers post Covid-19. It also has identified that the female consumers in India between the age groups 40-59 years form a majority when compared with the male consumers when purchasing textile products online.

Keywords: *textile products, online brand recognition, online purchase post Covid-19, Indian consumers, demographic factors*

Achiziția online de produse textile în timpul crizei de Covid-19 și rolul recunoașterii brandului – un studiu empiric

Textilele și îmbrăcămintea au fost considerate industrii majore încă de la nașterea civilizației indiene. Cererea de îmbrăcăminte și produse textile a fost întotdeauna mare în rândul consumatorilor indieni. Covid-19 și restricțiile de izolare impuse din cauza acestora i-au forțat pe consumatori să cumpere produse textile online, mai degrabă decât din magazinele fizice convenționale. Relația dintre recunoașterea brandului online în sectorul textil și intenția de cumpărare online a produselor textile de către consumatori a fost estimată empiric în această cercetare. Recunoașterea online a brandului a fost măsurată folosind cinci indicatori. Factorii demografici ai consumatorilor, și anume vârsta, sexul și nivelul educațional, au fost luați ca moderatori și a fost examinată și influența acestor factori asupra intenției de cumpărare. Datele de la 457 de respondenți au fost colectate prin intermediul unui chestionar cu întrebări închise, conceput cu instrumente standard. Rezultatele au arătat că recunoașterea online a brandului a creat un impact asupra deciziei de cumpărare online a consumatorilor după Covid-19. De asemenea, s-a identificat faptul că consumatorii de sex feminin din India, încadrați în grupele de vârstă 40-59 de ani, formează o majoritate în comparație cu consumatorii de sex masculin atunci când se cumpără produse textile online.

Cuvinte-cheie*: produse textile, recunoaștere online a brandului, achiziții online post Covid-19, consumatori indieni, factori demografici*

INTRODUCTION

Globally, the pandemic has changed people to adapt to technology and its services where the basic necessities and daily-use products should be brought through “online shopping” whether the consumer intends to opt for e-retailers are not is an option. In this study, how the brand as a factor impacts the consumers’ intention towards online shopping in the retail industry would be examined and studied for better understanding.

E-commerce and E-retailing have been booming since digitalization has uprooted its advantages and convenience into people’s minds. It could be witnessed during the pandemic (Covid-19) that businesses and companies that adopted online transactions and online shopping as their alternate source of product outlets have sustained their operations and gained profit, unlike traditional vendors and retailers. Though there are several advantages to e-shopping there are huge risks like fraudulent, late door deliveries, broken/damaged products, etc. hence people hesitate to opt for e-shopping, however, the impact of Covid-19 has altered this opinion and made people adapt towards online shopping [1].

The term/word “brand” was initially coined by the Romans and Greeks to promote their products and goods to the public. Though the modern Romans and Greeks introduced the concept of brands into

markets, it could be argued and witnessed that branding was introduced in the early 90s where an individual would name/ label his products under his "name", "address" and other "contact information" to implicate the top quality and services rendered by him towards his customers. Initially, the term was *"brandr"* which literally meant *burn,* i.e. where people burn their logo, name, symbol, terms, designs, number, ID or License number, etc. onto their goods and products or where farmers burn their ownership marks onto their cattle. This later became a recognition mark and reputation for the owners and thus the "brand" came into existence by fulfilling the psychological and basic needs of the consumers [2].

The products consumed by people globally could be categorized into two broad aspects, utility-based and pleasure based. The products bought by utility-based consumers are termed "utilitarian" and the pleasure-based consumers are termed "hedonic" [3]. The consumers intend to purchase products out of the following factors: necessity, desire, social status, lifestyle, fun and pleasure of buying [4]. Though consumers' purchase intention and brand factors differ from-one-another, the consumers either benefit themselves or benefit the sellers through profit. The necessity-based purchasing behaviour and decision by the consumers are termed *rational consumers* whereas the purchasing behaviour/decision of the consumers based on attraction, status, lifestyle and pleasure of buying/ shopping are termed, *emotional consumers.* Though consumption could be generally categorized as emotional and rational, there is also another factor that drives consumers towards purchasing products and that would be "ethical advertising/marketing" [5].

The factors or the determinants that attract consumers towards purchasing products could be summed up into three aspects: emotional need, basic need and status need [6] where the consumers' purchasing behaviour and buying decision vary according to brand, individual perception, product features and information. The perception could be categorized under theoretical models of marketing into five classifications: pro-environmental consciousness perspective, sociological perspective, responsible perspective, attitudinal perspective and altruistic perspective. Though these theoretical perspectives explain the consumers' general motivation towards purchasing products as beneficiary-based choices, it could also be argued that planned purchase is not necessarily always beneficiary and unplanned purchase is always not at loss [7].

The studies on the retail industry by authors [8–10] argued that the retail industry is an ever-booming industry where consumers' perception of demand and marketers' strategic ideas and products that would meet demands as supply will never diminish. However, the retail industry in every country could not be considered as a booming/ rising/ emerging factor that either directly or indirectly develops the economy of a country; for instance, due to Covid-19, many countries have stumbled to sustain within the market and run their operation and supply-chains. For instance, Macy's (an American high-end 160 years old store-chain: department that specialises in apparel, clothing and accessories: retailing) had gone to the gutter in the year 2019 had decided to cut the cost by closing-down 125 stores within 2024, cutting corporate jobs and offices around the globe. The loss of about US$ 4 billion where sales have not been exceeding 1% for the last 3 quarters occurred at Macy's, due to irrelevant demand and supply where the consumers' intention is way off from the brand offered by Macy's, especially during the pandemic Covid-19. The demands of the consumers were towards basic necessities and low-end clothing and apparel (since Covid-19 had made many jobless) which Macy's failed to provide their consumers with. Thus when the consumers are dissatisfied with products and their brands the retail industry and its associated retailer will witness a huge loss, whereas the consumers would prefer alternate solutions and indirectly benefit the competitors who offer the demands. Thus brand (i.e. high-end, low-end and moderate) as a factor in the retail industry plays a unique role where it could assist the retailers towards profit or huge loss [8, 11]. Though ethical marketing had been gaining many consumers globally and attracting online shoppers towards their brands, recently the new trend in the market, especially the textile/ fashion industry is "emotional branding" where the sellers and the retailers target their consumers towards their brand emotionally. The theories of Planned Behaviour [12], Reasoned Action Theory [13], Responsible Environmental Behaviour [14], Means-End Theory [15], Buying Behaviour [16], Moral Decision-making Theory [17, 18], Self-Perception Theory [19], etc had focused upon consumers' perception and necessity. However, in this research rather than just focusing on the consumer's end, how marketers and sellers lure the consumers towards their products through strategic thinking would be analysed where "brand" as a factor would be studied.

Thus by analysing the brand, the researcher focuses on the retail industry and online shopping through emotional branding, brand awareness, brand loyalty, brand recognition and purchase intention especially through Covid-19 as a factor and how the age, gender and education qualification as moderators impact each variable.

LITERATURE REVIEW

The literature on brand as a marketing strategy and consumer intentions along with the relevant factors and variables of branding and online consumers in India had been studied in this research.

In research, authors studied "Utilitarian motivation" through the online consumption model and found that youths and adults are the most common users of the internet that purchase necessity-based products, especially men of 30–50 years [20]. In the following year, a study by [21] where the Indian youths were targeted as the "target groups" who preferred online

shopping was conducted towards measuring utilitarian motivations. According to the study, India is considered the second largest country globally, where internet users are emerging rapidly succeeding the Chinese which indicates a huge opportunity for the digitalized and internet-based retailers and manufacturers, i.e. e-commerce. According to the author, youngsters (18–24 years) in India are the common internet users and thus the retailers and ecommerce firms advertise accordingly to grab the opportunity by attracting the youths of India. However, the youngsters are not the decision makers and thus deciding upon the final products would be made by the adults of age 30–50. Though the study found that young and adults are online consumers, it was also found by the authors that, the consumers opted for utilitarian-based products for their households and their elders than leisure and luxury products, where e-commerce offered: feature relevant information, monetary savings, assortment, convenience and anonymity.

In consumer behavioural research [22] hedonic motivations were measured and examined. According to the investigator's views and opinion, the hedonic values and approaches as benefits had not been thoroughly examined and analysed by researchers and thus partial information and unconfirmed facts have been in circulation among the literature and research. According to their perspectives, a hedonic product is termed as a "non-functional" value-based product that could be shopped/ purchased by consumers through the following factors: visual appeal, role shopping, sensation seeking, intrinsic enjoyment, hang-out, escape, socialise, self-expression and enduring involvement. The study was framed and organized upon the online consumers with focus groups and authors found that retailers must satisfy their customers with appropriate and rapid responses by offering the best services pre and post-purchase. Also, the retailers should concentrate on hedonic values along with utilitarian values and update themselves according to the market to sustain their position if not they could collapse and lose investments and the business without any returns and profits.

Pakistan's beverage industry and how the consumer intention was towards "brand" especially in fizzy drinks through trust and loyalty as variables were researched [23]. The study focused on 200 respondents through a survey as their "questionnaire" tool by examining the responses and analysing them with regression techniques. The study found that "emotional branding" as a strategic plan by companies and firms could attract more consumers where the customers could highly attach themselves to the brand to their past experiences. Though they concluded that the factors of consumers' buying decisions/behaviour and emotional branding have a strong relationship, they also argued that it might vary from consumers' age, gender and experience globally. Hence the authors concluded that consumer intention and perception is not stable factor that could offer researchers reliable outcome and hence the researchers should study the same experiment with the same respondents years apart to prove their facts and theories.

"Emotional branding" in her research [24] by focusing on 105 youngsters in India and their purchase intentions. She found that youngsters were attracted towards five factors when "brand" is mentioned, they are trust, lifestyle, personality, relationship and attitude of the brand. According to her findings and analyses, emotional branding (relationship, trust, personality and lifestyle) and brand as attitude have a strong and positive relationship that correlates with purchase intentions, where the variables brand lifestyle and brand trust play a huge role in consumers' buying decisions and intentions.

To validate the study, the author [24] also examined emotional confidence and brand as factors that impact consumers' intention towards products. However, the author found that brand attitude where utilizes "belief" (trust) as an important variable between the brand and consumer decides upon the buying intention rather than other factors in brand as a strategy by firms and companies. The author also argued that brand as the belief was utilized and is being utilized by the companies and firms to attract more consumers and retain the existing consumers and thus they could sustain in the market. However once the trust/loyalty/belief was demolished through negative emotions (for instance: anger, fear, loss, dissatisfaction, etc.) then the consumers would eventually drag the company down-fall with their negative feedback, bad responses and negative recommendations to other consumers, especially through online shopping and internet as a medium for communication.

Online shopping consumers during and post Covid-19 in Vietnam were researched [25]. According to their findings, the in-stores that were not digitized took a hit especially the retail stores, since the online consumers opted for familiar brands with reasonable pricing and better quality and hesitated to purchase similar products online since they were attached to their retailers and street vendors than brands and e-commerce firms. Also, the study revealed that even through the lockdown and pandemic situations the Vietnamese preferred traditional in-store shopping to online shopping due to a lack of brand recognition and brand awareness. Thus the authors concluded that government and the relevant officials should take necessary and effective measures towards consumers' demands and needs and support local marketers rather than providing new business opportunities and online-based firms with higher investment, especially when it affects industries, like retail, fashion and apparel, etc.

[26] Survey upon the fashion and retail industry during and post Covid-19 and how it impacted the consumers' intention towards the brand and design practices of similar minds in the markets, where 31 designers as targets were aimed. According to their outcomes and findings materials, product longevity, sustainable designs, product recycling, social

responsibility and ethical practices of the companies are the most predominant factors that attracted customers. Hence the authors recommended that though the pandemic affected many companies and firms financially, people and consumers seek ethicality and brand value higher where they could feel comfortable.

