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Reinventing the Portuguese knitwear industry: the case of Pedrosa & Rodrigues private label management model

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ABSTRACT – REZUMAT

Reinventing the Portuguese knitwear industry: the case of Pedrosa & Rodrigues private label management model

During the first decade of this century, the Portuguese knitwear industry, and textile cluster, were strongly affected by globalisation and seemed destined to decline. The Portuguese knitwear industry developed for decades a business model based on price as the main competitive factor, and that model was no longer able to support competitiveness against low wages countries. Portuguese knitwear industry made a dramatic change towards a competition based on value to the client. The companies adopted as primary differentiation drives technological innovation, design, fashion, and services customer-oriented, together with more presence on international fairs and exhibitions. The new strategy resulted in the significant growth of exports that reached 40% from 2009 to 2018. The restructuring of the cluster, however, changed it significantly, and the number of companies was reduced by almost 50%. The competitive change made the entire Portuguese textile cluster an international case study where the modern concept of private label business model is central.

The business model of private label adopted by the most competitive knitwear companies considered a full package of services to international clients. It integrated the collection's design, raw materials development, superior finishing, careful and cost-effective confection and sophisticated logistics. Pedrosa & Rodrigues, SA. is a midcap company from Barcelos County, North of Portugal, and is a highly successful example of the new competitive paradigms. This new model is now leading the Portuguese knitwear industry to a higher level in the value chain and gives it a strong reputation worldwide.

Keywords: *private label, design service oriented, textile industries new paradigms, organisational innovation, sustainable value chain*

Reinventarea industriei portugheze de tricotaje: cazul modelului de management al etichetei private Pedrosa & Rodrigues

În primul deceniu al acestui secol, industria portugheză de tricotaje și clusterul textil au fost puternic afectate de globalizare și păreau să intre într-un declin. Industria portugheză de tricotaje a dezvoltat timp de decenii un model de afaceri bazat pe preț ca principal factor competitiv, iar acel model nu mai era capabil să susțină competitivitatea în țările cu salarii mici. Industria portugheză de tricotaje a făcut o schimbare dramatică către o concurență bazată pe valoare adăugată pentru client. Companiile au adoptat ca motor de diferențiere primară inovația tehnologică, designul, moda și serviciile orientate către client, împreună cu o mai mare prezență la târgurile și expozițiile internaționale. Noua strategie a avut ca rezultat o creștere semnificativă a exporturilor, care a atins 40% în perioada 2009–2018. Cu toate acestea, restructurarea clusterului a schimbat acest lucru în mod semnificativ, iar numărul companiilor a fost redus cu aproximativ 50%. Schimbarea concurențială a făcut ca întregul cluster textil portughez să devină un studiu de caz internațional, în care conceptul modern al modelului de afaceri cu etichetă privată este central.

Modelul de afaceri cu etichetă privată adoptat de cele mai competitive companii de tricotaje a luat în considerare un pachet complet de servicii pentru clienții internaționali. A integrat designul colecției, dezvoltarea materiilor prime, finisaje superioare, produse atent create și rentabile, precum și logistică sofisticată. Pedrosa & Rodrigues SA este o întreprindere mijlocie din regiunea Barcelos, din nordul Portugaliei și este un exemplu de mare succes al noilor paradigme competitive. Acest nou model conduce acum industria portugheză de tricotaje la un nivel mai înalt în lanțul valoric și îi conferă o reputație puternică în întreaga lume.

Cuvinte-cheie: *etichetă privată, orientare către design, noi paradigme ale industriei textile, inovație organizațională, lanț valoric durabil*

INTRODUCTION

Globalisation has altered competitiveness dynamics [1]. In the last decades, the high degree of openness of the nations' economy, enhanced by globalisation, has transformed the world [2–4] causing nations, economic sectors and even individuals to adapt to an environment characterised by increased competition, speed and frequency of changes [5].

The fashion market also became synonymous with rapid changes and, as a result, commercial success or failure in the markets depends on the flexibility and responsiveness of organisations [6]. According to Henderson [7], the strategy contributes to a deliberate search for an action plan that will develop a competitive advantage for the business. The essence of the strategy is to choose a unique positioning and a differentiated value chain [8]. On the other hand, Rowley, Bareghehe and Sambrook [9] point out that there is widespread recognition of the growing importance of innovation for organisations and economies. In this way, companies' survival depends on their ability to implement R&D strategies and acquire advanced technological knowledge to generate ideas about new products or improve current ones, remaining ahead of their competitors [10].

As Cheng et al. [11] pointed out, the competitiveness between national brands and private label brands has been a fundamental research area in the last decade [1]. According to Hsiao et al. [12], some studies have focused on consumer attitudes towards private label (PL) brands. Other relevant studies examine the relationship between quality and price.

This research work aims to identify aspects of competitiveness and strategy adopted by companies that adopt the private label model to face global competitiveness in the textile and clothing industry. The case study method allowed an in-depth analysis of how companies implemented the private label model. Pedrosa & Rodrigues over the last decade has successfully implemented the private label model, and its' study can contribute to the understanding of the requirements faced by companies that wish to adopt this model.

COMPETITIVENESS IN THE NEW MARKET CONDITIONS

Competitiveness and strategy

Competitiveness is a concept that implies different meanings for companies and a country's economy [13]. In a general perspective, according to Mariotto [14] and Teixeira [5], the term competitiveness is applied to both nations and companies. The concept refers to the ability of an organisation or nation to be successful in the market despite national and world competition.

For Porter [15], the strategy consists of creating a unique and valuable position, involving a different set of activities. On the other hand, a strategy is the set of decisions and actions of the company that, consistently, seek to provide customers with more value than that offered by the competition. The strategy is a deliberate search for an action plan that will develop a competitive advantage for the business [7]. Thus, the essence of the strategy is to choose a unique positioning and a differentiated value chain [8]. For Miranda [16], from goals to policies, among other configurations, the strategy is described as a process of maturation and natural evolution of the complex activity of business management conditioned by technological, economic, social and environmental developments.

Teece, Pisano and Shuen [17] substantiate, on the other hand, that strategic management consists of the way companies achieve and sustain a competitive advantage. Porter and Kramer [8] emphasise that the strategy theory holds that, in order to be successful, a company must create a distinctive value proposition that meets the needs of a set of customers. The company obtains a competitive advantage through the way it sets up the value chain or the set of activities involved in the creation, production, sale, delivery and support of its products or services.

For a company, a competitive strategy is to be different. It means intentionally choosing a different set of activities to offer a unique combination of value [15; 18]. The objective is to find a way to position itself in the industry, in order to benefit from the competitive forces model: (1) rivalry between competing companies; (2) suppliers' bargaining power; (3) customers' bargaining power; (4) threat of new entries; and (5) threat of substitute products [19]. According to this model, customers, suppliers, substitutes and potential entries, as well as competitors, exert pressure on the company, which will be greater or lesser, according to each case [14]. The strategic decision process is considered an essential part of the process in which organisations adapt to the contextual environment. Porter [15] also presents a typology of strategies that the company can use to face the five forces of competition successfully [14]. They are called generic strategies because they can be adopted by any business unit [20]. The adoption of any of the three strategies (differentiation, cost and specialisation) would imply full support from the organisation concerning the chosen strategy, so this would imply a non-adoption of more than one strategy at the same time by the organisation [5].

However, as Moraes and Zilber [20] point out, several authors developed concepts that contradict Porter's model, generating so-called hybrid strategies that propose that companies can simultaneously and profitably adopt cost leadership and differentiation.

Competitiveness of the textile and clothing industry

Nowadays, companies face new challenges, and more aggressive competition prevails, with more complex products and more demanding consumers [21].

The textile industry and its' context struggle to keep developing the process of modernisation, driven by the emergence of entirely new or more sophisticated textile technology, together with the growing competition for markets and products. The process was developed in the industrialised countries and afterwards expanded to recently industrialised and developing countries, many of which use the latest textile technologies as a way to guarantee a competitive position, especially in export markets [22]. According to Lee and Östberg [23] due to its labour-intensive nature, this industry generally occurs in economies that are in the early stage of development. However, as the economy develops to become highly industrialised, wages increase, and the economy loses its price competitiveness.

Currently, in Europe, the textile and clothing sector continues to play a significant role in the European economy. Its eventual decline could have a significant impact on the EU economy [24] since 185,000 companies, mostly SMEs, remain in operation, employing 1.7 million workers (6% of employment in the EU), and generating a turnover of 166 billion euros (3% of the EU added value) widely distributed across the EU. However, a substantial part of textiles and clothing consumed in the EU is produced in other parts of the world, mainly Asia, taking advantage of the lower wage cost. The disadvantages of this model include long-distance supply chains, poor working conditions and high environmental costs [25].

The Portuguese textile and clothing industry is one of the most important manufacturing activities in the national economy. It represents about 3% of GDP, 10% of merchandise exports, 20% of employment, 9% of production and 11% of the GVA of the national manufacturing industry. In absolute numbers, its expression is even more significant: 7.6 billion in turnover, 7.5 billion in production, 5.3 billion in exports and 134 thousand direct jobs. It outranks more than five times the cork sector and more than 2.5 times the footwear industry [26]. The sector is more important from a regional point of view since the sector is strongly concentrated in the North Literal part of the country, with particular importance in areas, Braga and Porto that represent 57% and 24% of the total sector volume of trade (figure 1).

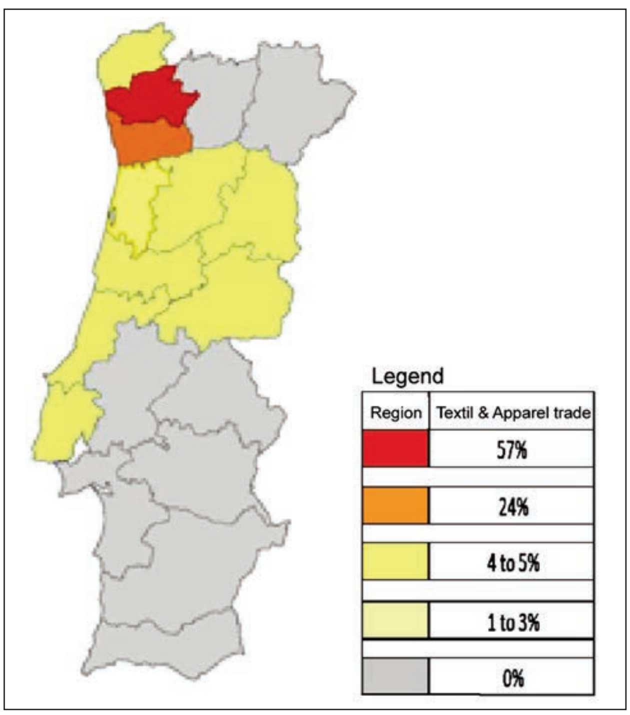

Fig. 1. Textile and clothing trade regional distribution in Portugal

The demand for the textile and clothing industry is highly dependent on the disposable income and the general economic well-being of the regions. The last decade the sector has benefited from an increasing number of consumers who have chosen to buy more garments at lower prices, generating revenue and profit in the sector [27].

Taking into account the Portuguese context it appears that textile companies face strong competitiveness in two ways. On the one hand, the presence of large international textile and clothing companies that mainly adopt a cost-leading strategy and, on the other hand, several brands of already established manufacturers that transfer a large part of their manufacture to low-income countries. However, the Portuguese textile companies that survive are those that continue with their production in the domestic market [10].

The new fashion design paradigm and the private label model

Fashion design aims to develop clothing and accessories respecting cultural, technical, and market trends. Fashion design is a means of communication, whether intentional or not, and Kratz [28] supports that fashion is an intangible and symbolic product. The analysis of this immaterial work produced by the designer cannot lose sight of what is inserted in the industrial process of fashion and clothing.

Preiholt [29] refers that in the past, fashion was connected with the leading fashion capitals, such as Paris, London, Milan and New York, and was primarily influenced by their intercultural environment. However, nowadays, it becomes more challenging to identify the sources of international fashion, in terms of global production and consumption. One of the characteristics of contemporary fashion is that it went from being a collective choice to becoming an individual choice, consumers mixing more and more styles, instead of adopting single brands.

The use of social networks contributed to change the way fashion is presented, disseminated and used. Consumers started to share information and create content. This new behaviour led designers and brands to consider consumers' opinions, in order to produce articles according to their needs and preferred trends, but also to listen to their opinion about competitors' products [12].

Rossi and Harger [30] consider it essential that companies follow market trends and innovations that, in the case of fashion, consider fabrics, colours, prints, cuts, shapes, among other elements.

Lima [31] states that the introduction of internal or external skills in terms of the design means a presentation of increasingly bold proposals with customers, with whom a relationship is established that provides an increase in the number of orders. Many companies, regardless of their size, already have internal creative departments, with textile and fashion designers, who develop solutions for their brands or third parties. Currently, companies, even those that work only for third party brands or in PL, offer a full-service package, consisting of the collection design, material development, industrial production and distribution logistics [32].

ATP [26] also highlights the importance of possessing skills in the field of design. Those competencies are essential to fully acquire the skills that the major brands transfer to the most sophisticated and qualified suppliers, retaining valuable customers and attracting new ones, in increasingly sophisticated markets and niches. Margins that are more significant reward the permanent removal from the competition based on price and the search for competition through differentiation.

In the future, it is expected that ITV's business in the PL model will be to maintain and evolve by integrating more benefit into the final product. For this, it will be necessary to invest in strategies for innovation in processes and organisation, in increasing cooperation with customers and suppliers, in increasing skills that allow improving the conditions of supply with advantages for the markets [26]. Companies must adopt a new position in these businesses, working as if they are the "innovation department" of their clients' brands and thus obtaining competitiveness through specialisation and innovation.

METHODOLOGY

Authors such as Sauders et al. [33] postulate an investigation process that allows the understanding of the object of study by successive approximations that was adopted. Given the nature of the study to be carried out and its objectives, it resulted the following steps: i) definition of the research theme; ii) critical review of the literature and existing information on the topic, in order to define the theoretical framework; iii) selection of companies, the object for study, that obeys a pre-defined set of criteria: location, dimension, specialisation, degree of internationalisation and intensity in the use of design as a critical factor of competitiveness and differentiating the respective value proposal; iv) data collection of the companies under study; v) data analysis and interpretation.

The case study was defined as the primary method in the work, as this is empirical research [34], that begins with exploratory goals and evolves to achieve an in-depth understanding of the evolution of the implementation of a concrete management model and in a real context, according to the guidelines proposed by Robson [35] and Yin [36]. There are several types of case study, and in the present research, the one we used is the "emancipatory" [35].

The case study of Pedrosa & Rodrigues will be combined and compared with others carried out on the same collective object of study [37], which is the circular knitting industry in the municipality of Barcelos. The case study considered three levels of information: the company's economic and financial indicators from the last ten years, the consultation with secondary sources, consisting of interviews and published reports about the company, and semi-structured interviews with its Directors, Casimiro Rodrigues, the founder of Pedrosa & Rodrigues, and Miguel Pedrosa Rodrigues, member of the company management. The information collected, processed and analysed allowed to achieve the objective of in-depth understanding of the implementation process of the strategic private label model in the knitwear industry and the drawing of conclusions regarding the possible adoption of this model by companies in the same or other industrial branches.

RESULTS

Pedrosa & Rodrigues is a textile company, semi-vertical, from the circular knitting subsector, located in the municipality of Barcelos, specialising in women's fashion, working practically exclusively for the foreign market, under private label regime. In 2017 this company had a turnover of 15,6 million euros and employed 109 direct workers.

On its website (www.pedrosa-rodrigues.pt), the company presents itself as an industrial company specialised in high-end clothing, that offers its' clients design and clothing items development according to the customer's specifications. The company follows a 21 steps protocol that goes from the design sketch, presented by the client or by its' design department, and ends with sending the invoice to the customer. The focus of this protocol is on high efficiency, fluidity and transparency in the process, in order to offer the client an excellency level service and reliability. The company differentiates itself from the competition by the solidity of these arguments put into practice.

Pedrosa & Rodrigues (P&R) was founded in 1982 by the couple Sabina Rodrigues and Casimiro Rodrigues, having taken off in the garage of Sabina's parents. Casimiro was involved in car repair, while his wife already worked in the clothing sector, in the cutting department. Both felt dissatisfied and unused in their abilities and desired higher challenges. The first years were hard, with the founders doing practically everything there was to do, working in a "multitask" and "nonstop" regime from Tuesday to Friday. The effort paid off, and gradually, the company abandoned the collaboration with national companies to produce and export directly to international clients. Casimiro Rodrigues stated that the strategic change aimed to obtain a more significant margin and to support the company expansion since it was necessary to offer higher benefit to conquer clients that are more demanding. The strategic option was to follow the evolution of the Italian market, transferring the offer of minutes to the offer of value. The founder of P&R also stressed as very important the territorial context in which the company operates, as in Barcelos region, all companies had exports as their goal, it did not matter how small they were.

Miguel Pedrosa Rodrigues, second-generation company manager, and a trained architect reinforce this last competitive factor and consider that to operate in a 'cluster' brings the company a significant competitive advantage. The proximity among the agents in the sector allows them to know the professionals and companies that compose it, along with their agility, competencies, and production quality. The central value within this cluster is to add more value to customers and satisfy orders with the minimum organisational dimension possible. The cluster became an

excellent hub of knowledge and credibility when investing in long-term strategies requiring solid relationships with workers, suppliers and customers.
Miguel Pedrosa Rodrigues vision follows the company's founders market perception concerning the values and principles that built and define the company's culture: focus on the solution to the customer, focus on the added value as a market differentiator, relational stability with the company's human capital and all other stakeholders, including suppliers and customers. He considers his vision is fully supported by the fact that the company has an enormous capacity for customer loyalty since after working two collections with the company, they tend to keep it as their supplier. This loyalty affects mainly high-end clients, brands like Helmut Lang, Zegna or Diane von Furstenberg, with whom the company may already be negotiating only manual operations. In the present, the company still works with a floating fringe of other customers of the superior medium segment, to obtain production scale, and customer requirements define the standard of quality. The mixture between superior medium and high-end clients is an asset, as the variety generates resilience and requires the company to implement and develop very robust processes in order to keep flexible, and highly efficient.
The complex and sophisticated private label business model developed Pedrosa & Rodrigues has another critical competency, the endogenous existence of skills of design and fashion knowledge, central to meet the demands of international customers. This strategic orientation determined a specific organisation that integrates the Design Department in the Commercial Department, and the designers are requested to work always assuming the clients' perspectives and visions, as an extension of the client's Design Department. The Design Department is also expected to contribute to bringing to the company new businesses. Pedrosa & Rodrigues management assumes that the company is a production, industrial one, focused on the private label model. This model, as developed by P&R, is an evolutionary process that requires permanent investment and organisational fully committed resources.
The present market challenges, the emergence of new generations of consumers with diverse values and purchasing behaviours, some even disruptive, based on sustainability, ecology and social responsibility, as well as new information and sales channels, of a digital nature, has led the company to invest in market knowledge and consumer behaviour. The investment in social networks, especially on Instagram, and industry 4.0, with a logic of collecting and processing permanent information about the product and the customer, is crucial to maintain continuous improvement and a superior degree of excellence in the provision of service to the clients. The private label model suits to a new client that is not interested in technical issues, equipment or the production process, as was the case with previous generations. Today, the focus is on the profit margins the client can get from the order he places, considering that the supply chain is reliable and the quality is achieved, at the right time and the right price.
The price kept its central importance in the value chain. However, it cannot be critical to the business model that was developed by P&R. The company faces the challenge of increase the number of customers who do not consider prices critical. Those targeted clients value above all the service package and other variables such as high-value finishing. Because of this strategy, the prices went up systematically since 2011, but the sales kept growing until 2017 at a double-digit pace, reaching almost 16 million Euros. In 2018, turnover fell slightly, due to “Brexit” and Turkish competition, with the aggressive currency devaluation and the country's political stabilisation. The present and future challenges are to invest in continuous organisational, product development, and manufacture improvement. The goal is to keep being better, more efficient, to do more with less, to eliminate waste and increase efficiency, in a continuous process. It is the strategy to maintain competitively over time. Other challenges for the future are the automation of clothing making, and the consolidation of industry 4.0 technologies and processes, in which they already operate. It is also expected that the industry will have growing difficulty in finding available workers and it will be necessary to socially value the work of the seamstress, situated between handicrafts, fundamental in luxury and high-end products. The company also expects that to keep competitive will have to relocate orders, especially those from clients more sensitive to price. This way it will be possible to offer clients a mix of service and price that holds them holistically, keeping the decision centre in the company, as well as the benefit generated.
The managers outlined another angle of their vision: the company is an industrial studio, dedicated to the medium, high and very high segments, which requires flexibility and very short lead-time. The customers already classify the Portuguese knitwear and textile industries as the “fastest lead time supplier”. P&R also works with small quantities, and customisation, which requires a great capacity for process management, including what today is called the industrialisation of customisation. However, this full range of service is available only for the high-end customer, who values it.
The future development of the private label model at P&R unfolds in a vision of organic growth, stability and sustainability. The company's managers defined a strategy that maintains the organisation as a family business, small and highly sophisticated, agile, flexible and specialised. They intend to gain scale through cooperation with other Portuguese companies in the cluster and keep the strategic focus on profitability overgrowth. The company's performance from 2007 to 2018 (tables 1) prove the efficiency of the private label model at P&R, on virtually all performance indicators, from sales volumes to workforce, net results and cost reduction by net results.

Table 1

"PEDROSA & RODRIGUES"/MAIN INDICATORS									
Indicators	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2014**	**2016**	**2018**
Turnover (1000 euros)	7.378	7.714	6.312	8.153	8.452	6.385	9.483	14.114	13.022
Direct Jobs	89	88	82	83	93	77	79	99	109
Exports	7.230	7.508	6.276	8.137	8.353	6.296	9.173	13.605	12.945
% on exports	98	97	99	99	99	99	97	96	99
Eat – earnings after taxes (1000 euros)	157	129	111	266	381	103	823	1.311	TBC
Ebita over sellings (%)	7	6	7	8	9	6	13	13	11
Medium price/1 piece (euros)	7.38	7.72	8.4	9.66	11.24	11.01	10.43	13.5	13.62
Investment fbcf (1000 euros)	N.A.	491	443	356	48	8	292	544	TBC
Investment on design and sustainability	-	-	-	-	-	-	40	33	62

Note: TBC – to be confirmed, as final numbers are not yet concluded for 2018; N.A. – not available.

CONCLUSIONS

The Portuguese Textile and Clothing Industry has undergone a profound paradigm shift in the last twenty years. Due to a set of global competitive shocks, the entire sector went through a continuous restructuring path. It reinvented itself by adopting new critical competitiveness factors, achieving, this way, a degree of success that is internationally recognised, to the point that the Portuguese textile and clothing sector is considered a "case study" on a global scale, which many want to emulate as a model.

This paradigm shift can be summed up in three fundamental considerations:

- the sector was no longer able to compete for price (aggressive Asian competition based on the low cost of labour) and started to compete for value (which differentiates companies and their products by design, technological innovation and service intensity, which today characterise the sophisticated private label models, which offer the market a "full package service");
- the sector is no longer a passive order taker but an active seller of solutions, oriented to the interests of the client, in which the "full package service", which characterises the Portuguese private label model is a crucial element in the business model;
- finally, the sector ceased to present itself as an erratic and straying sum of individual companies' initiatives, more or less voluntary, to have a collective strategy, capable of bringing together the different actors, including the scientific and technological system, the associations and the State itself (public policies and community funds), in order to better allocate scarce resources to perfectly defined and quantifiable goals.

Pedrosa & Rodrigues, a small/medium size company in the circular knitwear subsector, specialised in women's clothing in the medium, high and premium ranges, located in Gilmonde, Barcelos, is one of the best examples we can find in this domain.

In a constant process of continuous and sustainable incremental improvement, P&R built its private label business model that is, working for third-party brands always refusing to implement a brand strategy.

The private label model works the development of a "full-service package", which includes the offer of design services, creation and development of collections, materials and processes innovation, among other values to the client.

The focus on efficiency, adequate quality and customer service, which has become a real obsession, shared by all the company's professionals, positively differentiates Pedrosa & Rodrigues from its competition. Completely integrated into the new private label business model of the Portuguese knitwear industry, P&R can assert itself as one of this model best performer, contributing permanently to improve it.

The role of the Design Department, in this specific private label model developed by Pedrosa & Rodrigues, should be highlighted as it works under the supervision of the Commercial Department, permanently focused on interpreting the needs of the buyers. The design assumes, in this context, the organisational goal of understanding the client needs and requirements and deliver him this knowledge in the form of fashion or clothing items and collections. The service package of the model considers a logic of design oriented to business, in which creativity can have broadband, from the consolidation of the client's superior specifications to the freedom of innovative and disruptive proposals. The communication methods and tools that the company developed maximise production efficiency and promote a better interaction with its customers, and the market in general, without which it would not be possible to know and meet their needs and offer efficient service.

P&R business model analysis brings an example for other companies in the sector as well as for other sectors of activity specialised in B2B businesses. The present competition pressure places the competitive advantages in the domain of value generation supported by knowledge centres internal to the organisation that allow differentiating the offer by creating value for the customer, significantly reducing the weight of the competition on price.

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REFERENCES

[1] Girard, T., et al., *Consumer-based brand equity of a private-label brand: Measuring and examining determinants*, In: Journal of Marketing Theory and Practice, 2017, 25, 1, 39–56

[2] Wiersema, M.F., Bowen, H.P., *Corporate diversification: the impact of foreign competition, industry globalization, and product diversification*, In: Strategic Management Journal, 2008, 29, 115–132

[3] Carvalho, L., Serio, L., Vasconcellos, M., *Competitividade das nações: análise da métrica utilizada pelo World Economic Forum*, In: Revista de Administração de Empresas., 2012, 52, 4, 421–434

[4] Bang, K., Markeset, T., *Impact of Globalization on Model of Competition and Companies' Competitive Situation*, In: International Conference on Advances in Production Management Systems (APMS), 2017, 276–286

[5] Teixeira, F., *A influência das especificidades culturais locais na competitividade de clusters: estudo de caso do cluster da malacocultura da região da Grande Florianópolis*, Tese de Doutoramento. Escola de Engenharia, Universidade do Minho, 2016

[6] Christopher, M., Lowson, R., Peck, H., *Creating agile supply chains in the fashion industry*, In: International Journal of Retail and Distribution Management, 2004, 32, 8, 367–376

[7] Henderson, B., *The Origin of Strategy*, In: Harvard Business Review, 1989, November–December

[8] Porter, M., Kramer, M., *Creating Shared Value: How to reinvent capitalism – and unleash a wave of innovation and growth*, In: Harvard Business Review, 2011, January–February

[9] Rowley, J., Baregheh, A., Sambrook, S., *Towards an innovation-type mapping tool*, In: Management Decision, 2011, 49, 1, 73–86

[10] Rezazadeh, A., Carvallho, A., *Towards a surviivall capabiilliitiies framework: Lessons from the Portuguese Textiille and Clothing industry,* Working Paper Series, Núcleo de Investigação em Políticas Económicas. Universidade do Minho, 2018

[11] Cheng, J., et al., *Do consumers perceive differences among national brands, international private labels and local private labels? The case of Taiwan*, In: Journal of Product & Brand Management, 2007, 16, 6, 368–376

[12] Hsiao, S.-H., et al. *How social media shapes the fashion industry: The spillover effects between private labels and national brands*, In: Industrial Marketing Management, 2019

[13] Kupfer, D., *Padrões de concorrência e competitividade*, Conference: XX ANPEC 1992, At Campos do Jordão, 1992

[14] Mariotto, F., *O conceito de competitividade da empresa: uma análise crítica*, In: Revista de Administração de Empresas, 1991, 31, 2, 37–52

[15] Porter, M., *What is Strategy?*, In: Harvard Business Review, 1996, November–December

[16] Miranda, A., *Vantagem competitiva em pequenos negócios: perspectivas à luz das capacidades dinâmicas – caso São Luís,* Tese de Doutoramento, Istituto Universitário de Lisboa, 2017

[17] Teece, D., Pisano, G., Shuen, A., *Dynamic capabilities and strategic management*, In: Strategic Management Journal, 1997, 18, 7, 509–533

[18] Azeitão, J., Roberto, J., *O planeamento estratégico e a gestão estratégica nas PME*, Ordem dos Contabilistas Certificados, 2010, Março

[19] Porter, M., *How competitive forces shape strategy*, In: Harvard Business Review, 1979, March–April

[20] Moraes, C., Zilber, M., *Estratégia e vantagem competitiva: um estudo do setor petroquímico brasileiro*, In: Revista de Administração Mackenzie, 2004, 5, 1, 166–195

[21] Pinto, A., Henriques, C., Martinho, A.M., *O impacto da inovação na rendibilidade empresarial: O caso do setor têxtil português*, In: Revista Portuguesa e Brasileira de Gestão, 2014, Abr/Jun

[22] ITMF – International Textile Manufacturers Federation, *International Production Cost Comparison 2018 (Revised edition),* 2019

[23] Lee, Y.-J., Östberg, J., *A case study of the Swedish fashion industry from the systems perspective of creativity*, In: Journal of Global Fashion Marketing, 2013, 4, 2, 128–143

[24] Prunea, A., *The competitiveness of textile industry*, In: Annals of the University of Oradea. Fascicle of textiles, leatherwork, 2011

[25] Bontoux, L., Boucher, P., Scapolo, F., *Textiles and Clothing Manufacturing: Vision for 2025 and Actions Needed,* Joint Research Centre (JRC), European Commission's, 2017

[26] ATP – Associação Têxtil e Vestuário de Portugal, *Fashion From Portugal. Yearbook. Textile and Clothing Industry Statistics: World, Europe and Portugal*, Vila Nova de Famalicão: ATP, 2017

[27] Jang, J., et al., *A Study of a Social Content Model for Sustainable Development in the Fast Fashion Industry*, In: Journal of Global Fashion Marketing, 2012, 3, 2, 61–69

[28] Kratz, L., *O processo criativo para o designer de moda*, In: Estudos em Design, Revista (online), Rio de Janeiro, 2016, 24, 1, 169–196

[29] Preiholt, H., *From Collective Selection to Individual Style: A Symbolic Transfer in Fashion*, In: Journal of Global Fashion Marketing, 2012, 3, 1
[30] Rossi, A., Harger, P., *Influenciadoras digitais: o marketing de moda em tempos atuais*, In: NAMID/UFPB, 2017, XIII, 9, Available at: http://periodicos.ufpb.br/ojs2/index.php/tematica [Accessed on August 2020]
[31] Lima, J., *Os Empresários da Indústria Têxtil do Vale do Ave*, Edições Afrontamento, 2018
[32] AICEP, *Portugal Global – Indústria Têxtil e de Vestuário uma Referência a Nível Mundial*, 2018, 113, Available at: http://portugalglobal.pt/PT/Paginas/Index.aspx [Accessed on August 2020]
[33] Sauders, M., Lewis, P., Thornhill, A., *Research Methods for Business Students*, 5th Edition. London: Finantial Times Prentice-Hall, 2009
[34] Larsson, R., *Case Survey Methodology: Quantitative Analysis of Patterns Across Case Studies*, In: The Academy of Management Journal, 1993, 36, 6, 1515–1546, https://doi.org/10.2307/256820
[35] Robson, C., *Real world research: a resource for social scientists and practitiorer-researchers*, 2nd Edition. Oxford: Blackwell Publishers Inc., 2002
[36] Yin, R.K., *Case Study Research: Design and Method,* 4th Edition. London: Sage Publications, 2009
[37] Gaskell, G., *Pesquisa Qualitativa com texto, imagem e som – um Manual Prático*, 7ª Edição. Petropólis, RJ: Vozes, 2008

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Modelling factors of influence on business process management in the organizations of the clothing industry

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ABSTRACT – REZUMAT

Modelling factors of influence on business process management in the organizations of the clothing industry

Business process management (BPM) in organizations of the clothing industry can be considered as a practice of importance for establishing a stable and progressive business. In contemporary business, which considers the application of best business practices within production-business systems, effective process management becomes important and emerges as a practice that contributes to the overall improvement of the organization's operations. BPM focuses on improving both internal and inter-organizational operations that take place between organizations within the supply chain of clothing industry. The effective BPM in the organizations of the clothing industry may depend on the establishment of the various elements. The assumption is that influential elements are specifics of the garment industry such as the primary BPM activities, the different dimensions of BPM which are consistent with a comprehensive view of this approach, as well as the mere involvement of human resources in the business processes of the organizations. The defined influential elements are treated as variables of the structural model, created by the implementation of the IBM SPSS AMOS structural modelling program, exploring a number of hypothesized impacts. The results of this research help to understanding the impact of these elements on the strengthening BPM practice in the clothing industry organizations.

Keywords: *business process management (BPM), clothing industry, BPM dimensions, process management activities, human resources in clothing industry processes*

Modelarea factorilor de influență asupra managementului proceselor de afaceri în organizațiile din industria de îmbrăcăminte

Managementul proceselor de afaceri (BPM) în organizațiile din industria de îmbrăcăminte poate fi considerat o practică importantă, pentru stabilirea unei afaceri stabile și în evoluție. În mediul de afaceri contemporan, care are în vedere aplicarea celor mai bune practici de afaceri în cadrul sistemelor de producție-afaceri, gestionarea eficientă a proceselor devine importantă și apare ca o modalitate de îmbunătățire generală a operațiunilor organizației. BPM se concentrează atât pe îmbunătățirea operațiunilor interne, cât și a celor inter-organizaționale, care au loc între organizațiile din lanțul de aprovizionare al industriei de îmbrăcăminte. Un BPM eficient în organizațiile din industria de îmbrăcăminte poate depinde de stabilirea diferitelor elemente. Presupunerea este că elementele influente sunt specificul industriei de îmbrăcăminte, cum ar fi activitățile primare BPM, diferitele dimensiuni ale BPM care sunt în concordanță cu o viziune cuprinzătoare a acestei abordări, precum și simpla implicare a resurselor umane în procesele de afaceri ale organizațiilor. Elementele influente definite sunt tratate ca variabile ale modelului structural, create prin implementarea programului de modelare structurală IBM SPSS AMOS, explorând o serie de modele de impact ipotetice. Rezultatele acestei cercetări ajută la înțelegerea impactului acestor elemente asupra consolidării practicii BPM în organizațiile din industria de îmbrăcăminte.

Cuvinte-cheie*: managementul proceselor de afaceri (BPM), industria de îmbrăcăminte, dimensiunile BPM, activități de gestionare a proceselor, resurse umane în procesele din industria de îmbrăcăminte*

INTRODUCTION

Under the influence of contemporary business conditions organizations of the clothing industry have the task to harmonize their business with the new market demands and to find the best business practice which will provide their success. Each industrial branch is characterized by specific working conditions [1]. As Mareš [2] states, each industrial branch is specific in its own way in accordance with the production processes carried out within it.

Clothing industry is specific in terms of various issues. This research takes into account the intensity of work within the manufacturing processes of the clothing industry [3], the predominant presence of the female workforce in the workforce structure of the clothing industry [4], and predominant participation of micro, small and medium-sized enterprises [5] in the structure of companies engaged in the production of apparel. These characteristics reflect to the business processes within clothing and textile industry organizations, and the quality of the functioning of business processes can contribute to competitive advantage strengthening, in contemporary business conditions [6, 7].

Business processes represent the base of every business, and, accordingly, the formation of best business practices based on business process management (BPM) is justified [8]. Fleacă and Purcărea [9] state that any organization within the textile and apparel industry has three basic business process groups, namely: (1) the manufacturing process group, (2) the new garment product development process group, and, (3) the marketing process group. In accordance with these processes, it is necessary to determine the activities within the different process dimensions that, based on the nature of the process, are primary to achieve the improvement and development of the business of the clothing industry organizations. It has been known for a long time that human resources play a central role in the implementation and supervision of the functioning of business processes [10].

Consequently, this research focuses on the specific aspects of the clothing industry, the dimensions of BPM, and the primary activities of BPM in accordance with the specific characteristics of the clothing industry. The study also investigates the role of human resources as an element that significantly influence the success of BPM, and, finally, the creation of promising business practices for clothing industry organizations based on BPM.

The main objective of this paper is to examine the impact of factors that potentially might influence the adoption of best business practices within the clothing industry organizations through BPM. The first, theoretical part of the paper, accordingly, highlights and reviews aforementioned aspects in more detailed way. In the remaining, second part of the paper, the modelling approach of the assumed impacts is described and explained on the basis of gathered data.

FACTORS OF INFLUENCE ON THE BPM IN THE CLOTHING INDUSTRY

Clothing and textile industry represent resource-intensive as much as labour-intensive industry branches in which many production tasks, based on human work, are difficult to replace by automatic production [11, 12]. Taking the tailoring process as an example, one can see the need for the presence of human resources possessing specific knowledge and skills. Although a large number of solutions based on the application of Computerized Numerical Control (CNC) textile cutting technology have been developed, the cutting process is carried out manually in a large number of enterprises, especially micro and small ones [13, 14]. Although it is possible to create cut-outs using computers, in practice, manual work is still present in the tasks of creating, constructing, modelling, grading and fitting cut-outs [15, 16]. Dimitrijevic et al. [17] state that small and medium-sized enterprises (SMEs) must respond to contemporary challenges by modernizing production processes and achieving competitiveness, with labour expertise being considered as one of the influential factors. The female workforce has a significant share in the workforce structure of the clothing industry, which is cited as a characteristic of labour-intensive activities [18, 19]. These specific features appear as a starting point of a potential influence on BPM.

The processes represent a series of interconnected activities with clearly defined inputs and outputs [20]. A series of interconnected, structured tasks enables the creation of specific products or services and describes how organizations conduct their business [21, 22]. Their flexibility depends on human resources, decisions made and the level of expertise [23]. Within labour-intensive industries, such as the clothing industry, the role of human resources in the realization of business processes is particularly prominent. Sustainable business processes are performed by people, who, in turn, tend to find out a balance between learning from the past, experimenting and adapting to the future [24]. Process efficiency is, among other things, reflected in the adaptation of process skills, roles and activities [25]. Therefore, the next factor whose impact needs to be explored is the importance of human resources in managing the business processes of the garment industry.

Within the spectrum of different levels of managerial decision making, business process design is the primary step of managing business processes and has traditionally been considered a strategic issue [26]. Organizations within the textile and clothing industries need to be aware of the need to perform well-defined processes [27]. BPM contributes to improving organizational efficiency through standardization of activities and processes [28]. In today's business environment, all organizations try to achieve business efficiency and effectiveness that will allow them to be more innovative, flexible and successful, however, each organization, in accordance with the industry in which it operates, is specific in its own way, and one universal way of managing business processes will not contribute to the achievement of this aspiration of organizations [29, 30]. Accordingly, it is necessary to carry out a set of specific activities that will ensure the application of best business practice in BPM, and determining the primary BPM activities is another potentially influential factor.

BPM is established through dimensions such as human resource management, development of process-based information systems, focus on consumers and competitors, process structures, performance measurement and improvement of business processes, processes in supplier relations, process organizational culture, alignment of process and strategic goals and process identification, documentation, and standardization. These dimensions are the result of a holistic view of BPM issues [31], and, reasonably, they are considered as the fourth factor whose impact should be examined within the research part of the paper.

RESEARCH METHODOLOGY

Factors of potential influence on the BPM in the clothing industry, defined in the theoretical part of the work, are modelled in the research part of the work for the purpose of assessing their real impact, based on the responses of 508 respondents working in different organizations of the clothing industry.

Respondents' answers were collected with the help of a questionnaire, that was created and relied on the literature sources [22, 32–36], with some modifications. Respondents rated the claims on a 5-point Likert scale, with 1 indicating absolute disagreement with the claim presented, and 5 indicating absolute agreement of employees. The data collected in this way were coded and a database was formed within the software package for statistical processing of data SPSS 20. Table 1 shows the indicators used to test the hypothesized impacts within the model for assessing the impact of defined elements on BPM in clothing industry organizations.

The first step in the research part of the study is to identify basic characteristics of the sample by applying descriptive statistics analysis. The next step involves conducting a test of reliability of indicators within the variables included in the model. The reliability test is performed based on the Cronbach's Alpha coefficient calculation. Descriptive statistics analysis and Cronbach's Alpha coefficient calculation are performed within the SPSS program. Finally, structural modelling of assumed factors is performed using IBM SPSS AMOS package v23, which makes it possible to test the effects of defined components and draw conclusions about the functioning of BPM practices within the clothing industry based on the responses of employees of such organizations.

Defining potential impacts and research hypotheses

The assumption in this research is that the specific aspects of the clothing industry affect the different dimensions of BPM, and that these aspects influence through the BPM dimensions the quality of BPM. Specific features can also influence the application of primary BPM activities in the clothing industry organizations and human resources in the clothing industry BPM. The following hypotheses are formed: *Specific aspects of clothing industry influence different BPM dimensions* (H1); *Specific aspects of clothing industry have a significant impact on establishment of effective BPM over the impact of the BPM dimensions* (H2); *Specific aspects of clothing industry stimulate the application of primary BPM activities in clothing industry* (H3); and, *Specific aspects of clothing industry achieve the influence on reactions and perceptions of human resources about BPM in clothing industry* (H4).

In many similar studies, relating the subject of this research, there is a claim that BPM activities shape the quality, flexibility and efficiency of BPM initiatives [37]. The assumption is also that the primary activities of the clothing industry BPM can influence the perceptions and behaviors of humans performing certain process roles within the clothing industry process, the establishment of dimensions of BPM, and the quality of the BPM system itself. Therefore, the following additional hypotheses are formulated: *Primary BPM activities of the clothing industry influence perceptions and behaviors of employees about BPM of clothing industry* (H5); *Primary BPM activities of the clothing industry influence the establishment of BPM dimensions* (H6); and, *Primary BPM activities of the clothing industry stimulate the establishment of effective BPM* (H7).

Finally, an understanding of the processes and overall human resource management system can have a

Table 1

CODES OF FACTORS AND INDICATORS IN THE MODEL			
Influential factor	**Factor code**	**Indicators**	**Indicator code**
Clothing industry specific aspects	S	Labour-intensive character	S1
		Mostly female workforce	S2
		Dominant participation of micro and SMEs	S3
BPM dimensions	D	Assessment of compliance of all dimensions with BPM	D1
		Business process performance indicators are familiar to everyone within the organization	D2
HR in the BPM of the clothing industry	HR	Employees can be counted on to achieve business process goals	HR1
		Employees understand what elements of the process add value	HR2
Primary BPM activities in the clothing industry	A	Active involvement of top management in BPM	A1
		Definition and documentation of process roles and responsibilities	A2
Effective BPM in clothing industry	BPM	Standardization of business process description methodology – an element of internal establishment of BPM	BPM1
		Changes in business processes are communicated to supply chain actors – an element of external establishment of BPM	BPM2

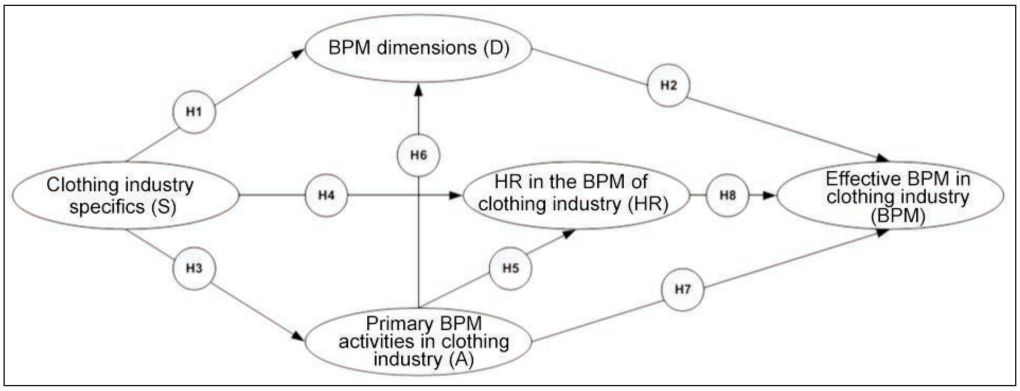

Fig. 1. Conceptual model of the research

significant impact on the effective management of business processes in the clothing industry. Human resources play a significant role in improving organizational processes because of their engagement within the process [38, 39]. That is why is created the last hypothesis: *Perceptions and behaviour of human resources connected to issue of BPM significantly influence the establishment of effective BPM* (H8).
On the basis of assumed relationships among described factors above, the conceptual model, presented in figure 1, is developed.

RESULTS AND DISCUSSION

Results of descriptive statistics offer a clear insight in the sample profile. The survey included a total of 508 employees in the clothing industry organizations, of which 245 (48.2%) were employed in micro, small and medium-sized organizations, while 263 (51.8%) were employed in large organizations. Production workers make up 69.9% of the sample. In regard to the age structure of employees, 14.8% are young, 70.1% are middle-aged and 15.2% are older employees. The survey covered 74.4% of female employees, while only 25.6% of male employees participated in the survey.
Results obtained on the basis of prepared questionnaire, before structural modelling and hypothesis testing, were firstly analysed and their reliability was evaluated. Cronbach's Alpha coefficient is useful in estimating the internal consistency of the reliability of a questionnaire containing a larger number of items [40]. Values of Cronbach's Alpha coefficients exceeding 0.7 are considered desirable and acceptable values [41]. The value of Cronbach's Alpha coefficient obtained in this study is given in table 2.
On the basis of the calculated value of Cronbach's Alpha coefficient (0.824) for the whole questionnaire, it is obviously that it may be used as a reliable instrument for testing defined hypotheses. It is possible, therefore, to examine the nature of the influence of chosen factors on the outcome of BPM in organizations within the clothing industry. Following the result of the reliability test, the modelling of the defined problem is conducted using IBM SPSS AMOS program.

Table 2

DATA RELIABILITY		
Cronbach's Alpha	**Cronbach's Alpha Based on Standardized Items**	**Number of items**
0.824	0.824	11

Structural Equation Modelling (SEM) provides answers on the relationships and impacts among the variables considered [42]. One of the basic steps of SEM is to evaluate the model based on quantitative indicators for assessing goodness of fit [43]. The recommended fit values of the model highlighted in [44] are presented in table 3, in addition to the fit values of the model calculated in this research.

Table 3

SUGGESTED AND CALCULATED MODEL FIT PARAMETERS		
Indicators of model fit	**Suggested values**	**Values from model output**
χ^2/df	≤3.00	1.694
Root mean square error of approximation (RMSEA)	≤0.08	0.037
Root mean square residual (RMR)	≤0.05	0.018
Goodness of fit index (GFI)	≥0.9	0.978
Adjusted goodness of fit (AGFI)	≥0.9	0.960
Normed fit index (NFI)	≥0.9	0.966
Comparative fit index (CFI)	≥0.9	0.986

It can be noticed from the values presented in table 3 that all the parameters, read from the output after the model evaluation, were in accordance with the recommended fit values. Since all parameters were satisfied, the structural model with standardized estimates was developed, and, it is presented in figure 2.
From the derived model, presented in figure 2, it is possible to read the R^2 value for the considered variable effective BPM in the clothing industry organizations, which is coded by the code BPM in the model. This value is 0.96 and, consequently, it means that the chosen predictor factors explain 96% of the variance of the considered endogenous variable. Table 4

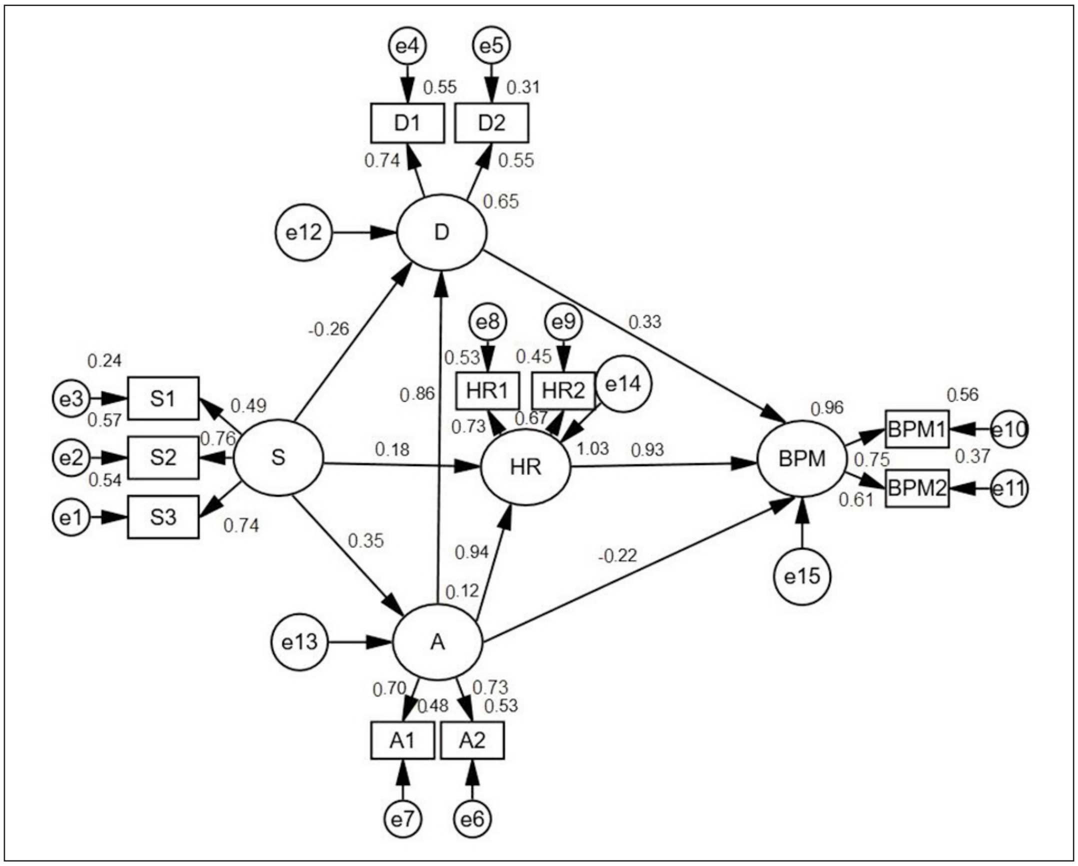

Fig. 2. Model of influences on efficient BPM in clothing industry organizations

presents the values that more closely explain the nature of the defined relationships and, they also show that impacts of the considered factors exist.

There are, according the results presented in table 4, significant influence between all the modelled elements, except one. Therefore, seven assumed possible impacts are statistically significant, and, among them six factors have a positive direction while one has a negative one. This observation stems from the insight into the values expressed in column C.R., and, in the value expressed in column P, where it is assumed that the value of C.R. is significant if greater than or equal to 1.96 at $p \leq 0.05$ [45]. Therefore, it is noticeable that the implementation of activities that would be called primary doesn't have a direct impact on the BPM because the value is the value of C.R. less than the adopted limit value and p value greater than 0.05. Based on these values, hypothesis H7 is rejected. Among other influences, which are confirmed by the model, the strongest is in the relation between the primary activities of UPP and human resources within the clothing industry business processes with a standardized estimate value (b) of 0.940 and a significance of ***, or less than 0.001. The effect of active involvement of top management and the definition and documentation of process

Table 4

MODEL ESTIMATIONS

Hypothesized path	Estimate	Standardised estimate	C.R.	P	Note
H1 (S-D)	–0.245	–0.263	–3.834	*** (<0.001)	Sig.
H2 (D-BPM) *indirect (S-D-BPM)	0.358	0.327 0.406	2.453	0.014 0.001	Sig. Sig.
H3 (S-A)	0.355	0.348	5.373	*** (<0.001)	Sig.
H4 (S-HR)	0.183	0.176	3.189	0.001	Sig.
H5 (A-HR)	0.958	0.940	13.021	*** (<0.001)	Sig.
H6 (A-D)	0.785	0.857	11.370	*** (<0.001)	Sig.
H7 (A-BPM)	–0.216	–0.216	–0.462	0.644	Not sig.
H8 (HR-BPM)	0.916	0.934	2.347	0.019	Sig.

roles, which were taken as priority activities, is not direct in relation to the effectiveness of BPM, but as the next strong influence is the link between the human resources element and the effective BPM, with $\beta = 0.934$ and $p = 0.019$, it is possible to consider the indirect effect of this element. A third effect on strength, based on the value of $\beta = 0.857$ and $p < 0.001$, was observed in the path between the primary activity variables and the BPM dimension, with the assessment of the use of activities that would emerge as primary, such as those highlighted in this research, contributes to the better establishment of different dimensions that ultimately contribute to a more effective BPM. The contribution of the BPM dimensions to the effective BPM is moderate and positive ($\beta = 0.857$, $p = 0.014$), and the hypothesis H2 is accepted on the basis that the measured indirect effect of the specific aspects of the clothing industry on the effective BPM which, through the BPM dimensions, is moderate and positive with the realized significance $p = 0.001$. The influence of specificity, as a starting element of research, has also been demonstrated in the model. Relative to the BPM dimensions, this impact is negative and weak ($\beta = -0.263$, $p < 0.001$), relative to the primary activities positive and moderate ($\beta = 0.348$, $p < 0.001$) and positive and weak relative to human resources in the BPM clothing industry organizations ($\beta = 0.176$, $p = 0.001$). Thus, among the variables that mostly helps to explain the dependent variable – effective BPM – in the clothing industry organizations, two variables stand out: the BPM dimensions and the human resources.

CONCLUSION

The effect of the specific aspects of the clothing industry, the primary BPM activities, BPM dimensions and human resources within the BPM system to the effective BPM, as well as mutual influences of the chosen factors, are investigated by structural modelling. The applied approach allowed us to describe direct as well as indirect effects. It is noticed that the strongest impact on effective BPM, based on the results generated by the model, might be attributed to the HR factor. Thus, perceptions and behaviours of employees significantly influence the establishment of an effective BPM in clothing industry organizations. Although indirect, the effect of the specific aspects of the clothing industry on the establishment of BPM is also recognized in the model. Primary activities represent the only factor, of the variables examined by the research, that doesn't directly affect the establishment of an effective BPM.

The recognized impacts within the model are derived as the outcome of evaluation made by 508 employees in clothing industry organizations. Yet, a more comprehensive research is inevitable. Further research, for instance, could address in-depth examination of influential factors, the potential of indirect impacts and impact of indicators of each factor, and generating measures to strengthen BPM in clothing industry organizations.

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REFERENCES

[1] Urošević, S., Radosavljević, D., Stefanović, V., Đorđević, D., Kokeza, G., *Multicriteria ranking of a job positions by ELECTRA methods in order to improce the analysis and conditions at work in companies in the textile industry,* In: Industria Textila, 2017, 68, 5, 388–395, https://doi.org/IT.068.05.1378

[2] Mareš, D., *The Key Factors in the Textile Industry*, In: Acta VŠFS-ekonomické studie a analýzy, 2019, 13, 1, 61–78

[3] Cuc, S., Tripa, S., *Redesign and upcycling-a solution for the competitiveness of small and medium-sized enterprises in the clothing industry*, In: Industria Textila, 2018, 69, 1, 31–36, http://doi.org/10.35530/IT.069.01.1417

[4] Stefanović, V., Urošević, S., *The impact of harmfulness in work process on safety and health of employed women with regard to the textile industry*, In: Tekstilna industrija, 2019, 67, 3, 4–13

[5] Tudor, L., *Change in textile and clothing industry*, In: Industria Textila, 2018, 69, 1, 37–43, http://doi.org/10.35530/IT.069.01.1449

[6] Dobrosavljević, A., *Managing the creative and labor-intensive business processes of the apparel industry*, In: Tekstilna industrija, 2019, 67, 4, 58–66

[7] Tonelli, F., Demartini, M., Loleo, A., Testa, C., *A novel methodology for manufacturing firms value modeling and mapping to improve operational performance in the industry 4.0 era*, In: Procedia CIRP, 2016, 57, 122–127

[8] Kaniški, I., Vincek, I., *Business processes as business systems*, In: Tehnički glasnik, 2018, 12, 1, 55–61

[9] Fleacă, E., Purcărea, A.A., *Raising the competitiveness of Romanian enterprises acting in textile industry based on process management modeling,* In: Industria Textila, 2014, 65, 1, 47–52

[10] Havur, G., Cabanillas, C., Mendling, J., Polleres, A., *Automated resource allocation in business processes with answer set programming*, In: International Conference on Business Process Management, Springer, Cham, 2016, 191–203

[11] Księżak, P., *The CSR challenges in the clothing industry*, In: Journal of Corporate Responsibility and Leadership, 2016, 3, 2, 51–65

[12] Taplin, I. M., Winterton, J., Winterton, R. *Understanding labour turnover in a labour intensive industry: evidence from the British clothing industry*, In: Journal of Management Studies, 2003, 40, 4, 1021–1046

[13] Nemeša, I., *Automatizovani sistemi za rezanje tekstila laserom,* In: Tekstilna industrija, 2018, 66, 4, 52–57
[14] Şen Kılıç A. (2019). *Comparison of Cad and Manual System Efficiency In Pre-Production Preparation Process*, In: Tekstil ve Konfeksiyon, 2019, 29, 1, 67–77
[15] Antić, S., Ilić, A., Đorđević, S., Petrović, D., *Analysis of the defined BlockBuffer parameters influence in computer making of pattern cutting images*, In: Tekstilna industrija, 2018, 66, 4, 45–51
[16] Gašović, M., Ćurčić, N., *Efekti marketinga i dizajna primenom CAD sistema u kompanijama-proizvođačima odeće*, In: Vojno delo, 2018, 70, 6, 309–320
[17] Dimitrijević, D., Adamović, Ž., Urošević., S., Prokopović, B., *Proces generisanja modela MSP – Participacija i benefiti kompjuterskog modelovanja (2. deo)*, In: Tekstilna industrija, 2019, 67, 1, 39–50
[18] Eraydin, A., Erendil, A., *The role of female labour in industrial restructuring: new production processes and labour market relations in the Istanbul clothing industry*, In: Gender, Place and Culture: A Journal of Feminist Geography, 1999, 6, 3, 259–272
[19] Kucera, D., Tejani, S., *Feminization, defeminization, and structural change in manufacturing*, In: World Development, 2014, 64, 569–582
[20] Armistead, C., Machin, S., *Implications of business process management for operations management*, In: International Journal of Operations & Production Management, 1997, 17, 9, 886–898
[21] Aagesen, G., Krogstie, J., *BPMN 2.0 for modeling business processes*, In: Handbook on Business Process Management 1, Springer, Berlin, Heidelberg, 2015, 219–250
[22] Glavan, L.M., *Upravljanje poslovnim procesima u poduzećima Republike Hrvatske*, In: Business and Economics Review, 2011, 31, 1, 105–125
[23] Schönig, S., Cabanillas, C., Jablonski, S., Mendling, J., *Mining the organisational perspective in agile business processes*, In *Enterprise,* Business-Process and Information Systems Modeling, Springer, Cham, 2015, 37–52
[24] Lindsay, A., Downs, D., Lunn, K., *Business processes-attempts to find a definition*, In: Information and software technology, 2003, 45, 15, 1015–1019
[25] Grover, V., Teng, J., Segars, A.H., Fiedler, K., *The influence of information technology diffusion and business process change on perceived productivity: The IS executive's perspective,* In: Information & Management, 1998, 34, 3, 141–159
[26] Reijers, H., *Design and Control of Workflow Precesses: Business Process Management for the Service Industry*, In: Springer-Verlag Berlin, 2003
[27] Meidan, A., García-García, J.A., Escalona, M.J., Ramos, I., *A survey on business processes management suites*, In: Computer Standards & Interfaces, 2017, 51, 71–86
[28] Daines III, J., *Re-engineering archives: Business Process Management (BPM) and the quest for archival efficiency*. In: The American Archivist, 2011, 74, 1, 123–157
[29] Gazova, A., Papulova, Z., Papula, J., *The application of concepts and methods based on process approach to increase business process efficiency*, In: Procedia Economics and Finance, 2016, 39, 197–205
[30] Ponsignon, F., Smart, P. A., Maull, R. S., (2012). *Process design principles in service firms: Universal or context dependent? A literature review and new research directions*, In: Total Quality Management & Business Excellence, 2012, 23, 11–12, 1273–1296
[31] Nezhad, H. R. M., Akkiraju, R., *Towards cognitive BPM as the next generation BPM platform for analytics-driven business processes*, In: International Conference on Business Process Management, Springer, Cham, 2014, 158–164
[32] McCormack, K.*, Business process orientation: Do you have it?*, In: Quality Progress, 2001, 34, 1, 51–58
[33] Škrinjar, R., Trkman, P., *Increasing process orientation with business process management: Critical practices'*, In: International Journal of Information Management, 2013, 33, 48–60
[34] Bosilj Vukšić, V., Hernaus, T., Kovačić, A., *Upravljanje poslovnim procesima – organizacijski i informacijski pristup*, In: Školska knjiga, Zagreb, 2008
[35] Vlahovic, N., Milanovic, L., Škrinjar, R. *Turning points in business process orientation maturity model: an east European survey*, In: WSEAS transactions on business and economics, 2010, 7, 1, 22–32
[36] Buh, B., Kovačič, A., Indihar Štemberger, M., *Critical success factors for different stages of business process management adoption – a case study*, In: Economic Research-Ekonomska Istraživanja, 2015, 28, 1, 243–257
[37] Hernaus, T., Vuksic, V.B., Štemberger, M.I.*, How to go from strategy to results? Institutionalising BPM governance within organisations*, In: Business Process Management Journal, 2016, 22, 1, 173–195
[38] Abdolvand, N., Albadvi, A., Ferdowsi, Z., *Assessing readiness for business process reengineering,* In: Business Process Management Journal, 2008, 14, 4, 497–511
[39] Zairi, M., *Business process management: a boundaryless approach to modern competitiveness*, In: Business process management journal, 1997, 3, 1, 64–80
[40] Sun, W., Chou, C.P., Stacy, A.W., Ma, H., Unger, J., Gallaher, P., *SAS and SPSS macros to calculate standardized Cronbach's alpha using the upper bound of the phi coefficient for dichotomous items*, In: Behavior research methods, 2007, 39, 1, 71–81
[41] Taber, K.S., *The use of Cronbach's alpha when developing and reporting research instruments in science education*. In: Research in Science Education, 2018, 48, 6, 1273–1296

[42] Srhoj, S., Batarelo Kokić, I., Krišto, T., *U potrazi za inovacijama: medijacijska uloga orijentacije učenju u odnosu odrednica poduzetničke klime i proizvodno-uslužnih inovacija,* In: Poslovna izvrsnost: znanstveni časopis za promicanje kulture kvalitete i poslovne izvrsnosti, 2017, 11, 1, 9–36

[43] Fan, Y., Chen, J., Shirkey, G., John, R., Wu, S.R., Park, H., Shao, C. *Applications of structural equation modeling (SEM) in ecological studies: an updated review*, In: Ecological Processes, 2016, 5, 1, 19

[44] Wu, J.H., Wang, S.C., Lin, L.M., *Mobile computing acceptance factors in the healthcare industry: A structural equation model*, In: International journal of medical informatics, 2007, 76, 1, 66–77

[45] Teo, T., Tsai, L.T., Yang, C.C., *Applying structural equation modelling (SEM) in educational research: An introduction*, In: Application of structural equation modeling in educational research and practice, Brill Sense, 2013, 1–21

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Impact properties of continuously textile reinforced double fabric layered riot-police-helmet-shells

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ABSTRACT – REZUMAT

Impact properties of continuously textile reinforced double fabric layered riot-police-helmet-shells

The manuscript is a section of research completed for the overall impact performance of riot-police-helmet-shells having continuously textile reinforcement. In this research paper, manufacturing of double fabric layered helmet and its impact analysis has been discussed. Moreover, energy contained and blocking forces at various zones at the police-head protector shells were assessed. Results are also compared with the previous work for the impact evaluation of single piece riot-police-helmet-shell. The comparative results show significant difference in values in comparison with single layered riot-police-helmet-shell. These results can lead to the development of Riot-police-helmet-shells that can resist high velocity impact.

Keywords: *impact, force blocking effectiveness, energy absorption, textile reinforcement, continuous, helmet*

Proprietățile de impact ale căștilor polițiștilor de la ordinea publică fabricate din țesătură întărită continuă, dublu stratificată

Lucrarea este o cercetare finalizată asupra performanței generale de impact a căștilor polițiștilor de la ordinea publică, care sunt fabricate din țesătură întărită continuă. În această lucrare de cercetare, s-a discutat despre fabricarea căștii cu strat dublu de țesătură și analiza impactului acesteia. Mai mult, a fost evaluată energia conținută și forțele de blocare în diferite zone ale căștilor de protecție. De asemenea, rezultatele sunt comparate cu lucrările anterioare pentru evaluarea impactului căștilor de protecție cu un singur strat. Rezultatele arată o diferență semnificativă de valori în comparație cu casca cu un singur strat. Aceste rezultate pot duce la dezvoltarea de căști pentru polițiștii de la ordinea publică care pot rezista impactului la viteze mari.

Cuvinte-cheie: *impact, eficiență de blocare a forței, absorbție de energie, armare textilă, continuu, cască*

INTRODUCTION

The purposes of riot-police-helmets are to shield the police officers from head damage. Harm to a person's head can cause indications, for example, cerebrum injuries and skull misshaping [1]. Problems like cerebra-concussion are the main reason due to the inertial effects in which due to movement of the brain and can lead to injury in brain tissues. These impacts can prompt loss of human body capacities or physical issue of neural tissues and the casualty can have unpleasant impacts. For police officers, brain protection has supreme importance due to vulnerable to thrown objects.

Riot is a violent disturbance of the peace by a crowd. Disturbances caused by disorganised rioters are normally destructive and continuously have created an intense situation. The nature of riots varies all from one place to another in the world. However, police officers have to control the situation. Frequently, while comforting depressed rioters, usually police officers have physical contact with the rioters.

The police use different techniques and tactics to control the crowd. These techniques for handling or calming down people may be also different for different regions depending on culture, environment and laws of that particular country or region. The dressing of police officers includes limb protectors, face shield, helmets and body armour. A huge number of mob protective helmets are required for cops in the United Kingdom. Each officer who is a member of riot squad must have a helmet for head protection. Demand for riot helmets is also increasing in other countries. Cost effectiveness, wearer comfort, light weight and impact protection are the basic requirements for helmet qualities.

HELMET SHELL MANUFACRTUIRNG

Current study was a phase onward for the manufacturing of continuous reinforced textile riot-police-helmet-shells. Angle interlock (AI) fabric (5-layer) was prepared on conventional shuttle loom – "Arbon 100W" made by Adolf Saurer^{TM}. Para-aramid Kevlar roving type 49 supplied by DuPont^{TM} is used for warp and weft yarns. Moreover, single-fabric layered (continuous reinforced) textile reinforced composite riot-police-helmet-shells were successfully established by modified vacuum bagging setup [2]. Additionally, mechanical and physical characteristics of the established composite flat-panels from Al-fabric (5-layer) has been examined [3]. In figure 1 [2], single-fabric layered riot-police-helmet-shell can be seen. Riot-police-helmet-shells were tested in University of Manchester's Instron Dynatup on modified drop weight impact testing device [4]. Moreover, the main aim of this paper is to compare the already developed single-fabric layered riot-helmet shells [5] with newly developed double-layered riot helmet shells.

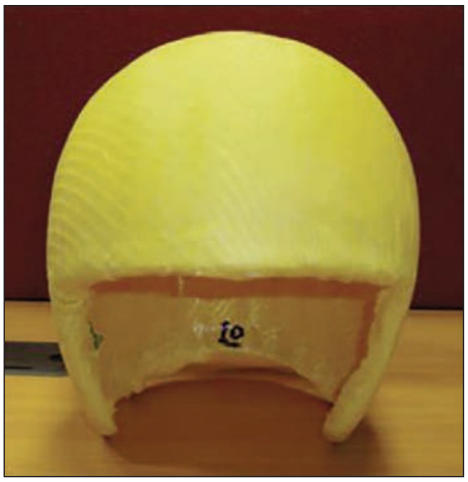


Fig. 1. Developed textile reinforced riot-police-helmet-shell

Double-layered composite riot helmet shells have been developed by conforming two fabric layers on a collapsible mould, followed by vacuum assisted draping and resin infusion. This technique was similar to the technique developed for manufacturing single-piece riot helmet shells [2]. The only difference was the draping of two layers of 5-8-28 angle-interlock fabric on the mould before vacuum bagging for composite manufacturing. Araldite LY5052 and Aradur HY5052 was used as epoxy and hardener respectively. To enhance the shell stiffness, helmet shells were further cured in the drying oven at 100°C for 4 hours.

REQUIREMENT OF DATA HANDLING

Essentials of drop weight impact test

Drop weight instrument works on the energy conversation principle. Impact velocity and dropweight head impact energy when initially it drops onto the specimen can be evaluated from equations 1 and 2:

$$E = \frac{1}{2} \cdot m \cdot v^2 \quad (1)$$

$$v = \sqrt{2gh} \quad (2)$$

At the point of impact onto the specimen, all the potential energy is converted into kinetic energy in a drop weight impact machine. Since, the motion of impactor is free fall, friction is taken as zero. The ratio of energy absorbed by the specimen to the impact energy gives energy contained in the specimen.

Force blocking effectiveness (Force Attenuation Factor, FAF)

Transmitted force F_t can be obtained from implanted sensor in the headform installed in the modified machine and impact force F_i was obtained by the load-cell installed on impactor assembly. Force-blocking effectiveness or attenuation factor, f_{att}, and can be determined from the equation 3:

$$f_{att} = (1 - \frac{F_t}{F}) \cdot 100 \quad (3)$$

where F_t is transmitted force thru the specimen, F – force collected on the anvil without any specimen.
Several scientists used force attenuation [6–9]. A higher number of FAF corresponds to less force being transmitted through the sample, and a smaller number of FAF indicates plentiful of the impact force has been transferred through the sample (0% equals all forces transferred and 100% equals no force transferred).

Calculation for energy absorption

Contact force or load commonly known as impact force is calculated from:

$$F_i = m \cdot a \quad (4)$$

where a is acceleration of free fall impactor and m – mass of impactor.
Load deflection curve gives the energy absorption [9]. Absorbed energy is calculated from the zone beneath the load-displacement chart as can be seen in figure 2.

$$E = \sum S_i = \frac{1}{2} \sum_{i=0}^{n} (F_i + F_{i+1})(y_{i+1} - y_i) \quad (5)$$

where, F_i is contact force applied on the sample, S_i – trapezoidal zone, E – absorbed energy and Y_i – displacement increment.

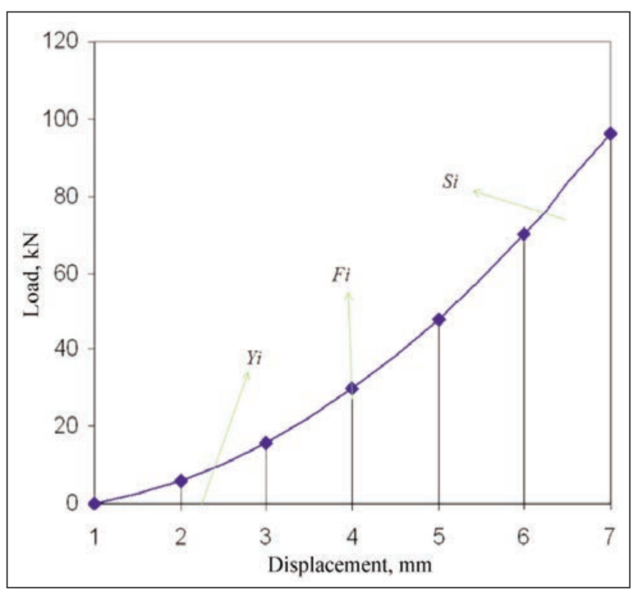


Fig. 2. Energy absorption graph for trapezoidal method

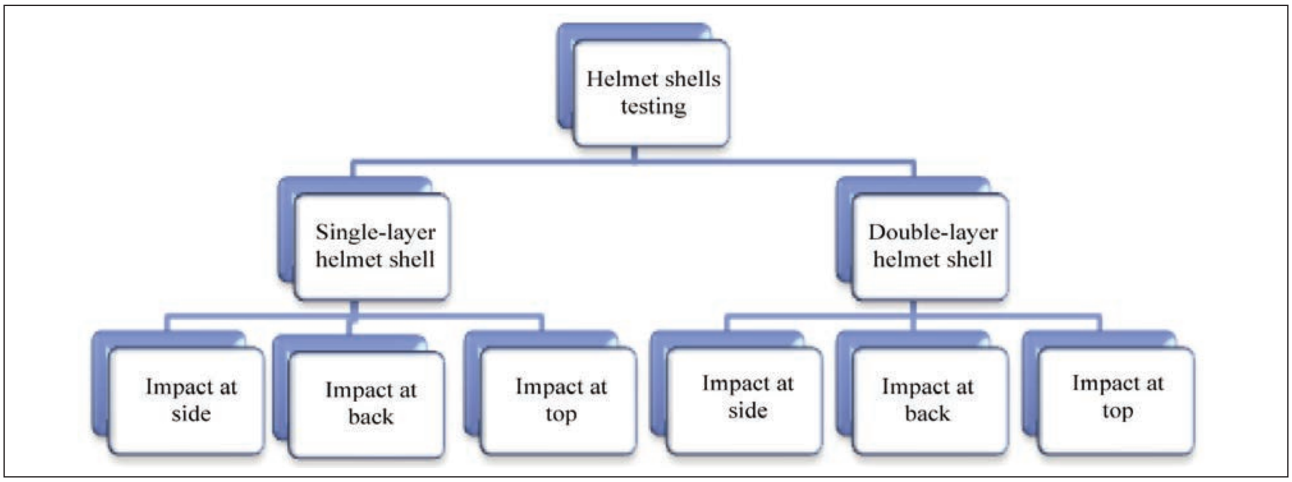


Fig. 3. Categories of developed riot-police-helmet-shells and zone for impact testing

EXPERIMENTAL RESULTS OF HELMET SHELL TESTING

The developed riot-police-helmet-shells were impacted at three different zones namely; helmet top, helmet side and helmet back with impact energies of 25.6 J approximately. Testing conditions were kept similar to the flat composite panel testing. Two different categories of composite riot-police-helmet-shell were developed. One was the single-layer riot-police-helmet-shell developed from a single-layer of 5-8-28 angle-interlock woven fabric. The second variety of riot-police-helmet-shell was developed from two layered of 5-8-28 angle-interlock woven fabric and double-fabric layered riot-police-helmet-shell. This variety was produced by overlapping two 5-8-28 layered fabric in the vacuum assisted draping technique.