Thus through the examined literature reviews, it could be understood that brand as visual appeal, brand ethicality as social reputation, brand emotion, brand awareness/familiarity and aesthetic attractions factors influence the consumers' purchase intentions of consumers with different ages, gender and qualification [27]. The following table (table 1) is a summarization of the reviewed literature in the research.

Research gap and contribution

The emotional branding strategies defined by Kim and Sullivan [28] state that, based upon the market trends the emotions of the consumers (refer to figure 2) could vary where the consumers are attracted by four factors: *stories* of the sellers and consumers through product experiences; *social causes* and the sellers' involvement in shaping-up the society and environment; *sensational branding* where the consumers are attracted through tastes, smell, vision (colour, pattern, features, design, etc), feel and sound; and *empowerment branding* where the sellers and consumers are directly involved as "us" rather than "we/me". Hence to bridge the existing literature/research gap on the impact of the brand as a strategy for evaluating the purchase intention of online consumers, the researcher will be attempting to conduct this study towards examining the brand strategies (awareness, emotion, loyalty: *altogether as brand recognition*) in advertising or marketing products towards consumers. The study will be focusing on branding strategies adopted by the textile industry or fashion industry and how these strategies impact "online shopping" consumers.

The study's focus will also be on the factor "Covid-19" since the number of users for online shopping increased due to the lockdown drastically, for instance, one author [1] conducted a study on online consumers and their buying behaviour towards products pre and post Covid-19 in Iraq and found that overall the in-store sales was about 98% in 2019 whereas just 2% of online sales. However, post and during Covid-19 people were compelled to purchase online/websites which made the in-store sales drop from 98% to 84% while online sales went up to 16% in 2020. However, the researcher failed to examine the strategic factor that has impacted the consumers towards online shopping (i.e. brand awareness, brand emotion, brand loyalty) in Iraq. Thus by focusing on purchase intention, Covid-19, the textile industry and also brands as a factor, this study would be funnelling down the existing gap and will also contribute the future researchers with valuable and reliable information that could be adopted for the similar topic in later studies. In future, the same study could be broadened by focusing on other factors than purchase intention to have an in-depth analysis towards brand recognition and consumers' buying patterns online as a medium for shopping.

Table 1

RELATIONSHIP BETWEEN DETERMINANTS OF BRAND AND ONLINE CONSUMERS AND THEIR PURCHASE INTENTIONS

S. No.	Author	Year	Findings
1	Martinez-Lopez et al. [20]	2014	The study found that youths and adults of 30–50 years are common users of online shopping sites towards "utilitarian" goods
2	Ahmed and Sathish [21]	2015	The study by authors revealed that Indian youths are more regular online shoppers than adults
3	Martinez-Lopez et al. [22]	2016	The study by authors examined youths and adult consumers towards "hedonic" goods and found that hedonic users are greater than utilitarian goods through brand recognition
4	Riaz et al. [23]	2017	Examined the "brand" as a factor towards beverages in Pakistan and found that consumers' intentions are impacted by emotional branding
5	Ankita [24]	2018	Studied the emotional branding upon youngsters in India and found brand as attitude impacts youngsters along with emotional branding
6	Rizvi and Oney [27]	2018	Emotional branding and consumers' intention towards purchase were examine\d by the author and found that negative emotions cause loss to retailers and positive emotions help retailers, especially in online shopping
7	Pham et al. [25]	2020	Examined online shopping during Covid-19 and how the brand as a factor impacted their decisions and buying behaviour and found that brands that satisfied "demand" through "supply" will flourish unlike trend-based retailers in pandemic situations.
8	Karell and Niinimaki [26]	2020	Examined the retail and fashion industry and how brand impacted consumer intention and found products' quality, longevity, material, sustainability and comfort made a brand recognized, unlike other competitors.

Theoretical framework

Figure 1 below represents the attributes of brand recognition as an independent variable impacting the online shopping of the textile industry during Covid-19 through consumer perception as the dependent variable.

Research hypotheses

The following hypotheses are framed towards assessing the study's objective-based issues.

H1: *Online brand recognition* in the textile industry has an impact on the Purchase Intentions of textile products by consumers post Covid-19

H1.1: *Online Brand Familiarity* creates an impact on the purchase Intentions of textile products by consumers post Covid-19

H1.2: *Online Brand Emotion* creates an impact on the purchase Intentions of textile products by consumers post Covid-19;

H1.3: *Online Aesthetic Attraction* creates an impact on the purchase Intentions of textile products by consumers post Covid-19;

H1.4: *Online Social Reputation* creates an impact on the purchase Intentions of textile products by consumers post Covid-19;

H1.5: *Online Visual Simplicity* creates an impact on the purchase Intentions of textile products by consumers post Covid-19.

H2: The relationship between Online brand recognition and Purchase Intentions of textile products by consumers post Covid-19 is moderated by the age of the consumers.

H3: The relationship between Online brand recognition and Purchase Intentions of textile products by consumers post Covid-19 is moderated by the gender of the consumers.

H4: The relationship between Online brand recognition and Purchase Intentions of textile products by consumers post Covid-19 is moderated by the educational qualification of the consumers.

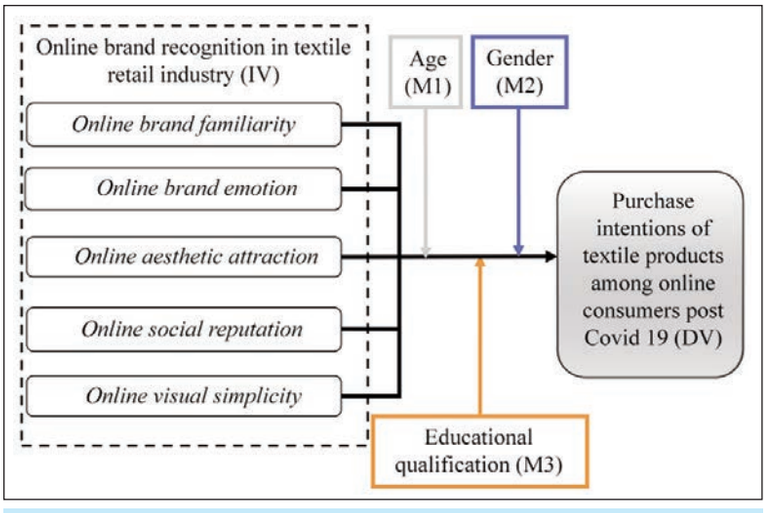


Fig. 1. Conceptual framework of online brand recognition and purchase intention of consumers in online shopping in the retail industry

RESEARCH METHODOLOGY

In general, research methodologies include network pathways for machine learning-based studies and every other research consists of techniques, tools, paradigms, design, approach, analyses (statistical, numerical, lingual/contextual, historical, software and hypothesis testing), sampling, data gathering, development of a scale for analysing the datasets. Based upon these basic techniques research is weighed and analysed for its accuracy, reliability, validity and continuity through ethical considerations.

This study adopts the top-down approach where the researcher would gather data from the primary targets of *Indian textile consumers* and relevant literature and studies from secondary resources (journals, articles, books, internet: e-books, e-journals, e-articles and more). Research paradigms commonly adopted by the researcher would be interpretivism (seeking reality rather than accepting the truth/ facts as it is), positivism (evaluating, examining and investigating the facts) and mixed (of both) [29]. This research would adopt the *positivism paradigm* since the researcher aims to evaluate the impact of purchase intentions upon a brand by online consumers. Thus the study could be classified as a *quantitative study* since it will be adopting measures of statistical and numerical analyses along with the *deductive* approach to gather reliable data. When the research is framed or developed by the researcher it is normally based on a pattern or a design (causal, descriptive and exploratory) where the researcher adopts the relevant and suitable design [30]. The research would be adopting the *descriptive design* since the study involves targets of similar interests, experiences and knowledge and analysis of their experiences as consumer values to evaluate the variables.

Sample

Since the study would be aimed at online consumers, the targets would be undetermined *1000+* and thus the sample would be calculated under-sampling techniques. The calculations of samples from targets are done through a 99% confidence level with 50 population proportions and 1% margin-of-error (MOE). Before cleansing data from irregularities, repetitions, data redundancy and incompleteness of questionnaires, and irrelevant participants, the size was 1000+ and post data cleansing, the size was corrected as 469. The sample size would be *457* according to the regulations of sampling techniques [31].

The sampling techniques for e-commerce-based studies technically fall under random/probability sampling since the researcher doesn't manipulate the environment. In probability sampling: area, simple-random, stratified, systematic, cluster and multi-stage

are the common techniques utilized for required purposes; whereas in non-probability/non-random sampling techniques: quota, judgement, panel, snow-ball and convenience sampling as approaches are dealt with by researchers to gain estimated outcomes from datasets. Since the research is online consumer behaviour upon brands in the textile industry, "cluster sampling" is appropriate. Market analyses and researchers adopt cluster sampling due to an undetermined population and could gain cluster datasets to group similar tastes, preferences, assumptions, opinions, values, beliefs and decisions of participants to conclude the research with valuable factors favouring individuals.

Methods and ethicality

The statistical/numerical analyses in this study comprise *Structured Equation Modelling using AMOS.* The ethicality and validation measures would also be considered under studies design and approach and thus the relevant measures would be undertaken to keep the respondents' information anonymous.

Data acquisition

The primary sources/data for the research would be gathered under the *closed-end questionnaire* model as the tool from the targets, which is considered a *survey* technique. Through closed-end, as a tool, the evaluation would be reliable/constant and valid instead of being vague or inconsistent. The secondary sources will be attained from relevant studies on brand, brand recognition, brand as emotion, purchase intention, online consumers, online shopping, e-retailing, etc. The targets were determined as online purchasers of different age groups (18–60+ years) and should know the brands in online ports and websites before participating; if not they would be discarded as invalid participants through oral confirmation.

Development of utilized scale

The scale was developed into two sections where online brand recognition factors that have 5 constructs (OBF, OBE, OAA, OSR and OVS) with every 5 items [32] totalling *25 items* were adopted along with *3 items* of purchase intentions (PI) [33] in [34], which totals to a *28 items scale,* which is:

1. Online Brand Familiarity (OBF) with (5 items);
2. Online Brand Emotions (OBE) with (5 items);
3. Online Aesthetic Attractions (OAA) with (5 items);
4. Online Social Reputation (OSR) with (5 items);
5. Online Visual Simplicity (OVS) with (5 items) and
6. Purchase Intention (PI) with (3 items).

The demographic profile contains the consumers' information where age, educational qualification and gender are the important factors since they are the moderators in this investigation that would be examined to study the relationship between the dependent variable (Online Brand Recognition: OBR) and independent variable (PI). The scale was 5 point Likert scale where Strongly Disagree values as 1 towards Strongly Agree values as 5. The study mainly examines the targets of Indian participants and thus other geographical area-based responses would be rejected or discarded.

Justification of scale adoption

The brand as awareness and loyalty among online shoppers were examined in research [35] by adopting the scale developed by Rahman [32] and the outcomes were consistent and reliable; similarly, the researchers adopted the scale from [33] towards purchase decisions and intentions of online consumers and found their outcomes consistent too. Henceforth adoption of scales from [32] and [36] is justified since the research is on the purchase intentions of online consumers towards the textile industry in weighing brands as the primary factor.