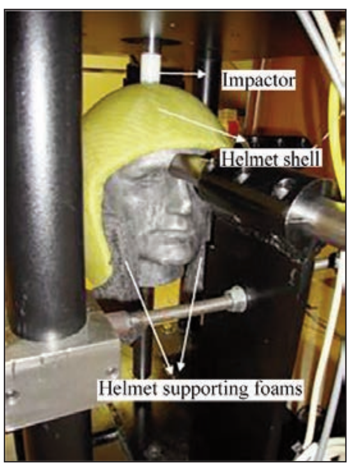


Fig. 4. Testing of riot-police-helmet-shell

Impact energy of 25.6 J was used to test helmets shells and impact tests were conducted at three different zones. The riot-police-helmet-shell categories along with the impact zones can be seen in figure 3.

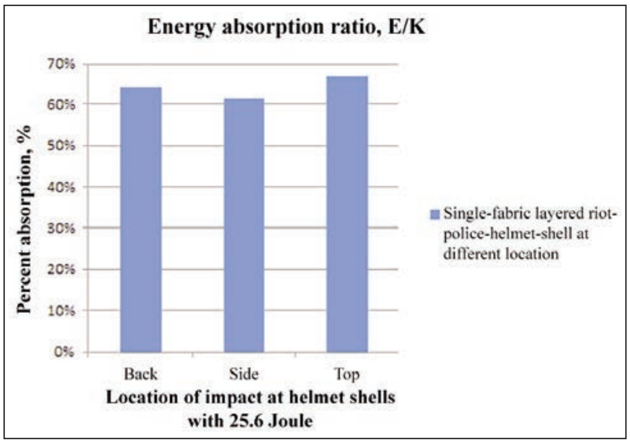
ENERGY ABSORPTION

The testing of Riot-police-helmet-shells were carried out on the modified Instron testing machine in the University of Manchester. The riot-police-helmet-shells were impacted with approx. 25.6 J of impact energy at different impact zones. The Low impedance voltage mode system and Impulse data acquisition system were used to extract results. The average results for energy absorption for various experiments are listed in table 1.
Figure 5 and table 1 show the energy absorption performance (average values) at different impact zones on riot-police-helmet-shells in which greater energy absorption performance at the upper helmet zone as related to the side and back zones. However, in both varieties of riot-police-helmet-shell, the side zone of helmets absorbs lesser impact energy with respect helmet top and helmet back zones. It should be noted, the helmet top zone has the maximum curvature intensity. It seems that curvature intensity is also influencing in energy absorption at the riot-police-helmet-shell top (upper) zone. In general riot-police-helmet-shell is a dome-shape structure. Dome-shape

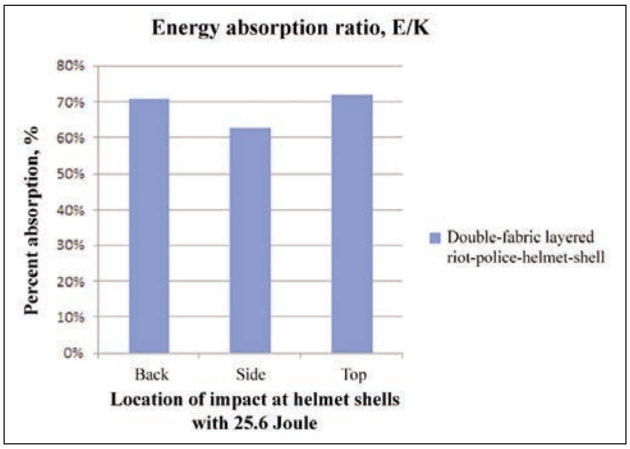
Table 1

EXPERIMENTAL DATA FOR ENERGY ABSORPTION RATIO

Type of riot-police-helmet-shell	Zone	Impact energy (J)	Energy absorbed (J)	Energy absorption ratio (%)
		K	E	E/K
Single-layer riot-police-helmet-shell	Back	25.64	16.40	63.96
Double-fabric layered riot-police-helmet-shell	Back	25.62	18.19	70.97
Single-layer riot-police-helmet-shell	Side	25.64	15.77	61.49
Double-fabric layered riot-police-helmet-shell	Side	25.63	16.04	62.57
Single-layer riot-police-helmet-shell	Top	25.61	17.07	66.65
Double-fabric layered riot-police-helmet-shell	Top	25.58	18.36	71.76



a



b

Fig. 5. Graphs of energy absorption of riot-police-helmet-shells at various zones on: *a* – single-fabric-layered riot-police-helmet-shells for 25.6 J energy; *b* – double-fabric-layered riot-police-helmet-shells for 25.6 J energy

structures are normally used in construction due to their inherent characteristics of supporting both in tensile as well as in compressive loads. The double-fabric layered riot-police-helmet-shells more or less behaves like the same as single-fabric layered riot-police-helmet-shells.

This can also be noted that in both the varieties of helmets (single and double fabric layered) shows, top impact zone as the better one as related to the other two back and side zone. One more reason for this phenomenon can be due to the fact that the top area is at the farthest position from the shell edges and also it has more fabric area to dissipate the energy till the edges.

Double-fabric layered riot-police-helmet-shells follows the same track of results as in single-fabric layered riot-police-helmet-shells i.e. helmet top impact location is much better than the other two locations.

PEAK TRANSMITTED FORCE

In table 2 it can be observed that peak transmitted force is proportionate to the energy impacted. Low impedance voltage mode system was used for measurement of peak transmitted force.

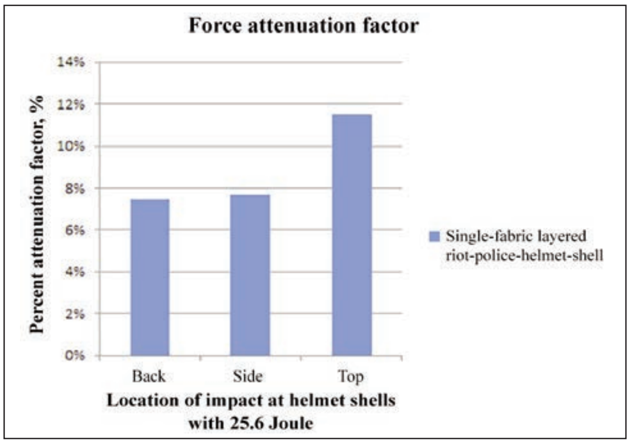
The above table shows that the top zone of riot-police-helmet-shell transmits singinificantly less peak force. For double-fabric layered helmets, the top of riot-police-helmet-shell also transmits significantly less force as compared to the other two zones. In table 2, double-fabric layered helmets at a similar impact energy of 25.6 Joules transmits less force to the headform than the single-fabric layered riot-police-helmet-shells. Moreover, the double riot-police-helmet-shells have more material at the impacted sites as compared to the single-layer riot-police-helmet-shells. If these results are normalised with respect to the thickness, the double-riot-police-helmet-shells will show less force is transmitted compared with the single-fabric layered hemet shells.

Force attenuated factor (FAF)

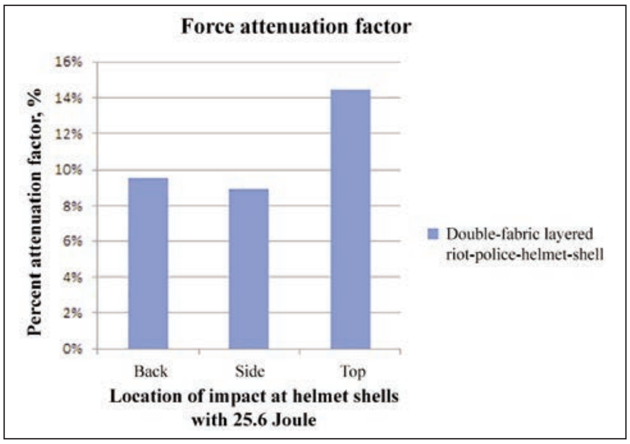
Force attenuation factor for various impact zones on riot-police-helmet-shells can be analysed in table 2 in which shows no substantial difference in the FAF at the side zone and back zone of helmets. However, force blocking effectiveness upper zone of riot-police-helmet-shell is always greater than at the counter

Table 2

EXPERIMENTAL DATA FOR FAF AT VARIOUS RIOT-POLICE-HELMET-SHELL'S ZONES					
Type of riot-police-helmet-shell	**Zone**	**Impact energy**	**Force on headform without specimen**	**Transmitted force**	**Attenuation factor**
		E (J)	**F_{trans} (kN)**	**F (kN)**	**f_{att} (%)**
Single-layer riot-police-helmet-shell	Back	25.64	19.843	18.354	7.503
Double-fabric layered riot-police-helmet-shell	Back	25.62	19.843	17.956	9.510
Single-layer riot-police-helmet-shell	Side	25.64	19.666	18.148	7.720
Double-fabric layered riot-police-helmet-shell	Side	25.63	19.666	17.915	8.905
Single-layer riot-police-helmet-shell	Top	25.61	20.381	18.028	11.544
Double-fabric layered riot-police-helmet-shell	Top	25.58	20.381	17.431	14.473



a



b

Fig. 6. Force attenuation factor at different zones on riot-police-helmet-shells: *a* – single-fabric layered riot-police-helmet-shells; *b* – double-fabric layered riot-police-helmet-shells

parts as can be seen in figure 6. The reason behind this phenomenon is the greater distance from the riot-police-helmet-shell edges and also due to the continuous fibre reinforcement. Further, the highest curvature intensity of the helmet top impact zone seems to have an influence on the force attenuation factor and less force is transmitted in the high curvature region of riot-police-helmet-shell.

The double-fabric layered riot-police-helmet-shell also behaves in the same way as the single-fabric layered riot-police-helmet-shells with a higher force percentage attenuation factor due to the greater amount of fabric in these riot-police-helmet-shells as can be seen in figure 6. Moreover, double-fabric layered riot-police-helmet-shells show a greater force attenuation factor as compared to the single-layer riot-police-helmet-shells with similar 25.5 J impacts.

CONCLUSION

In this manuscript experimental result has been described. Developed single and double fabric layered (continuously textile reinforced) riot-police-helmet-shells were impacted at various zones with 25.5 J energy; force blocking effectiveness at various zones were calculated and analysed. Furthermore, energy absorption and force blocking effectiveness of double fabric layered riot helmet shell has been compared for different impact locations.

Impact performance of the produced riot-police-helmet-shells has an influence on the impact zone. Least vulnerable position among the three zones was found out to be the helmet upper zone. This seems to be due to the fact that continuously fibre reinforced riot helmet shell's upper area is at the greater distance from the shell edges and has more chance to distribute the impact force and impact energy to a greater distance as compared to the side and back impacted areas. Moreover, the upper helmet zone needs higher impact energy to collapse and for this purpose less force will be communicated to the brain.

It can be concluded that in double-fabric layered riot-police-helmet-shells, top/upper position is also the least threatening impact position as compared to the side and back area of the helmet shells.

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REFERENCES

[1] Ryan, G.A., *Improving head protection for cyclists, motorcyclists, and car occupants*, In: World Journal Surgery, 1992, 16, 398–402

[2] Zahid, B., Chen, X., *Manufacturing of single-piece textile reinforced riot helmet shell from vacuum bagging*, In: Journal of Composite Materials, 2012, 47, 19, 2343–2351, https://doi.org/10.1177/0021998312457703

[3] Zahid, B., Chen, X., *Properties of 5-layer angle-interlock Kevlar-based composite structure manufactured from vacuum bagging*, In: Journal of Composite Materials, 2012, 47, 25, 3227–3234, https://doi.org/10.1177/0021998312463457

[4] Zahid, B., Chen, X., *Development of a Helmet Test Rig for Continuously Textile Reinforced Riot Helmets*, In: International Journal of Textile Science, 2013, 2, 1, 12–20

[5] Zahid, B., Chen, X., *Impact performance of single-piece continuously textile reinforced riot helmet shells*, In: Journal of Composite Materials, 2014, 48, 6

[6] Maach, I.E., et al., *Forces resulting from bat impact on the chest of adult human hybrid do not depend on the torso inertia*, Med-Eng Systems, Ottawa, Ontario, Canada, 2004

[7] Robinovitch, S.N., et al., *Hip protectors: Recommendations for biomechanical testing – an international consensus statement* (part I), In: Osteoporosis International, 2009, 20

[8] Dionne, J.P., et al., *Performance of crowd management shin guards subjected to ball and baseball bat impacts*, Med-Eng Systems, Ottawa, Ontario, Canada, 2002

[9] Gong, X., *Investigation of different geometric structure parameter for textile honeycomb composites on their mechanical performance*, The University of Manchester, 2010

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Research on double-faced jacquard fabric with compound full-backed structure of three wefts

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ABSTRACT – REZUMAT

Research on double-faced jacquard fabric with compound full-backed structure of three wefts

Weft-backed structures with compound weft colours can express the mixed colour effect. However, this structure is not suitable for jacquard fabrics with a double-faced shading effect in the traditional single layer design mode. Taking twenty-thread sateen with a step number (S) of 7 as an example, this paper investigates a design method for compound full-backed structure with three shaded-weave databases (SWDs) by selecting the primary weaves (PWs), designing the compound full-backed technical points and establishing the compound structure database with three SWDs. With this design method, a double-faced shading effect in combination with non-backed and full-backed effects on different sides of the jacquard fabric at the same position is generated. The fabric colour card was produced with three SWDs and three sets of different coloured wefts, and their colour values were measured, followed by an analysis of the compound structures on the reverse side, lightness, colour purity and colour difference (ΔE^*_{ab}) of the specimens. The results showed that the three covering effects on the reverse side, partly covered, critical position and totally covered, could be adjusted by controlling the step number and the transition direction of PW-C. For the specimens on the edges of the fabric colour card, their lightness and colour purity values showed a uniform transition effect along with the shading process; their colour differences ranged from 1.23 to 3.69, both in the range of 2–5, and showed a trace or slight colour difference between two adjacent fabric specimens, indicating that the colour shading effect with the three SWDs is stable.

Keywords: *weft-backed structure, compound full-backed structure, double-faced, shading effect, colour rendering law*

Studiu privind țesătura jacquard cu două fețe cu structură compusă – semitriplă de bătătură

*Structurile semiduble de bătătură, în combinatie cu bătături colorate pot exprima efectul de amestec de culoare. Cu toate acestea, această structură nu este adecvată pentru țesăturile jacquard cu efect de umbrire cu față dublă, proiectată tradițional, cu un singur strat. Luând ca exemplu un raport de douăzeci de fire cu legatură atlas cu un salt (S) de 7, această lucrare investighează o metodă de proiectare pentru structura compusă, semitriplă de bătătură cu trei baze de date cu legături cu efect de umbrire (SWD), prin selectarea legăturilor de bază (PW), proiectând puncte tehnice de legare completă a sistemelor de fire și stabilirea bazei de date a structurii compuse cu trei SWD-uri. Cu această metodă de proiectare, se generează un efect de umbrire cu două fețe în combinație cu efecte de nelegare și legare completă a sistemelor de fire, pe diferite părți ale țesăturii jacquard, în aceeași poziție. Grila de culori a țesăturii a fost produsă cu trei SWD-uri și trei seturi de bătături diferit colorate, iar valorile tonurilor de culoare au fost măsurate, fiind urmată de o analiză a structurilor compuse, pe partea din spate, luminozitate, puritatea culorii și diferență de culoare (△E*ab) a probelor. Rezultatele au arătat că cele trei efecte de acoperire pe partea din spate, parțial acoperită, poziție critică și total acoperită, ar putea fi ajustate prin controlul saltului și direcția de trecere/legare a PW-C. Pentru probele de pe marginile grilei de culoare ale țesăturii, valorile lor de luminozitate și puritate a culorii au arătat un efect de trecere uniform, împreună cu procesul de umbrire; diferențele lor de culoare au variat între 1,23–3,69, ambele în intervalul 2–5 și au arătat o urmă sau o ușoară diferență de culoare între două probe de țesături adiacente, indicând faptul că efectul de umbrire a culorii cu cele trei SWD-uri este stabil.*

Cuvinte-cheie*: structură semidublă de bătătură, structură compusă cu legare completă a sistemelor de fire, două fețe, efect de umbrire, lege de redare a culorilor*

INTRODUCTION

Double-faced jacquard fabric is a special woven fabric that can express the patterning and colour effects on both the face and reverse sides of the fabric. Among the structures woven by warp and weft yarns, five types of structures can form a double-faced effect [1–3], which are single-layer structure woven by one set of warps and one set of wefts, weft-backed structure woven by one set of warps and two or more sets of wefts, warp-backed structure woven by one set of wefts and two or more sets of warps, double-layer structure woven by two sets of warps and wefts, and multi-layer structure woven by multiple sets of warps and wefts, respectively.

Weft-backed jacquard fabric, a typical product of the Chinese traditional woven fabric industry, has an exquisite patterning woven effect with the weft-backed structure that is composed of one set of warps and two or more sets of colour wefts [4]. The main feature of the weft-backed structure is that the weft yarns are arranged in an overlapping manner in the compound structure combined by several single weaves; thus, the patterning and colour effects are textured by one or several sets of wefts, and the remaining sets of wefts are totally covered. The richness of the woven colours is realized only by the exchange of the surface and inner wefts; thus, the more the weft groups, the richer the woven pattern effect [5], but correspondingly, the more difficult the design process. Moreover, this structure has only one set of warps, and it is necessary to consider both sides when designing fabrics with a double-faced effect. Therefore, weft-backed jacquard fabric mostly has a single-faced effect, which leads to the under-utilization of the colour information of the woven yarns [6]. The shaded-weave structure has been used as an optimum solution for structural barriers to colour expression [7], which can achieve a double-faced shading effect. By increasing or decreasing the interlacing points by a certain rule, a series of waves shading from weft face weave to warp face weave or from warp face weave to weft face weave, are gathered in a shaded weave database (SWD) [8, 9]. By combining several SWDs, a compound structure is created with high reliability to realize a smooth colour shading effect.

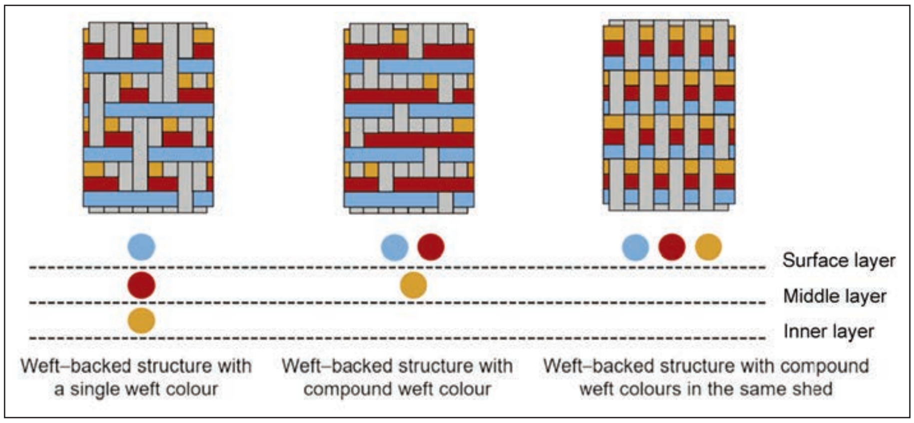


Fig. 1. Three weft-backed structures with three wefts (the arrangement ratio is 1:1:1 in the weft direction)

In general, the patterning effect of weft-backed fabric is formed by long weft floats. To make the pattern more visible against the ground, its ground weave is normally woven by a plain weave or regular satin weave with a coloured warp. The ground structure of weft-backed fabric has three colour effects-single weft colour, compound weft colours, and compound weft colours in the same shed [4, 10, 11]:

- In a weft-backed structure with a single weft colour, a weft with more weft floats serves as the fabric surface, whereas the wefts with fewer weft floats are totally covered and have no influence on the colour effect of the surface wefts. Thus, the colour information of only one group of wefts is shown on the surface layer of the fabric (figure 1).
- In a weft-backed structure with compound weft colours, two or more sets of coloured wefts are interwoven with one set of warp yarns, forming the fabric surface to cover the remaining wefts that are backed on the reverse side. Thus, a mixed colour effect with two or more coloured wefts is generated on the surface layer (figure 1).
- In a weft-backed structure with compound weft colours in the same shed, the surface weave is woven by two or more wefts in the same shed; in other words, the weaves of the compound structure are precisely the same. Therefore, any weft yarns may be visible on the surface layer (figure 1), and a shot-effect can be expressed on the fabric surface. However, the coverage degree of the woven yarns and the colour effect are difficult to determine.

Among the three compound structures, the weft-backed structure with compound weft colours has the most abundant changes. When applying shaded weaves on this structure with three wefts, a compound shading effect with two different colour wefts on one side and a single colour shading effect with another weft on the other side can be realized on the same position of the double-faced jacquard fabric; at the same time, the structural features of the weft-backed structure are retained. Thus, based on the weft-backed structure with compound weft colours, a novel compound structure with SWDs is proposed with details for the compound structure design, colour rending characteristics and coverage relationship of the three wefts.

DESIGN OF A COMPOUND FULL-BACKED STRUCTURE WITH THREE WEFTS

According to the compound structure design principle, interwoven yarns arranged in the same direction have three relationships-full-backed, non-backed and partial-backed [12, 13] (figure 2), referring to the "backed" degree between the yarns in the same position and the same side of a fabric:

- In a full-backed structure, the weft yarns overlap each other and the surface wefts cover the inner wefts totally. Full-backed technical points have to be set up to ensure the effectiveness of single colour shading effect with the full-backed structure [14]. As for the full-backed structure with double-faced shading effect, the surface weave and the inner weave are changed at the same time along with the colour shading process. Thus, it is not need to design full-backed technical points.
- In the non-backed structure, all wefts are visible on the surface layer, and all of them are served as the fabric surface. There is no overlapping effect between the juxtaposed wefts. In the colour shading design process, full-colour points are the key to prevent the wefts from overlapping [12].

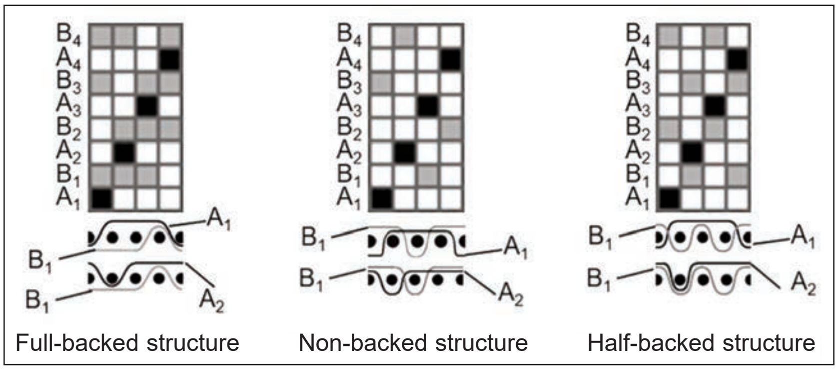


Fig. 2. Three “backed” structures

- In a partial-backed structure, the effects of full-backed and non-backed exist simultaneously. Half-backed structure produced on the basis of a partial-backed structure is characterized in that half of the wefts are covered by its adjacent wefts [15], and half-backed points are designed to produce the half-backed effect.

The structure based on the weft-backed structure with compound weft colours, named a “compound full-backed structure” is created by the combination of three or more groups of SWDs that are derived from the primary weaves (PWs) in a way that increases or decreases the interlacing points [13]. A basic weave (BW) is a weave of a SWD. With this structure, two or more sets of different coloured wefts shading on the surface layer can completely cover the other weft yarns (a group or more groups). When the covered weft yarns are shading on the reverse side of the fabric at the same time, the compound full-backed structure with a double-faced shading effect will be created.

Design principle

The design idea of a compound full-backed structure with three wefts is that the two sets of colour wefts (their corresponding weaves are PW-A and PW-B) are juxtaposed with each other and totally cover the remaining set of wefts (the corresponding weave is PW-C), meanwhile, the two juxtaposing wefts are shading on one side and the remaining wefts are shading on the other side (figure 3).Thus, there is a “covering” relationship between the covered wefts with a single colour effect and the juxtaposed wefts with a no-covering colour effect. Any one of the two juxtaposed wefts can cover one end or two ends of the adjacent covered wefts; in other words, the two wefts share at least one warp interlacing point.

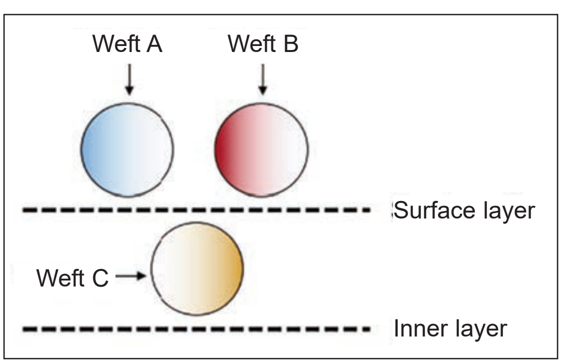


Fig. 3. Structural model of the three wefts

Given the above design idea, the two juxtaposed wefts have an opposite configuration to satisfy the requirement of a no-covering colour effect (figure 4); what is more, some kinds of technical compound full-backed points are necessary for the PWs to prevent the overlapping of the juxtaposed wefts. On the design process of the SWDs based on the PWs, the process of increasing or decreasing the interlacing points to control the float length, thereby making the most use of the colour information of the woven yarns.

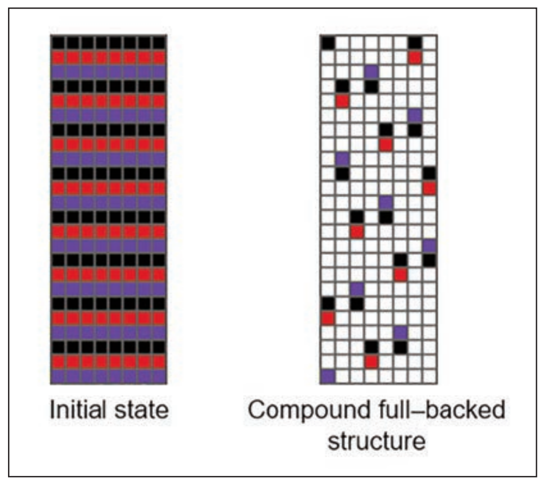


Fig. 4. Compound structure with three wefts (the arrangement ratio is 1:1:1 in the weft direction)

Design method

Selection of PWs

PW-A, PW-B and PW-C are the three PWs of the compound full-backed structure with three wefts. As mentioned above in the design principle, the combination of PW-A and PW-B should cover PW-C in the compound structure; therefore, the design method of PW-C is moving the warp points of PW-A one weft down along the weft direction, and then superimpose the warp points on PW-B (figure 5). Clearly, the number of the warp points of PW-C is larger than that of PW-A and PW-B.

The selection of the three PWs for the SWDs mainly depends on three design methods:

- Separating the odd and even wefts of a regular sateen weave. A regular sateen weave is an ideal choice for a PW among the three elementary weaves (plain weave, twill weave and satin weave) because of its uniform distribution of interlacing

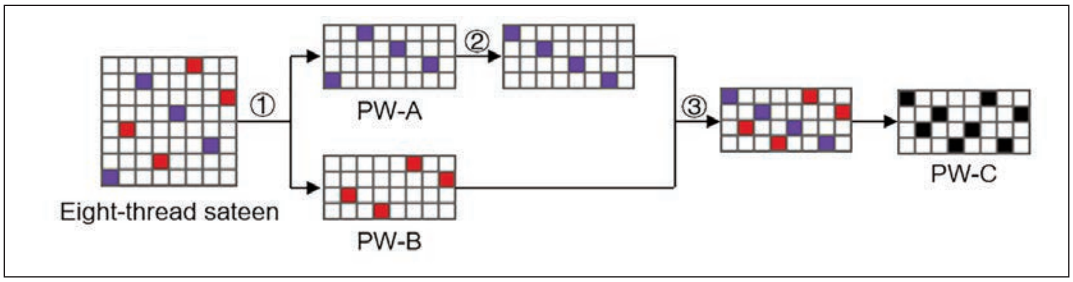


Fig. 5. Separation of the even and odd wefts of a sateen weave: *1* – the process of the separation of even and odd wefts; *2* – the process of moving PW-A one weft down along the weft direction; *3* – the process of superposing the interlacing points

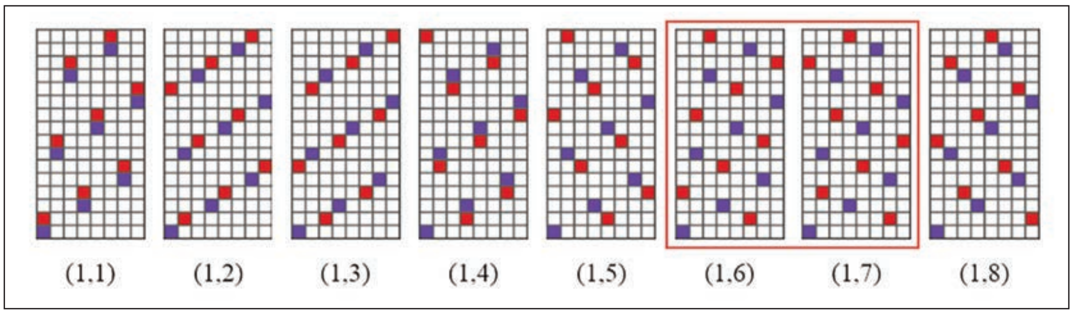


Fig. 6. Displacement of the starting points of PWs

points and its large expansibility with a high weave repeat (between 5 and 48) [16]. These advantages of a sateen weave can optimize the colour effects of the fabric surface because there are no apparent slanting lines to disturb the colour mixing effects.

- Shifting the starting points of PWs. PW-B is designed by the displacement of the starting point of PW-A in a point-by-point way; therefore, PW-A and PW-B have the same weave repeat and step number but with different starting points. As shown in figure 6, the same two sets of eight-thread sateen with the starting point of (1, 1) were arranged with the combination method of 1-and-1 along the weft direction. One group remained unchanged, and the other group was shifted to the right point by point. This process generated eight combination effects, in which the starting points of (1, 6) and (1, 7) (the compound structures in the red frames) had an optimal uniform distribution of interlacing points. With this method, the starting point of PW-A was (1, 1) and that of PW-B could be (1, 6) or (1, 7).
- Using the formula to calculate the starting position of PW-B. PW-A with the parameters of weave repeat (R), starting point position (N_{1A}) and step number (S) is fixed; the starting point position of PW-B (N_{1B}) is calculated with equation 1 or 2 to make the distance between the interlacing points on any weft with its adjacent wefts as equal as possible. In figure 7, $D1$ and $D2$ are the distance of three adjacent warp points, the closer $D1$ and $D2$ are, the more uniform the interlacing points are distributed. In this study, taking twenty-thread sateen as the PW, the starting point of PW-A was (1, 1), and that of PW-B was (1, 4) with the formula method; after this, PW-C was designed based on PW-A and PW-B (figure 8).

$$N_{1B} = \frac{R - N_{2A} - 1}{2} + N_{2A} + 1 = \frac{R + S}{2} + 1 \quad (S < R/2) \qquad (1)$$

$$N_{1B} = \frac{N_{2A} - N_{1A} - 2}{2} + 2 = \frac{S + 2}{2} \quad (S > R/2) \qquad (2)$$

where $N_{1A} = 1$, $N_{2A} = N_{1A} + S$; N_{1A} and N_{1B} are the starting positions of PW-A and PW-B, respectively; N_{2A} is the position of the second warp point of PW-B; R is the number of weave repeats; and S is the step number. The digit after the decimal point can be discarded or rounded off if the fraction is not an integer according to the length of D_1 and D_2.

Design of the compound full-backed technical points

For the PWs, the compound full-backed point is the key factor in the establishment of a compound full-backed structure, as follows: the technical points of

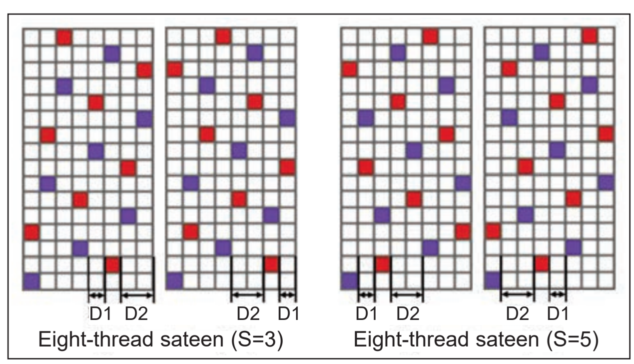


Fig. 7. Starting points of PWs

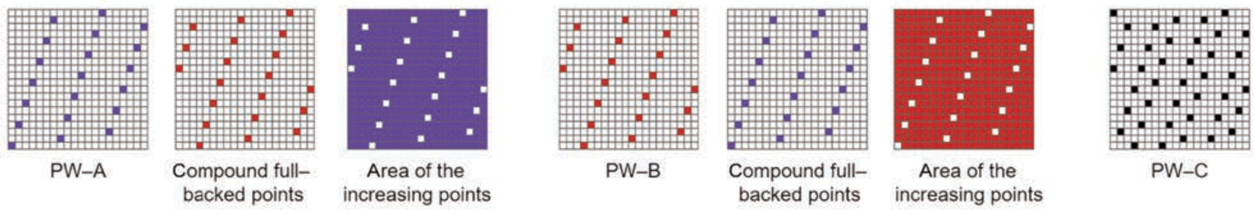


Fig. 8. PWs and compound full-backed technical points

PW-A are to reverse the interlacing points of PW-B; similarly, that of PW-B are to reverse the interlacing points of PW-A. J is the number of the compound full-backed points of a weft, and J = 1 here.

Design of SWDs

An SWD contains information on the design process of the derived weaves based on the PWs. In addition to the PW, two other key design factors are the increasing number at a time (coded as N) and the transition direction of the interlacing points, which separately determine the capacity and the structural balance of an SWD. The capacity of an SWD is maximal when $N = 1$; thus, the variation between the shaded weaves is minimal; when $N = R$, the capacity of an SWD is minimal, and the variation between the shaded weaves is maximal [16]. Because the patterning and colour effects of the weft-backed jacquard fabric are woven by weft floats, continuous weft floats can make the woven effect more delicate; thus, the horizontal transition, in which the interlacing points are reinforced continuously in the weft direction [8], is adopted in this study to ensure the effectiveness of a compound full-backed structure. After the basic parameters are confined, three SWDs based on the above three PWs ($R = 20$) were designed by increasing the warp interlacing points ($N = R$) in the coloured area of figure 8. Meanwhile, the compound full-backed points must be skipped in the increasing process for PW-A and PW-B. Figure 9 is the minimal SWD that is named by the number of warp points of the PWs.

To ensure the “backing” effect of the combination process of the three SWDs, two demands should be met: the arrangement ratio of the three weft yarns

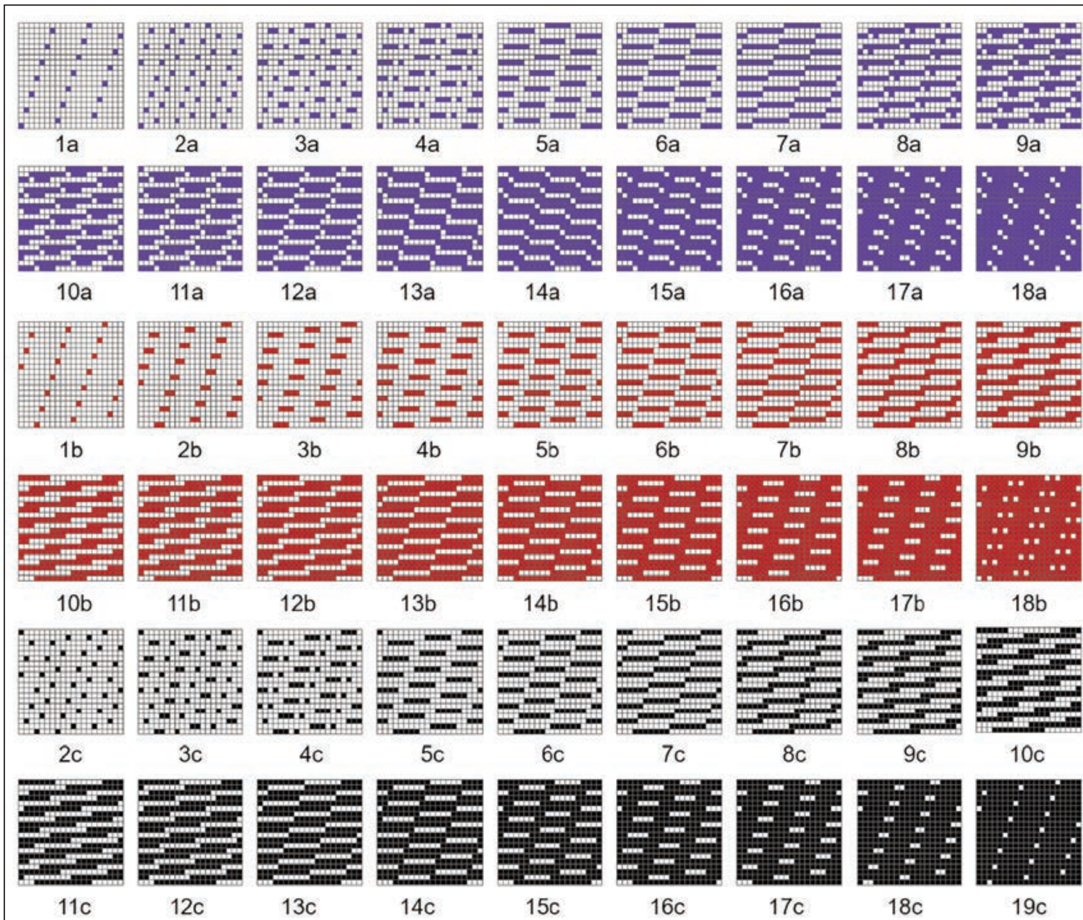


Fig. 9. Three minimal SWDs

should be 1:1:1, and the weft float length of PW-C should be shorter than that of PW-A and PW-B (i.e., the warp points of PW-C are more than those of PW-A and PW-B). Based on these foundations, the database of the compound full-backed structure has three combinations: i) one set of SWD is shading from weft-faced weave to warp-faced weave while the other two sets are kept unchanged; ii) two sets of SWDs are shading and the rest set is kept unchanged; iii) all three SWDs are changed simultaneously. The capacity of the compound full-backed structure database will be as shown below:

$$\sum[(n - M + 1)(M - 1) + \sum(n - M + 1)] \qquad (3)$$

where n is the number of BW-A or BW-B, n = 18 here; M = 1,2,3,…,n. So the capacity is 2109.

EXPERIMENTATION AND DISCUSSION

Weaving of fabric colour card

Taking the simultaneous shading effect of the three wefts as an example, the initial position of the compound full-backed structure database is 1a-1b-2c (the combination of three BWs), and the corresponding warp points are (1, 1, 2). According to the aforementioned analysis, only the combination of 1a (BW of SWD-A), 1b (BW of SWD-B) and 2c (BW of SWD-C) is effective when the PW-B is unchanged, and the colour level is 1. Similarly, the compound structure has 2 colour levels (1a–1b–3c and 2a–2b–3c) when the number of warp points of PW-C is 3 (3c). The remaining points can be determined in the same manner. Equation 4 is the capacity of the compound full-backed structure database with the three SWDs that changed simultaneously.

$$1 + 2 + 3 + \cdots + (R - J - 1) \qquad (4)$$

According to equation 4, the capacity of the three SWDs that changed simultaneously is 171.

Meanwhile, its fabric colour card was produced and the weaving specifications were listed in table 1. Red and blue weft yarns were woven on the face side, and yellow weft yarns were woven on the reverse side. Figure 10 shows the expanded effect of the fabric colour card; the lines with arrows are the shading direction (dark to light) of the specimens.

Table 1

WEAVING SPECIFICATIONS		
Parameters	**Warp**	**Weft**
Fineness (D)	50	70
Density (ends/cm)	114	105
Colour	white	red (weft A) blue (weft B) yellow (weft C)
Material	100% polyester	100% polyester
Weave	three SWDs of 20-thread sateen	
Specimens size (cm)	3.5 × 3.5	
Specimens quantity	171 × 2 = 342	

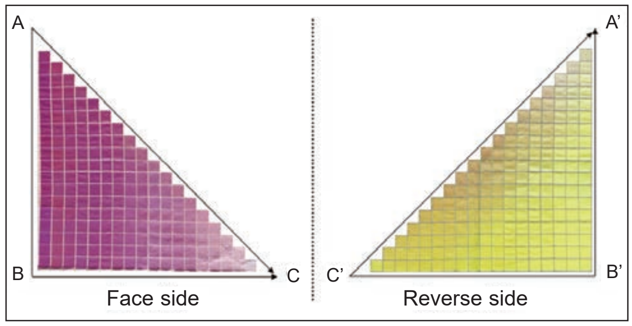


Fig. 10. Fabric colour card with three SWDs

Analysis of the compound full-backed structure

The colour card has the following characteristics through visual observation.

- Along the vertical direction, the surface waves in the same column are the same, and the backing weaves with one SWD (SWD-C) are transitioned from the weft-faced weave to the warp-faced weave with the colour shading from light to dark.
- Along the horizontal direction, the backing weaves are the same in the same line, and the surface waves with two SWDs (SWD-A and SWD-B) are transitioned from the weft-faced weave to the warp-faced weave with the colour shading from dark to light.
- Along the diagonal direction with three SWDs (SWD-A, SWD-B and SWD-C), the surface weaves are transitioned from the weft-faced weave to the warp-faced weave, and the backing weaves are transitioned from the warp-faced weave to the weft-faced weave; correspondingly, the colour of the face side shading changes from dark to light and that of the reverse side shading changes from light to dark.
- The specimens on the reverse side of the colour card are the interlacing of white warps not only with yellow wefts but also with red and blue wefts, exhibiting a complicated colour effect.

There are three covering effects between the three coloured wefts on the reverse side, namely, partly covered, critical position and totally covered (figure 11). In a partly covered effect, the yellow wefts cover only part of the red and blue wefts simultaneously; thus, the three coloured wefts are visible on the reverse side at the same time. In the critical position, the red and blue wefts begin to become visible on the surface layer of the reverse side so that the yellow wefts cannot cover the red and blue wefts simultaneously. In a totally covered effect, the yellow wefts completely cover the red and blue wefts at the same time and serve as the fabric surface of the reverse side. Figure 12 shows the statistics of the coverage degree on the reverse side of the colour card.

Viewed from the reverse side of the colour card, the three abovementioned coverage effects are closely related to the float length of the coloured weft yarns. When the weft floats of two adjacent yellow wefts (Y_1 and Y_2) are not overlapped (figure 13), according to

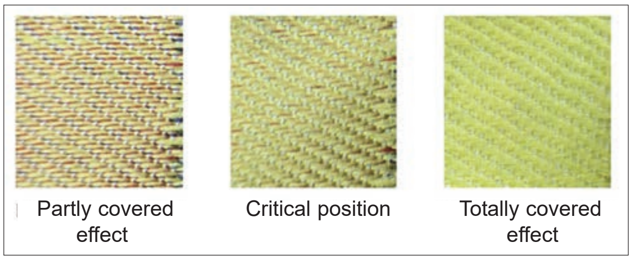


Fig. 11. Three coverage effects on the reverse side of the colour card

the design principle of the weft-backed structure, the yellow weft can separately cover either the adjacent blue weft (*B*) or the red weft (*R*), but because the arrangement ratio of the three wefts is 1:1:1 and the specifications are the same, the yellow weft cannot completely cover the blue and red wefts that are juxtaposed in the compound structure at the same time. Therefore, the yellow wefts can cover only parts of the adjacent blue and red wefts at once. The critical position is the transition position between the partly covered effect and the totally covered effect. When the weft floats of two adjacent yellow wefts have one weft overlapping point, as shown in figure 13, Y_1 can cross B_2 under the action of the beating force and then cover R_2, which can also be covered by Y_2; to this end, the weft points of R_2 can be covered by Y_1 and Y_2 at the same time. However, W_{11}, which is in the warp bundles of W_4–W_{11} (gathered together by the weft floats of Y_1) and W_{11}–W_{18} (gathered together by the weft floats of Y_2) at the same time, will be pulled simultaneously into their respective warp bundles under the action of the tension of the weft floats; in this scenario, the red weft point on W_{11} is not completely covered and is partially exposed. When the overlapping weft points of two adjacent yellow wefts are more than the weft points of the red wefts, a total-

1-1-2																	
PC																	
1-1-3	2-2-3																
PC	PC																
1-1-4	2-2-4	3-3-4															
PC	PC	PC															
1-1-5	2-2-5	3-3-5	4-4-5														
PC	PC	PC	PC														
1-1-6	2-2-6	3-3-6	4-4-6	5-5-6													
PC	PC	PC	PC	PC													
1-1-7	2-2-7	3-3-7	4-4-7	5-5-7	6-6-7												
CP	PC	PC	PC	PC	PC												
1-1-8	2-2-8	3-3-8	4-4-8	5-5-8	6-6-8	7-7-8											
TC	CP	PC	PC	PC	PC	PC											
1-1-9	2-2-9	3-3-9	4-4-9	5-5-9	6-6-9	7-7-9	8-8-9										
TC	TC	CP	PC	PC	PC	PC	PC										
1-1-10	2-2-10	3-3-10	4-4-10	5-5-10	6-6-10	7-7-10	8-8-10	9-9-10									
TC	TC	TC	CP	PC	PC	PC	PC	PC									
1-1-11	2-2-11	3-3-11	4-4-11	5-5-11	6-6-11	7-7-11	8-8-11	9-9-11	10-10-11								
TC	TC	TC	TC	CP	PC	PC	PC	PC	PC								
1-1-12	2-2-12	3-3-12	4-4-12	5-5-12	6-6-12	7-7-12	8-8-12	9-9-12	10-10-12	11-11-12							
TC	TC	TC	TC	TC	CP	PC	PC	PC	PC	PC							
1-1-13	2-2-13	3-3-13	4-4-13	5-5-13	6-6-13	7-7-13	8-8-13	9-9-13	10-10-13	11-11-13	12-12-13						
TC	TC	TC	TC	TC	TC	CP	PC	PC	PC	PC	PC						
1-1-14	2-2-14	3-3-14	4-4-14	5-5-14	6-6-14	7-7-14	8-8-14	9-9-14	10-10-14	11-11-14	12-12-14	13-13-14					
TC	TC	TC	TC	TC	TC	TC	CP	PC	PC	PC	PC	PC					
1-1-15	2-2-15	3-3-15	4-4-15	5-5-15	6-6-15	7-7-15	8-8-15	9-9-15	10-10-15	11-11-15	12-12-15	13-13-15	14-14-15				
TC	TC	TC	TC	TC	TC	TC	TC	CP	PC	PC	PC	PC	PC				
1-1-16	2-2-16	3-3-16	4-4-16	5-5-16	6-6-16	7-7-16	8-8-16	9-9-16	10-10-16	11-11-16	12-12-16	13-13-16	14-14-16	15-15-16			
TC	TC	TC	TC	TC	TC	TC	TC	TC	CP	PC	PC	PC	PC	PC			
1-1-17	2-2-17	3-3-17	4-4-17	5-5-17	6-6-17	7-7-17	8-8-17	9-9-17	10-10-17	11-11-17	12-12-17	13-13-17	14-14-17	15-15-17	15-15-16		
TC	TC	TC	TC	TC	TC	TC	TC	TC	TC	CP	PC	PC	PC	PC	PC		
1-1-18	2-2-18	3-3-18	4-4-18	5-5-18	6-6-18	7-7-18	8-8-18	9-9-18	10-10-18	11-11-18	12-12-18	13-13-18	14-14-18	15-15-18	16-16-18	17-17-18	
TC	TC	TC	TC	TC	TC	TC	TC	TC	TC	TC	CP	PC	PC	PC	PC	PC	
1-1-19	2-2-19	3-3-19	4-4-19	5-5-19	6-6-19	7-7-19	8-8-19	9-9-19	10-10-19	11-11-19	12-12-19	13-13-19	14-14-19	15-15-19	16-16-19	17-17-19	18-18-19
TC	TC	TC	TC	TC	TC	TC	TC	TC	TC	TC	TC	CP	PC	PC	PC	PC	PC

Fig. 12. Coverage degree on the reverse side of the colour card: Blue – PC–Partly Covered; Pink – CP–Critical Position; Yellow – TC–Totally Covered

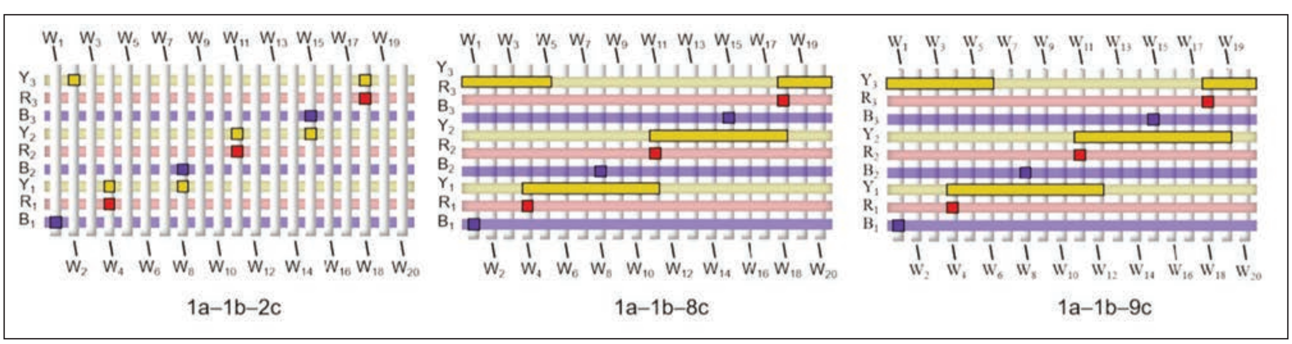
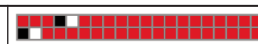
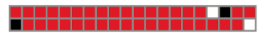
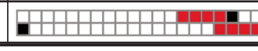


Fig. 13. The reverse side of the compound full-backed structures

Table 2

OVERLAPPING ANALYSIS OF PW-C (PART OF THE COMPOUND STRUCTURE)							
Step number	**Interlacing direction**	**Interlacing number**		**Step number**	**Interlacing direction**	**Interlacing number**	
3	right	4		3	left	18	
7		8		7		14	
9		10		9		12	
11		12		11		10	
13		14		13		8	
17		18		17		4	

ly covered effect is generated. W_{11} is shifted to the left side under the gathering effect of the weft floats of Y_1, and the red weft point on R_2 can be covered by both Y_1 and Y_2. Based upon the interaction of all of these factors, the red weft point can be totally covered (figure 13). The longer the overlapping length of the yellow weft floats, the better the coverage effect.

Based on the above analysis, the location of the critical position determines the number of partly covered effects and totally covered effects; which is in turn determined by the increasing number of interlacing points at the overlapping adjacent weft yarns of PW-C. In the case in which the repeat weave and the starting point of PW-C are fixed, the three effects can be freely controlled by regulating the step number and the transition direction of PW-C. For a 20-thread sateen weave, six effective step numbers may occur in the weft direction, namely, 3, 7, 9, 11, 13 and 17. As shown in table 2, when the transition direction of PW-C is right, to reach a totally covered effect, the increasing number of interlacing points is 4, 8, 10, 12, 14 and 18; therefore, the larger the step number of PW-C, the smaller the totally covered effect and the greater the partly covered effect. When the transition direction of PW-C is left, the increasing number of interlacing points is 18, 14, 12, 10, 8 and 4; thus, the larger the step number of PW-C, the greater the totally covered effect and the less the partly covered effect. In the process of fabric design, the step number and the transition direction of PW-C can be flexibly selected according to the design effect, which in turn affects the parameters of PW-A and PW-B.

Analysis of the colour rendering law

The specimens at the edge of the colour card (on the lines of AB, BC, AC, A'B', B'C' and A'C') were measured two times using X-rite Colour i7 under a temperature of approximately 25°C, a humidity of 65% and the following settings [17–20]: D65, 17 mm aperture, and CIE 10° supplementary standard observer to collect the colour values (L^*, a^*, b^*, C). Uniform and smooth transition of the SWDs is necessary for studying the colour shading effect of woven fabrics with the compound full-backed structure. The colour shading effect of the compound structures is analysed in terms of the colour values.

As shown in figure 14, for the face side of the colour card, the L^* value of AB with unchanged surface weaves was relatively stable, and that of BC with two sets of SWDs (SWD-A and SWD-B) and AC with three sets of SWDs (SWD-A, SWD-B and SWD-C) showed a steady upward trend, demonstrating that the L^* values on the face side of the specimens are consistent with visual observation. For the reverse side of the colour card, the L^* values of A'B' with a set of SWD (SWD-C) increased slightly because the L^* of the warp yarn (90.20) is very close to that of the yellow weft yarn (83.30), so the L^* values of A'B' do not change significantly along with the shading process, but the overall trend is consistent with the visual observation. The L^* values of B'C' with unchanged weaves had a balanced downward trend, and that of A'C' with three sets of SWDs steadily declined first and then increased gradually. Considering that the colour effects on the reverse side of the colour card are slightly complicated, the analysis of their L^* values cannot accurately reflect the shading effect in detail; thus, colour purity and colour difference were further studied.

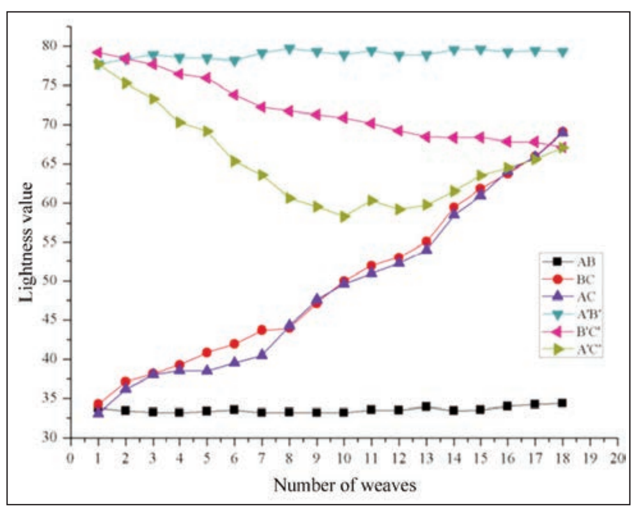


Fig. 14. L^* values of the fabric specimens

The length of the weft floats along with the shading weaves causes the change in the colour purity. In figure 15, the R^2 of AB was 0.078, which is close to 0, indicating that the fitted line was nearly parallel to the

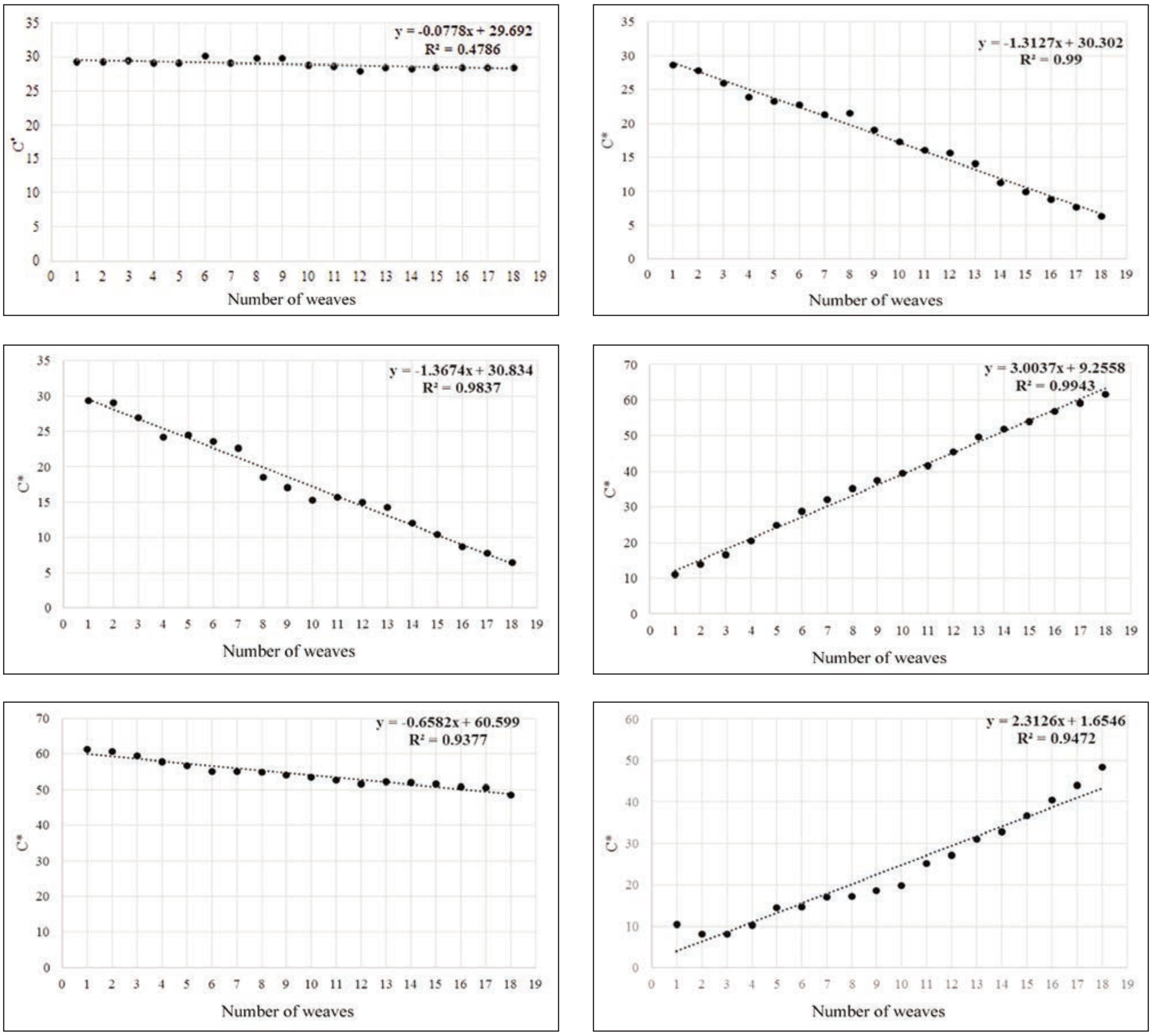


Fig. 15. Colour purity of the specimens

X-axis, so the colour purity was almost constant; the R^2 values of BC, AC, A'B', B'C' and A'C' were 0.990, 0.984, 0.994, 0.938, 0.947, respectively, all greater than 0.7 and close to 1, showing good linearity and indicating that the colour purity exhibited a substantially uniform change.

The colour differences (equation 5) [18] of the specimens with three SWDs were calculated by comparing the colour values of two adjacent fabric specimens with each edge of the colour card:

$$\Delta E^*_{ab} = \sqrt{\sum_{i=1}^{n}(\Delta L^{*2} + \Delta a^{*2} + \Delta b^{*2})} \qquad (5)$$

where ΔE^*_{ab} is the colour difference of the fabric specimens, n – the number of specimens, and $\Delta L^* = L^*_i - L^*_{i+1}$, $\Delta a^* = a^*_i - a^*_{i+1}$, and $\Delta b^* = b^*_i - b^*_{i+1}$.

In the evaluation of the colour mixing effect of the woven fabrics, ΔE^*_{ab} in the range of 2–5 is generally supposed to indicate a trace or slight colour difference [21]. As illustrated in tables 3 and 4, the calculation results showed that the average colour differences of AB, BC, AC, A'B', B'C', and A'C' are 2.54, 3.15, 3.32, 3.03, 1.23 and 3.69, respectively, all in the range of 2–5, indicating that the colour shading effect was adequate. In addition, the colour difference of the specimens with three sets of SWDs was the highest (3.32 of AC and 3.69 of A'C'), followed by those with two sets and one set of SWD (3.15 of BC and 3.03 of A'B'), and that of the unchanged weaves (2.54 of AB and 1.23 of B'C') was the smallest.

APPLICATION DESIGN

With digital jacquard design technology under layered-combination design mode, a compound full-backed structure can produce double-faced shading effect fabrics with three coloured wefts. For the face side of the fabric, there is one or two sets of weft colours shaded into warp colour, or into each other. For the reverse side of the same position of the fabric, along with the shading process of the rest set of wefts, three effects which are partly covered effect, totally covered effect and these two effects existing at the same time can be generated. For a compound full-backed structure, the effects on the face and

Table 3

LIGHTNESS DIFFERENCES AND AVERAGE COLOUR DIFFERENCES ON THE FACE SIDE OF THE FABRIC SPECIMENS									
Number	**AB**			**BC**			**AC**		
	ΔL*	**Δa***	**Δb***	**ΔL***	**Δa***	**Δb***	**ΔL***	**Δa***	**Δb***
1	0.39	0.21	0.55	–2.87	–2.16	–7.91	–3.13	–1.79	–7.18
2	0.15	0.34	0.88	–1.03	2.53	2.14	–1.81	1.96	–0.9
3	0.04	0.24	–0.27	–1.13	3.71	3.41	–0.54	3.45	2.81
4	–0.17	–0.93	–1.86	–1.57	0.72	–0.06	0.06	0.61	2.79
5	–0.16	–1.99	–2.78	–1.07	0.19	–0.68	–1.05	0.53	–1.07
6	0.35	1.82	2.47	–1.77	1.62	0.01	–0.96	1.43	1
7	–0.05	–1.49	–2.26	–0.28	0.4	0.9	–3.75	3.33	–2.78
8	0.06	0.09	–0.04	–3.16	1.93	–1.52	–3.31	1.27	–0.95
9	–0.01	1.93	2.69	–2.84	1.33	–1.11	–2.04	1.54	–0.7
10	–0.36	0.39	0.5	–1.94	0.88	–0.93	–1.34	0.01	1.01
11	0.08	1.61	1.5	–1.12	0.46	–0.04	–1.32	0.68	–0.12
12	–0.51	–1.05	–0.95	–2.05	1.13	–1.29	–1.75	0.56	–0.63
13	0.54	4.41	6.5	–4.4	2.36	–1.47	–4.45	2.22	–0.61
14	–0.08	–1.93	–2.35	–2.36	1.54	0.04	–2.53	1.82	0.39
15	–0.47	1.29	1.8	–1.92	1.29	–0.18	–3.12	1.57	–0.82
16	–0.27	–3.93	–6.06	–2.17	1.2	–0.24	–1.76	1.35	0.34
17	–0.11	0.75	1.46	–3.15	1.48	–0.39	–3.05	1.9	0.21
AVG of ΔE^*_{ab}	2.54			3.15			3.32		

Table 4

LIGHTNESS DIFFERENCES AND AVERAGE COLOUR DIFFERENCES ON THE REVERSE SIDE OF THE FABRIC SPECIMENS									
Number	**A’B’**			**B’C’**			**A’C’**		
	ΔL*	**Δa***	**Δb***	**ΔL***	**Δa***	**Δb***	**ΔL***	**Δa***	**Δb***
1	–0.55	0.7	–2.85	0.74	–0.01	0.77	2.46	–0.2	2.22
2	–0.54	0.63	–2.79	0.73	–0.51	1	2.03	–1.09	0.06
3	0.36	1.03	–3.68	1.22	–0.33	1.65	2.99	–1.13	–2.09
4	0.02	0.72	–4.25	0.53	–0.4	1.07	1.15	–0.14	–4.17
5	0.31	0.75	–4.04	2.16	–0.49	1.61	3.8	–0.37	–0.22
6	–0.94	0.61	–3.05	1.58	–0.78	–0.22	1.72	–1.15	–2.04
7	–0.56	0.98	–3.03	0.48	–0.49	0.31	2.99	–2.85	0.65
8	0.37	0.38	–2.2	0.47	–0.29	0.83	1.07	–0.41	–1.46
9	0.42	0.21	–2.21	0.38	–0.17	0.52	1.29	–0.48	–1.14
10	–0.51	0.22	–2.06	0.71	–0.72	0.84	–2.07	0.51	–5.6
11	0.61	0.28	–3.87	0.95	–1.45	0.81	1.13	–1.19	–1.79
12	–0.11	0.36	–4.17	0.77	–0.56	–0.53	–0.58	1.63	–4.43
13	–0.63	–0.13	–2.32	0.1	0.08	0.05	–1.73	2.73	–2.24
14	–0.03	0.45	–1.97	–0.02	–0.29	0.37	–2.02	1.44	–3.9
15	0.35	0.21	–2.85	0.53	–0.69	0.88	–0.95	0.58	–3.7
16	–0.19	0.37	–2.31	0.03	–0.41	0.3	–1.08	0.77	–3.69
17	0.14	0.27	–2.34	0.66	–0.16	1.87	–1.49	1.48	–4.35
AVG of ΔE^*_{ab}	3.03			1.23			3.69		

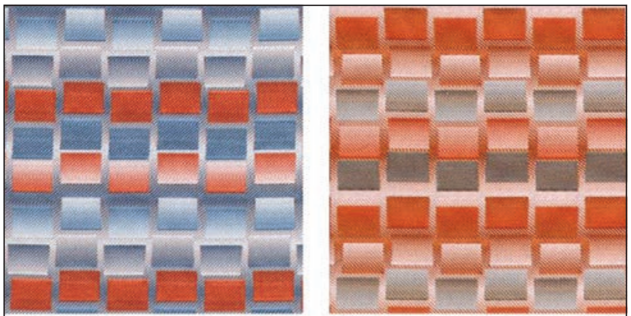


Fig. 16. Double-faced jacquard fabric with a compound full-backed structure with three wefts

reverse sides can also be reversed on the jacquard fabrics based on the structure features. What calls for special attention in the design process is that the float length of the surface weaves should always be longer than that of the backing weaves. With this structure, double-faced fabrics can be mass produced and have no limitation on the subject of design patterns.

CONCLUSIONS

The traditional jacquard design method has great limitations in structural design when designing double-faced weft-backed fabric with three sets of wefts. A compound full-backed structure based on the weft-backed structure with compound weft colour effects is employed for its possibility of creating double-faced weft-backed fabric. The main features of the combination of the non-backed effect on one side and full-backed effect on the other side with the composition of the three SWDs are applied when designing a double-faced fabric with three wefts. By reasonably configuring of the PWs and designing compound full-backed technical points, colour shading effects are generated in which two sets of wefts produce shading effect on one side totally covering the remaining set of weft yarns that are producing shading effect on the other side of the fabric. In addition, the experimental results show that a uniform colour shading effect can be realized with three SWDs, and the covering effect on the reverse side of the jacquard fabric can be controlled by changing the parameters (the step number and the transition direction) of the PWs. The design method described in this study further perfects the digitization of the weft-backed structure and provides a reference for the innovation of structural design and colour design of double-faced weft-backed fabrics.

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REFERENCES

[1] Han, R., Zhang, S., *Design and production of the digital double-faced jacquard fabric with different photographic patterns on face and back*, In: Journal of Textile Research, 2006, 27, 8, 89–91

[2] Pelin, G.U., Gonca, O.K., Zehra, E.K., *The Effect of Different Connections in Double Layered Woven Fabrics on Comfort Properties*, In: Fibers and Polymers, 2012, 13, 2, 258–263

[3] Jin, Z., Xu, J., *Double Face with Pattern Effect Design of Thermal Jacquard Based on Three-Layer Weave Structure*, In: Applied Mechanics and Materials, 2014, 442–446

[4] Zhejiang Institute of Silk and Textiles, Suzhou Institute of Silk and Textiles, *Weave and Structure of Woven Fabric: volume two*, In: Textile Industry Press, Beijing, 1997

[5] Luo, B., *Structure design of weft decorative fabric*, In: Shanghai Textile Science & Technology, 2003, 31, 3, 59–62

[6] Zhang, A., Wang, X., *Design and Research of the Foldable Decorative Screen with Ethnic Style Based on Weft-Backed Structure*, In: Advanced Materials Research, 2011, 331, 69–72

[7] Kim, K.R., Ng, F., Zhou, J., Hu, J., *Diamond-shaped shaded weave series created by transforming small twills to enrich the surface texture of woven Jacquards*, In: Textile Research Journal, 2016, 86, 10, 1032–1040

[8] Zhang, A., Zhou, J., *Colour rendering in single-layer jacquard fabrics using sateen shaded weave databases based on three transition directions*, In: Textile Research Journal, 2018, 88, 11, 1290–1298

[9] Kim, K.R., Ng, F., Zhou, J., Hu, J., *Gradient colour deviation in woven textiles to correspond to pictorial images in diversity*, In: International Journal of Fashion Design, Technology and Education, 2016, 9, 1, 32–40

[10] Zeng, D., *Cooperation of banister harness and stitch weave*, In: Jiangsu Silk, 1986, 4, 39–44

[11] Ma, X., Luo, B., *Decorative fabric design based on analysis of traditional brocade*, In: Shandong Textile Scie., 2016, 2, 15–18

[12] Ng, F., Zhou, J., *Full-colour compound structure for digital jacquard fabric design,* In: The Journal of the Textile Institute, 2010, 101, 1, 52–57

[13] Zhou, J., Hu, D., *Design of superimposition-effect digital jacquard fabric based on layered-combination design mode*, In: Journal of Textile Research, 2013, 34, 41–44

[14] Zhou, J., Bai, L., *Design research and practice on gradient weft-full-backed structure*, In: Journal of Textile Research, 2018, 39, 1, 34–39

[15] Zhou, J., Zhang, M., *Design principle and method of combined jacquard half-backed structure*, In: Journal of Textile Research, 2017, 38, 6, 40–45

[16] Ng, F., Zhou, J., *Innovative layered-combination mode for digital jacquard fabric design*, In: Textile Research Journal, 2009, 79, 8, 737–743

[17] Keiji, O., *Reproduction of various colors on Jacquard textiles by only eight kinds of color wefts*, In: 9th Congress of the International Colour Association, Proceedings of SPIE, 2002, 442102

[18] Mathur, K.A., Donaldson, D., Hinks, A.M.S., *Color on Demand for Jacquard Fabrics*, In: Research Journal of Textile and Apparel, 2005, 9, 4, 26–37

[19] Dimitrovski, K., Gabrijelčič, H., *Influence of size and distribution of colour components on colour values of woven fabric*, In: 5th International Conference TEXSCI 2003, Czech Republic, 2003, 305–312

[20] Harpa, R., Visileanu, E., *From fabric design to the dress manufacturing considering the fabric's suitability with the end use*, In: Industria Textila, 2018, 69, 6, 434–439, http://doi.org/10.35530/IT.069.06.1570

[21] Robertson, A.R., *The CIE 1976 colour-difference formula*, In: Colour Research and Application, 1977, 2, 7–11

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Predicting financial distress in the Indian textile sector

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ABSTRACT – REZUMAT

Predicting financial distress in the Indian textile sector

The purpose of this paper is to predict the financial distress of companies of the Indian textile sector using Altman Z score. The analysis conducted on 161 listed textile companies in India for a period of 10 years from 2009 to 2018. All the listed companies are categorized into large, medium, and small using the median split method based on the size of total assets. Kruskal Wallis test is applied to test whether the mean z-score is different for each category of companies. This research study shows that majority of the companies in the Indian textile sector are facing financial distress. Further, it shows that the z score of small, medium, and large-scale textile companies in India is significantly different.