RESULTS AND FINDINGS

Results

The demographic data was found through the analyses and it shows that respondents of age groups 50–59 years were the major users (35.8%) followed by 40–49 years (30.2%) than the elders and youths which contradicts the study by [21] and similarly the findings prove that "utilitarian motives" are higher during Covid-19 which in-turn supports the study conducted by [20] towards age as a factor in online shopping; however when the gender is considered it is observed that 69% are female shoppers and only 31% are male shoppers which again contradicts the study by [20]. It is found that during the Covid-19 Female shoppers were major shoppers who had purchased "utilitarian" products and had educational qualification levels of Post-Graduation (33.2%), Under-Graduation (32.8%) and high-schooling (23.7%).

As per the analyses and examination, it has been found that the brand as "visual simplicity" and "familiarity" in online shopping has attracted the respondents more, than social reputation, aesthetic attraction and brand emotion in online retailing through consumers' purchase intentions.

Findings

The reliability of the developed concept was tested out with Cronbach alpha (refer to table 2) and the results pointed out that constructs are within the standard value (i.e. above 0.6–0.7) and thus it is reliable and valid to adopt the constructs to attain the objective.

Table 2

RELIABILITY TEST THROUGH CRONBACH'S ALPHA

S. No.	Construct	Items	Alpha
1	Online brand familiarity	5	0.882
2	Online brand emotion	5	0.787
3	Online aesthetic attraction	5	0.919
4	Online social reputation	5	0.772
5	Online visual simplicity	5	0.926
6	Purchase intentions of the consumers upon online shopping	3	0.855

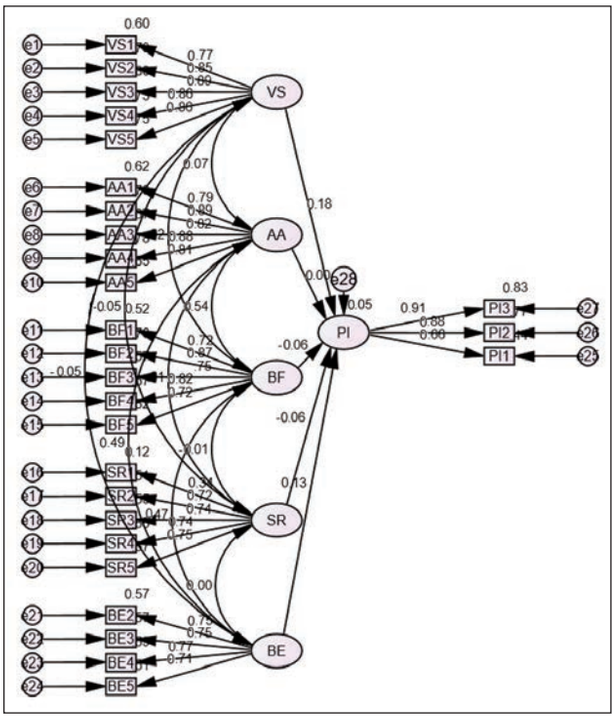


Fig. 2. Casual fit – Model fit

Figure 2 depicts that the values of OBF (0.882), OBE (0.787), OAA (0.919), OSR (0.772), OVS (0.926), and PI (0.855) are well within the acceptable and reliable ranges in alpha testing.

The model fit through the examination also shows a good fit (refer to figure 2) interpreting that the constructs and the variables correspond well together stating the facts that the sample and the variables are valid to conduct the study upon the developed aim.

The casual model fit's interpretation (refer to table 3) states that the attained outcome and the estimated outcome are similar, which makes the fit valid. The values of the factors under the model test obtained are CMIN/DF (statistics of chi-square fit/degree-of-freedom) = between 1 & 3, (comparative-fix-index) CFI>0.95, (root-mean-squared-residual) SRMR<0.08, (root-mean-square-error of approximation) RMSEA < 0.06 and PClose is > 0.05.

Table 3

MODEL FIT – INTERPRETATION			
Measure	**Estimate**	**Threshold**	**Interpretation**
CMIN	503.712	-	-
DF	391	-	-
CMIN/DF	1.288	Between 1&3	Excellent
CFI	0.968	>0.95	Excellent
SRMR	0.048	<0.08	Excellent
RMSEA	0.035	<0.06	Excellent
PClose	0.998	>0.05	Excellent

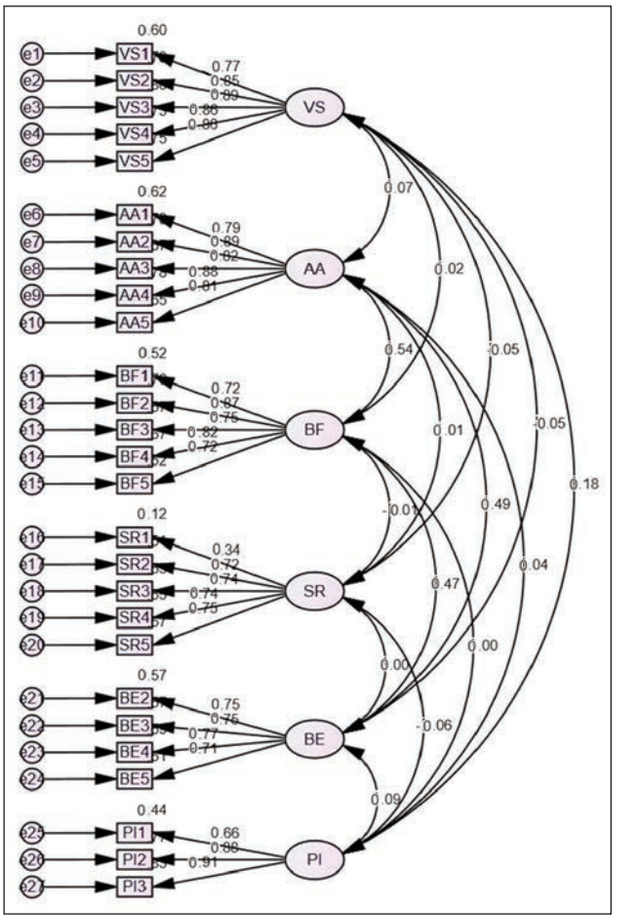


Fig. 3. Measurement fit – Structural fit

Through the structural fit model (refer to figure 3) the relationships of the constructs and the reliability of the constructs are verified for better fitness through the highest likelihood estimation testing process towards achieving the pre-determined criterion.

The convergent reliability of research should be greater than 0.07, where *"average variance extract"* (AVE) should be 0.5 and greater and the *maximum shared variance* (*MSV*) should be eventually lesser than AVE. Through the structural fit it could be interpreted that, the CR values are above 0.07, AVE is greater than 0.5 and MSV < AVE (refer to table 4).

Table 4

CFA MODEL – INTERPRETATION									
Indicator	**CR**	**AVE**	**MSV**	**MaxR (H)**	**SR**	**VS**	**AA**	**BF**	**BE**
SR	0.739	0.783	0.002	0.831	**0.719**				
VS	0.893	0.607	0.005	0.933	–0.046	**0.779**			
AA	0.876	0.785	0.293	0.927	0.014	0.068	**0.765**		
BF	0.832	0.508	0.293	0.897	–0.011	0.019	0.541	**0.713**	
BE	0.778	0.748	0.237	0.835	0.004	–0.050	0.487	0.472	**0.670**

The values of each construct of the brand as a variable are: SR with 0.719, VS with 0.779, AA with 0.765, BF with 0.713 and BE with 0.670. It could be inferred that constructs are above 0.6 and are reliable.
Thus it is examined and inferred that the developed model is a success, where the constructs, variables and samples are valid and reliable to conduct the study.

ANOVA regression for hypothesis testing

Regression analysis through ANOVA was carried upon the model to test the hypotheses to examine the relationship between PI and OBF, OBE, OAA, OSR and OVS.
The developed hypotheses were examined and tested out with the sample and the outcomes were attained through statistical analyses results of the hypotheses were all accepted (refer to tables 5–10) since the significant level of "p-value" (0.000) in ANOVA regression testing was < 0.05. It is also well established that the OBR has an impact on PI where the moderators have a positive relationship between the variables (refer to table 10).

Table 5

ANOVA FOR PURCHASE INTENTION AND ONLINE BRAND FAMILIARITY					
Model	**Sum of Squares**	**df**	**Mean Square**	**F**	**Sig.**
Regression	0.062	1	0.062	0.015	0.000[a]
Residual	942.955	230	4.100		
Total	943.017	231			

Note: a – Predictors: (Constant), OBFTOT.

Table 6

ANOVA FOR PURCHASE INTENTION AND ONLINE BRAND EMOTIONS					
Model	**Sum of Squares**	**df**	**Mean Square**	**F**	**Sig.**
Regression	7.613	1	7.613	1.872	0.000[a]
Residual	935.404	230	4.067		
Total	943.017	231			

Note: a – Predictors: (Constant), OBETOT.

Table 7

ANOVA FOR PURCHASE INTENTION AND ONLINE AESTHETIC ATTRACTIONS					
Model	**Sum of Squares**	**df**	**Mean Square**	**F**	**Sig.**
Regression	2.939	1	2.939	0.719	0.000[a]
Residual	940.078	230	4.087		
Total	943.017	231			

Note: a – Predictors: (Constant), OAATOT.

Table 8

ANOVA FOR PURCHASE INTENTION AND ONLINE SOCIAL REPUTATION					
Model	**Sum of Squares**	**df**	**Mean Square**	**F**	**Sig.**
Regression	3.812	1	3.812	0.933	0.000[a]
Residual	939.206	230	4.084		
Total	943.017	231			

Note: a – Predictors: (Constant), OSRTOT.

Table 9

ANOVA FOR PURCHASE INTENTION AND ONLINE VISUAL SIMPLICITY					
Model	**Sum of Squares**	**df**	**Mean Square**	**F**	**Sig.**
Regression	30.266	1	30.266	7.627	0.000[a]
Residual	912.751	230	3.968		
Total	943.017	231			

Note: a – Predictors: (Constant), VSTOT.

Table 10

OUTCOMES OF HYPOTHESES TESTING		
S. No.	**Hypothesis**	**Accepted/Rejected**
H1	*Online brand recognition* in the textile industry has an impact on the Purchase Intentions of textile products by consumers post Covid-19	Accepted
H1.1	*Online Brand Familiarity* creates an impact on the purchase Intentions of textile products by consumers post Covid-19	Accepted
H1.2	*Online Brand Emotion* creates an impact on the purchase Intentions of textile products by consumers post Covid-19	Accepted
H1.3	*Online Aesthetic Attraction* creates an impact on the purchase Intentions of textile products by consumers post Covid-19	Accepted
H1.4	*Online Social Reputation* creates an impact on the purchase Intentions of textile products by consumers post Covid-19	Accepted
H1.5	*Online Visual Simplicity* creates an impact on the purchase Intentions of textile products by consumers post Covid-19	Accepted
H2	The relationship between Online brand recognition and Purchase Intentions of textile products by consumers post Covid-19 is moderated by the age of the consumers	Accepted
H3	The relationship between Online brand recognition and Purchase Intentions of textile products by consumers post Covid-19 is moderated by the gender of the consumers	Accepted
H4	The relationship between Online brand recognition and Purchase Intentions of textile products by consumers post Covid-19 is moderated by the educational qualification of the consumers.	Accepted

DISCUSSION AND CONCLUSION

Discussion

The study primarily focuses on branding and its strategies to attract consumers through traditional and modern marketing as a tool. Recently digitized or computerized-based businesses and their operations are being identified as the most effective and helpful strategy where the consumers purchase what they intend to and retailers sell what the demand in the market is about [10]. Although there are several advantages to online shopping or digitized retailing, people who have lesser knowledge towards computers, technology, the internet, online shopping, online retailing and sorts and the illiterate are the ones who suffer greatly. There are several studies [11, 37–39] that had been focused on online shopping, online retailing, online shoppers, teenagers and e-shopping, etc. where the focus is mainly on the shoppers/consumers and how e-retailing has an impact on them. No studies or research have focused on multiple factors that impact the purchase intention of consumers, especially where brand as a strategy plays a unique and vital role in examining the consumers' purchasing behaviour and decision upon their intention of Utility and Hedonic attributes.