Keywords: *textile sector, performance, Altman Z score, bankruptcy, discriminant analysis, financial investment, customer*

Predicția distresului financiar în cazul sectorului textil din India

Obiectivul acestui articol de cercetare este de a previziona distresul financiar al companiilor din sectorul textil indian folosind modelul Scorului Z a lui Altman. Analiza a fost efectuată la nivelul a 161 de companii din sectorul textil, listate pe piața bursieră din India pentru o perioadă de 10 ani, respectiv din 2009 până în 2018. Toate companiile listate sunt clasificate în mari, medii și mici, utilizând metoda divizării mediane bazată pe mărimea activelor totale. Testul Kruskal Wallis este aplicat pentru a testa dacă scorul mediu Z este diferit pentru fiecare categorie de companii. Acest studiu de cercetare demonstrează că majoritatea companiilor din sectorul textil indian se confruntă cu probleme financiare. Mai mult, arată că scorul Z al companiilor mici, mijlocii și mari din sectorul textil din India, este semnificativ diferit.

Cuvinte cheie*: sectorul textil, performanță, scor Altman Z, faliment, analiză discriminantă, investiție financiară, consumator*

INTRODUCTION

The textile sector is one of the oldest sectors in India and the contribution of the sector in the Indian economy is remarkable. It employs more than 45 million skilled and unskilled labour. The industry contributes 2% to GDP of the economy and 15% to export earnings of India in the fiscal year ended 2017–18. However, the recent insolvency cases registered with NCTL of textile companies like Alok Industries Ltd., Reid and Taylor India Ltd., Mandhana Industries, and Provogue India Ltd. are indeed alarming, and it becomes important to know the risk involved in the sector. Alok Industries alone has defaulted on a loan of as high as Rs. 29,500 crores (based on Indian numbering system). The overall sector also saw a major hit due to GST implementation and demonetization. The current study is an attempt to predict the bankruptcy of 161 listed companies in the Indian textile sector. It further attempts to find the relationship of selected financial ratios and Z score.

Financial distress is the inability of the company to fulfil its debt obligations which ultimately can lead to bankruptcy. If the financial distress can be predicted in advance using such models, then huge losses can be avoided by taking appropriate steps. With the use of business failure prediction models, companies have got warning signals and can lower their chances of going into bankruptcy.

The Z-Score bankruptcy model was developed by Edward Altman in 1968 [1]. Altman tested the predictive power of 22 financial ratios using multiple discriminant analysis and finalized five specific ratios to predict the financial distress of the companies. The ratios like Profitability ratio, Liquidity ratio, Productivity ratio, leverage ratio, and asset turnover ratio were found to have the greatest predictive power to forecast bankruptcy.

The z score is computed using the following equation:

$$Z = 1.2x1 + 1.4x2 + 3.3x3 + 0.6x4 + 0.999x5 \quad (1)$$

where $x1$ is Working Capital/Total Assets, $x2$ – Retained Earnings/Total Assets, $x3$ – Earnings before Interest and Taxes/Total Assets; $x4$ – Market Capitalization/Total Liabilities; $x5$ – Sales/Total Assets.

LITERATURE REVIEW

The empirical research on bankruptcy prediction is varied and large. Beaver used a univariate discriminant analysis to study the ratios of bankrupt and non-bankrupt firms [2]. After his initial work, many bankruptcy prediction models are developed and tested by researchers. The most renowned research in this area is proposed by Altman [1]. He employed multiple discriminant analysis (MDA) to identify bankruptcy prediction ratios. Moreover, contagion represents an unpredictable propagation of shocks [3]. Some other researchers [4] highlighted the fact that volatility does not diverge to infinity, but it is influenced differently considering high positive or high negative stock market returns. Later, a similar technique was used by researchers such as: Grice and Ingram [5], Agarwal and Taffler [6], but also Batchelor [7]. Moreover, Ullal et al. [8] suggested that Indian customers are more emotional. Significant work in MDA is also done by Springate [9] and Fulmer et al. [10] who developed their bankruptcy models. On the other hand, Ohlson [11] argued that assumptions about multivariate normality and independence of predictor variables of MDA are restrictive. Thus, he proposed a new model based on logit Regression analysis taking into consideration nine accounting ratios. Similar work is done by Campbell et al. [12], Sun et al. [13], Jones et al. [14]. Zmijewski [15] used a probit analysis to develop a bankruptcy prediction model. The difference between logit and probit analysis is that the later assume normal distribution of independent variables in the model. His model was further tested by authors like Wu et al. [16]. For instance, Meher et al. [17] suggested that due to the global financial crisis of 2008 the whole banking sector of India was under deep stress because of Non-Performing Assets (NPA). Mehdiabadi et al. [18] argued that global economy is constantly changing so it is very important to consider innovation and technological development as main factors in order to achieve a sustainable growth. Moreover, Meher et al. [19] suggested that considering the ongoing dynamics it is more preferable for India, which is an emerging country, to be an active part of the digitization process. In the Asian context in general and Indian context, many researchers have applied the Altman Z score and other models to predict bankruptcy of varied sectors. Bandyopadhyay [20] evaluated the default probability of Indian corporate bonds using logit analysis. Mishra [21] performed the credit risk evaluation of BSE 200 companies and found that 63.6 percent of the original grouped companies are correctly classified using the Z score model. Patanwala [22] examined the financial distress among the major players in the FMCG sector using Altman's Z-Score. Sanesh [23] assessed the Altman Z-score of NIFTY 50 companies excluding banks and financial companies. It was found that most companies are in a safe zone and 9 companies are in the grey zone and 5 companies are in danger zone. Malik et al. [24] analysed the Textile sector of Pakistan using a z score. The study concluded that the textile industry of Pakistan failed to survive in the international market during the crisis period (2007–2009) and in the recovery period (2010–2012), financial health was found to be comparatively better. Archana [25] predicted the z-score of selected retail firms in India. Rim and Roy [7] applied the Altman Z score to evaluate Lebanon companies and found that it is a sound tool to predict financial distress. Batchelor [8] tested the efficacy of Altman Z-score and concluded that manipulating variables of the Altman Z-score yields better results. Altman [26] tested the prediction accuracy of the original Altman Z score in the international context and concluded that the model works well in most of the countries.

In the backdrop of such findings in the literature, the current study has emphasized on Altman Z score over the other bankruptcy models. Further, very few studies are conducted on the textile sector in general and the Indian textile sector in specific. Thus, the current study attempts to predict bankruptcy in the Indian textile sector.

RESEARCH ANALYSIS

In the financial domain, where wealth multiplication is involved, the most vulnerable players are the investors. Corporate bankruptcy is the biggest danger to investor's wealth. Bankruptcy can wipe out the entire equity capital of a firm and can significantly impact its stock prices. In the recent past, giant players in the Indian textile sector have reported financial distress impacting various stakeholders like investors, employees, and practitioners. Therefore, it becomes important to review the financial performance of the traditional textile sector of the economy. To assess the likelihood of bankruptcy of a company, the Altman Z Score model can be employed. This paper attempts to study the probability of failure of selected textile firms. The study further analysis if there is any difference in the bankruptcy score of small, medium, and large-scale companies. Given the volatile sales and earnings of textile manufacturers, there is an indispensable need to assess the financial position of the Indian textile sector. As per the financial stability report of RBI, June 2019, the textile sector has recorded the stressed advance ratio of 16.1%, which means that the textile industry is significantly contributing to stress assets of banks. The main objectives of this empirical study are the following:

1. To predict the Z score of selected textile companies in India using the Altman Z score model.
2. To examine the strength of financial ratios for measuring Z score values.
3. To examine if there exists any significant difference in z scores of selected companies based on their size.

The hypotheses of this empirical study are the following:

H01: There is no significant impact of selected financial ratios on the z score of selected textile companies in India.

H02: There is no significant difference in the z score of selected textile companies in India based on their size.

RESEARCH METHODOLOGY

This study is based on the secondary financial data of textile companies extracted from the database of Ace analyser and the annual reports of the selected companies. The study is based on the panel data of selected financial ratios of 161 companies for 10-year period from 2009 to 2019 comprising 1,771 data points.

The following tools are used for the analysis of the data:

- Altman Z score Model (1968) is used to predict financial distress of selected companies.
- Correlation and Regression analysis is used to examine the strength of selected financial ratios for measuring z scores values.
- Median Split is used to categorize firms into large, medium, and small scale based on their total assets.
- Levene Statistics is used to test the homogeneity of variances in z score values.
- Kruskal-Wallis is used to test the significant difference in Z score values based on the size of the firm.

DATA ANALYSIS AND INTERPRETATION

This section deals with the data analysis and interpretation.

Figure 1 and table 1 show that on an average 118 out of 161 companies analysed are financially distressed. 37 companies are in the grey area and only 6 companies are financially strong. The analysis shows that only 3.72% of the selected textile firms are financially strong. The recent government initiatives such as "Make in India", special package to boost exports, technology upgradation fund scheme could prove favourable for the sector and can improve the financial viability of the textile sector soon.

The table 2 shows that the mean z score value of the textile sector is less than 1.8, therefore it can be said that the overall textile sector is facing distress.

The mean values of the ratios X2 and X3 are the lowest. Thus, Retained Earnings/Total Assets and EBIT/ Total assets are the key ratios which are

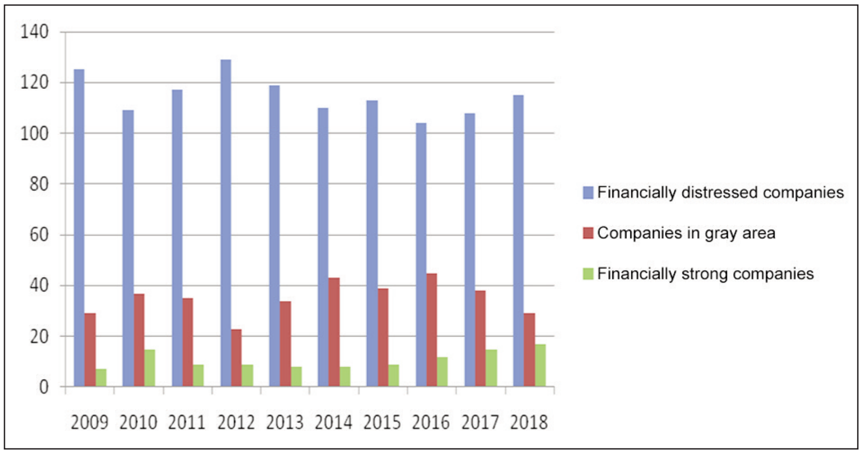

Fig. 1. Z-score Results

Table 1

Z-SCORE RESULTS				
Year	**Financially distressed companies (Z score < 1.8)**	**Companies in the grey area (Z score between 1.8 and 3)**	**Financially strong companies (Z score > 3)**	**Total**
2009	125	29	7	161
2010	109	37	15	161
2011	117	35	9	161
2012	129	23	9	161
2013	119	34	8	161
2014	110	43	8	161
2015	113	39	9	161
2016	104	45	12	161
2017	108	38	15	161
2018	115	29	17	161
10-year Average	118	37	6	161

Table 2

DESCRIPTIVE STATISTICS					
Indicators	**N**	**Minimum**	**Maximum**	**Mean**	**Std. deviation**
z_score	1771	–9.91	43.39	1.3495	1.69469
X1	1771	–6.46	1.00	0.1087	0.38885
X2	1771	–1.40	8.76	0.0093	0.24568
X3	1771	–1.03	9.08	0.0556	0.24867
X4	1771	0.00	22.39	0.3137	1.00934
X5	1771	–0.34	6.58	0.8353	0.60075
Valid N (listwise)	1771	-	-	-	-

Table 3

CORRELATION ANALYSIS							
Indicators		z_score	X1	X2	X3	X4	X5
z_score	Pearson Correlation	1	0.493**	0.801**	0.800**	0.413**	0.472**
	Sig. (2-tailed)	-	0.000	0.000	0.000	0.000	0.000
	N	1771	1771	1771	1771	1771	1771

Note: ** Correlation is significant at the 0.01 level (2-tailed).

contributing to the lower z-score value of the textile sector.

Table 3 shows that p-values of all variables are less than 0.05, therefore the null hypothesis is rejected, and the selected financial ratio has a significant positive relation with z score.

Tables 4 and 5 show that the p-value of all selected variables is less than 0.05, therefore the null hypothesis is rejected and all selected financial ratios have a significant impact on z score values.

Table 4

REGRESSION ANALYSIS MODEL SUMMARY				
Model	R	R Square	Adjusted R Square	Std. error of the estimate
1	1.000[a]	1.000	1.000	0.00000

Note: Predictors: (Constant), X5, X4, X2, X1, X3.

Table 5

COEFFICIENTS					
Model	Unstandardized coefficients		Standardized coefficients	t	Sig.
	B	Std. error	Beta		
(Constant)	–9.442E-012	0.000	-	–0.003	0.998
X1	1.200	0.000	0.275	236273753.564	0.000
X2	1.400	0.000	0.203	29616750.193	0.000
X3	3.300	0.000	0.484	71786600.220	0.000
X4	0.600	0.000	0.357	375230591.446	0.000
X5	0.999	0.000	0.354	346256603.116	0.000

Note: Dependent Variable: z_score.

It is evidence from table 6 the results of Levene statistics shows that the p-value is less than 0.05, therefore the null hypothesis is rejected and the assumption of homogeneity of variances of one-way ANOVA is violated. Hence, ANOVA cannot be applied to test the significant difference in z score values.

Table 6

HOMOGENEITY OF VARIANCES			
Levene statistic	df1	df2	Sig.
11.952	2	1768	0.000

The appropriate non-parametric alternate to ANOVA for such data with heterogeneity in variances is the Kruskal-Wallis test which is a rank-based nonparametric test that can be used to determine if there are statistically significant differences between two or more groups of an independent variable. Table 7 shows the SPSS output of Kruskal Wallis test.

It is evidence from tables 7 and 8 the p-value is less than 0.05, the null hypothesis is rejected and there exists a significant difference in z-score values based on the size of the company. Since the result of the test is significant, a post hoc test is conducted, and the results of the test are given in the table 8.

Table 9 shows that z score values of small & large firms and Small & Medium firms have a statistically significant difference, whereas there is no significant difference in z score values of Large & Medium firms. Each row tests the null hypothesis that the Sample 1 and Sample 2 distributions are the same. Asymptotic

Table 7

KRUSKAL WALLIS TEST RANKS			
Indicator	Category	N	Mean rank
z-score	Large	616	911.73
	Medium	583	921.95
	Small	572	821.65
	Total	1771	-

Table 8

TEST STATISTICS	
Particulars	z_score
Chi-Square	13.503
df	2
Asymp. Sig.	0.001

Table 9

POST HOC TEST					
Sample 1 – Sample 2	**Test statistic**	**Std. error**	**Std. test statistic**	**Sig.**	**Adj. Sig.**
Small-Large	90.081	29.689	3.034	0.002	0.007
Small-Medium	100.300	30.091	3.333	0.001	0.003
Large-Medium	–10.219	29.543	–0.346	0.729	1.000

Table 10

CATEGORY WISE DESCRIPTIVE STATISTICS OF Z SCORE		
Category	**Median**	**N**
Large	1.3756	616
Medium	1.3793	583
Small	1.2072	572
Total	1.3400	1771

significances (2-sided testes) are displayed. The significance level is 0.05.

From table 10, it can be seen that small companies have a lower average z score compared to large and medium companies.

FINDING AND CONCLUSIONS

The study analysed the selected financial ratios and Z score values of listed textile companies in India. The following aspects represent the most important findings of this empirical study:

- Based on a 10-year average z score, only 3.72% of the selected companies are financially strong and most of the companies are in danger zone.
- The results of descriptive statistics show that the two ratios i.e., Retained Earnings/Total Assets and EBIT/Total assets contribute to the lower z-score value of the textile sector.
- The correlation and regression output show that selected five financial ratios of the Altman Model have a significant impact on Z score values. It means that these ratios have significant power to predict bankruptcy.
- Kruskal and Wallis test show that there exists a significant difference in Z score values of Large, Medium, and Small-scale companies. The small-scale companies have a lower z score compared to large and medium companies which means that these companies have higher financial distress.

This study shows that majority of the companies in the Indian textile sector are facing financial distress. Altman Z score model has the predictive power to predict the financial unsoundness before the company realizes or declares bankruptcy. It is therefore recommended to all stakeholders in general and investors to employ the Z score model before investing.

This research will enable the researchers to understand the bankruptcy profile of the Indian textile sector and the role played by different financial indicators in causing bankruptcy. Furthermore, the findings of this study will also help the investors and practitioners associated with the textile industry to adopt more specific techniques to predict bankruptcy.

The current research has applied only Altman Z score to predict bankruptcy. Further studies can be done in the textile sector using logit and probit analysis or other bankruptcy models. Also, a comprehensive study can be conducted comparing the financial distress of varied sectors in the Indian context.

REFERENCES

[1] Altman, E.I., *Financial ratios, discriminant analysis, and the prediction of corporate bankruptcy,* In: The Journal of Finance, 1968, 23, 4, 589–609

[2] Beaver, W.H., *Financial ratios as predictors of failure*, In: Journal of Accounting Research, 1966, 71–111

[3] Spulbar, C., Trivedi, J., Birau, R. *Investigating abnormal volatility transmission patterns between emerging and developed stock markets: a case study,* In: Journal of Business Economics and Management, 2020, 21, 6, 1561–1592, https://doi.org/10.3846/jbem.2020.13507.

[4] Spulbar, C., Birau, R., *Emerging research on monetary policy, banking, and financial markets*, IGI Global, USA, 2019, https://doi.org/10.4018/978-1-5225-9269-3

[5] Grice, J.S., Ingram, R.W., *Tests of the generalizability of Altman's bankruptcy prediction model*, In: Journal of Business Research, 2001, 54, 1, 53–61

[6] Agarwal, V., Taffler, R., *Comparing the performance of market-based and accounting-based bankruptcy prediction models*, In: Journal of Banking & Finance, 2008, 32, 8, 1541–1551

[7] Batchelor, T., *Corporate Bankruptcy: Testing the Efficacy of the Altman Z-Score*, In: International Research Journal of Applied Finance, 2018, 9, 9, 404–414

[8] Ullal, M.S., Spulbar, C., Hawaldar, I.T., Popescu, V., Birau, R., *The impact of online reviews on e-commerce sales in India: a case study*, In: Economic Research-Ekonomska Istraživanja, 2021, DOI: 10.1080/1331677X.2020.1865179, https://www.tandfonline.com/doi/full/10.1080/1331677X.2020.1865179.

[9] Springate, G.L., *Predicting the Possibility of Failure in a Canadian Firms*, Research Project, January, Simon Fraser University, Canada, 1978

[10] Fulmer, J.G. Jr., Moon, J.E., Gavin, T.A., Erwin, M.J., *A bankruptcy classification model for small firms*, In: Journal of Commercial Bank Landing, 1984, 25–37
[11] Ohlson, J.A., *Financial ratios and the probabilistic prediction of bankruptcy*, In: Journal of Accounting Research, 1980, 109–131
[12] Campbell, J.Y., Hilscher, J., Szilagyi, J., *In search of distress risk*, In: The Journal of Finance, 2008, 63, 6, 2899–2939
[13] Sun, J., Li, H., Huang, Q.H., He, K.Y., *Predicting financial distress and corporate failure: A review from the state-of-the-art definitions, modeling, sampling, and featuring approaches*, In: Knowledge-Based Systems, 2014, 57, 41–56
[14] Jones, S., Johnstone, D., Wilson, R., *Predicting corporate bankruptcy: An evaluation of alternative statistical frameworks,* In: Journal of Business Finance & Accounting, 2017, 44, 1–2, 3–34
[15] Zmijewski, M.E., *Methodological issues related to the estimation of financial distress prediction models,* In: Journal of Accounting Research, 1984, 59–82
[16] Wu, Y., Gaunt, C., Gray, S., *A comparison of alternative bankruptcy prediction models*, In: Journal of Contemporary Accounting & Economics, 2010, 6, 1, 34–45
[17] Meher, B.K., Puntambekar, G.L., Hawaldar, I.T., Spulbar, C., Birau, R., Rebegea, C., *An Effectiveness Assessment of Preventive Management Strategies in order to Manage Non Performing Assets in Indian banks: A Case Study*, In: Scientific Annals of Economics and Business, 2020, 67, 2, 235–258, http://saeb.feaa.uaic.ro/index.php/saeb/article/view/1026
[18] Mehdiabadi, A., Tabatabeinasab, M., Spulbar, C., Karbassi Yazdi, A., Birau, R., *Are We Ready for the Challenge of Banks 4.0? Designing a Roadmap for Banking Systems in Industry 4.0.*, In: International Journal of Financial Studies, Special Issue “The Financial Industry 4.0”, 2020, 8, 2, 32, https://doi.org/10.3390/ijfs8020032
[19] Meher, B.K., Thonse, H.I., Latasha, M., Spulbar, C.M., Birau, F.R., Rebegea, C., *The Impact of Digital Banking on the Growth of Micro, Small and Medium Enterprises (MSMES) in India: A Case Study,* In: Business: Theory and Practice, 2021, 22, 1, 18–28, https://doi.org/10.3846/btp.2021.12856, Available at SSRN: https://ssrn.com/abstract=3770889 [Accessed on January 2021]
[20] Bandyopadhyay, A., *Predicting the probability of default of Indian corporate bonds: logistic and Z-score model approaches*, In: The Journal of Risk Finance, 2006, 7, 3, 255–272
[21] Mishra, S., *Credit Risk Evaluation of BSE 200 Manufacturing Companies Using a Z-Score Model,* In: IPE Journal of Management, 2013, 3, 1, 1
[22] Patanwala, A., *A Prediction of the Financial Distress of the Major Players in the FMCG Sector Using Revised Altman Z-Score Model and Liquidity Ratios,* In: Business Sciences International Research Journal, 2017, 4, 1, 77–82
[23] Sanesh, C., *The analytical study of Altman Z score on NIFTY 50 Companies*, In: IRA-International Journal of Management & Social Sciences, ISSN 2455–2267, 2016, 3, 3
[24] Malik, M.S., Awais, M., Timsal, A., Hayat, F., *Z-Score Model: Analysis and Implication on Textile Sector of Pakistan*, In: International Journal of Academic Research, 2016, 4, 2, 140–158
[25] Archana, H.N., *Default Prediction using Altman Z Score Model-A Study of some Select Retail Firms*, In: Sumedha Journal of Management, 2018, 7, 4, 60–75
[26] Altman, E.I., *Predicting financial distress of companies: Revisiting the Z-score and ZETA models*. In: Stern School of Business, New York University, 2000, 9–12

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Competency framework validation: application in textile industry

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ABSTRACT – REZUMAT

Competency framework validation: application in textile industry

Previous research on the subject has reported that competency-based management has a constructive impact on organizational and employees' performance. One way of presenting human resource competencies is through a formal framework. This study is part of a project to validate a scientifically developed competency framework and assesses the prospects of its application in specific industrial sectors of Pakistan. This methodological work was carried out with background learning in the first phase and a survey was conducted in second phase involving practitioners and experts from the textile industry. Their responses were used to validate the face and content of the framework. Participants were given a presentation on the methodology followed in developing the competency framework and provided a questionnaire for feedback. Out of 75 participants from the textile industry, the majority were from human resource, sales, marketing, information technology, finance, operations, engineering, quality and logistics at managerial level. Participants validated the framework design and contents without suggesting any changes. This study gave confidence about the framework, its development methodology, its format and presentation before bringing in practice.

Keywords: *competence, framework, methodological study, survey, practitioners and experts in textile, validation*

Validarea cadrului competențelor: aplicarea acestuia în domeniul textil

Cercetările anterioare asupra acestui subiect au arătat că managementul bazat pe competențe are un impact constructiv asupra performanței organizaționale și a angajaților. O modalitate de prezentare a competențelor resurselor umane se realizează pe baza unui cadru formal. Acest studiu face parte dintr-un proiect de validare a unui cadru de competențe dezvoltat științific și evaluează perspectivele aplicării acestuia în sectoarele industriale specifice din Pakistan. Această lucrare metodologică a fost realizată în prima fază pe baza documentării și în a doua fază printr-un sondaj implicând practicieni și experți din industria textilă. Răspunsurile lor au fost utilizate pentru a valida aspectul și conținutul cadrului competențelor. Participanților li s-a prezentat metodologia urmată în dezvoltarea cadrului competențelor și aceștia au furnizat date într-un chestionar pentru feedback. Din cei 75 de participanți din industria textilă, majoritatea provine din resurse umane, vânzări, marketing, tehnologia informației, finanțe, operațiuni, inginerie, calitate și logistică la nivel managerial. Participanții au validat aspectul și conținutul cadrului, fără a sugera modificări. Acest studiu a oferit încredere în acest cadru, în metodologia sa de dezvoltare, formatul și prezentarea acestuia înainte de a fi pus în practică.

Cuvinte-cheie*: competență, cadru, studiu metodologic, sondaj, practicieni și experți în textile, validare*

INTRODUCTION

Though the term organizational capability and competence (or competency) is new and fashionable [1], the concept is old. Competency-based management has reported a positive influence on organizational and employees' performance [2]. Competencies are, therefore, essential for meeting performance standards and achieving important results in an explicit work role in any organization [3]. However, a mere listing of competencies has more value for its users if similar competencies are grouped to form a framework [4]. The practice of competency frameworks may appeal to scholars and practitioners to serve as the foundation for many human resource development activities. Among its advantages is that the employees know precisely which competencies are required for success and how they will be evaluated [5]. Unfortunately, the use of competency frameworks is often hindered because of conceptual ambiguity, a lack of methodological rigor in the development of such systems, and psychometric issues [6]. This challenge could be met:

- If the framework is developed based on some established work regarding jobs' classification, roles and functions.
- If the framework is formalized by involving a group of experts from various professions.
- If scientific methods are used to reduce subjectivity.

The development of competency frameworks starts with the identification of required competencies and excerpts from literature, study of the documents and conversing. The process is furthered by acquiring consensus from the experts for validity [7].

There are a variety of competency frameworks available mostly developed to cater to particular needs or are job-specific and perceived as knowledge-specific and task-specific [8]. Some generic frameworks are moreover presented with varied shapes and formats

from having no structure or just a collection of competencies or structured by the relationship among the containing competencies [9].
The need for a framework exists, which is generic and could be utilized without significant modifications as the core competencies remain the same in any managerial position across organizations and countries [10]. This generic framework could be implemented in any industrial or business sector.
Competency frameworks ideally should be validated before being put into use to provide a sound platform upon which various HR applications may be based [11]. This study was conducted to validate the framework for its outlook and presentation. Also, the framework was validated for having relevant content and the likelihood of its usefulness in the textile sector of Pakistan at various stages of the human resource lifespan.
The results of the study are promising in a manner that the face and content validity of the framework in subject is established. The presentation and arrangement of information in the framework make it pragmatic to apply. The framework is accepted to be appropriate for application in the textile industry for recruitment, performance evaluation, training need analysis and career planning.

METHODOLOGY

In this study, methodology employing a questionnaire was used to validate a recently developed competency framework. The subjects were professionals working in textile who could be benefited from the application of the framework. Textile is one of the major contributors of earning foreign exchange for Pakistan. The industry has been facing incremental changes and global competition requiring a commensurate set of managerial skills [12]. The key to the success of any organization in present-day competition lies in its human resource proficient in identifying distinctive and ingenious solutions to the challenges [13]. The study was conducted in the industrial hub of Karachi city inviting 75 managers and senior managers working in the area of human resource, sales, marketing, information technology, finance, operations, engineering, quality and logistics from the textile sector.
The participants were provided a questionnaire in two parts. The first part comprising of five questions, was to face validate the framework and asses its utilization prospects. Participants were also to rate the chances of competency framework utilization, methodology undertaken, presentation of the framework and its comprehensiveness in the textile sector's perspective of Pakistan.
The second part compromising of ten questions were about knowing how the framework contents are appropriate in terms of their coverage of the subject. The questions asked were related to the appropriateness of job title, key roles, key performance indicators, job responsibilities, and their linkage with competencies, progressive levels and weight-ages of competencies. 25 professionals in five groups of five each and in three sessions discussed the matter to provide uninfluenced feedback of their own.

Inclusion criteria

The participants were required to fulfil the following criteria: (i) must be currently employed and working on a managerial position in the textile sector; (ii) should be a graduate, with an exception of diploma in apparel design; (iii) should have a minimum of ten years of professional experience; (iv) should have an official concern regarding selection and recruitment, deployment and promotion, development planning of subordinates and/or performance evaluation.

Number of respondents per framework

Table 1 shows the qualification/ area of expertise with a number of professionals working in the textile sector who participated in validation exercise. The number of participants shows that there are no less than 7 participants (cost accountancy and business management in finance taken together) to provide feedback for a framework of any particular job (framework was available for eight jobs). For face validity, researchers recommend to have at least seven to ten people. For content validity, it should not be less than 2 [14].

Table 1

AREA OF EXPERTISE FOR PROFESSIONALS WHO PARTICIPATED

Sr. no.	Education/Area of expertise in	Number of participants
1	Business management, finance	8
2	Business management, marketing	12
3	Business management, supply chain	7
4	Cost accountancy	2
5	Engineering (mechanical, electrical, textile*)	7
6	Human resource management	13
7	Information technology	10
8	Science (physics and chemistry)	9
9	Apparel design	7
Total		**75**

* Three of the textile engineers worked in production and two in quality.

Sampling methodology

It was targeted to connect with as many professionals in textile as possible through HR and textile fora. The number of such professionals living in Karachi is a big population of unknown size. The sampling technique based on Cochran's formula was used to determine the sample (number of participants) size [15]. Cochran's formula was applied:

$$n_0 = \frac{z^2pq}{e^2} \quad (1)$$

where n_0 is sample size, p – estimated proportion of population which has the attribute (to attend), $q = 1 – p$, e – error or desired level of precision and Z – standard normal random variable.

It was assumed that 5% of the entire population would attend (p). We will calculate the sample size with 5% precision (e) and at 95% confidence level ($Z = 1.96$).

$$n_0 = [(1.96)^2 \times 0.05 \times 0.95] / (0.05)^2 = 72.99 \approx 73 \quad (2)$$

Administration of questionnaire

Details about the methodology and scientific tools used in developing the competency framework were briefed. The presentation was followed by a question-answer session and collecting feedback on a questionnaire. This questionnaire was previously tested for internal consistency based on 32 HR professionals' feedback and calculating Cronbachαvalue, which came out to be 0.82.

Modus operandi of the session was also briefed and instructions were given on the questionnaire. The participants were additionally asked to solicit their feedback considering questions: (i) do you have any suggestions for improving the contents in terms of information or format? (ii) do you have any new item/information which you would like to add? No suggestions came forward requiring any review or change in the framework and its contents. The whole methodology is presented in figure 1.

Face validity

355 out of 375 possible responses (98.40%) are on higher side as shown in table 2 and plotted in figure 2, thus validating its outlook and presentation.