Though during Covid-19 people have adopted and adapted to the internet as a mode of shopping for utilities and goods, there are people (for instance: aged and illiterate people) who don't know Smartphones and online shopping. However, in this digital era, there would be at least one person in a family who would be interested in advanced or hi-tech mobile phones (androids and smartphones) and the internet where online shopping is a possibility, where they would not bother about product information or the brands that offer the goods. Hence to study the impact of purchase intention versus the brand would be an ideal subject matter to find the usefulness of online shopping and how the brand as a factor has impacted people to purchase products rather than product availability, product placement and pricing strategies. The study would also be significant in future for researchers who seek information and facts through the brand as a strategy that impacts the consumers' decisions and behaviour as purchase intention.

Conclusion

The study aims at analysing the purchase intentions of online shoppers through the brand as a factor during Covid-19, in the textile industry. Though the study is based on consumer purchases where the brand plays an important role in examining the online shoppers' purchasing intention, it has certain limitations, such as the study: is conducted for examining the intention of the online shoppers; only focuses on Indian participants and respondents who have brand knowledge; doesn't concentrate or analyses the traditional shopping intention of consumers during Covid-19 and focuses on the impact of brand upon the consumers' purchase intention and thus other variables would be ignored if irrelevant. The research will be conducted for the Indian online consumers as our targeted respondents and thus the other country or non-India state-based responses would be rejected. It could be concluded that female purchasers or online shoppers during Covid-19 are major than male shoppers; the age (i.e. major users are 40–59 years shoppers) as moderator has a positive impact on the variables along with gender (i.e. female shoppers) and educational qualification (i.e. major users are from high school, UG, PG). The outcome proves that

the independent variable OBR (Online Brand Recognition) were the factors: online brand familiarity, online brand emotion, online social reputation, online aesthetic attraction and online visual simplicity has a positive impact on the dependent variable PI (purchase intention) in the retail industry, in which the "online visual simplicity" and "online brand familiarity" attract the shoppers greatly, then online brand emotion, online social reputation and online aesthetic attraction.

REFERENCES

[1] Ali, B.J., *Impact of COVID-19 on consumer buying behaviour toward online shopping in Iraq*, In: Journal of Economic Studies, 2020, 18, 3, 267–280.

[2] Kotler, P., Armstrong, G., Saunders, J., Wong, V., *Principles of marketing*, The European ed., Prentice Hall Europe, Hertfordshire, 1996

[3] Kim, H.-S., *Using Hedonic and Utilitarian Shopping Motivations to Profile Inner City Consumers*, In: Journal of Shopping Center Research, 2006, 13, 1, 58–80

[4] Rahman, M.T., Pial, T., *Influence of Rational and Emotional Appeals on Purchasing Through Online: The Case on Social Media*, In: International Journal of Financial Research, 2019, 11, 1, 34–42

[5] Lee, J.-Y., Jin, C.-H., *The Role of Ethical Marketing Issues in Consumer-Brand Relationship*, In: Sustainability Report, 2019, 11, 6536, 1–21

[6] Popovic, I., Bossink, B.A.G., Peter, C., van-der-Sijde, *Factors Influencing Consumers' Decision to Purchase Food in Environmentally Friendly Packaging: What Do We Know and Where Do We Go from Here?*, In: Sustainability J. Review, 2019, 11, 7197, 1–22

[7] Steenis, N.D., Van-Herpen, E., Van-der-Lans, I.A., Ligthart, T.N., Trijp, H.C.M., *Consumer response to packaging design: The role of packaging materials and graphics in sustainability perceptions and product evaluations*, In: J. Clean. Prod, 2017, 162, 286–298

[8] Huda, S.S.M.S., Zubayer, M., Faruq, O., *Marketing Strategies of Retail Stores: An Evaluation of Grocery Shops of Dhaka City*, In: Global Journal of Management and Business Research, 2011, 11, 7.1, 81–87

[9] Suguna, P., Mathipoorani, V.B., *Strategies for Retail Marketing*, In: IOSR Journal of Business and Management (IOSR-JBM), 2016, 18, 6, 21–29

[10] De-Juan-Vigaray, M.D., Segui, A.I.E., *Retailing, Consumers, and Territory: Trends of an Incipient Circular Model,* In: Social Sciences, 2019, 8, 300, 1–15

[11] Saha, S., Sharma, A., Kumar, A., *Factors That Influence Retail Store Preference and Impact of in-Store Digitization*, In: International Journal of Recent Technology and Engineering (IJRTE), 2019, 8, 4, 8715–8722

[12] Ajzen, I., *The theory of planned behaviour*, In: Organisation Behavioural and Human Decision Process Journal, 1991, 50, 179–211

[13] Ajzen, I., Fishbein, M., *Understanding Attitudes and Predicting Social Behaviour*, Pearson: London, UK, 1980

[14] Hines, J.M., Hungerford, H.R., Tomera, A.N., *Analysis and Synthesis of Research on Responsible Environmental Behaviour: A Meta-Analysis*, In: Journal of Environmental Education, 1987, 18, 1–8

[15] Gutman, J.A., *Means-End Chain Model Based on Consumer Categorization Processes*, In: Journal of Marketing, 1982, 46, 60–72

[16] Haines, G.H., Howard, J.A., Sheth, J.N., *The Theory of Buyer Behaviour*, Wiley: New York, NY, USA, 1969

[17] Schwartz, S.H., *Elicitation of moral obligation and self-sacrificing behaviour: An experimental study of volunteering to be a bone marrow donor*, In: J. Pers. Soc. Psychology, 1970, 15, 283–293

[18] Maslow, A.H., *A Theory of Meta-motivation: the Biological Rooting of the Value-Life*, In: Journal of Humanist Psychology, 1967, 7, 93–127

[19] Bem, D.J., *Self-perception: An alternative interpretation of cognitive dissonance phenomena*, In: A. Psychol. J. Rev, 1967, 74, 183–200

[20] Martinez-Lopez, F.J., Pla, C., Gázquez-Abad, J.C., Rodríguez, I., *Utilitarian motivations in online consumption: dimensional structure and scales*, In: Electronic Commerce Research and Applications, 2014, 13, 3, 188–204

[21] Ahmed, K.A.A., Sathish, A.S., *Unleashing the Utilitarian Motivations of Online Shopping among Indian Youth*, In: Mediterranean Journal of Social Sciences, MCSER Publishing, Rome-Italy, 2015, 6, 2, 391–398

[22] Martinez-Lopez, F.J., Pla-Garcia, C., Gazquez-Abad, J., Gazquez-Abad, J.C., Rodriguez-Ardura, I., *Hedonic motivations in online consumption Behaviour*, In: Int. J. Business Environment, 2016, 8, 2, 121–151

[23] Riaz, H., Ahmed, H., Akhter, S., Hussain, M., *The Impact of Emotional Branding in Customer Buying Behaviour in Soft Drink Beverage Industry of Pakistan*, In: KASBIT Business Journal (KBJ), 2017, 10, 131–150

[24] Ankita, N., *Emotional Branding: A New Way to Connect to Customers*, In: International Journal of Management Studies, 2018, 5, 4.2, 1–9

[25] Pham, V.K., Thi, T.H.D., Le, T.H.H., *A study on the COVID-19 awareness affecting the consumer perceived benefits of online shopping in Vietnam*, In: Cogent Business & Management, 2020, 7, 1, 1–16

[26] Karell, E., Niinimaki, K., *A Mixed-Method Study of Design Practices and Designers' Roles in Sustainable-Minded Clothing Companies*, In: Sustainability, 2020, 12, 4680, 1–25

[27] Rizvi, W.H., Oney, E., *The influence of emotional confidence on brand attitude: Using brand belief as mediating variable*, In: Economic Research-Ekonomska Istraživanja, 2018, 31, 1, 158–170

[28] Kim, Y.-K., Sullivan, P., *Emotional branding speaks to consumers' heart: the case of fashion brands*, In: Fashion and Textiles, Springer, 2019, 6, 2, 1–16

[29] Kivunja, C., Kuyini, A.B., *Understanding and Applying Research Paradigms in Educational Contexts*, In: International Journal of Higher Education, 2017, 6, 5

[30] Kothari, C.R., *Research Methodology: Methods and Techniques*, New Age International publishers, New Delhi, 2013, 26–41

[31] Al-Omari, A.I., Haq, H., *A new sampling method for estimating the population mean*, In: Journal of Statistical Computation and Simulation, 2019, 89, 11, 1973–1985

[32] Rahman, M.S., Hossain, Md.-A., Rushan Hoque, M.T., Hassan, H., *Conceptualising online fashion brand recognition: scale development and validation*, In: Spanish Journal of Marketing – ESIC, 2020, 24, 1, 73–96

[33] Ramayah, T., Ignatius, J., *Impact of perceived usefulness, perceived ease of use and perceived enjoyment on intention to shop online*, In: ICFAI Journal of Systems Management, 2005, 3, 3, 36–51

[34] Moon, M.A., Khalid, M.J., Awan, H.M., Attiq, S., Rasool, H., Kiran, M., *Consumer's perceptions of website's utilitarian and hedonic attributes and online purchase intentions: A cognitive-affective attitude approach*, In: Spanish Journal of Marketing – ESIC, 2017, 21, 2, 73–88

[35] Henriksson, J., Eriksson, O.K., *Managing brand equity during an ongoing pandemic – A qualitative study in the tourism-and-hospitality industry during Covid-19,* Dissertation of Business and Economics, Masters, Lulea University of Technology, 2021, 1–72, Available at: https://www.diva-portal.org/smash/get/diva2:1566529/FULLTEXT01.pdf [Accessed on October 31, 2021]

[36] Room, A., *History of Branding*, In: Hart S. and Murphy J. (eds.), Brands: The new wealth creators, Inter-brand McMillian Business, London, 1998, 13–23

[37] Gandhi, B.M., Chinnadorai, K.M., *Retail in India*, In: International Journal of Engineering Development and Research: IJEDR, 2017, 5, 1, 433–435

[38] Kumar, B.A., Rao, A.V.S., *Evolution of Retail Sector in India*, In: International Journal of Multidisciplinary: A Research Review Journals, 2018, 3, 5, 32–38

[39] Butu, A., Bruma, I.S., Tanasa, L., Rodino, S., Vasiliu, C.D., Dobos, S., Butu, M., *The Impact of COVID-19 Crisis upon the Consumer Buying Behaviour of Fresh Vegetables Directly from Local Producers. Case Study: The Quarantined Area of Suceava County, Romania*, In: International Journal of Environmental Research and Public Health, 2020, 17, 5485, 1–24

Authors:

DHEENADHAYALAN ARUMUGAM[1], ADALARASU BALRAJ[2]

[1]Anna University, Research Scholar, Management, Centre For Research, Chennai, India

[2]R.V.S.Faculty of Management, Management Studies, Kumaran Kottam Campus, Sulur, Coimbatore, India
e-mail: Dr.adalarasu.b@gmail.com

Corresponding author:

DHEENADHAYALAN ARUMUGAM
e-mail: deenaadeens@yahoo.co.in

Therapeutic strategies for nerve injuries: current findings and future perspectives. Are textile technologies a potential solution?

DOI: 10.35530/IT.073.06.2021115

CRISTIAN VLADIMIR VANCEA
ANDREEA GROSU-BULARDA
ANDREI CRETU
FLORIN-VLAD HODEA
KHALID AL-FALAH
ALEXANDRU STOIAN
ALEXANDRU LAURENTIU CHIOTOROIU
CARMEN MIHAI
CRISTIAN SORIN HARIGA
IOAN LASCĂR
RĂZVAN NICOLAE TEODOREANU

ABSTRACT – REZUMAT

Therapeutic strategies for nerve injuries: current findings and future perspectives. Are textile technologies a potential solution?

Peripheral nerve lesions represent debilitating conditions that determine sensitive, motor and associated psychosocial losses, deeply and severely affecting the quality of life. Despite adequate microsurgical repair, functional results are variable and often dissatisfying.
This study aimed to analyse and discuss peripheral nerve lesion cases from our clinic, involving the upper limb, an anatomical segment with impactful functional importance. We followed the distribution of nerve lesions throughout a three-year period, describing the patients' characteristics and the therapeutic protocols. Furthermore, we reviewed the relevant literature to identify potential therapeutic strategies that may help optimize functional results.
In the presented clinical study, most of the patients benefited from direct microsurgical repair of the nerve injury. However, we had a series of cases of nerve defects that could not be approached with primary repair. When a nerve cannot be repaired by direct neurorrhaphy, there are different options for bridging the nerve gap, each with its indications and advantages. Autografts still represent the gold standard in treating nerve gaps, but other procedures, such as vascularized nerve grafting, nerve conduits, allografts and nerve transfers, can be successfully used in some cases.
The current focus in the field is the development of nerve conduits. Textile technologies represent a promising field in creating nerve conduits, given the ease of the manufacturing process, the affordable production cost and good mechanical properties.

***Keywords**: peripheral nerve injury, nerve gap, graft, nerve conduits, textile technologies*

Strategii terapeutice în leziunile nervoase: abordările actuale și direcții viitoare. Reprezintă tehnologia textilă o soluție fezabilă?

Leziunile nervilor periferici reprezintă condiții debilitante care determină disfuncții senzitive, motorii și psihosociale, afectând profund și sever calitatea vieții. În ciuda unei rezolvări microchirurgicale adecvate, rezultatele funcționale sunt variabile și ,frecvent, nesatisfăcătoare.
Scopul acestui studiu a fost să analizeze si să discute cazurile de leziuni nervoase periferice din clinica noastră, implicând membrul superior, un segment anatomic cu impact funcțional important. Am urmărit distribuția leziunilor nervoase pe o perioadă de trei ani, prezentând caracteristicile pacienților și protocolul terapeutic. În afară de aceasta, am analizat literatura de specialitate cu scopul de a identifica potențiale strategii terapeutice care ar putea fi utile în a optimiza rezultatele funcționale.
În studiul clinic prezentat, majoritatea pacienților au beneficiat de sutura directă microchirurgicală a leziunii nervoase. Cu toate acestea, am avut o serie de cazuri prezentând defect nervos care nu au putut fi reparate prin sutură primară. Când o leziune nervoasă nu poate fi rezolvată prin sutură directă, există diferite opțiuni pentru a repara defectul nervos, fiecare cu propriile indicații si avantaje. Autografele reprezintă încă standardul de aur în tratamentul defectelor nervoase, dar alte proceduri, cum ar fi grefele nervoase vascularizate, conductorii nervoși, allografele și transferurile nervoase pot fi folosite cu succes în unele cazuri.
Atenția actuală în domeniu se îndreaptă către dezvoltarea de conductori nervoși. Tehnologia textilă reprezintă un domeniu promițător în crearea de conductori nervoși, având în vedere ușurința procesului tehnologic, costurile de producție accesibile și proprietățile mecanice corespunzătoare.

***Cuvinte cheie:** leziunea nervilor periferici, defect nervos, grefă, conductori nervoși, tehnologia textilă*

INTRODUCTION

Peripheral nerve lesions represent a difficult medical problem determining sensitive, motor and associated psychosocial losses that may deeply and severely impact the quality of life of affected patients [1, 2].
After peripheral nerve lesion, a complex process consisting of degeneration of the entire distal nerve end

as well as degeneration over a short length of the proximal nerve stump occurs [3]. Nerve repair facilitates a unique axonal regeneration pattern that involves generating new distal axons, distal to the lesion site, concomitant with the restoration of original neuronal microstructure through proliferation and migration of all other adjacent cellular components. It is considered that the nerve growth rate after sectioning and repair is approximately 1 to 2 millimetres per day on average [4, 5].

Surgical repair of sectioned peripheral nerves involves microsurgical suture trimmed to healthy stumps, under magnification with magnification loupes or surgical microscope. Correct microsurgical repair is the only method that may ensure functional recovery of the affected segment [5, 6].

The principle of nerve repair is micro-suturing the nerve ends without tension using epineural sutures. If the injury resulted in a nerve defect and a direct suture without tension is not possible, then a structure is needed to fill in the gap. This can be achieved with nerve conduits or grafts. They will act as support for axon regeneration [5, 7].

Autografts are considered the gold standard for nerve gap repair. The grafts are obtained from the same patient, from a different site than the location of the defect. The most common source of nerve grafts is the sural nerve. Autografts provide support for axon regeneration with ideal biocompatibility. The disadvantages of autografts are the need for a donor site that comes with its morbidity and function impairment, the number of available grafts being limited and the difference in nerve thickness between the injured nerve and the graft [8, 9].

Allografts are obtained from a different person and act as a guide for axon regrowth. By using allografts there is no donor site morbidity and a better match in nerve calibre than with autografts, but allografts lead to intense immune reactions. To counter the immune response immunosuppressive treatment is needed which comes with severe adverse reactions, limiting the use of allografts [5, 10].

Nerve conduits have been developed as an alternate strategy in an attempt to overcome the disadvantages of nerve grafts. The ideal nerve conduit needs to be biocompatible and biodegradable, with no immune response, and proper mechanical characteristics such as strength and elasticity and it need to create an ideal environment for nerve regeneration [11–13].

This study aimed to analyse and discuss peripheral nerve lesion cases from our clinic, involving the upper limb, an anatomical segment with highly impactful functional importance. We followed the distribution of nerve lesions, applied therapeutic protocols and attempted to identify potential therapeutic strategies that may optimize functional results.

METHODS

We performed a retrospective analysis of the cases admitted in the Clinic of Plastic Surgery and Reconstructive Microsurgery of the Clinical Emergency Hospital Bucharest and selected only those who suffered from nerve injuries in the upper limb. The analysis was focused on a period of 3 years, between January 1st, 2017 and December 31st, 2019.

On admission to the hospital, all patients consented to their medical data being used for future research purposes. Variables collected were the date of admission, age, gender, nerves involved, associated acute injuries and the presence of comorbidities. All data were collected and processed using Microsoft Excel, version 16.66.1. The only quantitative variable was the patients' age, for which we calculated the average, the median and the standard deviation.

STUDY RESULTS

We identified 734 patients who suffered from nerve injuries of the upper limb, 156 of which were admitted in 2017 (21.25%), 263 in 2018 (35.83%) and 315 in 2019 (42.91%). Out of the 734 patients included in the study, 600 (81.74%) were male and only 134 (18.26%) were female. The patient distribution based on their age is illustrated in figure 1. The mean age was 45.81 (±15.23) years and the median age was 46 years. The youngest patient was a 16-year-old male and the oldest was a 94-year-old female.

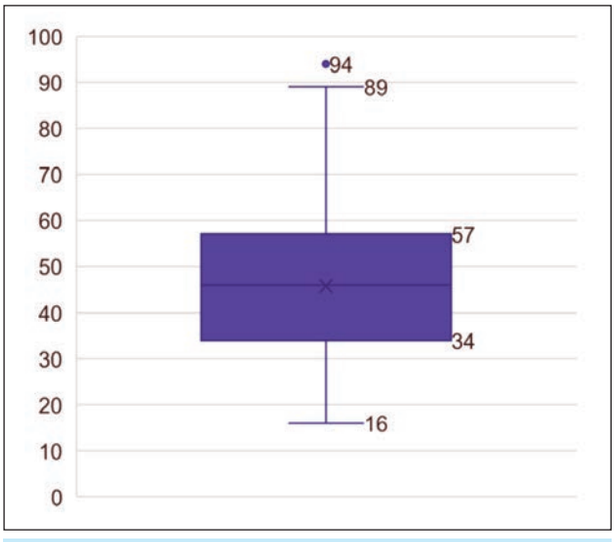


Fig. 1. Patient distribution based on age

The most frequently injured nerves of the upper limb were the digital nerves, adding up to a total of 785 nerves (80.59%), followed by the median nerve (83 nerves; 8.52%), the ulnar nerve (73 nerves; 7.49%), the radial nerve (31 nerves; 3.18%) and, lastly, the musculocutaneous nerve (2 nerves; 0,21%), amounting to a total of 974 injured nerves in the upper limb. The distribution of the injured nerves is illustrated in figure 2.

Some patients had injuries to more than just one nerve, with different combinations arising all presenting in an emergency setting. Hence, the most

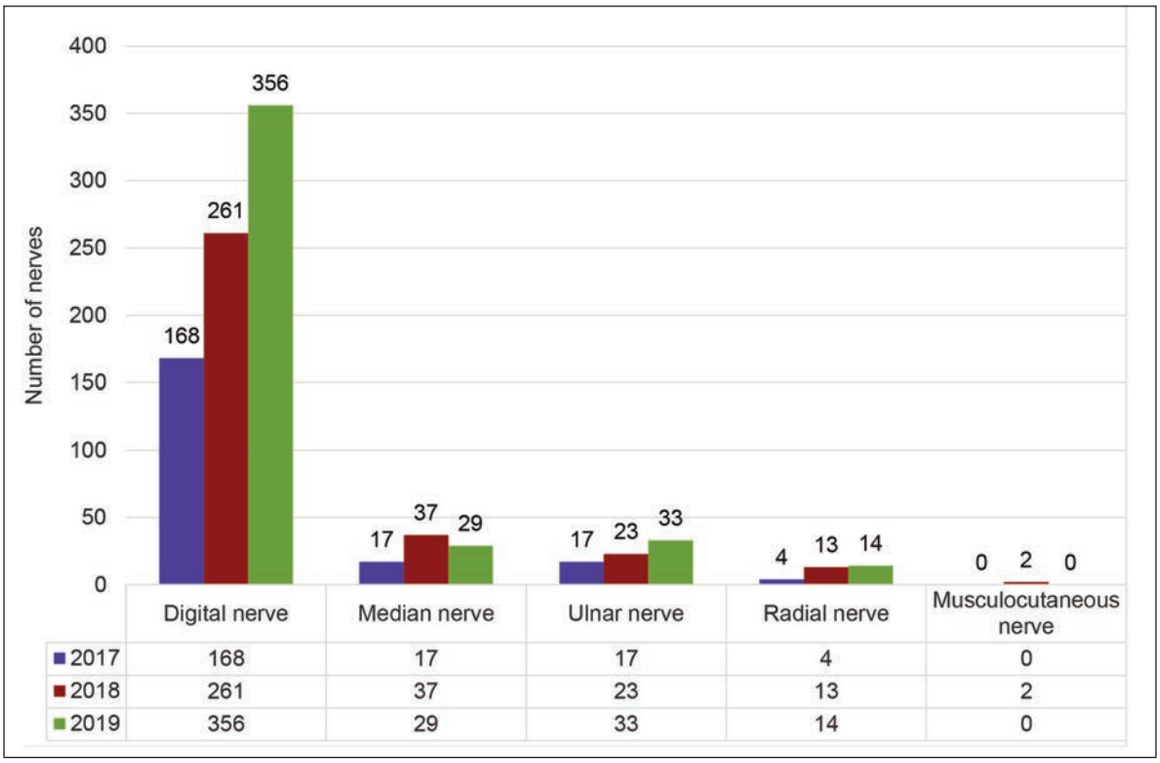


Fig. 2. Yearly distribution of injured nerves

common was an injury to both digital collateral nerves in 27.24% of cases.