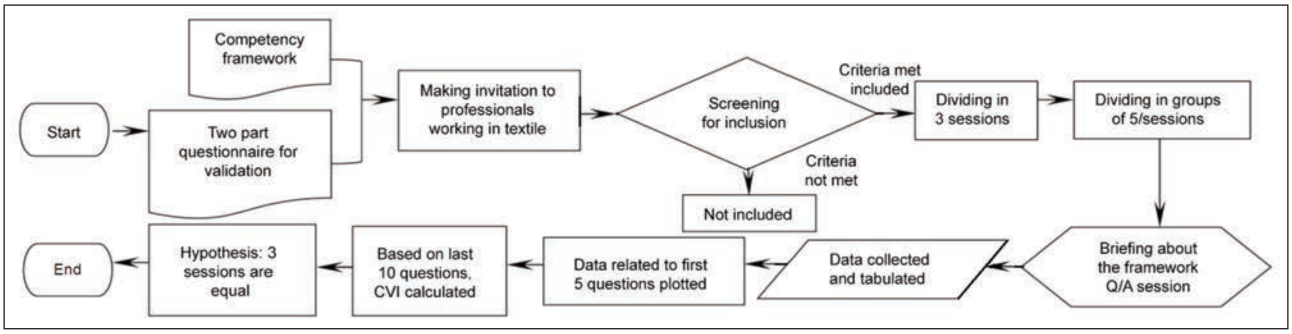

Fig. 1. Methodology followed for this study

Table 2

RESPONSES AGAINST THE FIRST FIVE QUESTIONS		
Questions	**Given choices**	**Number of responses**
Question 1	Yes, very strong	53
	Can consider	21
	Do not know	0
	Probably not	1
Question 2	Recruitment	9
	Performance evaluation	49
	Training needs analysis	14
	Other	3
Question 3	Very high	61
	High	13
	Moderate	1
	Low	0
Question 4	Quite comprehensive	41
	Detailed and connected	34
	Subject information	0
	Need more information	0
Question 5	Very appropriate	62
	Easy to comprehend	12
	Reasonable	1
	May improve	0

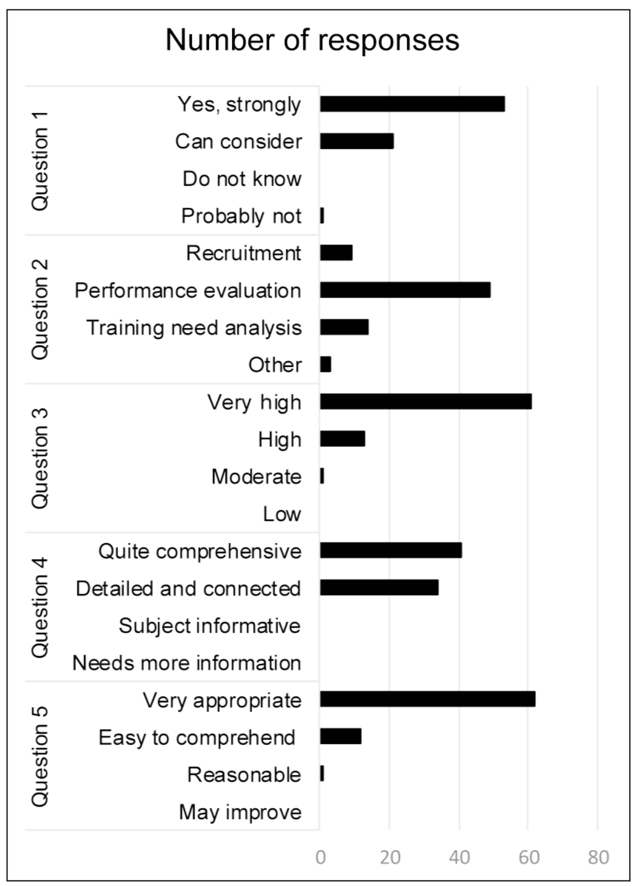

Fig. 2. Responses against first five questions

Content validity

Average of the item-level content validity index (S-CVI/Avg) was calculated for each question asked. An S-CVI reaching 90% qualifies the instrument to be content valid [28]. Table 3 for sessions 1 to 3 respectively, show the respondents' feedback data and the calculation of CVI. Each session was independent with a mix of professionals. The data, Scale Level Content Validity Index (S-CVI), were discrete values. It was appropriate to evaluate that all sessions

Table 3

AVERAGE OF THE ITEM-LEVEL CONTENT VALIDITY INDEX

	Practitioner 1	Practitioner 2	Practitioner 3	Practitioner 4	Practitioner 5	Agreement	I-CVI	Practitioner 6	Practitioner 7	Practitioner 8	Practitioner 9	Practitioner 10	Agreement	I-CVI	Practitioner 11	Practitioner 12	Practitioner 13	Practitioner 14	Practitioner 15	Agreement	I-CVI	Practitioner 16	Practitioner 17	Practitioner 18	Practitioner 19	Practitioner 20	Agreement	I-CVI	Practitioner 21	Practitioner 22	Practitioner 23	Practitioner 24	Practitioner 25	Agreement	I-CVI
Question 6	4	3	4	4	4	4	0.80	3	4	4	4	4	4	0.80	4	4	4	4	3	4	0.80	4	4	4	4	4	5	1.00	4	4	4	4	4	5	1.00
Question 7	3	4	3	4	4	3	0.60	4	4	4	4	4	5	1.00	4	4	4	4	3	4	0.80	4	4	4	4	4	5	1.00	4	4	4	3	4	4	0.80
Question 8	4	4	4	4	4	5	1.00	4	4	4	4	4	5	1.00	4	4	4	4	4	5	1.00	4	4	4	4	4	5	1.00	4	4	4	4	4	5	1.00
Question 9	4	4	4	4	4	5	1.00	4	4	4	4	4	5	1.00	4	4	4	4	4	5	1.00	4	4	4	4	4	5	1.00	4	4	4	4	4	5	1.00
Question 10	4	3	4	4	4	4	0.80	3	4	4	4	4	4	0.80	4	4	4	4	4	5	1.00	4	4	4	4	4	5	1.00	4	4	4	4	4	5	1.00
Question 11	4	4	4	4	4	5	1.00	4	4	4	4	4	5	1.00	4	4	4	4	4	5	1.00	4	4	4	4	4	5	1.00	4	4		4	4	4	0.80
Question 12	4	4	4	4	4	5	1.00	4	4	4	4	4	5	1.00	4	4	4	4	3	4	0.80	4	4	4	4	4	5	1.00	4	4	4	4	4	5	1.00
Question 13	4	4	4	4	4	5	1.00	4	4	4	4	4	5	1.00	4	4	4	4	4	5	1.00	4	4	4	4	4	5	1.00	4	4	4	4	4	5	1.00
Question 14	4	4	4	4	4	5	1.00	4	4	4	4	4	5	1.00	4	4	4	4	4	5	1.00	4	4	4	4	4	5	1.00	4	4	4	4	4	5	1.00
Question 15	4	4	4	4	4	5	1.00	4	4	4	4	4	5	1.00	4	4	4	4	4	5	1.00	4	4	4	4	4	5	1.00	4	4	4	4	4	5	1.00
					S-CVI/Avg		0.92					S-CVI/Avg		0.96					S-CVI/Avg		0.94					S-CVI/Avg		1.00					S-CVI/Avg		0.96

	Practitioner 26	Practitioner 27	Practitioner 28	Practitioner 29	Practitioner 30	Agreement	I-CVI	Practitioner 31	Practitioner 32	Practitioner 33	Practitioner 34	Practitioner 35	Agreement	I-CVI	Practitioner 36	Practitioner 37	Practitioner 38	Practitioner 39	Practitioner 40	Agreement	I-CVI	Practitioner 41	Practitioner 42	Practitioner 43	Practitioner 44	Practitioner 45	Agreement	I-CVI	Practitioner 46	Practitioner 47	Practitioner 48	Practitioner 49	Practitioner 50	Agreement	I-CVI
Question 6	4	3	4	4	4	4	0.80	3	4	4	4	4	4	0.80	4	4	4	4	3	4	0.80	4	4	4	4	4	5	1.00	4	4	4	4	4	5	1.00
Question 7	3	4	3	4	4	3	0.60	4	4	4	4	4	5	1.00	4	4	4	4	3	4	0.80	4	3	4	4	4	4	0.80	4	3	4	4	4	4	0.80
Question 8	4	4	4	4	4	5	1.00	4	4	4	4	4	5	1.00	4	4	4	4	4	5	1.00	4	4	4	4	4	5	1.00	4	4	4	4	4	5	1.00
Question 9	4	4	4	4	4	5	1.00	4	4	4	4	4	5	1.00	4	4	4	4	4	5	1.00	4	4	4	4	4	5	1.00	4	4	4	4	4	5	1.00
Question 10	4	3	4	4	4	4	0.80	3	4	4	4	4	4	0.80	4	4	4	4	4	5	1.00	4	3	4	4	4	4	0.80	4	3	4	4	4	4	0.80
Question 11	4	4	4	4	4	5	1.00	4	4	4	4	4	5	1.00	4	4	4	4	4	5	1.00	4	4	4	4	4	5	1.00	4	4	4	4	4	5	1.00
Question 12	4	4	4	4	4	5	1.00	4	4	4	4	4	5	1.00	4	4	4	4	4	5	0.80	4	4	4	4	3	4	0.80	4	4	4	4	3	4	0.80
Question 13	4	4	4	4	4	5	1.00	4	4	4	4	4	5	1.00	4	4	4	4	4	5	1.00	4	4	4	4	4	5	1.00	4	4	4	4	4	5	1.00
Question 14	4	4	4	4	4	5	1.00	4	4	4	4	4	5	1.00	4	4	4	4	4	5	1.00	4	4	4	4	4	5	1.00	4	4	4	4	4	5	1.00
Question 15	4	4	4	4	4	5	1.00	4	4	4	4	4	5	1.00	4	4	4	4	4	5	1.00	4	4	4	4	4	5	1.00	4	4	4	4	4	5	1.00
					S-CVI/Avg		0.92					S-CVI/Avg		0.98					S-CVI/Avg		0.96					S-CVI/Avg		0.94					S-CVI/Avg		0.94

	Practitioner 51	Practitioner 52	Practitioner 53	Practitioner 54	Practitioner 55	Agreement	I-CVI	Practitioner 56	Practitioner 57	Practitioner 58	Practitioner 59	Practitioner 60	Agreement	I-CVI	Practitioner 61	Practitioner 62	Practitioner 63	Practitioner 64	Practitioner 65	Agreement	I-CVI	Practitioner 66	Practitioner 67	Practitioner 68	Practitioner 69	Practitioner 70	Agreement	I-CVI	Practitioner 71	Practitioner 72	Practitioner 73	Practitioner 74	Practitioner 75	Agreement	I-CVI
Question 6	4	3	4	4	4	4	0.80	3	4	4	4	4	4	0.80	4	4	4	4	3	4	0.80	4	4	4	4	4	5	1.00	4	4	4	4	4	5	1.00
Question 7	3	4	3	4	4	3	0.60	4	4	4	4	4	5	1.00	4	4	4	4	3	4	0.80	3	4	4	4	4	4	0.80	3	4	4	4	4	4	0.80
Question 8	4	4	4	4	4	5	1.00	4	4	4	4	4	5	1.00	4	4	4	4	4	5	1.00	4	4	4	4	4	5	1.00	4	4	4	4	4	5	1.00
Question 9	4	4	4	4	4	5	1.00	4	4	4	4	4	5	1.00	4	4	4	4	4	5	1.00	4	4	4	4	4	5	1.00	4	4	4	4	4	5	1.00
Question 10	4	3	4	4	4	4	0.80	3	4	4	4	4	4	0.80	4	4	4	4	4	5	1.00	4	4	4	4	4	4	1.00	4	4	4	4	4	5	1.00
Question 11	4	4	4	4	4	5	1.00	4	4	4	4	4	5	1.00	4	4	4	4	4	5	1.00	4	4	3	4	4	5	0.80	4	4	4	4	4	5	1.00
Question 12	4	4	4	4	4	5	1.00	4	4	3	4	4	4	0.80	4	4	4	4	4	5	1.00	4	4	4	4	4	4	1.00	4	4	4	4	4	5	1.00
Question 13	4	4	4	4	4	5	1.00	4	4	4	4	4	5	1.00	4	4	4	4	4	5	1.00	4	3	4	4	4	5	0.80	4	3	4	4	4	4	0.80
Question 14	4	4	4	4	4	5	1.00	4	4	4	4	4	5	1.00	4	4	4	4	4	5	1.00	4	4	4	4	4	5	1.00	4	4	4	4	4	5	1.00
Question 15	4	4	4	4	4	5	1.00	4	4	4	4	4	5	1.00	4	4	4	4	4	5	1.00	4	4	4	4	4	5	1.00	4	4	4	4	4	5	1.00
					S-CVI/Avg		0.92					S-CVI/Avg		0.94					S-CVI/Avg		0.96					S-CVI/Avg		0.94					S-CVI/Avg		0.96

Note: I-CVI – Item wise Content Validity Index; S-CVI – Scale Level Content Validity Index; I-CVI = (agreed item)/(number of experts); Scale level content validity index S-CVI – the average of the I-CVI score of all items; S-CVI/Ave = (sum of I-CVI scores)/(number of items); item level content validity index I-CVI – the proportion of experts giving items a relevance rating.

Table 4

U STATISTICS FOR ALL THREE SESSIONS AT 5% SIGNIFICANCE LEVEL						
Sessions in comparison		**Sum of ranks R**	$\frac{n(n+1)}{2}$	$U = R - \frac{n(n+1)}{2}$	**Critical U at p<0.5**	**Comment**
Session 1	Session 2	24.5	15	9.5	2	Populations are not significantly different
Session 1	Session 3	23.5	15	8.5	2	Populations are not significantly different
Session 2	Session 3	26.5	15	11.5	2	Populations are not significantly different

belong to a similar population. We used Mann & Whitney statistics 'U' to evaluate if all three sessions provided a similar response. Hypothesis created were as follows.

H_0: Distributions of both populations, to whom S-CVIs of any two sessions belong, are equal.

H_1: Distributions are not equal.

Table 4 illustrates the critical values of U to find out the difference being significant or not. The values of U lie in the acceptance region, so there is no evidence to reject the H_0 hence all three sessions gave the same response.

RESULT AND DISCUSSION

Establishing face and content validity is a systematic process. The participants were briefed about the competency framework and its development methodology. The first question was to evaluate the acceptability chances of the competency framework in the textile sector of Pakistan. The second question identifies the areas of implementation and further research. The third question evaluates the confidence on the framework development. Last two questions were to face validate the framework. Table 5 further elaborates and analyses the collected data; the average face validation score is 99%.

The last ten questions were to assess the content validity of the framework on a 5-point rating scale. 75 participants were distributed in 3 sessions so that they can be presented the competency framework for replying to the questionnaire. Each session was further divided into a group of 5 to facilitate any discussion. I-CVI for each question was calculated and then S-CVI. With S-CVI from 0.92 to 1.00, the instrument had good content validity. The results indicate that the framework developed and presented for this study is a reliable instrument for adopting in human resource life cycle within the textile sector of Pakistan. It was further tested that S-CVI responses of different sessions are not significantly different.

CONCLUSION

Human resource competencies are essential for meeting performance standards and achieving important results. Competencies are easy to apply if these are presented in a scientifically designed framework involving experts from various professional disciplines. Practitioners of the industry, where the framework is planned to be implemented, should validate the outlook and contents of the framework.

Feedback of the practitioners from different professions working in the textile sector provided enough evidence that the framework in focus ranks on the higher side in terms of presentation. Approximately, 99% respondents ranked it on two higher choices. The framework stands a good chance of implementation at various human resource stages. The calculated content validation index for each item of the framework and average of all ranging from 0.92 to 1.00, qualify the entrails of this instrument.

The following inferences were also apparent from the study: Firstly, the validation provided a stable and

Table 5

ANALYSIS OF THE RESPONSES AGAINST FIRST FIVE QUESTIONS				
Question	**Content**	**Purpose**	**Total of First Two Choices out of 75**	**%age**
5	Comprehensiveness of the Framework	Face Validity	74	98.66
4	Presentation of the Framework	Face Validity	75	100.00
3	Confidence on the development methodology	Confidence on the Framework contents	74	98.66
2	Preferred area(s) of implementation	For further research	Performance evaluation, training needs analysis, recruitment (72)	96.00
1	Support of generic Framework	Specific industry supports the idea of a generic Framework or not	74	98.66

appropriate presentation of the framework related to generic competencies specifically in the textile sector. Secondly, it gives professionals a better idea of what competencies they should look for when dealing with the human resource at various stages. Hence, the findings will help improve professional development opportunities essential for overcoming the perceived deficiency in human resource management areas.

These findings could further be verified in settings like other industries or trades, larger geography, more diverse and assorted groups.

This study limits the validation to face and content; further research can validate the framework while applying to areas of human resource management for example, recruitment, performance evaluation, career development, training needs identification, promotion and deployment.

REFERENCES

[1] Sebastian, C.I., et al., *Comparative analysis of small and medium enterprises organizational performance in clothing industry*, In: Industria Textila, 2017, 68, 2, 156–162, https://doi.org/10.35530/IT.068.02.1305

[2] Tripathi, K., Agrawal, M., *Competency Based Management in Organizational Context: A Literature Review.*, In: Global Journal of Finance and Management, 2014, 6, 4, 349–356

[3] Chouhan, V.S., Srivastava, S., *Understanding Competencies and Competency Modeling – A Literature Survey*, In: IOSR Journal of Business and Management, 2014, 16, 1, 14–22

[4] Parry, S.B., *The quest for competencies. Training*, 1996, 33, 7, 48–54

[5] Girneata, A., et al., *Performance management practices in Romanian textile and clothing companies*, In: Industria Textila, 2015, 66, 2, 108–113

[6] Stevens, A., *Critical Review of the Science and Practice of Competency Modeling*, In: Human Resource Development Review, 2013, 12, 1, 86–107

[7] Suhairom, N., et al., *The development of competency model and instrument for competency measurement: The research methods*, In: Procedia – Social and Behavioral Sciences, 2014, 152, 1300–1308

[8] Garavan, T., McGuire, D., *Competencies and Workplace Learning: Some Reflection on the Rhetoric and the Reality*, In: Journal of Workplace Learning, 2001, 13, 4, 144–164

[9] Robson, R., Poltrack, J., *Using Competencies to Map Performance across Multiple Activities*, In: Interservice/Industry Training, Simulation and Education Conference, Orlando, Florida, 2017, 1–12

[10] Tay Chinyi, H., et al., *People Performance Competency Assessment – An Objective Psychometric Measure*, In: International Journal of Research in Business Management, 2017, 5, 4, 1–18

[11] Geoff, R., et al., *Development and Validation of a Customized Competency-Based Questionnaire*, In: Cross-Cultural Management, 2012, 19, 1, 90–103

[12] Tudor, L., *Change in Textile and Clothing Industry*, In: Industria Textila, 2018, 69, 1, 37–43, http://doi.org/10.35530/IT.069.01.1449

[13] Nastase, M., et al., *The specific elements of strategic human resources management for competitive business development*, In: Industria Textila, 2019, 70, 6, 579–586, http://doi.org/10.35530/IT.070.06.1749

[14] Lam Kim W., et al., *Evaluating the Face and Content Validity of an Instructional Technology Competency Instrument for University Lecturers in Malaysia*, In: International Journal of Academic Research in Business & Social Sciences, 2018, 8, 5, 367–385

[15] Israel, G.D., *Determining Sample Size*, PEOD6, Institute of Food and Agricultural Sciences (IFAS), University of Florida, 2003

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How does occupational stress affect individuals employed in textiles? An exploratory study from Pakistan

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ABSTRACT – REZUMAT

How does occupational stress affect individuals employed in textiles? An exploratory study from Pakistan

Occupational stress among the employees has become a major concern for the organizations without exemption for the textile and clothing industry, a major manufacturing industry of the developing countries. In Pakistan, it contributes 8.5% to the GDP and is a source of employment for 30% of the workforce. This research aims at exploring the effects of job stress amongst the individuals employed in textiles. For the purpose, data was collected from 1212 textile industry employees. Deployment of exploratory factor analysis (EFA) on the information collected resulted four stress impact factors, namely psychological, behavioural, performance and effectiveness, and physical. The factors described an overall accumulative variance of 60.87%, with psychological as the most significant, explaining 40% of the total. Results of this work disclose that how Occupational Stress affect the employees of textile and clothing industry. There is a need to understand the complexity of stress phenomenon so that the stress management intervention strategies could be designed and implemented accordingly. Findings of this research may be helpful in unfolding the complexity of stress phenomenon and these can be used as a guideline for the design and promotion of more acceptable and viable approaches or strategies for real-time benefits realization at individual and organizational level in terms of higher job satisfaction, motivation and productivity.

Keywords: *behavioural, effects, employees, exploratory factor analysis, job stress, performance and effectiveness, physical, psychological, textile industry*

Cum influențează stresul profesional persoanele angajate în domeniul textil? Un studiu explorator din Pakistan

Stresul profesional în rândul angajaților a devenit o preocupare majoră pentru organizațiile din industria textilă și de îmbrăcăminte, o industrie importantă în țările în curs de dezvoltare. În Pakistan, aceasta reprezintă 8,5% din PIB și o sursă de ocupare a forței de muncă pentru 30% din populație. Această cercetare vizează analiza influenței stresului la locul de muncă în rândul persoanelor angajate în industria textilă. În acest scop, au fost colectate date de la 1212 angajați din industria textilă. Implementarea analizei factorilor exploratori (EFA) asupra informațiilor colectate a avut ca rezultat patru factori de impact asupra stresului, și anume cel psihologic, cel comportamental, cel de performanță și eficiență și cel fizic. Factorii au descris o varianță cumulativă globală de 60,87%, factorul psihologic fiind cel mai semnificativ, cu 40% din total. Rezultatele acestei lucrări dezvăluie modul în care stresul profesional afectează angajații din industria textilă și de îmbrăcăminte. Este necesar să se înțeleagă complexitatea fenomenului, astfel încât strategiile de intervenție în gestionarea stresului să poată fi proiectate și implementate în consecință. Rezultatele acestei cercetări pot fi utile pentru a dezvolta complexitatea fenomenului și acestea pot fi folosite ca ghid pentru proiectarea și promovarea unor abordări sau strategii acceptabile și viabile, pentru realizarea beneficiilor în timp real la nivel individual și organizațional, în termeni de satisfacție profesională, motivație și productivitate.

Cuvinte-cheie*: comportamental, efecte, angajați, analiza factorilor exploratori, stresul la locul de muncă, performanță și eficiență, fizic, psihologic, industria textilă*

INTRODUCTION

There is no worldwide harmony upon the definition of stress. According to McEwen [1], "Stress is a word used to describe experiences that are challenging emotionally and physiologically". Opposing the vision of stress as a disturbing stimulus, other definitions give a sight into which organism are confronted and as to how stress is reacted by human being. Stress responses are constantly tracked by healing course of actions, which might be negotiated when stresses are dangerous, long-lasting, or unacquainted [2, 3]. For that reason, stressful occasions emerge to mount up from the beginning of life, and this collective hardship might have an intense effect on a broad spectrum of health upshots [4]. In the decade of 1980, occupational stress was recognized amongst the ten foremost occupational health issues in the United States and probable all through the Western developed countries. Thereupon, researchers started designing a prevention plan to deal with that was called a pandemic of stress [5]. It is a collectively agreed fact that effective use of HR is vital for the successful accomplishment of organizational objectives in terms of optimized work performance where human is the fundamental constituent of any system that controls executions throughout and ultimately responsible for achieving benefits in terms of repute of the organization, profit, productivity, quality etc. Organizational work performance is linked with stability of the human resource whose wellness is coupled with the effective occupational stress management [6]. Job-related stress is an international issue. In the year 2017–2018 in Great Britain, according to the HSE-2019 report cited by Ahmad et al., job-stress related infirmities were established as major reasons for 44% of the occupational ill-health cases which lost around 57% working days [7, 8]. In a study on the textile industry employees, 70% reported in the range of moderate through severe stress levels [7] while 86% in another study which was carried only on the managers [9]. Addressing stress related issue of the employees of any organization is vital. This research aims at investigating the effects or impacts of job-related stress amongst the individuals employed in textiles at Pakistan.

The textile and clothing industry is considered as the biggest export-oriented manufacturing sector of Pakistan. The textile industry is believed to be very acute and central player in the country's economy. This sector gives 8.5% to the GDP and a source of employment to about 30% of 49 million workforce of the country. It adds up above 50% in the nation's entire out country sales. Within Asian countries, Pakistan is fourth largest cotton producer and the 8th leading exporter of textiles [10]. Like other sectors, competitiveness is considered as one of the main challenges being faced by the textile sector as well. In fact, effective and optimal use of the human resource is the fundamental variable that directly affects productivity and quality. In this respect, top management put high pressure on their employees which is likely to produce stress. Currently markets are becoming more competitive and globally well-connected where work stress is becoming a more prominent among the employees and its management is becoming more challenging.

LITERATURE REVIEW

Occupational stress is accepted as a real well-being problem for individuals, companies, and the society at large. It is clear that *WMSDs* (work-related musculoskeletal disorders) are the outcomes of the interface of manifold stressors linked with the work itself, the work organization, the work environment and other personal factors [11, 12]. It impacts the human body unfavourably and negatively affects the organizational and individual performance [13, 14]. Reduction in efficacy, capacity to work as per plans, enthusiasm; dearth of creativity, lack of compassion for the organization, and augmented happening of "perceived contract breach" are also among the consequences of stress [15–18]. Job stress linked with disagreement and intense work-load is substantiated to be considerably and adversely related with almost entire aspects of job satisfaction (career opportunities, physical environment, job enrichment, management style, job security and rewards) [19]. Subsistence of negative inter-relationship has been observed in-between workplace stress and the individuals' job performance [20]. As far as the well-being of the employees is concerned, job-stress is an established issue for the stakeholders. As stress affects all the organizational functions, hereafter proper deliberation is needed for its prevention and control [21].

Stress is a complex phenomenon so it is imperative to comprehend all of its acquaintances. The earlier stress-related reviews mainly speak about medical services, sports, teaching, and occupations in general [15, 22–24]. The stress-related literature pertaining to the textile industry is scarce, even the literature to play with does not wrap up the entire sector [25]. Moreover, as mentioned earlier that little emphasis has been given to explore stress phenomenon in industrial environments in detail especially textile sector organizations of developing countries like Pakistan where deployment of efficient research activities is indispensable [26]. Keeping in mind the complexity of the stress and its management, in this article, we have tried to address a very important question that how stress impacts the individuals as far as their psychological; behavioural; physical; and performance and effectiveness conditions are concerned. In this way, this research attempts to further unfold work stress phenomenon that can help in developing a better understanding of the process and how it is linked with different demographic variables so that more logical and effective intervention mechanisms could be designed and implemented.

MATERIALS AND METHODS

In order to explore the occupational-stress effect factors among the employees of textile and clothing industry a self-designed research instrument was used to obtain the opinions of the subjects of the study. Thereafter, the data collected was analysed.

Study subjects

Overall, 1212 personnel were at random chosen for the data collection. The personnel positioned at all levels, in the four major sub-sectors of the textile and clothing industry, explicitly: fibre and fabric manufacturing (spinning and weaving); socks manufacturing; apparel manufacturing and home textiles, were chosen to take part in the poll. Data was collected from 23 diverse organizations. Employees of these organizations, irrespective of their gender were qualified to be the subjects of the study. For the purpose of collecting an overall perspective of the employees of textile organizations, personnel working at all levels of the organizations were selected for this study. All of them were from divergent branches of the companies under study.

Opinion poll

So as to reach the desired objectives of this cross-sectional study, data was gathered by making the use of a survey which was the collection of variables relating to the impacts of workplace stress. Prior to commencing the poll, well-prepared staff educated all the subjects about the intention behind the activity, structure of the poll and how to record their responses. While filling the survey, the trained research staff remained reachable to answer back the questions of participants. Also, every review was instantly ensured for missing information and the subjects were insisted for the same. Respondents were informed as the surveys are anonymous and no specific information will be shared with anyone at any stage of the research and the information will be used only for research purpose.

Instrument

A self-designed Instrument was used to attain the study objective. It is the part of the instrument designed for a big research project, though its development is not the purview of this study, and has been used by authors [27]. It was composed of 22 items framed to explore the effects of workplace stress on the individuals belonging to manufacturing sector organizations. The opinions of the respondents were taken on a 5-point Likert type scale ranging between 1 (signifying no impact) and 5 (signifying high impact): 5 = Always, 4 = Often, 3 = Sometimes, 2 = Seldom, 1 = Never. The respondents were required to opt for any number of the scale as a response and the responses were then summed to calculate the impact score; where higher scores indicated higher impact and vice versa. Assertions were typically like: I suffer from *frequent depression*. The instrument was instituted as the most consistent as had the Cronbach's alpha value 0.924.

Statistical procedures

Descriptive analyses besides Exploratory Factor Analysis (EFA) utilizing Principal Component Analysis as the Extraction Method and Oblimin with Kaiser Normalization as the Rotation Method were used to ascertain the effects of stress. EFA has been widely used by the researchers in exploring a set of latent constructs underlying a series of calculated variables, for example, Bayraktar et al. used in case of employee involvement and rewarding [28–32]. Before doing this, validation of the appropriateness of EFA as an exploratory tool was determined by employing Bartlett's test of sphericity in addition to the KMO (Kaiser-Meyer-Olkin) measure of sampling adequacy. After identification of the factors, their reliability was determined by means of computing the Cronbach alpha coefficient [33]. Furthermore, two descriptive statistics, arithmetic means, and standard deviations were calculated for each factor. The response score of individual items for each point of the Likert scale was aggregated to determine a summary score. SPSS version 23.0, for Windows, was employed to generate the results of the study.

RESULTS AND DISCUSSION

Exploratory Factor Analysis

Prior to deploying EFA, sample adequacy for the factor analysis of the information gathered for identification of the effects of occupational stress was assessed through the KMO measure of sample adequacy and Bartlett's test of sphericity. Bartlett's test of sphericity provided a value of zero that is acceptable as it's less than 0.05 while the KMO test shows value 0.946 which is also acceptable (table 1). The quality of the correlation among the variables has been concluded strong and hence data is appropriate for multivariate investigations such as factor analysis.

Table 1

KMO AND BARTLETT'S TEST		
Indicator		**Value**
Kaiser-Meyer-Olkin Measure of Sampling Adequacy		0.946
Bartlett's Test of Sphericity	Approx. Chi-Square	11296.647
	df	231
	Sig.	0.000

After employing Principal Component Analysis as an extraction method; rotating the component matrix by employing Oblimin with Kaiser Normalization and utilizing the factors' retention principle based on the Eigen value where the factors having value greater than 1 are to be retained, four factors were identified (table 2). Scree plot criterion recommended for retention of the factors also confirmed 4 factors (figure 1).

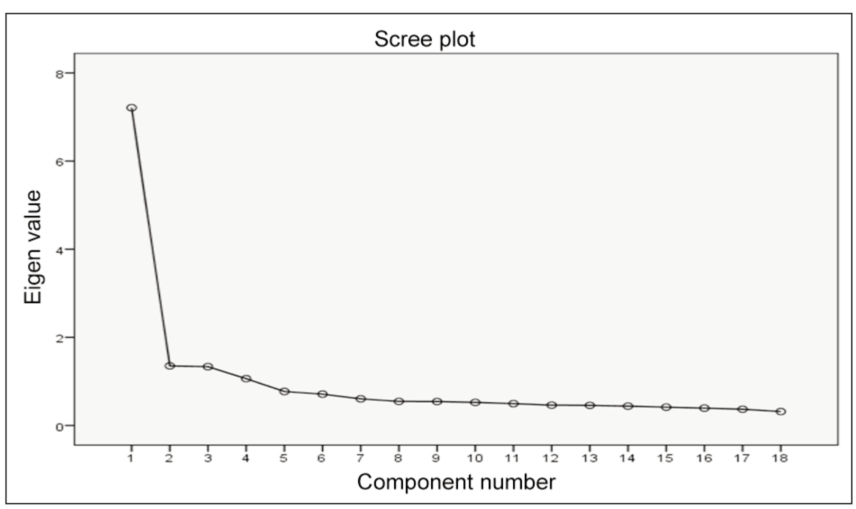

Fig. 1. Scree Plot (N=1212)

Table 2

EXPLORATORY FACTOR ANALYSIS			
Item description (Eigen values; variance proportion; Cronbach's alpha; mean ± SD)		**Factor loading**	**Mean (SD)**
Factor 1: Psychological (7.21; 40.08%; 0.87; 1.88 ± 0.74)			
1	I suffer from frequent depression	0.811	1.8 (1.0)
2	I often suffer from sleeplessness	0.806	2.0 (1.0)
3	I used to avoid people	0.803	1.9 (0.9)
4	I often suffer from anger/ hostility	0.706	1.9 (1.0)
5	I have had dizzy spells	0.697	1.7 (0.9)
6	I experience worsening relations with colleagues, family and friends	0.654	1.9 (1.0)
7	I often suffer from anxiety	0.591	2.0 (1.0)
Factor 2: Performance and Effectiveness (1.35; 7.52%; 0.79; 2.15 ±/0.81)			
1	My judgment is clouded or not as good as it was	0.846	2.2 (1.0)
2	I am ineffective in resolving family issues	0.775	2.0 (1.0)
3	Often, I am unable to complete the task as per schedule	0.762	2.2 (1.0)
4	Usually, I am unable to do all the things in a day that I must do	0.678	2.2 (1.1)
Factor 3: Behavioural (1.33; 7.35%; 0.75; 2.26 ±/±0.87)			
1	I have become short tempered	0.862	2.4 (1.1)
2	I become very frustrated at having to wait in a queue	0.835	2.3 (1.1)
3	I experience mood swings	0.491	2.1 (1.0)
Factor 4: Physical Effects (1.06; 5.92%; 0.77; 2.15 ±/0.76)			
1	I have headaches	–0.806	2.1 (0.9)
2	I have felt tired	–0.802	2.4 (1.0)
3	I get tension or muscle spasms/pains in my face, jaw, neck, chest, head, lower back or shoulders	–0.724	2.0 (1.0)
4	I lack physical energy	–0.629	2.0 (1.0)

The items which did not load onto a specific factor with an item loading of 0.30 or greater were not taken. Altogether, there were 18 items which meet the criteria. These four factors explain variation of 60.87% which is more than the requisite value of 60% variance. In the subsequent paragraphs, further details of the factors selected have been described.

Factor 1: Seven items laden on the factor where all speaks about the psychological impact thus the factor is termed as *Psychological*. All the items loaded well on the factor while three loaded heavily, above 0.80. It is an important factor as more than half of the entire variance (40.088%) is explained by this only component or factor. Nevertheless, mean of the component on the 5-point Likert type scale is 1.88 with standard deviation 0.74 (table 2).

Factor 2: Four variables subsist into the factor and all of them have significant loading. Since all the variables attributes to the impact of work-stress on the performance and effectiveness of the personnel, so the factor is termed as *Performance and Effectiveness*. As shown in table 2, factor mean is 2.15 with a standard deviation 0.81.

Factor 3: The factor 3 is emerged by the variance derivation of three variables on the factor having factor mean as 2.26 with standard deviation 0.87. All the variables speak about the behavioural effects of stress so termed as *Behavioural* (table 2).

Factor 4: Four variables describe factor 4 and each is heavily loaded (table 2). As each relates to the physical impact on the individuals and hence the factor is titled as *Physical*. The factor mean is 2.15 with standard deviation 0.76 (table 2).

Reliability

Table 2 also shows statistics for the Cronbach alpha coefficient of every factor. Factor 1 has the highest reliability coefficient value (0.873) and all the remaining factors have values greater than 0.70 representing good reliability levels and distinctive evenness [33]. The reliability coefficients are in agreement with other studies available in the literature [34].

Correlations among the components

The component correlation matrix shown in table 3 depicts that inter correlation among the factors emerged from deployment of EFA. It is obvious that the correlations are beyond 0.5 except two which are slightly above 0.5. It depicts that each component explores distinctive aspects.

Previous stress related literature mainly pertains to other sectors and is rare on textile industry. Even the available does not cover the sector as whole [25]. In the areas other than textile, for example, fatigue, loss of focus, occupational lake of interest, obstruction of alertness, and monotony were found as effects of stress in radiographers at Ghana, [35]. A study on the shift workers found adverse effects on employees' mental health and mood states [36]. Rapid turn down in global cognition came out as the effect of severe stress among older African Americans [37]. Evidently, numerous studies, in the past, were conducted to on stress. Though, very little work is found about the potential effects of stress at work and particularly in textiles. The present study focuses on a single sector where attempt has been made to find out the stress impact factors in textile industry by capturing a broader perspective by covering almost all types of textile organizations, explicitly fiber and fabric manufacturer, socks manufacturer, apparel manufacturer, and home textiles.

Table 3

CORRELATION MATRIX				
Factors	**1**	**2**	**3**	**4**
Psychological	1.000			
Performance and effectiveness	0.533	1.000		
Behavioural	0.413	0.325	1.000	
Physical effects	–0.516	–0.476	-0.394	1.000

CONCLUSIONS

This research aims at capturing an insight of job stress phenomenon in terms of its effects. Deployment of EFA for finding effects of job stress concluded four factors: *Psychological, Performance and Effectiveness, Behavioural* and *Physical* as key effect areas. Factors described a 60.87% total variance where *Psychological factor* happened to be the most significant factor in terms of variance explained. However, more employees have reported having behavioural impact followed by physical; and performance and effectiveness impacts. Health outcomes, namely anxiety, depression were identified as the effects of stress in RMG at Bangladesh [25]. Both the symptoms relate to the *Psychological* factor, the most significant factor explored in the current examination. The situation is much worrying and needs intercessions. This article contributes a comprehensive and prioritized list of factors pertaining to the effects of job stress among the individuals employed in textiles. Findings of this work further highlight that work stress is a multifarious phenomenon which is subjective to number of internal as well as external factors; so before devising some control or prevention strategies, it should be investigated appropriately at some earlier stage so that effectiveness of the interventions might be enhanced. Findings of this work can be used by the stakeholders in devising interventions which, apart from controlling the phenomenon, may lessen its effects on the individuals. For instance, here *Psychological* has been emerged as the most significant effect so the strategies can target this particular factor. In short, the strategies can be 'findings specific'. Future work might be done on finding the relationship between different causes of job stress and how a particular cause is linked with a specific effect. This will help in developing and applying stress controlling strategies in a more logical and realistic way so that their effectiveness might be increased. Such kind of studies can further help in understanding the phenomenon that can ultimately leads towards the development of more realistic intervention models. In this way, challenges like human variability, diversity and socio-technical complexities of modern working systems can be addressed in a better way.