Also, associated lesions of large nerves were encountered in our cases (as seen in table 1). The association between the median and the ulnar nerves was encountered in 23 patients (3.13%) presenting to the hospital with trauma to both these nerves. There were 6 patients (0.81%) who had associated injuries in both the median and the radial nerves. The three main nerves in the forearm (median, ulnar and radial nerves) were all damaged in 5 patients (0.68%). We also identified one patient (0.13%) who suffered trauma to the musculocutaneous and radial nerves. Moreover, there was one patient (0.13%) who presented a lower limb injury in addition to the one to the upper limb, thus having injured the radial and the ipsilateral common peroneal nerve.

Table 1

ASSOCIATED LESIONS OF LARGE NERVES	
Type of injured nerves	**No. of patients**
Median & ulnar	23
Median & radial	6
Median & ulnar & radial	5
Radial & musculocutenous	1
Radial & common peroneal	1

Of all the 734 patients included in the study, the large majority benefited from the standard nerve repair, which ensures optimal results. However, for some patients, direct neurorrhaphy could not be performed due to the size of the nerve defects. We identified 42 such cases, most of which involved the digital nerves (24 patients; 57.14% of defects), followed by the ulnar nerve (7 patients; 16.66% of defects), the median nerve (5 patients; 11.90% of defects), the radial nerve (3 patients; 7.14% of defects), both the median and ulnar nerves (2 patients; 4.76% of defects) and, lastly, the posterior interosseous nerve (1 patient; 2.38% of defects). These nerves were injured at different levels, so the reconstructive procedures varied accordingly, as seen in table 2.

Figures 3 and 4 illustrate two of the surgical techniques used for bridging nerve gaps in our patients: Figure 3 displays the use of sural nerve grafts in bridging significant defects of large nerves – radial nerve (figure 3, *a* and *b*) and median nerve (figure 3, *c* and *d*); figure 4 presents the use of muscle-in-vein autologous conduit for a digital nerve defect of the index finger.

DISCUSSIONS

Traumatic injuries of the upper extremities are a common finding, with a reported incidence varying from 7 to 37/1000 inhabitants/year in Europe for hand injuries. The incidence of nerve injuries is 0.14/1000 inhabitants/year, the most affected being the nerves of the upper extremities [14].

In our clinical study, we observed that there was an inclusion of a large number of patients with peripheral nerve lesions of the upper limb. The majority of the patients are males, with an average age of 46 years, which shows that most of them pertain to the young, professionally active population. This data reveals

Table 2

RECONSTRUCTIVE PROCEDURES FOR INJURED NERVES AT DIFFERENT LEVELS				
Injured nerve	**Level of injury**	**No. of patients**	**Reconstructive procedure**	**No. of procedures**
Digital	Digit	19	Spare part nerve graft	6
			Muscle-in-vein conduit	2
			Heterodigital sensate flaps	5
			Nerve transfer from the contralateral non-functional side	6
	Palm	5	Lateral antebrachial cutaneous nerve graft	1
			Spare part nerve graft	3
			Muscle-in-vein conduit	1
Median	Forearm	4	Sural nerve graft	4
	Arm	1	Sural nerve graft	1
Ulnar	Forearm	3	Sural nerve graft	3
	Proximal forearm	4	Ulnar nerve anterior transposition	4
Median+ulnar	Forearm	2	Sural nerve graft	2
Radial	Arm	3	Sural nerve graft	3
Posterior interosseous	Forearm	1	Lateral antebrachial cutaneous nerve graft	1

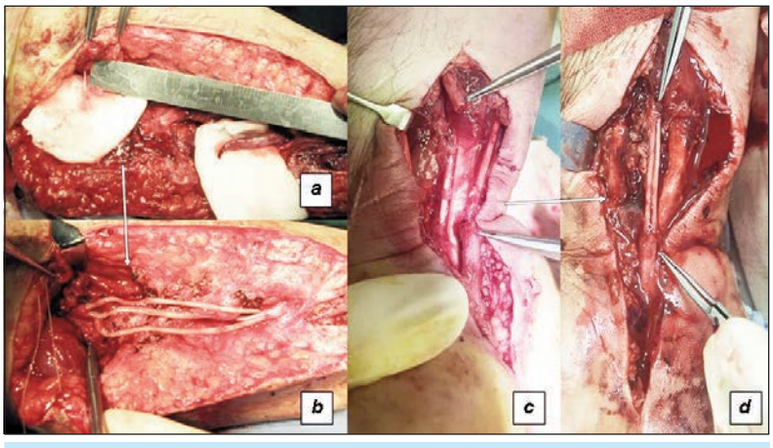


Fig. 3. Sural nerve grafts used for bridging significant defects of large nerves: *a* – radial nerve defect; *b* – sural graft bridging the defect of the radial nerve; *c* – median nerve defect; *d* – sural graft bridging the defect of the median nerve

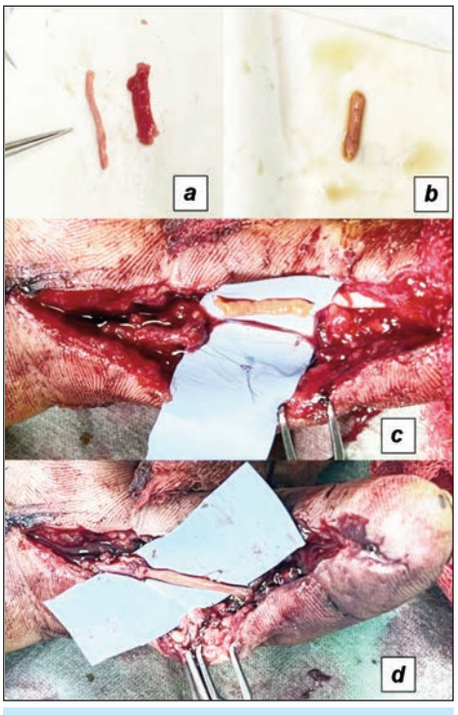


Fig. 4. Muscle-in-vein autologous conduit used for a digital nerve defect of the index finger: *a* – vein (left) and muscle (right) harvested from the anterior aspect of the forearm; *b* – muscle-in-vein conduit; *c* – defect of the digital nerve; *d* – muscle-in-vein conduit bridging the digital nerve defect

the importance of peripheral nerve lesions as a public health concern, these patients suffer from mild to severe nerve damage, determining temporary or definitive functional loss, dramatically impacting both the personal quality of life and professional activity. Peripheral nerve lesions are known to have a lengthy recovery, requiring complex surgical interventions, as well as integration into a sustained and efficient rehabilitation program in specialized institutions [15].

The motivation of the patient, the addressability to the physician and medical services, and the existent infrastructure are parameters that impact the functional outcome, with possible precarious results.

Damage to the main nerves of the upper limb leads to difficult and longer recovery, directly proportionate to the proximal site of the lesion [3, 5, 16].

In our clinic, such lesions involving the median, ulnar, radial and musculocutaneous nerves were reported in several 149 patients, representing a fifth of the total patients.

Reconstructive options for nerve defects

Direct, primary repair of lesions represents to date the best possible solution for nerve damage. When a nerve cannot be repaired by direct neurorrhaphy,

there are some options that a surgeon must keep in mind, each with its indications and advantages: autologous nerve grafting, vascularized nerve grafting, nerve conduits, allografts and nerve transfers [5, 7, 17]. However, in cases where there is a gap, autologous nerve grafting represents the gold standard. Several nerves can be used as donors, but the sural nerve is the most frequently used due to the ease of dissection and available length [18]. The sural nerve can be a source of roughly 30-40 cm of nerve graft. It has the advantage of low morbidity, leaving denervated only the lateral aspect of the foot, with partial sensitization of the aforementioned area over time [18, 19]. On the other hand, when it comes to nerve defects in the upper limb, harvesting a graft from the lower limb can be regarded as a disadvantage, due to anaesthesia concerns and generating another surgical field.

Often, local options, within the same surgical field can be employed, an example being the medial antebrachial cutaneous nerve, which can provide as much as 20–25 cm of nerve graft. It is a suitable choice for gaps greater than 0.5 cm in the digital nerves. Its posterior branch innervates the skin above the elbow, providing important sensate information about a highly tactile area. This is the reason why it is preferred to use the anterior branch, with lower morbidity resulting in numbness only on the anterior aspect of the forearm. Despite the advantage of having a hidden scar on the medial side of the arm, the donor site may be left with hyperesthesia and dysesthesia [20, 21].

Another local feasible choice that leaves a less important sensory deficit at the donor site is the lateral antebrachial cutaneous nerve because it overlaps with the sensitive branch of the radial nerve. It can provide up to 8-15 cm of nerve graft. A minor concern is that the scar on the volar aspect of the forearm is one that the patient might not consent to as easily [20, 22]. Similarly, the superficial branch of the radial nerve may be used as a donor, but this is reserved only for those cases associating an irreversible injury to the main trunk of the radial nerve or to its cervical roots of origin, cases in which its superficial branch is no longer of use [20].

When harvesting a nerve graft, the surgeon must take into consideration the diameter of the donor's nerve. If the trunk of the donor's nerve is too large, the graft will suffer central necrosis. Hence, vascularized nerve grafting comes as a solution where the nerve is harvested along with its vessels, making it ideal for situations where the recipient bed is heavily devascularized or has suffered extensive fibrosis. The most used vascularized nerve graft is harvested from the ulnar nerve [23–25].

If the patient refuses an autologous nerve graft, or if the case contraindicates it, the next ideal option is nerve conduits. These are used for nerve gaps smaller than 3 cm, so they can provide a pathway through which the axons can regenerate while preventing protrusion of endoneural contents during healing [5, 7, 26, 27]. Veins have been used as nerve autologous conduits, mainly because they are highly accessible within the same surgical field, determining no inflammatory and immunology response and have an inferior donor site morbidity than a nerve graft. Even though vein grafts have acceptable results, the two-point discrimination is slightly inferior but comparable to nerve grafts. They present come to a risk of collapsing when the graft is longer than 1–2 cm, mechanically blocking the axonal regeneration through the vein, needing sometimes to be filled with either muscle, fibrin or textile fibres [28, 29].

Freeze-thawed muscle grafts have also been used as conduits, especially for injuries of cutaneous nerves, but the harvested muscle must be prepared so that the graft becomes acellular. This process leaves intact only the basal membrane, which acts as a promoter for axonal regeneration. Using a composite muscle-in-vein graft as a nerve conduit brings in the advantages of both the vein and the freeze-thawed muscle grafts. With the muscle inserted inside the vein, the conduit can no longer collapse and it has been proved that the myocytes generate growth factors that are beneficial, stimulating Schwann cell regeneration and axonal migration [28, 30, 31].

Nerve transposition, which is frequently used for ulnar nerve lesions of the proximal forearm or elbow, can help compensate for the existing gap between the nerve-sectioned ends. When the proximal nerve stump is not available for adequate repair, a nerve transfer can be performed using a synergistic donor nerve, which is transferred and microsurgically sutured to the distal end of the nerve.

In the presented clinical study, the vast majority of the patients benefited from direct microsurgical repair of the nerve injury. However, we had a series of cases of nerve defects that were repaired using the methods discussed above, with good functional results.

Nerve allografts are the next feasible option, being useful when there is an extensive injury to peripheral nerves, and either the donor sites are not sufficient or the patient refuses such procedures. The advantage is that there is no donor site morbidity whatsoever. Even though host immunosuppression is necessary, it is only temporary, because after the nerve regeneration is completed through the graft, there will be no non-self-cells remaining. Interestingly, it has been shown that short-term immunosuppression has neural regenerative effects. Processed acellular nerve allografts have been developed to avoid the need for immunosuppression, with promising results even in larger nerve gaps (up to 5 cm) [5, 32, 33].

In an attempt to overcome the limitations of nerve grafts, the attention of nerve repair has switched towards nerve conduits The last decades of research brought to attention new sources of nerve conduits, which aimed to decrease the immunologic response, offer good mechanical quality, speed and enhance the regenerative process, match the efficiency of autologous nerve grafts, while providing the same, results and functional outcomes, through accessible and affordable means. Promising attempts have

been made with collagen, polysaccharides and even synthetic polymers [11, 12, 34–36].

Promising area: the use of textile technologies for bridging nerve defects

Textile technologies have been implicated in the process of making different kinds of materials for implants, stents, and grafts, each having different purposes such as vascular prostheses, intestinal stents, and nerve conduits. Given the fact that the production cost is affordable, the fabrication process is versatile and it offers very good mechanical characteristics the textile conduits are very promising and have generated a lot of interest over time. Textile technologies present advantages over other manufacturing techniques such as 3D printing. The whole process is more facile, takes less time and is more cost-effective [12, 37–40].

Nerve conduit materials

Various materials can be used to manufacture nerve conduits and they can be classified into natural and synthetic polymers. Natural polymers used in nerve repairs are chitosan, collagen, laminin, silk fibroin and alginates, while known usable synthetic materials are silicone polymers, polylactic acid, polyglycolic acid, poly(lactic-co-glycolic acid), polycaprolactone and composites [12, 41, 42].

Natural polymers:

- Chitosan is a linear polysaccharide that resembles the extracellular matrix, with particular mechanical properties. It is biodegradable, non-toxic and promotes nerve regeneration, making it a good material for nerve conduits. It can be used alone or in combination with other natural or synthetic materials and growth factors and offers good results in experimental studies, enhancing axon regeneration [41, 42].
- Collagen is the most important protein in the body, offering structure to human tissues and providing promising results in nerve regeneration. The challenges in using collagen in nerve conduits are its high production cost and poor mechanical resistance [12, 41–44].
- Laminin is a protein from the basal lamina of blood vessels. It promotes axonal regeneration and myelination and can be used to construct nerve conduits. It can be used as a gel to fill other nerve conduits or it can be used in combination with other materials in multi-layered nerve conduits [39, 41].
- Silk fibroin is a protein found in silk, it has good mechanical characteristics, it dissolves slowly and is non-toxic. It is better used in combination with other fibres because silk is friable when used alone. It can be combined with polylactocaprone or poly lactico-glycolic acid to form electrospun nanofibers [12, 30, 45].
- Alginate is found in algae's cells and it has a similar form to connective tissue. It can promote nerve regeneration, has good biocompatibility and is biodegradable making it suitable for nerve conduits. [39, 41]

Synthetic Polymers:

Synthetic materials have been at the centre of nerve conduit development since they can achieve better mechanical and physiological properties than natural materials. There are two kinds of synthetic polymers degradable and non-degradable.

- Silicone polymers have been one of the first materials to be used in nerve conduit manufacture. Silicone conduits have shown some good outcomes, but due to the property of being non-degradable, there is usually a need for a second surgery for removal. If left in place, they can lead to nerve compression syndrome [11, 12, 41].
- Polylactic acid is a biodegradable polymer that can be obtained from natural sources such as potatoes. It is one primary choice when it comes to basic materials because it can be easily designed and moulded into the desired shape and it helps nerve regeneration. The natural course follows metabolization to lactic acid [41].
- Polyglycolic acid can be extracted from pineapple or sugarcane. It is a polyester and degrades to glycolic acid. It is more hydrophilic than polylactic acid and is stabilized by the ester group [41].
- Poly(lactic-co-glycolic acid) is composed of both polylactic and polyglycolic acids. It is more malleable and has better mechanical properties while being less toxic. It degrades slowly, has good biocompatibility and it can be more suitable for nerve conduits [41, 46].
- Polycaprolactone is a polyester, obtained from lactone or hydroxycarboxylic acid. It is degraded to oligolactone, and it takes up to 24 months to be metabolized completely, making it efficient for cases in which the conduit needs very-slow biologic integration [41].

Lastly, composite materials can be employed in nerve conduits. The advancement of manufacturing technologies leads to composite materials by mixing different polymers. By mixing different polymers, one can obtain different degrees of degradation and mechanical properties [12, 41].

Textile technologies

Natural and synthetic materials are used to create different kinds of nerve conduits by using different manufacturing techniques such as 3D printing, enzymatic and chemical treatments or textile technologies. The goals and challenges are to develop conduits with the aforementioned and emerging textile materials to obtain the ideal combination of mechanical, structural and biological properties [12, 30, 41, 42].

There are four kinds of manufacturing processes used in obtaining nerve conduits:

- Firstly, the weaving process consists of lacing warp yarn and weft yarn in different patterns specific to different materials. By changing the patterns, and working with different fabrics and arrangements we can achieve different strengths and permeability. This technique offers more in-plane support, offering more strength and flexibility in the same plane as the direction of the fibres, making it less ideal for

a tubular shape structure. The mechanical strength can be enhanced by calibrating the looms and different variables [12].

- Secondly, the knitting process consists of making different kinds of loops and interconnected threads in different planes resulting in different, complex designs that offer strength in both in- and out-plane direction. This manufacturing process is already used in all kinds of medical applications, but the challenge rests in obtaining nerve conduits, which are small in diameter, with the current machines [12, 47].
- Thirdly, the braiding process consists of twisting groups of threads in different patterns. This process can be 2-dimensional or 3-dimensional. The 2-dimensional manufacturing process is used to obtain thin conduits, while the 3-dimensional manufacturing process can only obtain thicker conduits. Besides the thickness, the 2-dimensional process is simpler and more effective and is used to obtain conduits that have better mechanical properties than using the 3-dimensional technique, making it the preferred technique for manufacturing nerve conduits. The braiding process allows more flexibility regarding the design of the conduit, with researchers creating tube-in-tube structures that simulate the nerve bundles or multi-layered structures, each layer with different mechanical and physiological properties [12, 30, 39].
- Electrospinning is a manufacturing process that allows for obtaining very small diameter fibres from polymer solutions by using electric force. This technique can be used to obtain nanofibers that act as an extracellular matrix inside the nerve conduit [12, 48]. Nanofibers can be obtained from different compounds found in the extracellular matrix such as elastin or collagen. The advantage of electrospinning is that it offers freedom in choosing the fabric. Natural materials are preferred over synthetic ones because they offer a better balance between mechanical properties and biocompatibility. The electrospinning technique is used in combination with various other techniques to manufacture different kinds of multi-layered nerve conduits. The versatility of the electrospinning technique allows the researchers to add different nanoparticles that offer better nerve regeneration such as magnesium or iron oxides [12, 49–52]. Due to the precise synthesis of the nanofibers and the biodegradable properties of various polymers the nanoparticles can be released slowly, continuously and uniformly inside the conduit to help in nerve regeneration [41]. Electrospinning devices are constantly evolving allowing for more powerful nerve conduits.

CONCLUSIONS

Peripheral nerve lesions determine in many cases severe functional deficits, affecting young, active people. Primary nerve repair using microsurgical techniques is attempted as the first therapeutic intention. When a nerve cannot be repaired by direct neurorrhaphy, there are different options for bridging the nerve gap, each with its indications and advantages: autologous nerve grafting-still the gold standard, vascularized nerve grafting, nerve conduits, allografts and nerve transfers. These findings were encountered also in our study group, with a large number of young, working active, predominantly male patients presenting with significant functional impairment determined by upper extremity nerve injuries especially when nerves are affected proximally.

Alternative solutions are currently being explored for bridging nerve gaps to promote better functional recovery in our patient population with affordable resources.

Recently developed nerve conduits made from combinative materials, using modern technologies possess good mechanical properties and biological functions, ensuring the nerve regeneration process. Textile technologies represent a promising field, allowing nerve conduit fabrication with optimal biological properties in a fast and cost-effective manner.

REFERENCES

[1] Heinzel, J.C., Dadun, L.F., Prahm, C., et al., *Beyond the Knife-Reviewing the Interplay of Psychosocial Factors and Peripheral Nerve Lesions*, In: Journal of Personalized Medicine, 2021, 11, 11, http://doi.org/10.3390/jpm11111200

[2] Wojtkiewicz, D.M., Saunders, J., Domeshek, L., Novak, C.B., Kaskutas, V., Mackinnon, S.E., *Social impact of peripheral nerve injuries*, In: Hand, 2015, 10, 2, 161–167, http://doi.org/10.1007/s11552-014-9692-0

[3] Menorca, R.M., Fussell, T.S., Elfar, J.C., *Nerve physiology: mechanisms of injury and recovery*, In: Hand Clinics, 2013, 29, 3, 317–330, http://doi.org/10.1016/j.hcl.2013.04.002

[4] Sulaiman, W., Gordon, T., *Neurobiology of peripheral nerve injury, regeneration, and functional recovery: from bench top research to bedside application*, In: Ochsner Journal, 2013, 13, 1, 100–108

[5] Grinsell, D., Keating, C.P., *Peripheral nerve reconstruction after injury: a review of clinical and experimental therapies*, In: Biomed Research International, 2014, 2014, 698256, http://doi.org/10.1155/2014/698256

[6] Hems, T., *Operating on nerves: Surgical approaches, primary and secondary repair, nerve grafting and nerve transfer*, In: Living Textbook of Hand Surgery, 2014, http://doi.org/10.5680/lhhs000025

[7] Griffin, M.F., Malahias, M., Hindocha, S., Khan, W.S., *Peripheral nerve injury: principles for repair and regeneration*, In: The Open Orthopaedics Journal, 2014, 8, 1, 199–203, http://doi.org/10.2174/1874325001408010199

[8] Hoben, G.M., Ee, X., Schellhardt, L., et al., *Increasing Nerve Autograft Length Increases Senescence and Reduces Regeneration*, In: Plastic and Reconstructive Surgery, 2018, 142, 4, 952–961, http://doi.org/10.1097/PRS.0000000000004759

[9] Tada, K., Nakada, M., Matsuta, M., Yamauchi, D., Ikeda, K., Tsuchiya, H., *Long-Term Outcomes of Donor Site Morbidity After Sural Nerve Graft Harvesting*, In: Journal of Hand Surgery Global Online, 2020, 2, 2, 74–76, http://doi.org/10.1016/j.jhsg.2020.01.001

[10] Bittner, G.D., Bushman, J.S., Ghergherehchi, C.L., et al., *Typical and atypical properties of peripheral nerve allografts enable novel strategies to repair segmental-loss injuries*, In: Journal of Neuroinflammation, 2022, 19, http://doi.org/10.1186/s12974-022-02395-0

[11] Nectow, A.R., Marra, K.G., Kaplan, D.L., *Biomaterials for the development of peripheral nerve guidance conduits*, In: Tissue Engineering Part B: Reviews, 2012, 18, 1, 40–50, http://doi.org/10.1089/ten.TEB.2011.0240

[12] Yan, Y., Yao, R., Zhao, J., et al., *Implantable nerve guidance conduits: Material combinations, multi-functional strategies and advanced engineering innovations*, In: Bioactive Materials, 2021, 11, 57–76, http://doi.org/10.1016/j.bioactmat.2021.09.030

[13] Fornasari, B.E., Carta, G., Gambarotta, G., Raimondo, S., *Natural-Based Biomaterials for Peripheral Nerve Injury Repair*, In: Frontiers in Bioengineering and Biotechnology, 2020, 8, 554257, http://doi.org/10.3389/fbioe.2020.554257

[14] Dahlin, L.B., Wiberg, M., *Nerve injuries of the upper extremity and hand*, In: EFORT Open Reviews, 2017, 2, 5, 158–170, http://doi.org/10.1302/2058-5241.2.160071

[15] Lopes, B., Sousa, P., Alvites, R., et al., *Peripheral Nerve Injury Treatments and Advances: One Health Perspective*, In: International Journal of Molecular Science, 2022, 23, 2, 918, http://doi.org/10.3390/ijms23020918

[16] Wang, M.L., Rivlin, M., Graham, J.G., Beredjiklian, P.K., *Peripheral nerve injury, scarring, and* recovery, In: Connective Tissue Research, 2019, 60, 1, 3–9, http://doi.org/10.1080/03008207.2018.1489381.