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REFERENCES

[1] McEwen, B., *Physiology and neurobiology of stress and adaptation: central role of the brain*, In: Physiological Reviews, 2007, 87, 3, 873–904

[2] Koolhaas, J., Bartolomucci, A., Buwalda, B., et al., *Stress revisited: a critical evaluation of the stress concept*, In: Neuroscience and Biobehavioral Reviews, 2011, 35, 5, 1291–1301

[3] Stults-Kolehmainen, M., Bartholomew, J., *Psychological stress impairs short-term muscular recovery from resistance exercise,* In: Medicine and Science in Sports and Exercise, 2012, 44, 11, 2220–2227

[4] Miller, G., Chen, E., Cole, S., *Health psychology: developing biologically plausible models linking the social world and physical health,* In: Annual Review of Psychology, 2009, 60, 501–524

[5] Sauter, S., Murphy, L., Hurrell, J., *Prevention of work-related psychological disorders: A national strategy proposed by the National Institute for Occupational Safety and Health (NIOSH),* In: American Psychologist, 1990, 45, 1146–1158, http://doi.org/10.1037/0003-066X.45.10.1146

[6] Quick, J., Henderson, D., *Occupational Stress: Preventing Suffering, Enhancing Wellbeing,* In: International Journal of Environmental Research and Public Health, 2016, 13, 5, 459, http://doi.org/10.3390%2Fijerph13050459

[7] Ahamd, A., et al., *Perceived stress: role and levels of demographics – a cross-sectional study of textile industry employees,* In: Industria Textila, 2020, 71, 2, 180–185, http://doi.org/10.35530/IT.071.02.1643

[8] Ahmad, A., et al., *Do Demographic Factors Affect Work-stress? A Case Study of Textile and Clothing Industry in Pakistan*, In: Pakistan Journal of Agriculture Sciences, 2021, 58, 1, 307–313, https://doi.org/10.21162/PAKJAS/21.597

[9] Ahmad, A., et al., *Workplace Stress Assessment among Managers of Textile Industries at Developing Countries: A Case Study from Pakistan,* In: Advances in Human Factors, Business Management and Leadership, AHFE 2017, Springer, Cham, 2018, 594, 382–391

[10] Simion, C.-P., et al., *Economic and IT determinants of innovative projects in the textiles, wearing apparel, leather and related products industry*, In: Industria Textila, 2018, 69, 4, 338–344, http://doi.org/10.35530/IT.069.04.1478

[11] Ahmad, A. et al., *Investigation of Ergonomic Working Conditions of Sewing and Cutting Machine Operators of Garment Manufacturing Industry*, In: Industria Textila, 2021, 72, 3, 309–314, http://doi.org/10.35530/IT.072.03.1723
[12] Sharma, R., Singh, R., *Work-related musculoskeletal disorders, job stressors and gender responses in foundry industry,* In: International Journal of Occupational Safety and Ergonomics, 2014, 20, 2, 363–373
[13] Tucker, M., Jimmieson, L., Nerina L., Oei, T.P., *The relevance of shared experiences: A multi-level study of collective efficacy as a moderator of job control in the stressor-strain relationship*, In: Work & Stress: An International Journal of Work, Health and Organizations, 2013, 27, 1, 1–21
[14] Senaratne, S., Rasagopalasingam, V., *The causes and effects of work stress in construction project managers: the case in Sri Lanka,* In: International Journal of Construction Management, 2017, 17, 1, 65–75
[15] Adriaenssens, J., Veronique, D., Maes, S., *Causes and consequences of occupational stress in emergency nurses, a longitudinal study,* In: Journal of Nursing Management, 2015, 23, 3, 346–382
[16] Bridger, R., Day, A., Mortan, K., *Occupational stress and employees turnover,* In: Ergonomics, 2013, 56, 11, 1629–1639
[17] Choi, S., Lee, J., Park, H., *The effects of Psychological problems in employees' stress, self-esteem, and organizational commitment: the case of South Korean workplaces*, In: Journal of Workplace Behavioural Health, 2015, 30, 1, 2, 179–190
[18] Xavier, I., Jepsen, D., *The Impact of Specific Job Stressors on Psychological Contract Breach and Violation,* In: Human Factors and Ergonomics in Manufacturing & Service Industries, 2015, 25, 5, 534–547
[19] Trivellas, P., Panagiotis, R., Charalambos Platis, C., *The effect of job related stress on employees' satisfaction: A survey in Health Care*, In: Procedia – Social and Behavioral Sciences, Budapest , 2013, 73, 718, 2013, 718–726
[20] Kakkos, N., Trivellas, P., *Investigating the link between motivation, work stress and job performance. Evidence from the banking industry.* In: 8th International Conference on Enterprise Systems, Accounting and Logestic (8th ICESAL, '11), 2017, Thassos, 408–428
[21] Brown, Z., Uehara, D., *Coping with teacher stress: A research synthesis for Pacific Resources for Education and learning,* 2009, Available at: http://www.prel.org/products/ [Accessed on January 2020]
[22] Kizhakkeveettil, A., et al., *Perceived stress and fatigue among students in a doctor of chiropractic training program,* In: Journal of Chiropractic Education, 2017, 31, 8–13
[23] Pettit, M., DeBarr, K., *Perceived Stress, Energy Drink Consumption, and Academic Performance Among College Students,* In: Journal of American College Health, 2011, 59, 335–341
[24] Baka, Ł., Bazińska, R., *Polish adaptation of three self-report measures of job stressors: the Interpersonal Conflict at Work Scale, the Quantitative Workload Inventory and the Organizational Constraints Scale*, In: International Journal of Occupational Safety and Ergonomics, 2016, 22, 1, 32–39
[25] Steinisch, M., et al., *Work stress: Its components and its association with self-reported health outcomes in a garment factory in Bangladesh – Findings from a cross-sectional study*, In: Health & Place, 2013, 24, 123–130
[26] Kanat, S., et al., *SWOT analysis of Pakistan's textile and clothing industry,* In: Industria Textila, 2018, 69, 502–510, http://doi.org/10.35530/IT.069.06.1488
[27] Ahmad, A., et al., *Effects of Workplace Stress on Managers of Textile Industries of Developing Countries: A Case Study from Pakistan,* In: Advances in Human Factors, Business Management and Society, AHFE 2018, Advances in Intelligent Systems and Computing, Springer, Cham, 2019, 783, 500–507
[28] Ahmad, A., Hussain, A., Ahmad, Q.W., Islam, B.U., *Causes of Workplace Stress in Textile Industry of Developing Countries: A Case Study from Pakistan*, In: Goossens R. (eds) Advances in Social & Occupational Ergonomics. Advances in Intelligent Systems and Computing, Springer, Cham, 2017, 487, 283–294
[29] Ahmad, A. et al., *Impacts of Workplace Stress: An Exploratory Cross-Sectional Study of Oil and Gas Sector in Pakistan*, In: Sukkur IBA Journal of Management and Business, 2021, 8, 1, 70–79
[30] Ahmad, A., et al., *Quantifying the Consequences of Perceived Stress in the Textile & Clothing Sector through Structural Equation Modeling*, In: Mathematical Problems in Engineering, 2021, 2021, 5597111, https://doi.org/10.1155/ 2021/5597111
[31] Bayraktar, C., Araci, O., Karacay, G, Calisir, F., *The mediating effect of rewarding on the relationship between employee involvement and job satisfaction,* In: Human Factors and Ergonomics in Manufacturing and Service Industries, 2017, 27, 45–52
[32] Ahmad, A., Hussain, A., Mughal, M., Mufti, N., Saleem, M., *Path Analysis of the Antecedents and Occupational Stress Among the Managers of the Textile Industries: A Cross-Sectional Study from Pakistan Using PLS-SEM,* In: Advances in Social and Occupational Ergonomics, Proceedings of the AHFE 2019 International Conference on Social and Occupational Ergonomics, Goossens R.H.M. and Murata A. ed., Springer, Cham, 2020, 480–490
[33] Field, A., *Discovering Statistics Using SPSS*, 2nd ed., Sage Publications, London, 2005
[34] Jackson, L., Rothmann, S., *An Adapted Model of Burnout for Teachers in South Africa,* In: South African Journal of Education, 2005, 25, 2, 100–108,
[35] Ashong, G.G.N.A., et al., *Effects of occupational stress and coping mechanisms adopted by radiographers in Ghana,* In: Radiography, 2015, 22, 2, 112–117, http://dx.doi.org/10.1016/j.radi.2015.09.002
[36] Srivastava, U., *Shift Work Related to Stress, Health and Mood States: A Study of Dairy Workers,* In: Journal of Health Management, 2010, 12, 2, 173–200
[37] Turner, A., James, B., Capuano, A., Aggarwal, N., *Perceived stress and cognitive decline in different cognitive domains in a cohort of older African Americans*, In: The American Journal of Geriatric Psychiatry, 2016, 25, 1, http://doi.org/10.1016/ j.jagp.2016.10.003

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Textile prostheses in abdominal and pelvic surgery

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ABSTRACT – REZUMAT

Textile prostheses in abdominal and pelvic surgery

Textile prostheses have been used in abdominal surgery since ancient times. Industrial development of the last one hundred years changed it from simple cloth to highly improved materials that are better integrated and provide superior functional outcomes.

Understanding of the physicochemical properties of surgical meshes is essential for the rational choice of the optimal device. This needs to be closely adapted to mechanical and biological conditions of the anatomical region that will be placed in. The quality of the materials and the manufacturing technique are also of great importance, influencing both the mechanical parameters and the integration of the prosthetic material. Although a hard-to-reach concept, the ideal mesh should have high porosity, a monofilamentous structure and it should be composed of durable, non-carcinogenic, non-allergenic, and highly biocompatible materials. These qualities will ensure a good integration of the prosthesis and will make it easy to handle intraoperatively, resulting in a satisfactory clinical outcome.

Based on the above considerations, this article aims to bring to light useful manufacturing information regarding textile prostheses used in surgical reconstructions, in order to support surgeons in making the correct and rational choice of the prosthetic material, based on its physicochemical properties, thus avoiding postoperative complications.

Textile implants apply to various surgical fields such as abdominal or thoracic wall reconstruction, visceral defect repair, pelvic floor stabilization or tissue replacement.

Postoperative complications of mesh use include chronic pain, infection, ulceration of the wound, adhesion formation, intestinal obstruction, recurrence of parietal defect, rejection of the prosthesis, and mesh granuloma.

Keywords: *surgical mesh, hernia, transobturatory tape procedure, mechanical properties, structural parameters*

Protezele textile în chirurgia abdominală și pelviană

Protezele textile au fost utilizate în chirurgia abdominală încă din cele mai vechi timpuri. Dezvoltarea industrială din ultimii o sută de ani a schimbat proteza textilă de la o simplă pânză la materiale extrem îmbunătățite, care sunt mai bine integrate și oferă rezultate funcționale superioare.

Înțelegerea proprietăților fizico-chimice ale plaselor chirurgicale este esențială pentru alegerea rațională a dispozitivului optim. Acest lucru trebuie adaptat îndeaproape la condițiile mecanice și biologice ale regiunii anatomice în care va fi plasat. Calitatea materialelor și tehnica de fabricație sunt, de asemenea, de o mare importanță, influențând atât parametrii mecanici, cât și integrarea materialului protetic. Deși este un concept greu accesibil, plasa chirurgicală ideală ar trebui să aibă o porozitate ridicată, o structură monofilamentară și ar trebui să fie compusă din materiale durabile, non-cancerigene, non-alergenice și extrem de biocompatibile. Aceste calități vor asigura o bună integrare a protezei și vor facilita manipularea intraoperatorie, cu un rezultat clinic satisfăcător.

Pe baza considerațiilor de mai sus, acest articol își propune să aducă la lumină informații utile de fabricație privind protezele textile utilizate în reconstrucțiile chirurgicale, pentru a sprijini chirurgii în alegerea corectă și rațională a materialului protetic, pe baza proprietăților sale fizico-chimice, evitând astfel complicațiile postoperatorii.

Implanturile textile se aplică în diverse domenii chirurgicale, cum ar fi reconstrucția peretelui abdominal sau toracic, repararea defectelor viscerale, stabilizarea planșeului pelvin sau înlocuirea țesuturilor.

Complicațiile postoperatorii ale utilizării plaselor includ durerea cronică, infecția, ulcerația plăgii, formarea aderențelor, obstrucția intestinală, recurența defectului parietal, respingerea plasei și granulomul de fir.

Cuvinte-cheie: *plasă chirurgicală, hernie, procedeul benzii transobturatoare, proprietăți mecanice, parametri structurali*

INTRODUCTION

Reconstructive surgery for inguinal hernias is one of the most frequent surgeries involving textile prosthesis (meshes). Hernia has been first mentioned in history in the 16th century BC, when recognized by Praxagoras of Kos as surgical pathology which needed immediate treatment [1]. As Hippocrates reveals, traces of textile materials sutured with golden threads were found in Egyptian sarcophaguses.

Subsequently, there were used silver filigrees, representing the first mesh created by the ancient Greeks

[2]. The term “prosthesis” actually comes from the ancient Greek *prostíthēmi,* as *prós* means “*near*” or “*attached*v and *títhēmi* means “*to place*” [3].
Theodore Billroth, a pioneer in modern prosthesis production, suggested, in 1890, that textile materials were the solution for parietal defects. Many types of materials were used over time, but each of them failed as complications or recurrences occurred, amplifying the bias linked to surgical meshes. In 1995, Francis Usher turned his attention to synthetic materials as Nylon, Orlon acrylic fibres, Dacron or Teflon, which could solve issues related to complications or recurrences, but had their own inconveniences. Afterwards, he used polymeric materials and created woven meshes initially, then knitted, which proved remarkable qualities. In 1958, he published his own surgical technique using a polypropylene mesh and 30 years later the procedure became very popular as “tension-free” mesh surgical repair, known until today as Lichtenstein procedure.
A meta-analysis of 58 randomized trials, performed in 2002, proved the superiority of surgical meshes over other tissue repair procedures used in hernia treatment, regarding the recurrence rate (2.7% vs. 8.2% in ventral hernias and a 50% to 75% decrease in inguinal hernias recurrences) [4].
Nowadays, over 200 types of textile meshes are available worldwide for tissue reinforcement surgeries of the abdominal wall, pelvic floor, diaphragm, or thoracic wall [5]. A correct and rational choice of the optimal textile prostheses in abdominal and pelvic surgery is of great importance in reducing, as much as possible, the risk of postoperative complications and poor clinical outcome.

CLASSIFICATION OF SURGICAL MESHES

Surgical meshes can be classified by the type, properties, and structure of the fibres that compose them. Depending on the fibre type, meshes may be: **biological** (acellular collagen matrix from human, bovine or porcine dermis, bovine pericardium or porcine intestinal submucosa) or **synthetic**, which, in turn, may be polymer (polypropylene – PP, polytetrafluoroethylene – PTFE, including the expanded form ePTFE, polyester, polyethylene terephthalate – PET, polyvinylidene fluoride – PVDF, polylactide – PLA, polyglycolic acid – PGA, polycaprolactone – PCL, polydioxanone – PDO, monocryl, hyaluronate), metallic (titanium) or composite (multiple layers of combined materials).
Regarding fibre properties, there are **absorbable** or **non-absorbable** meshes.
According to the fibre structure, implantable textiles could be **monofilament** or **multifilament**.
Another classification criterion is porosity. Consequently, meshes are **micro-porous, macroporous** or **submicron.**
Finally, based on their density (weight), meshes may be **ultra-lightweight** (< 35 g/m^2), **light-weight** (35–69 g/m^2), **standard** (70–139 g/m^2) or **heavyweight** (≥ 140 g/m^2) [2, 6–8].

PROSTHETIC MATERIAL INTEGRATION

Any prosthetic material implantation is rapidly followed by a complex series of events that mark the beginning of tissue healing. This process occurs in 3 successive stages: inflammation, cellular proliferation, and tissue remodelling.
After implantation, the prosthetic material absorbs proteins, creating a coagulum that contains albumin, fibrinogen, plasminogen, complement factors, immunoglobulin. The next stage is platelet aggregation and degranulation, with release of chemotactic factors that will recruit neutrophils (thus starting the acute inflammation process), monocytes, T lymphocytes, fibroblasts. The primary role of neutrophils is to destroy bacteria and cellular debris. Also, cytokines are released and play a role in angiogenesis and collagen synthesis. After PMN cells destruction, components that act like mediators and sustain inflammatory process are released on the surface of the implanted material [9].
Proliferation stage (days 4 to 12) is characterized by granulation tissue formation. During this stage, fibroblasts recruited by the chemotactic factors proliferate. Components of the extracellular matrix are synthesized and contribute to the structural integrity of the conjunctive tissue. Stimulated by the chemokines and by the growth factors, endothelial cells proliferate, migrate, and take part in the angiogenesis process. Angiogenesis requires ATP, oxygen and nutrients and is an essential stage in the tissue healing process. Regarding the prosthetic material-tissue interaction, three histological aspects are of major importance: the extent of tissue reaction, cellular density, and fibroblast activity. The optimum quantity of fibroblasts required for an adequate healing is reached 2 weeks after contact (aggression).
Additional recruitment of fibroblasts leads to inflammation with associated fibrosis and more rapid integration of the prosthetic material. As a result, pain and paresthesia may occur. The inflammatory process may lead to adhesions and subsequent fistulas [9].
The last stage of tissue healing consists in extracellular matrix reorganization. The thin fibres of immature collagen thicken and reorganize, transforming into mature type 1 collagen. Myofibroblasts reduce in size and produce tissue shrinkage, to reduce collagen deposition. The retraction is accentuated by cross-linking of the collagen fibres. There is a constant turnover of collagen in the extracellular matrix, both at the level of the tissues undergoing healing and during the normal tissue homeostasis, which is ensured by the balance between collagen production and its degradation, under the action of collagenase, a metalloproteinase whose activation is controlled by cytokines and growth factors. This balance is the ultimate determinant of tissue integrity and resistance [9].

Prosthetic material integration is a progressive process. It starts with the first stage of the tissue healing process. Tissue resistance increases during the maturation and remodelling stages (may last up to 12 months). The result is a rigid tissue with 70–80% of the initial structure's elasticity [9].

Latest research on parietal defects brought valuable information regarding the structural and functional parameters of surgical meshes that may influence the immune response or may reduce fibrosis.

PHYSICOCHEMICAL PROPERTIES

The quality of the implanted material has an impact on the benefit-risk balance of the surgery [5]. Understanding of the physicochemical properties of surgical meshes is essential for the rational choice of the optimal device [10].

Mechanical parameters

Tensile strength

Tensile strength is the maximum force that can be applied to a mesh, without causing it to deteriorate or break, accidents that could lead to an unsatisfactory clinical outcome or complications such as recurrence. Thus, the material from which the mesh is constructed must withstand the maximum tension that can be generated at the level of the abdominal wall. This was measured in multiple studies, having individual variations and depending on the anatomical region (maximum 39 N/cm at the white line, 28 N/cm in the transverse direction, or 16 N/cm in the groin region [11–14].

Elasticity

Elasticity is the property of a material to return to its original shape and dimension, following the deformation produced by force acting on it.

The use of meshes for the surgical treatment of incisional hernias increases the parietal elasticity, thus decreasing the recurrence rate. At tensile strength of 16 N/cm, light meshes develop elasticity of 20–35%, while heavy meshes reach halved values (4–15%). At the same time, using a mesh with improper tension can lead to a change in its elasticity, having an impact on the functional results, as well as generating complications such as pain, prolapse or recurrence, the latter being more frequent at the edges of the mesh [15, 16].

Structural parameters

Porosity

Porosity is the main determinant of tissue reaction to implanted material [6]. Cellular and bacterial proliferation depends to a large extent on the porosity, both in terms of pore size and their shape change, occurring through the tensioning of the mesh, having, along with the mechanical, structural or mesh size characteristics, a major influence on its integration [15]. Porosity is generally defined as the percentage of the mesh not covered by filaments. This notion defines the "textile" porosity, while the effective porosity, a term introduced by Muhl et al., is represented by the percentage of the mesh not covered by the fibrous bridges (formed by the confluence of the granulomas) and is ensured by keeping a minimum inter-filament distance. Studies showed that macroporous meshes with PTFE coating were correlated with the lowest rate of inflammatory response, while micro-porous meshes exhibited a larger inflammatory response and were more frequently associated with complications such as infection or pain [17].

Multiple classification attempts have resulted from the difficulty of establishing the ideal size of the pores, as this is influenced by the type of the composing fibres, but also by the pore geometry [15, 18, 19]. Macro-porous meshes develop inflammatory reaction, fistulas, calcification of small magnitude compared to micro-porous ones and will have better flexibility, by avoiding the formation of fibrosis bridges. Micro-porous polypropylene meshes, are more susceptible to bridging, leading to encapsulation of the prosthetic material, resulting in a flat, rigid scar. Also, the pore geometry can have an impact on the integration of the meshes, the hexagonal pores demonstrating the best tissue impregnation, followed by the square and the rhomboid ones [20].

Density (weight)

The density of the prosthetic material depends on the weight and quantity of fibres from which it is manufactured. Heavy meshes (generally > 100 g/m^2) are made of thick polymeric fibres, are micro-porous and have high tension, while light meshes contain thinner filaments, have large pores (> 1 mm) and, therefore, a small amount of material, resulting in a low-intensity foreign body reaction, with higher mesh integration and fewer complications [2]. Light meshes are also more elastic and the new generation of ultra-light composite (titanium/polypropylene) meshes offers faster post-operative recovery, sometimes in exchange for reduced tensile strength (12 N/cm), in the case of the lightest ones in this category [6, 21].

Although it is generally considered an advantage, the low weight can also have shortcomings, the lightweight meshes being more elastic and flexible, which can create problems in their intra-operative handling. This may be solved by adding absorbable filaments that will increase the weight and, consequently, the manoeuvrability of the prosthetic material.

Composition

Synthetic meshes

The surgical meshes are made of monofilament or multifilament yarns. Monofilament yarns provide satisfactory support, but form a rigid and slightly foldable mesh. By contrast, the meshes made of multifilament yarn (twisted or braided) are softer and can be folded more easily, but they present a higher risk of infection, leading to the erosion of the mesh in 20–30% of cases. Bacterial adhesion and proliferation occur mainly in the small spaces (< 10 μm) between the yarns or between the filaments that compose the yarns [22].The fibres that form the mesh are, in turn, made of various materials, so that the meshes can be synthetic, biological or composite, absorbable or non-absorbable [1], the ultimate goal being to ensure the best biocompatibility, thus preventing complications such as recurrence of hernia, abdominal pain, infection or seroma formation [23]. The most commonly used non-absorbable synthetic materials are polypropylene, polyester and expanded polytetrafluoroethylene (ePTFE).

Polypropylene is a widely used polymer due to its special strength, comparable to that of steel. Available polypropylene meshes, single- or multi-filament, are either coated – for intra-peritoneal use, or uncoated – for extra-peritoneal mounting (figures 1 and 2). Both forms can cause complications, mainly due to the weight of the mesh. These consist of an intense inflammatory response, with the formation of thick scars and mesh shrinkage (up to 30–50%), which may eventually cause the recurrence of the hernia. Lately, in an attempt to prevent these shortcomings, ultra-light meshes have been created, which generate a less rigid abdominal wall-mesh complex, with greater mobility and significantly reduced pain [1]. In general, polypropylene is considered to be an inert material, stable and sufficiently resistant over time, offering a suitable service life *in vivo* [24].

Polyester meshes are multifilament meshes, made of PET, which can generate resistant fibres [1,2]. These meshes have advantages such as minimal adhesion, reduced stiffness and contraction or better integration and are available in multiple configurations for repair of inguinal, ventral or hiatal parietal defects, mainly by classical approach. In order to be intra-peritoneal mounted, these meshes are coated with collagen, which prevents adhesion to the intestines and complications occurrence. The multifilament nature of the fibres that compose them results in an increased susceptibility of these meshes to postoperative infections and fistulas. During infections, mesh degradation is accelerated, which may lead to recurrence of hernia. Regarding the inflammatory response generated, the adverse reactions or the complications occurrence rate, these are comparable to those of polypropylene meshes [1, 22].

ePTFE is used in the manufacture of micro-porous meshes, having disadvantages like: poor tissue integration, with encapsulation and possible parietal defect recurrence, or increased risk of infection – as small pores allow bacterial passage, but not that of macrophages, so that an infected encapsulated mesh will have to be explanted [2, 22]. Compared to PP and PET, ePTFE causes minimal inflammatory reaction and formation of scar tissue with comparable densities, which makes it suitable for intra-peritoneal use, allowing it to be placed in contact with viscera. However, it has low resistance, so it is important to be well fixed [1, 2].

Composite meshes

To prevent visceral adhesion, synthetic surgical meshes can be coated with absorbable or non-absorbable materials. Those are attached to the surface that will come in contact with the viscera, forming a protective barrier, which will diminish the inflammatory response. The substances used to create barrier layers can be: ePTFE, polyurethane, oxidized regenerated cellulose, omega-3 fatty acids, collagen or Beta-glucans.

Another method to reduce the tissue reaction is to use partially absorbable meshes, which reduce their density by up to 50% in up to 9 months after implantation. Reducing the amount of biomaterial leads to the reduction of inflammation and results in enlargement of the pores, facilitating the integration of the prosthesis [1, 24].

Also, to prevent complications, dual meshes can be used, which will benefit from the advantages of both materials. Those made of polyester and PTFE, having different chemical properties and porosity, will allow a good integration at the level of the abdominal wall, preventing visceral adhesion. Recently, dual meshes of polyester or polypropylene with temporary barriers were created, as, according to studies, visceral adhesions occur in the first postoperative week [1].

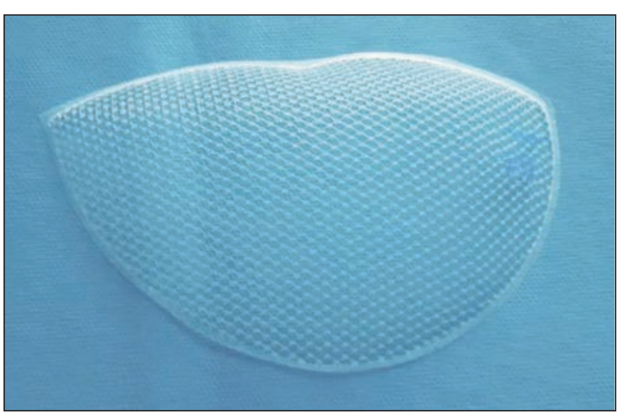

Fig. 1. Polypropylene mesh used in inguinal hernia repair. Courtesy of ‘‘Carol Davila’’ Central Military Emergency University Hospital, Department of General Surgery

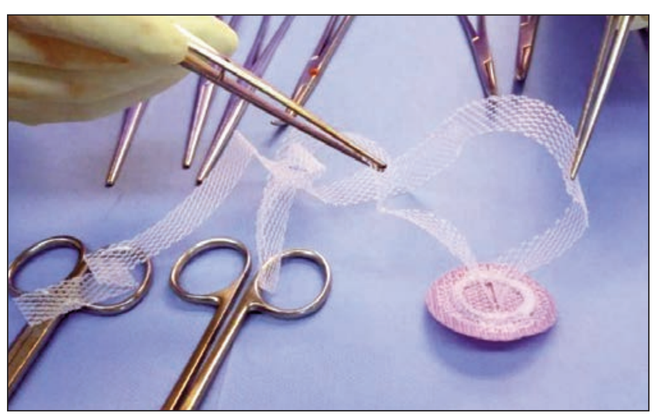

Fig. 2. Polypropylene mesh used in umbilical hernia repair. Courtesy of ‘‘Carol Davila’’ Central Military Emergency University Hospital, Department of General Surgery

Biological meshes

Hernia repair may be a major challenge in case of complex parietal defects, which require open surgery and which involve contamination or infection. In these circumstances, the use of a biological prosthesis may be considered, both at the time of closure per primam and at revision, in order to avoid further interventions in advanced stages, with high morbidity. Biological meshes have been successfully used in over 75% of the ventral defects repair, under contamination conditions, while, under aseptic conditions, the rates reach even 90% [2].

The biological materials are derived from human or porcine dermis, fetal tissue, bovine pericardium or porcine intestinal submucosa, tissues that are decellularized and will only have a supporting role, providing the collagenous matrix on which the future connective tissue will be attached. Removal of cellular components offers the advantage of eliminating the inflammatory response and immune-mediated rejection, while retaining structural and functional proteins, glycosaminoglycans, glycoproteins or growth factors, which will predominantly modulate the tissue healing response, disfavouring scar tissue formation. Biologic materials can also induce angiogenesis, being successfully used in contaminated interventions and having shown some degree of resistance to adhesion formation [4].

Although extremely promising for repair surgery, biological prostheses, however, have shortcomings such as low resistance of the newly formed connective tissue (70–80%), with high long-term recurrence rates, or the possibility, at least theoretically, of transmitting other diseases. All of these come at a relatively high cost, thus limiting their use [4].

Mesh manufacturing

Meshes can be woven or knitted. By bending the yarns, the latter form much more flexible and elastic structures than the woven ones, whose yarns have a unilateral orientation. Knitted meshes adapt more easily to the anatomical changes generated by the movement of the body, can generate higher tensile strengths and have a good porosity, key features of any implantable material. Also, the knitting process generates a stable structure, which does not loosen or peel off when cut. Implantable knitted textiles, monofilament or multifilament, composed of various materials are successfully commercialized and used worldwide [4].

INDICATIONS

Surgeons should choose a mesh adequate to the situation. Prosthetic meshes are categorized according to their purpose: i) abdominal or thoracic wall reconstruction; ii) visceral defects repair; iii) pelvic floor stabilization (rectal or vaginal prolapse); iv) tissue replacement (skin graft, endovascular graft for by-pass).

A lightweight mesh, with high porosity and minimal contact surface, ideally monofilament, is usually preferred. Therefore, polypropylene or polyester meshes are commonly used due to their viability and low infection rate. The ideal mesh should be monofilament, with high porosity, anisotropic properties and biocompatible with the host [10].

In general surgery, meshes are electively used to repair abdominal wall defects. Placing a mesh can be done by classic surgery (Rives-Stoppa, Lichtenstein) or laparoscopic (TAPP, TEP, IPOM).

Indications for surgical mesh are: recurrent hernias, an abdominal defect larger than 4 cm, incisional hernias, multiple hernias, defects in proximity of bones, older patients, and presence of ascites, obesity, conjunctive tissue abnormalities, important weight loss or the need for a fast recovery. One special indication is the incisional hernia after minimally invasive surgery like laparoscopic techniques or robotic surgery techniques. Robotics is a minimally invasive technique, similar to laparoscopic surgery, in which working tools are inserted through small incisions of 5–15 mm in the peritoneal cavity through which cannula are introduced to work [25].

For plastic and reconstructive surgery, biomaterials are used in order to support and repair soft tissue. These biomaterial prosthetics are indicated for breast, hand, or face reconstruction [26]. In gynecology, meshes are used to strengthen the pelvic floor in order to treat prolapse or urinary incontinence. Transobturatory tape procedure is efficient in low morbidity cases and it may become the new gold standard for treating this affection in women [27]. However, there are some complications associated with this procedure such as: rupture or contraction of the vaginal mesh, dyspareunia, dysuria, recurrent urinary tract infections, haemorrhage, and uterine prolapse recurrence. In case of pelvic prolapse, polypropylene and polyester meshes are the most susceptible to erosion [28].

COMPLICATIONS

The complications are minimal if the selected material is suitable for the surgical situation and is combined with a meticulous operating technique. Postoperative complications include chronic pain, infection, ulceration of the wound, adhesion formation, intestinal obstruction, recurrence of the parietal defect, rejection of the prosthesis and mesh granuloma or “meshoma”.

CONCLUSIONS

The right choice of a suitable mesh for the surgical context is of vital importance. In the case of abdominal wall surgery, regardless of the surgical technique, it has to take into consideration the selection of a mesh with the right mechanical properties (tensile strength, elasticity, weight, pore size, biocompatibility, etc.) for the physiological characteristics of the patient (such as age, defect size, obesity, underlying disease process, etc.). Compatibility between these two factors is important because it can lead to a good postoperative outcome or it can be the source of complex and recurrent complications. Acquiring knowledge about these materials by the surgeon is necessary for adapting it to the situation. Therefore, in most of the cases, a monofilament light-weighted mesh with large pores is useful, whereas if the mesh is to be placed in contact with the viscera, a composite mesh with an absorbable surface should be chosen; in cases with infection, an absorbable mesh is recommended. Despite the variety of materials available for surgical meshes, surgical skill still has a high role in preventing hernia recurrence and other types of complications.

REFERENCES

[1] Elango, S., Perumalsamy, S., Ramachandran, K., & Vadodaria, K., *Mesh materials and hernia repair*, In: BioMedicine, 2017, 7, 3, 16, https://doi.org/10.1051/bmdcn/2017070316

[2] Yilmaz, B., Ilker, A., *The search for ideal hernia repair; mesh materials and types*, In: International Journal of Surgery, 2012, 10, 6, 317–321, https://doi.org/10.1016/j.ijsu.2012.05.002

[3] Online Etymology Dictionary, Available at: https://www.etymonline.com [Accessed on June 2020]

[4] Baylón, K., Rodríguez-Camarillo, P., Elías-Zúñiga, A., Díaz-Elizondo, J.A., Gilkerson, R., Lozano, K., *Past, Present and Future of Surgical Meshes: A Review,* In: Membranes (Basel), 2017, 7, 3, 47, https://doi.org/10.3390/membranes7030047

[5] Klinge, U., Park, J.-K., Klosterhalfen, B., *The Ideal Mesh?*, In: Pathobiology, 2013, 80, 169–175, https://doi.org/10.1159/000348446

[6] Brown, C.N., Finchm, J.G., *Which mesh for hernia repair?,* In: Ann. R. Coll. Surg. Engl., 2010, 92, 272–278, https://doi.org/10.1308/003588410X12664192076296

[7] Amid, P.K., *Classification of biomaterials and their related complications in abdominal wall hernia surgery,* In: Hernia, 1997, 1, 15–21, https://doi.org/10.1007/BF02426382

[8] Coda, A., Lamberti, R., Martorana, S., *Classification of prosthetics used in hernia repair based on weight and biomaterial,* In: Hernia, 2012, 16, 9–20, https://doi.org/10.1007/s10029-011-0868-z

[9] Schwartz, S.I., Brunicardi, F.C., eds. *Schwartz's Principles Of Surgery*, New York: McGraw-Hill Medical, 2011, 1, 171–176

[10] Zhu, L.M., Schuster, P., Klinge, U., *Mesh implants: An overview of crucial mesh parameters,* In: World J. Gastrointest. Surg., 2015, 7, 10, 226–236, https://doi.org/10.4240/wjgs.v7.i10.226

[11] Hollinsky, C., Sandberg, S., *Measurement of the tensile strength of the ventral abdominal wall in comparison with scar tissue,* In: Clin. Biomech. (Bristol, Avon), 2007, 22, 88–92

[12] Williams, J.F., Kirkpatrick, J., Syme, G.A., *Force measurement in the abdominal wall,* In: Biomed. Eng., 1975, 10, 181–183

[13] Deeken, C.R., Abdo, M.S., Frisella, M.M., Matthews, B.D., *Physicomechanical evaluation of polypropylene, polyester, and polytetrafluoroethylene meshes for inguinal hernia repair,* In: J. Am. Coll. Surg., 2011, 212, 68–79

[14] Klinge, U., Klosterhalfen, B., Conze, J., Limberg, W., Obolenski, B., Ottinger, A.P., Schumpelick, V., *Modified mesh for hernia repair that is adapted to the physiology of the abdominal wall,* In: Eur. J. Surg., 1998, 164, 12, 951–960

[15] Zhu, L.-M., Schuster, P., Klinge, U., *Mesh implants: An overview of crucial mesh parameters*, In: World J. Gastrointest. Surg., 2015, 7, 10, 226–236, https://doi.org/10.4240/wjgs.v7.i10.226

[16] Junge, K., Klinge, U., Prescher, A., Giboni, P., Niewiera, M., Schumpelick, V., *Elasticity of the anterior abdominal wall and impact for reparation of incisional hernias using mesh implants,* In: Hernia, 2001, 5, 3, 113–118, https://doi.org/10.1007/s100290100019

[17] Klinge, U., Klosterhalfen, B., *Modified classification of surgical meshes for hernia repair based on the analyses of 1,000 explanted meshes,* In: Hernia: the journal of hernias and abdominal wall surgery, 2012, 16, 3, 251–258, https://doi.org/10.1007/s10029-012-0913-6

[18] Earle, D.B., Mark, L.A., *Prosthetic Material in Inguinal Hernia Repair: How Do I Choose?,* In: Surg. Clin. North Am., 2008, 88, 179–201, https://doi.org/10.1016/j.suc.2007.11.002

[19] Mühl, T., Binnebösel, M., Klinge, U., Goedderz, T., *New objective measurement to characterize the porosity of textile implants,* In: Journal of Biomedical Materials Research, Part B. Applied Biomaterials, 2008, 84B, 1

[20] Lake, S.P., Ray, S., Zihni, A.M., Thompson, D.M., Gluckstein, J., Deeken, C.R., *Pore size and pore shape – but not mesh density – alter the mechanical strength of tissue ingrowth and host tissue response to synthetic mesh materials in a porcine model of ventral hernia repair,* In: J. Mech. Behav. Biomed. Mater., 2015, 42, 186–197, https://doi.org/10.1016/j.jmbbm.2014.11.011

[21] Koch Frisén, A., Bringman, S., Myrelid, P., Smeds, S., Kald, A., *Randomized clinical trial of groin hernia repair with titanium-coated lightweight mesh compared with standard polypropylene mesh,* In: British Journal of Surgery, 2008, 95, 10, 1226–1231, https://doi.org/10.1002/bjs.6325

[22] Sanbhal, N., Miao, L., Xu, R., Khatri, A., Wang, L., *Physical structure and mechanical properties of knitted hernia mesh materials: A review,* In: Journal of Industrial Textiles, 2018, 48, 1, 333–360, https://doi.org/10.1177/1528083717690613

[23] Rosch, R., Junge, K., Schachtrupp, A., Klinge, U., Klosterhalfen, B., Schumpelick, V., *Mesh Implants in Hernia Repair,* In: Eur. Surg. Res., 2003, 35, 161–166, https://doi.org/10.1159/000070045
[24] Peniston, S., *Modulated Properties of Fully Absorbable Bicomponent Meshes,* In: All Dissertations, 2010, 647, Available at: https://tigerprints.clemson.edu/all_dissertations/647 [Accessed on June 2020]
[25] Săvulescu, F., Duţu, C., Cirlan, C., *Minimally invasive surgical techniques – robotic surgery*, In: Romanian Journal of Military Medicine, 2015, CXVIII, 3
[26] Yu, D., Patel, A.T., Rossi, K., Topham, N.S., Chang, E.I., *Comparison of Phasix, polypropylene, and primary closure of the abdominal donor site after bilateral free flap breast reconstruction: Long‐term evaluation of abdominal hernia and bulge formation*, 2019, Available at: https://onlinelibrary.wiley.com/doi/abs/10.1002/micr.30541 [Accessed on June 2020]
[27] Magon, N., Chopra, S.V., *Transobturator Tape in Treatment of Stress Urinary Incontinence: It is Time for a New Gold Standard,* In: North American journal of medical sciences, 2012, 4, 5, 226–230, https://doi.org/10.4103/1947-2714.95905
[28] Ellington, D., Richter, H., *Indications, Contraindications, and Complications of Mesh in Surgical Treatment of Pelvic Organ Prolapse*, In: Clinical Obstetrics and Gynecology, 2013, 56, 2, 276–288, https://doi.org/10.1097/grf.0b013e318282f2e8

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Diversification opportunities in European stock markets and their impact on textile industry development based on a financial education approach

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ABSTRACT – REZUMAT

Diversification opportunities in European stock markets and their impact on textile industry development based on a financial education approach

This research study explores the diversification opportunity among 18 European stock market indices for the sample period from January 2001 to December 2019. However, financial education plays an important role in the development of the textile industry, considering the dynamics of the companies listed on the European stock exchanges. The correlation matrix, pairwise cointegration and Johansen cointegration reveal that selected 18 European stock market indices do not reduces the portfolio risk because exhibit higher positive correlation among them, and their movement pulsed in tandem. Potential investors are attracted by high investment opportunities in order to maximize their return based on portfolio diversification. Financial education can effectively contribute to the sustainable growth of the textile industry in Europe. This empirical research provides an integrated perspective on the long-term evolution of certain major European stock exchange indices. The findings have significant implications for investors interested in selecting these European stock indices in order to diversify their portfolio risk. Our study also imply that selected stock indices have been strongly affected by similar political and financial belies across Europe thus, eliminating the possibility of portfolio risk diversification.