[17] Ray, W.Z., Mackinnon, S.E., *Management of nerve gaps: autografts, allografts, nerve transfers, and end-to-side neurorrhaphy*, In: Experimental Neurology, 2010, 223, 1, 77-85, http://doi.org/10.1016/j.expneurol.2009.03.031

[18] Piedra Buena, I.T., Fichman, M., *Sural Nerve Graft*, In: StatPearls [Internet], 2022, https://www.ncbi.nlm.nih.gov/books/NBK557715/

[19] Bamba, R., Loewenstein, S.N., Adkinson, J.M., *Donor site morbidity after sural nerve grafting: A systematic review*, In: Journal of Plastic, Reconstructive & Aesthetic Surgery, 2021, 74, 11, 3055–3060, http://doi.org/10.1016/j.bjps.2021.03.096

[20] Poppler, L.H., Davidge, K., Lu, J.C., Armstrong, J., Fox, I.K., Mackinnon, S.E., *Alternatives to sural nerve grafts in the upper extremity*, In: Hand, 2015, 10, 1, 68–75, http://doi.org/10.1007/s11552-014-9699-6

[21] Li, H., Zhu, W., Wu, S., Wei, Z., Yang, S., *Anatomical analysis of antebrachial cutaneous nerve distribution pattern and its clinical implications for sensory reconstruction*, In: PLOS One, 2019, 14, 9, http://doi.org/10.1371/journal.pone.0222335

[22] Unal, M.B., Gokkus, K., Sirin, E., Cansü, E., *Lateral Antebrachial Cutaneous Nerve as a Donor Source for Digital Nerve Grafting: A Concept Revisited*, In: The Open Orthopaedics Journal, 2017, 11, 1041–1048, http://doi.org/10.2174/1874325001711011041

[23] Isaacs, J., Safa, B., *A Preliminary Assessment of the Utility of Large-Caliber Processed Nerve Allografts for the Repair of Upper Extremity Nerve Injuries*, In: Hand, 2017, 12, 1, 55–59, http://doi.org/10.1177/1558944716646782

[24] Broeren, B.O., Duraku, L.S., Hundepool, C.A., et al., *Nerve recovery from treatment with a vascularized nerve graft compared to an autologous non-vascularized nerve graft in animal models: A systematic review and meta-analysis*, In: PLOS One, 2021, 16, 12, http://doi.org/10.1371/journal.pone.0252250

[25] Terzis, J.K., Kostopoulos, V.K., *Vascularized nerve grafts and vascularized fascia for upper extremity nerve reconstruction*, In: Hand, 2010, 5, 1, 19–30, http://doi.org/10.1007/s11552-009-9189-4

[26] Muheremu, A., Ao, Q., *Past, Present, and Future of Nerve Conduits in the Treatment of Peripheral Nerve Injury*, In: Biomed Research International, 2015, 2015, 237507, http://doi.org/10.1155/2015/237507

[27] Deal, D.N., Griffin, J.W., Hogan, M.V., *Nerve conduits for nerve repair or reconstruction*, In: Journal of the American Academy of Orthopaedic Surgeons, 2012, 20, 2, 63–68, http://doi.org/10.5435/JAAOS-20-02-063

[28] Heinzel, J.C., Quyen Nguyen, M., Kefalianakis, L., et al., *A systematic review and meta-analysis of studies comparing muscle-in-vein conduits with autologous nerve grafts for nerve reconstruction*, In: Scientific Reports, 2021, 11, 1, http://doi.org/10.1038/s41598-021-90956-3

[29] Sabongi, R.G., Fernandes, M., Dos Santos, J.B., *Peripheral nerve regeneration with conduits: use of vein tubes*, In: Neural Regeneration Research, 2015, 10, 4, 529–533, http://doi.org/10.4103/1673-5374.155428

[30] Houshyar, S., Bhattacharyya, A., Shanks, R., *Peripheral Nerve Conduit: Materials and Structures*, In: ACS Chemical Neuroscience, 2019, 10, 8, 3349–3365, http://doi.org/10.1021/acschemneuro.9b00203

[31] Kornfeld, T., Vogt, P.M., Radtke, C., *Nerve grafting for peripheral nerve injuries with extended defect sizes. Nerventransplantate für periphere Nervenverletzungen ausgedehnterer Defektgrößen*, In: Wiener Medizinische Wochenschrift, 2019, 169, 9–10, 240–251, http://doi.org/10.1007/s10354-018-0675-6

[32] Brooks, D.N., Weber, R.V., Chao, J.D., et al., *Processed nerve allografts for peripheral nerve reconstruction: a multicenter study of utilization and outcomes in sensory, mixed, and motor nerve reconstructions*, In: Microsurgery, 2012, 32, 1, 1–14, http://doi.org/10.1002/micr.20975

[33] Safa, B., Jain, S., Desai, M.J., et al., *Peripheral nerve repair throughout the body with processed nerve allografts: Results from a large multicenter study*, In: Microsurgery, 2020, 40, 5, 527–537, http://doi.org/10.1002/micr.30574

[34] Rebowe, R., Rogers, A., Yang, X., Kundu, S.C., Smith, T.L., Li, Z., *Nerve Repair with Nerve Conduits: Problems, Solutions, and Future Directions*, In: Journal of Hand and Microsurgery, 2018, 10, 2, 61–65, http://doi.org/10.1055/s-0038-1626687

[35] Isaacs, J., Browne, T., *Overcoming short gaps in peripheral nerve repair: conduits and human acellular nerve allograft*, In: Hand, 2014, 9, 2, 131–137, http://doi.org/10.1007/s11552-014-9601-6

[36] Carvalho, C.R., Oliveira, J.M., Reis, R.L., *Modern Trends for Peripheral Nerve Repair and Regeneration: Beyond the Hollow Nerve Guidance Conduit*, In: Frontiers in Bioengineering and Biotechnology, 2019, 7, 337, http://doi.org/10.3389/fbioe.2019.00337

[37] Singh, C., Wong, C.S., Wang, X., *Medical Textiles as Vascular Implants and Their Success to Mimic Natural Arteries*, In: Journal of Functional Biomaterials, 2015, 6, 3, 500–525, http://doi.org/10.3390/jfb6030500

[38] Doersam, A., Tsigkou, O., Jones, C., *A Review: Textile Technologies for Single and Multi-Layer Tubular Soft Tissue Engineering*, In: Advanced Materials Technology, 2022, 2101720, http://doi.org/10.1002/admt.202101720

[39] Arslantunali, D., Dursun, T., Yucel, D., Hasirci, N., Hasirci, V., *Peripheral nerve conduits: technology update*, In: Medical Devices (Auckland, N.Z.), 2014, 7, 405–424, http://doi.org/10.2147/MDER.S59124

[40] Kang, N.U., Lee, S.J., Gwak, S.J., *Fabrication Techniques of Nerve Guidance Conduits for Nerve Regeneration*, In: Yonsei Medical Journal, 2022, 63, 2, 114–123, http://doi.org/10.3349/ymj.2022.63.2.114

[41] Zhang, M., Li, C., Zhou, L.P., Pi, W., Zhang, P.X., *Polymer Scaffolds for Biomedical Applications in Peripheral Nerve Reconstruction*, In: Molecules, 2021, 26. 9, http://doi.org/10.3390/molecules26092712

[42] Fornasari, B.E., Carta, G., Gambarotta, G., Raimondo, S., *Natural-Based Biomaterials for Peripheral Nerve Injury Repair*, In: Frontiers in Bioengineering and Biotechnology, 2020, 8, 554257, http://doi.org/10.3389/fbioe.2020.554257

[43] Dong, C., Lv, Y., *Application of Collagen Scaffold in Tissue Engineering: Recent Advances and New* Perspectives, In: Polymers, 2016, 8, 2, http://doi.org/10.3390/polym8020042

[44] Li, X., Zhang, X., Hao, M., et al., *The application of collagen in the repair of peripheral nerve defect*, In: Frontiers in Bioengineering and Biotechnology, 2022, 10, 973301, http://doi.org/10.3389/fbioe.2022.973301

[45] Nguyen, T.P., Nguyen, Q.V., Nguyen, V.H., et al., *Silk Fibroin-Based Biomaterials for Biomedical Applications: A Review*, In: Polymers, 2019, 11, 12, http://doi.org/10.3390/polym11121933

[46] Yu, T., Zhao, C., Li, P., Liu, G., Luo, M., *Poly(lactic-co-glycolic acid) conduit for repair of injured sciatic nerve: A mechanical analysis*, In: Neural Regeneration Research, 2013, 8, 21, 1966–1973, http://doi.org/10.3969/j.issn.1673-5374.2013.21.005

[47] Zhang, X., Ma, P., *Application of Knitting Structure Textiles in Medical Areas*, In: Autex Research Journal, 2018, 18, 2, 181-191, http://doi.org/10.1515/aut-2017-0019

[48] Xue, J., Wu, T., Dai, Y., Xia, Y., *Electrospinning and Electrospun Nanofibers: Methods, Materials, and Applications*, In: Chemical Reviews, 2019, 119, 8, 5298–5415, http://doi.org/10.1021/acs.chemrev.8b00593

[49] Xie, J., MacEwan, M.R., Liu, W., et al., *Nerve guidance conduits based on double-layered scaffolds of electrospun nanofibers for repairing the peripheral nervous system*, In: ACS Applied Materials & Interfaces, 2014, 6, 12, 9472–9480, http://doi.org/10.1021/am5018557

[50] Yan, B., Zhang. Y., Li, Z., Zhou, P., Mao, Y., *Electrospun nanofibrous membrane for biomedical application*, In: SN Applied Sciences, 2022, 4, 6, http://doi.org/10.1007/s42452-022-05056-2

[51] Behtaj, S., Ekberg, J.A.K., St John, J.A., *Advances in Electrospun Nerve Guidance Conduits for Engineering Neural Regeneration*, In: Pharmaceutics, 2022, 14, 2, http://doi.org/10.3390/pharmaceutics14020219

[52] Pala, I.E., Kaya, Ç.P., *Textile fibres in product design*, In: Industria Textila, 2021, 72, 3, 340–345, http://doi.org/10.35530/IT.072.03.1673

Authors:

CRISTIAN VLADIMIR VANCEA[1,2], ANDREEA GROSU-BULARDA[1], ANDREI CRETU[1], FLORIN-VLAD HODEA[1], KHALID AL-FALAH[1,2], ALEXANDRU STOIAN[1], ALEXANDRU LAURENTIU CHIOTOROIU[2,3], CARMEN MIHAI[4], CRISTIAN SORIN HARIGA[1,2], IOAN LASCĂR[1,2], RĂZVAN NICOLAE TEODOREANU[1,2]

[1]Clinic of Plastic Surgery, Aesthetic and Reconstructive Microsurgery, Clinical Emergency Hospital Bucharest, Romania

[2]UMF Carol Davila Bucharest, Romania

[3]General Surgery Clinic, Clinical Emergency Hospital Bucharest, Romania

[4]National Research and Development Institute for Textiles and Leather, Bucharest, Romania

Corresponding author:

ANDREEA GROSU-BULARDA, MD, PhD
e-mail: andreeabularda@gmail.com