Keywords: *portfolio diversification, correlation, Johansen cointegration, textile industry, financial education, stock market*

Oportunități de diversificare pe piețele bursiere europene și impactul acestora asupra dezvoltării industriei textile pe baza unei abordări privind educația financiară

Acest studiu de cercetare analizează oportunitatea de diversificare existentă între 18 indici bursieri europeni pentru perioada de eșantionare cuprinsă între ianuarie 2001 și decembrie 2019. Cu toate acestea, educația financiară joacă un rol important în dezvoltarea industriei textile, având în vedere dinamica companiilor cotate pe piețele bursiere din Europa. Matricea de corelație, cointegrarea pereche și cointegrarea de tip Johansen relevă faptul că cei 18 indici bursieri europeni selectați nu reduc riscul de portofoliu, deoarece prezintă o corelație pozitivă ridicată între ei și mișcarea lor pulsează în tandem. Investitorii potențiali sunt atrași de oportunitățile investiționale semnificative pentru a-și maximiza rentabilitatea pe baza diversificării portofoliului. Educația financiară poate contribui în mod eficient la creșterea sustenabilă a industriei textile din Europa. Această cercetare empirică oferă o perspectivă integrată asupra evoluției pe termen lung a anumitor indici bursieri majori din Europa. Constatările au implicații semnificative pentru investitorii interesați să selecteze acești indici bursieri europeni pentru a-și diversifica riscul de portofoliu. Studiul nostru implică, de asemenea, că indicii bursieri selectați au fost puternic afectați de perturbațiile din zona politică și financiară, similare în toată Europa, eliminând astfel posibilitatea diversificării riscului de portofoliu.

Cuvinte-cheie*: diversificarea portofoliului, corelație, cointegrarea de tip Johansen, industria textilă, educația financiară, piața bursieră*

INTRODUCTION

Bullón Pérez et al. [1] highlighted the linkage between textile industry and the real economy based on the production of fibres, yarns, fabrics, clothing and textile goods for domestic, decoration, technical and industrial purpose of consumption. According to Tsa [2] traditional textile industry remains a labour-intensive process, while the outcome constitutes a result of yarn spinning, weaving, dyeing and finishing. Moreover, Bullón Pérez et al. [3] argued that effective scheduling and planning in the case of textile industry is a very challenging issue considering that serious foreign competition influences the evolution of the market. Negoita et al. [4] suggested that textile and leather industry sector faces a number of threats, but a variety of opportunities can be exploited based on suitable management strategies. Küsters et al. [5] argued that smart textile products discharge a high growth potential, but companies in the related business sectors like textile machinery, automotive suppliers, and synthetic fibre manufactures have a significant contribution to the development of the textile industry. Many of these companies are listed on stock exchanges from all over the world, including in Europe. It was suggested that the fierce competition generated by globalization has various implications for textile and garment manufacturers which resort to lower production costs, increase their efficiency and to create leaner value-adding processes.

Financial education programs are efficient in providing an optimal level of knowledge. Thus, new development alternatives for the textile sector in Europe can be identified. International investors focus on potential correlation between stock returns of different national capital markets in order to diversify portfolio risks by allocating financial asset investments [6]. Liivamägi [7] stated that education is perceived as a main factor determining portfolio diversification options of investors considering that it is correlated with investor risk-taking behaviour on the stock market. This research article provides an applied framework on investment opportunities based on portfolio diversification based on selected European stock market indices. Understanding the behaviour of stock markets requires a certain level of financial education. The textile industry can achieve a higher level of sustainable development by implementing financial education programs. This research study involves an interdisciplinary approach based on a complex empirical investigation focused on broadening the horizon of investment knowledge that could contribute to the growth of the European textile sector.

Portfolio diversification in global financial market indices is a well-known practice among various investors to diversity their portfolio risk by holding risk factor constant and maximizing their portfolio returns and vice versa. Finance literature carries a stream of studies to ascertain the possible opportunities available to diversify the portfolio risk among stock market indices. One possible way to study such interplay consists of estimating cointegration among stock market indices. For instance, if stock market indices have low or negative correlation to each other and also cointegrated then they provide favourable diversification opportunities. Segmented stock markets are more promising for portfolio diversification rather than integrated stock market [8, 9]. Previous literature explores the integration among developed stock markets [8], developed with developing stock markets [10, 11], developing market with developing markets [12, 13] and among regional financial markets [9]. We explore the diversification opportunities in 18 selected stock market indices in Europewhich allow us to examine opportunity of integration among market that located in same geographical region, however, varies in terms of their regulatory bodies and development phases. Our data of 18 stock indices are subject to non-stationary therefore cointegration Vector Autoregression (VAR) lag length is used as a selection criterion to estimate the cointegration among 18 sample stock indices. Analogous to past studies, all 18 stock indices are highly correlated to each other that provide first evidence against diversification among these stocks.

Furthermore, Multivariate Johansen's Co-integration test also confirms the absence of any cointegration equation. Nevertheless, pairwise cointegration test echoes the existence of cointegration among many stock indices however, they will not help to reduce portfolio risk as correlation indicates they move in the same direction and their movements are tandem. For instance, if we construct a portfolio based on Stoxx Europe 600 E and FTSE Europe 100 E which has a correlation coefficient 0.99, there is a pairwise cointegration and there is a significant causality as well. However, it will not reduce portfolio risk as both indices have positive higher correlation which means both are tandem.

LITERATURE REVIEW

Markowitz [14] designed the modern portfolio theory in order to diversify and reduces the risk associated to investment. However, the extent to which a risk can be reduced not only depends upon the correlation among securities returns, with in the portfolio, but also correlation between portfolio returns and the economy as a whole in which these securities are being bought and sold. Spulbar et al. [15] suggested that portfolio diversification investment strategy plays a key role in managing stock market risks. Moreover, Spulbar and Birau [16] highlighted that volatility does not diverge to infinity but apparently it is characterized by a very different reaction depending on high positive or high negative stock returns. The effect of globalization, changes in technology and financial innovations in financial markets were highly debated in the era of 1970's, and established that the trends are higher level to take advantage from cross border diversification. Thus, investors started investing into foreign companies to diversify their portfolios. By diversifying their portfolios internationally, these investors also earn capital gain through exchange rate fluctuations. According to World Bank report financial markets around the world now becoming international stock market places that provide an opportunity to investors to fully diversify their portfolios in various developing countries to achieve higher returns with minimized level of risk. Bodie et al. [17] found that internationally diversified portfolios have risk less than half of the risk associated to the portfolios that have been diversified by only US based securities. There have been many studies subject to empirical tests to examine the relationship between stocks in the United States and stock market around the world [18]. The fundamental reason behind comparing world stock markets with the United States is the fact that the United States has not only been a major investor in many countries but also enforces an enormous political and technological influence on countries across the world. This is the reason that the United States has been considered a main driving force for the world major stock markets. Maldonado and Saunders [19] examine inter-temporal trends of the correlation coefficients between the monthly stock returns on the United States based index with the monthly stock returns of indices based in Germany, United Kingdom, Canada and Japan from 1957 to 1978. The evidence supports the existence of predictable relationship between these countries in the short run; however, the weak and unstable correlation is present in the stock markets in the long run. Another study, Eun and Shim [20] analysed nine major stock markets around the world, namely, the United States, the United Kingdom, Australia, France, Hong Kong, Canada, Germany, Japan and Switzerland, and conclude that all these international stock market follow the United State stock market. On the other hand, Bessler and Yang [8] established that the United State stock markets are also influenced by the United Kingdom, Hong Kong, France, Germany and Switzerland stock markets. These findings are in line with the increasing rate of integration of world economies with the United States. These international markets are neither fully integrated nor fully segmented which imply a potential opportunity for investment diversification. Numerous studies investigate the various stock markets to establish integration among them, such as Ripley [21] studied the covariance between stock prices around 19 developed stock markets and find stock prices partly move uncorrelated to stock prices of other stock market. Panton et al. [22] found weekly stock prices exhibit stronger relationship among the stock markets of Canada, Netherlands, Belgium, United States and Switzerland whereas lesser strong relationship is found among France and Belgium, Germany and Netherlands and England and Australia. On the other hand, Spulbar and Birau [23] argued that stock market interdependencies are a significant pillar in terms of international portfolio diversification.

Arshanapalli and Doukas [24] examined Japan, United Kingdom, Germany, France and United States stock markets from 1980 to 1990 and found interdependence among daily stock prices of these stock markets with an incremental effect since 1987 except Nikkei Index Japan. Corhayet et al. [25] studied Australia, Singapore, Japan, Hong Kong and New Zealand and found no evidence of a single trend among these countries. Cheung and Mak [26] found causal relationship between Asian and United States and Japan stock markets where Asian stock markets are led by United States stock market. A cointegration test provides evidence that Hong, Kong, South Korea, Singapore, Taiwan, United States and Japan stock markets have weak form of market efficiency where investors can obtain profits from international diversification. Furthermore, Kwan et al. [27] examined Australia, South Korea, Hong Kong, Taiwan, Japan, Singapore, United Kingdom, Germany and the United States stock markets. They find a lead-lag relationship among these stock markets which imply that these markets are not weak form efficient. DeFuscoet al. [28] found no cointegration among United States and emerging Asian stock markets of Thailand, Malaysia, Hong Kong, Taiwan, Korea, Singapore, and the Philippines in the 1980s and early 1990s. Korajczyk [29] found developing stock market are more segmented as compared to developed stock markets which provides an opportunity for diversification.

Ghosh et al. [30] applied cointegration theory on daily stock prices of Asia Pacific stock market to identify whether these markets are driven by Japan and United States. The results indicate that Indian, Malaysia, Korea and Hong Kong stock market exhibits long run equilibrium relationship with U.S. stock markets. Whereas Singapore, Philippines and Indonesia stock markets are related to Japan stock market. Taiwan and Thailand stock markets are influenced by both Japan and U.S. stock markets. Tuluca and Zwick [31] applied Granger causality test on stock indices on Asian and non-Asian stock markets before and after the financial crises of 1997. They find that the co-movement of stock prices among these is stronger in Asian financial crises of 1997 than before. Antonio [32] studied long run relationship in European stock markets through a co-integration test. The results reveal that there is not long run relationship among these European stock markets. Plummer and Reid [33] found Thailand, Indonesia, Malaysia, Singapore and Philippines stock markets are completely integrated and investors cannot attain benefits of diversification in these countries.

Error correction vector autoregression (VAR) and cointegration tests Chen et al. [13] found limited aspects to diversify risk in Latin American stock markets. Hardouveliset al. [34] investigated the existence of integration between stock market in eleven European Union countries and UK stock markets. They find higher integration in late 90 that leads to the formulation of EMU but UK stock market is not found to be integrated with other European Union stock markets. Partial correlation-based networks were used to estimate the linkages between global equity markets. Singh et al. [9] revealed that regional markets are more correlated while the negative correlations exist in global markets providing diversification opportunities.

DATA AND METHODOLOGY

The section sheds light on data and elaborates the methodology. We collected daily data of 18 stock market indices for Europe from 1st of January 2001 to 13th December 2019 from Data Stream. The selected European stock market indices are the following: STOXX EUROPE 600 E, EURONEXT 100, NEXT 150, FTSE EUROTOP 100 E, FTSEUROFIRST 80 E, STOXX EUROPE LARGE 200, STOXX EUROPE SMALL 200, STOXX EUROPE MID 200, FTSE W EUROPE E, MSCI EUROPE E, FTSE EPRA Nareit DEV EUROPE, MSCI EUROPE:SE, EMIX GLOBAL MINING EUROPEAN E, EMIX SMALLER EUROPE AER&DEF E, EMIX SMALLER EUROPE BANKS E, EMIX SMALLER EUROPE BASIC MAT E, EMIX SMALLER EUROPE BEV&TOB E, and EMIX SMALLER EUROPE BUS PROV E. To ascertain the benefits of portfolio diversification, it is important that stock must possess certain characteristics. If two stock indices have higher negative correlation, they will reduce the standard deviation or the portfolio risk [35]. In this vein current study will estimates pairwise correction to have a first glimpse of interplay among 18 stock market indices. Then multiple and pairwise cointegration and Granger causality integration will be examined. The following test will be applied to ascertain the opportunity of diversification among 18 stock market indices.

Correlation Matrix

The correlation estimates the relationship between two stock market indices. The correlation coefficient runs between +1 to –1 where +1 indicates positive movement between two indices and their relationship is tandem whereas –1 exhibits negative movement. Nevertheless 0 indicates no relationship at all. For portfolio diversification it is important that two indices must have negative interplay to reduce portfolio risk. The relationship between correlation and portfolio risk is estimated through following equations:

$$Var(R_p) = \omega_i^2 var(R_i) + \omega_j^2 var(R_j) + 2\omega_i\omega_j cov(R_i R_j) \quad (1)$$

where $Var(R_p)$ is variance of Portofolio returns, ω_i^2 – weights of stock i in portofolio, $cov(R_i R_j)$ – covariance between stock i and stock j, which is calculated through following equation:

$$cov(R_i R_j) = SD(R_i) * SD(R_j) * cor(R_i R_j) \quad (2)$$

Thus, a lower or negative correlation between two stocks reduces portfolio risk.

Unit Root Test

It is precursor for cointegration that all the data should be stationary at same level. To obtain the existence of unit root test we apply Dickey Fuller Augmented test on time series. The null hypothesis states that data is stationary. The test estimates the following equation:

$$Y_t = \varphi Y_{t-1} + \mu_t \quad (3)$$

Where Y_t is stock market index for a given day, Y_{t-1} – stock market index for previous day, φ – coefficient and μ_t – error term.

Johansen's Multivariate Co Integration Test

Two or more indices are said to be co-integrated with each other if their movements are tandem. This test examines if two or more indices are co-integrated with each other or not in short run and long run. Johansen's Multivariate Co Integration Test uses the following equation in this regard:

$$\lambda \text{ trace} = -T \sum \ln(1 - \lambda i) \quad (4)$$

where λi is estimated eigen value and λ trace – trace statistic.

Granger Causality Test

This test examines if one index causes another index. This "cause" can be unidirectional or bidirectional. If it is unidirectional it means that one index causes another index. If the causality is bidirectional it means that both variables are causing each other.

EMPIRICAL ANALYSIS AND RESULTS

This section provides empirical findings whether the 18 stock market indices echo the possibility of diversification. Table 1 encapsulates the summary statistics for international indices across 18 stock markets. Total number of observations for each index is 4944. Emix Smaller Europe Bus Prov E and Emix Smaller Europe BEV&TOB E generate on average greater returns with the highest mean returns of 0.05 whereas lowest mean returns 0.0 belongs to Emix Smaller Europe Banks E (please write country name here). The standard deviation ascertains the level of risk associated to each index. In this precept the returns of Emix Global Mining European E (country name) index exhibit greater risk, around 2.10, as opposed to the risk related to EMIX Smaller Europe Bus Prov E and Emix Smaller Europe Bev&Tob E which is 0.98. Index that has greater level of risk experiences wider level of variation between minimum returns (–15.85) and maximum returns (18.27). The same can also be observed that lowest return variation with maximum (minimum) returns (8.55) –6.56 are associated to the indices that have lower level of risk. Table 1 infers that Emix Smaller Europe Bus Prov E and Emix Smaller Europe Bev&Tob E yield higher level of returns with lowest level of risk whereas all indices that have lower returns associated with higher risk.

Table 1 also shows lower (higher) level of risk is associated to index that have greater (lower) mean returns. The correlation among the 18 selected stock indices reveals if two stock indices behave independent to each other or there is some level of association exits. The degree of association between two variables is measured through correlation coefficient between +1 to –1 where +1 infer perfect positive and –1 indicates perfect negative relationship between two indices and no relationship if correlation coefficient is 0. However, for portfolio diversification there should be some level of correlation required to diversify the risk. Fabozziet al. [35] show portfolio standard deviation decreases, keeping expected returns constant, when correlation between two assets decreases. It can be observed from our empirical analysis that majority of the sample stock indices have higher correlation, which are in tandem. By investing in such stocks will not decrease portfolio risk. Substantial amount of literature support application of Dickey Fuller test before using co-integration between two series. Co-integration among indices requires that time series must be stationary at same level to rule out the possibility of any growth within the series. To confirm the stationarity level of each index, table 2 includes the results for Augmented Dickey Fuller test for each index at level 0 and level 1.

Table 1

DESCRIPTIVE STATISTICS						
Sr. no.	Index name	No. of obs.	Mean	Std. Dev.	Min	Max
1	STOXX EUROPE 600 E	4944	0.01	1.18	–7.62	9.87
2	EURONEXT 100	4944	0.01	1.28	-8.56	10.87
3	NEXT 150	4944	0.03	1.08	-7.76	8.88
4	FTSE EUROTOP 100 E	4944	0.01	1.23	–7.86	10.33
5	FTSEUROFIRST 80 E	4944	0.01	1.37	–8.12	11.28
6	STOXX EUROPE LARGE 200	4944	0.01	1.21	–7.85	10.32
7	STOXX EUROPE SMALL 200	4944	0.02	1.11	–7.72	7.32
8	STOXX EUROPE MID 200	4944	0.02	1.13	–8.05	8.17
9	FTSE W EUROPE E	4944	0.01	1.19	–7.70	10.13
10	MSCI EUROPE E	4944	0.01	1.18	–7.61	10.05
11	FTSE EPRA Nareit DEV EUROPE	4944	0.02	1.12	–8.95	7.40
12	MSCI EUROPE :S E	4944	0.03	1.02	–7.63	7.25
13	EMIX GLOBAL MINING EUROPEAN E	4944	0.04	2.10	–15.85	18.27
14	EMIX SMALLER EUROPE AER&DEF E	4944	0.04	1.24	–6.89	6.12
15	EMIX SMALLER EUROPE BANKS E	4944	0.00	1.12	–11.48	9.61
16	EMIX SMALLER EUROPE BASIC MAT E	4944	0.03	1.12	–7.99	8.08
17	EMIX SMALLER EUROPE BEV&TOB E	4944	0.05	0.98	–6.56	8.55
18	EMIX SMALLER EUROPE BUS PROV E	4944	0.05	0.98	–6.56	8.55

Table 2

STATIONARITY DIAGNISTIC: UNIT ROOT TEST AT LEVEL 0 AND LEVEL 1							
Index name	1% Critical value	Level 0		Remarks	Level 1		Remarks
		t-stat	prob.		t-stat	prob.	
STOXX EUROPE 600 E	–3.43	–1.57	0.4987	Non-stationary	–70.48	0	Stationary
EURONEXT 100	–3.43	–1.571	0.498	Non-Stationary	–70.771	0	Stationary
NEXT 150	–3.43	–0.208	0.9376	Non-Stationary	-63.563	0	Stationary
FTSE EUROTOP 100 E	–3.43	–2.781	0.061	Non-Stationary	–72.081	0	Stationary
FTSEUROFIRST 80 E	–3.43	–2.764	0.0636	Non-Stationary	–71.978	0	Stationary
STOXX EUROPE LARGE 200	–3.43	–2.184	0.2121	Non-Stationary	–71.479	0	Stationary
STOXX EUROPE SMALL 200	–3.43	–0.288	0.9271	Non-Stationary	–66.138	0	Stationary
STOXX EUROPE MID 200	–3.43	–0.272	0.9294	Non-Stationary	–67.014	0	Stationary
FTSE W EUROPE E	–3.43	–1.764	0.3986	Non-Stationary	–70.635	0	Stationary
MSCI EUROPE E	–3.43	–1.832	0.3648	Non-Stationary	–70.71	0	Stationary
FTSE EPRA Nareit DEV EUROPE	–3.43	1.185	0.6798	Non-Stationary	–66.408	0	Stationary
MSCI EUROPE :S E	–3.43	0.083	0.9649	Non-Stationary	–63.987	0	Stationary
EMIX GLOBAL MINING EUROPEAN E	–3.43	–2.163	0.22	Non-Stationary	–69.65	0	Stationary
EMIX SMALLER EUROPE AER&DEF E	–3.43	–0.379	0.9135	Non-Stationary	–65.79	0	Stationary
EMIX SMALLER EUROPE BANKS E	–3.43	–0.743	0.8353	Non-Stationary	–64.421	0	Stationary
EMIX SMALLER EUROPE BASIC MAT E	–3.43	–1.148	0.6956	Non-Stationary	–62.473	0	Stationary
EMIX SMALLER EUROPE BEV&TOB E	–3.43	0.678	0.9894	Non-Stationary	–67.63	0	Stationary
EMIX SMALLER EUROPE BUS PROV E	–3.43	–0.332	0.9208	Non-Stationary	–63.385	0	Stationary

Note: 1% Critical value = –3.430.

The null hypothesis suggests the presence of unit root within the series. All the indices are non-stationary at level 0 because their probability value is not less the 0.05 which does not reject the null hypothesis. Moreover, table 2 presents critical values –3.43 at 1% level of significance. To make data stationary at level 0, the t-statistics should be less –3.43 along with the p-value less than 0.05. Nevertheless, it can be observed that even t-statistics are less than critical values but still probability value fails to reject the null hypothesis. However, all indices are stationary at level 1 indicated by p-values less than 0.05 and t-statistics are also less than the critical values –3.43. Hence, rejecting the null hypothesis it can be inferred that all indices does not contain unit root at level 1. For instance, Bouriet et al. [36] also applied same test before estimating co-integration among Indian stock market and gold and oil sector. Cheong [38] study weak form of market efficiency through unit root test. Similarly, Alamet et al. [32] use Dickey Fuller test to estimate the level of stationarity to examine the sectoral efficiency of Islamic stock indices. Thus, the significance of using unit root test is well justified and verified by past studies.

Lag length number is determined in table 3 which is a prerequisite to run co-integration and granger causality test. VAR leg length test is utilized to estimate the number of lag length for further use of co-integration and granger causality. Table 3 includes 5 selection criteria to determine the lag length namely, LR test statistics, Final Predication Error, Akaike information criterion, Schwarz Bayesian information criterion and Hannan-Quinn information criterion. As a rule of thumb, the lag length should be the one that is supported by maximum number of selection criteria however, if two lag lengths are supported by same number of selection criteria then we select the one which is justified by AIC. Table 3 indicates that lag length 3 and lag length 1 are supported by AIC, FPE and HQIC, SBIC, respectively. We will select lag length 3 as it is justified by AIC for co-integration and granger causality tests.

Multivariate cointegration is estimated in table 4 to confirm whether stock market indices are cointegrated to

Table 3

VAR LAG LENGTH SELECTION CRITERIA

Lag	LL	LR	df	p-vale	FPE	AIC	HQIC	SBIC
0	–3099.27	-	-	-	2.30E-22	1.26205	1.27037	1.28576
1	–1497.61	3203.3	324	0	1.40E-22	0.744781	0.90272*	1.19514*
2	–1010.54	974.15	324	0	1.30E-22	0.67876	0.986324	1.55577
3	–660.965	699.14	324	0	1.3e-22*	0.668407*	1.1256	1.97206
4	–377.997	565.94*	324	0	1.30E-22	0.685019	1.29184	2.41533

Note: * indicates lag order selected by the criterion.

Table 4

MULTIVARIATE JOHANSEN'S CO-INTEGRATION TEST

Maximum rank	Parms	LL	Eigenvalue	Trace statistic	5% Critical value
0	666	–139928	-	817.9442*	-
1	701	–139864	0.02538	690.8987	-
2	734	–139814	0.01998	591.1404	-
3	765	–139766	0.01915	495.6026	-
4	794	–139727	0.01572	417.3083	-
5	821	–139692	0.01399	347.6826	-
6	846	–139663	0.01168	289.6405	-
7	869	–139636	0.01094	235.2588	277.71
8	890	–139613	0.00929	189.1251	233.13
9	909	–139594	0.00758	151.5457	192.89
10	926	–139579	0.00624	120.6117	156
11	941	–139565	0.00576	92.0483	124.24
12	954	–139552	0.00527	65.9468	94.15
13	965	–139542	0.00393	46.4752	68.52
14	974	–139533	0.00361	28.5824	47.21
15	981	–139527	0.00255	15.9416	29.68
16	986	–139522	0.0019	6.5545	15.41
17	989	–139519	0.00132	0.0027	3.76
18	990	–139519	0	-	-

Note: * indicates co integrated equations.

each other. According to the criteria the trace value should be less than 5% critical value. Trace statistics become less than 5% critical value; the corresponding maximum ranks represent number of cointegration equation. Trace statistics states null hypothesis that stock market indices do not carry any cointegration among them, whereas, alternative hypothesis state that at least one cointegration equation exits. Table 4 shows traces statistics where significant trace statistics are marked with asterisk (*), but corresponding maximum ranks is 0. This implies that there is no cointegration equation exits among stock market indices.

Tables 5–7 reveal pairwise cointegration among stock market indices on one-to-one basis. As a rule of thumb trace statistics compared with critical value 15.41 at 5% level of significance. If trace statistics greater (less) than the critical value, then it proves evidence of presence (absences) of cointegration between two stock indices. Tables 5–7 indicate that there are 31 pairs that exhibit cointegration indicated by 1, in parenthesis, and remaining indices that are represented by 0, in parenthesis, are not cointegrated. The stock indices that carry N/S are not significant.

The results of Granger causality test is used to ascertain if one stock market index is related to another stock market index. Granger Causality test formulates null hypothesis that states there is no causality between two stock indices. If the probability value is less than 0.05, we can reject the null hypothesis. Granger Causality has a brighter side that it only confirms the existence of causality, nevertheless, the dark side is that it does not provide causality coefficient. Our research study provides evidence that majority of the selected stock indices highlights

Table 5

THE RESULTS OF PAIRWISE COINTEGRATION

Index name	STOXX EUROPE 600 E	EURONEXT 100	NEXT 150	FTSE EUROTOP 100 E	FTSEUROFIRST 80 E	STOXX EUROPE LARGE 200
STOXX EUROPE 600 E						
EURONEXT 100	12.3684* (0)					
NEXT 150	12.3225* (0)	12.6388* (0)				
FTSE EUROTOP 100 E	0.2772* (1)	14.8068* (0)	15.0432* (0)			
FTSEUROFIRST 80 E	14.7146* (0)	11.9795* (0)	12.7106* (0)	18.2504 (N/S)		
STOXX EUROPE LARGE 200	0.4642* (1)	10.4995* (0)	13.5122* (0)	0.2255* (1)	3.5302* (1)	
STOXX EUROPE SMALL 200	14.4175* (0)	14.9202* (0)	7.3123* (0)	0.3600* (1)	13.3904* (0)	14.9395* (0)
STOXX EUROPE MID 200	14.0195* (0)	14.7389* (0)	7.7468* (0)	0.2143* (1)	13.0589* (0)	14.7866* (0)
FTSE W EUROPE E	11.5289* (0)	10.9006* (0)	12.4148* (0)	0.5336* (1)	15.2892* (0)	1.1424* (1)
MSCI EUROPE E	12.2552* (0)	10.9111* (0)	12.4709* (0)	0.4988* (1)	2.9937* (1)	1.3071* (1)
FTSE EPRA Nareit DEV EUROPE	2.4821* (1)	3.2227* (1)	4.3596* (0)	2.6131* (1)	3.7359* (1)	2.6368* (1)
MSCI EUROPE :S E	14.7952* (0)	14.4290* (0)	5.7977* (0)	0.0358* (1)	12.9009* (0)	15.1495* (0)
EMIX GLOBAL MINING EUROPEAN E	8.0168* (0)	8.2856* (0)	5.2077* (0)	14.5535* (0)	14.5912* (0)	10.9502* (0)
EMIX SMALLER EUROPE AER&DEF E	11.7445* (0)	10.7576* (0)	6.5791* (0)	14.5255* (0)	11.8388* (0)	13.0729* (0)
EMIX SMALLER EUROPE BANKS E	4.5923* (0)	5.1210* (0)	6.5728* (0)	7.6257* (0)	8.3832* (0)	5.3935* (0)
EMIX SMALLER EUROPE BASIC MAT E	2.5690* (1)	18.5495 (N/S)	7.4542* (0)	2.6900* (1)	19.5318 (N/S)	2.6478* (1)
EMIX SMALLER EUROPE BEV&TOB E	10.0681* (0)	10.5630* (0)	7.3207* (0)	12.5145* (0)	10.9316* (0)	11.1159* (0)
EMIX SMALLER EUROPE BUS PROV E	0.7128* (1)	1.4688* (1)	4.1867* (0)	0.7200* (1)	15.1648* (0)	0.7524* (1)

Table 6

THE RESULTS OF PAIRWISE COINTEGRATION (CONTINUED)						
Index name	**STOXX EUROPE SMALL 200**	**STOXX EUROPE MID 200**	**FTSE W EUROPE E**	**MSCI EUROPE E**	**FTSE EPRA Nareit DEV EUROPE**	**MSCI EUROPE :S E**
STOXX EUROPE MID 200	12.1571* (0)					
FTSE W EUROPE E	14.0840* (0)	13.5861* (0)				
MSCI EUROPE E	14.0369* (0)	3.7520* (0)	12.4340* (0)			
FTSE EPRA Nareit DEV EUROPE	3.8491* (0)	3.8747* (0)	2.6735* (1)	2.5803* (1)		
MSCI EUROPE :S E	10.8557* (0)	0.0023* (1)	14.2878* (0)	14.3678* (0)	3.7192* (0)	
EMIX GLOBAL MINING EUROPEAN E	5.0615* (0)	5.0011* (0)	8.8782* (0)	9.1610* (0)	10.4766* (0)	5.1446* (0)
EMIX SMALLER EUROPE AER&DEF E	6.9062* (0)	6.6450* (0)	11.7769* (0)	11.8482* (0)	2.7155* (0)	5.4469* (0)
EMIX SMALLER EUROPE BANKS E	6.3064* (0)	5.3169* (0)	4.9547* (0)	4.7194* (0)	2.6064* (0)	5.5325* (0)
EMIX SMALLER EUROPE BASIC MAT E	6.6209* (0)	6.2644* (0)	2.7154* (1)	2.6205* (1)	6.2228* (0)	10.5148* (0)
EMIX SMALLER EUROPE BEV&TOB E	8.1836* (0)	8.3781* (0)	10.2130* (0)	10.2648* (0)	3.2191* (0)	6.8033* (0)
EMIX SMALLER EUROPE BUS PROV E	4.0632* (0)	4.2118* (0)	0.7144* (1)	0.6966* (1)	4.7315* (0)	3.0576* (0)

Table 7

THE RESULTS OF PAIRWISE COINTEGRATION (CONTINUED)						
Index name	**EMIX GLOBAL MINING EUROPEAN E**	**EMIX SMALLER EUROPE AER&DEF E**	**EMIX SMALLER EUROPE BANKS E**	**EMIX SMALLER EUROPE BASIC MAT E**	**EMIX SMALLER EUROPE BEV&TOB E**	**EMIX SMALLER EUROPE BUS PROV E**
EMIX SMALLER EUROPE AER&DEF E	5.3260* (0)					
EMIX SMALLER EUROPE BANKS E	1.9640* (1)	4.2775* (0)				
EMIX SMALLER EUROPE BASIC MAT E	7.2135* (0)	4.3862* (0)	5.1433* (0)			
EMIX SMALLER EUROPE BEV&TOB E	5.6800* (0)	6.6285* (0)	4.4555* (0)	6.0293* (0)		
EMIX SMALLER EUROPE BUS PROV E	5.5431* (0)	4.7548* (0)	5.4579* (0)	5.5486* (0)	4.7942* (0)	

Note: 5% for rank (0) critical value = 15.41; for rank (1) critical value = 3.76,(0) indicates no co-integration, (1) indicates co-integration and N/S indicates not significant.

causality linkage among each other. This aspect implies that the change in one index will bring change in another index in the short run.

CONCLUSIONS

Current study explores the opportunities of portfolio diversification among 18 selected stock market in Europe. For minimizing the portfolio risk, these stock indices must be low or negatively correlation and should be integrated. We apply pairwise correlation, cointegration and pairwise cointegration. Based on our analysis, these 18 sample stock market indices are not an option for investment opportunity because they have higher positive correlation to each other whereas investment in these indices will not reduce portfolio risk. The subsequent analysis such as pairwise cointegration and granger causality test provide further support to our initial prediction. Although pairwise and granger causality establish the relationship among majority of the indices, however, due to higher positive correlation, they move in one direction. For instance, if we construct a portfolio based on

Stoxx Europe 600E and FTSE Europe 100 E which has a correlation coefficient 0.99, there is a pairwise cointegration and there is a significant causality as well. However, it will not reduce portfolio risk as both indices have positive higher correlation which means both are tandem. The same pattern applies on all other indices. Future research can be carried out to evaluate diversification opportunities among Asian stock indices or a comparison between Asian and American stock indices. The plausible reason for higher positive correlation is that these stock indices belong to Europe that is almost get affected on a same magnitude by similar political and financial contradictions. Moreover, the controlling regulatory of these 18 stock indices are somehow related to each other and formulate similar policies.

REFERENCES

[1] Bullón Pérez, J., González Arrieta, A., Hernández Encinas, A., Queiruga-Dios, A.,*Manufacturing processes in the textile industry. Expert Systems for fabrics production*, In: ADCAIJ: Advances in Distributed Computing and Articial Intelligence Journal, 2017, 6, 1, 41–50

[2] Tsa, W.H.,*Green Production Planning and Control for the Textile Industry by Using Mathematical Programming and Industry 4.0 Techniques*, In: Energies, 2018, 11, 2072

[3] Bullón Pérez, J., González Arrieta, A., Hernández Encinas, A., Queiruga-Dios, A. *Industrial Cyber-Physical Systems in Textile Engineering*, In: Graña, M., López-Guede, J., Etxaniz, O., Herrero, Á., Quintián, H., Corchado, E. (eds), International Conference on EUropean Transnational Education, Springer, 2016, 527, 126–135

[4] Negoita, O.I., Ghituleasa, C., Negoita, O.D., Purcarea, A.A.,*Branding process – An important factor in guiding the company towards success*, In: IndustriaTextila, 2015, 66, 2, 103–107

[5] Küsters, D., Praß, N., Gloy, Y.S.,*Textile Learning Factory 4.0 – Preparing Germany's Textile Industry for the Digital Future*, In: 7th Conference on Learning Factories, CLF 2017, Procedia Manufacturing, 2017, 9, 214 – 221

[6] Spulbar, C., Birau, R., *Emerging Research on Monetary Policy, Banking, and Financial Markets*, In: IGI Global USA, 2019, 322, ISBN13: 9781522592693, ISBN10: 1522592695, EISBN13: 9781522592716, https://doi.org/10.4018/978-1-5225-9269-3

[7] Liivamägi, K., *Investor education and trading activity on the stock market*, In: Baltic Journal of Economics, 2016, 16, 2, 114–131

[8] Bessler, D.A., Yang, J., *The structure of interdependence in international stock markets*, In: Journal of international money and finance, 2003, 22, 2, 261–287

[9] Singh, V., Li, B., Roca, E., *Global and regional linkages across market cycles: evidence from partial correlations in a network framework*, In: Applied Economics, 2019, 51, 33, 3551–3582

[10] Vo, X.V., Ellis, C., *International financial integration: Stock return linkages and volatility transmission between Vietnam and advanced countries*, In: Emerging Markets Review, 2018, 36, 19–27

[11] Trivedi, J., Spulbar, C., Birau, R., Mehdiabadi, A., Modelling volatility spillovers, cross-market correlation and co-movements between stock markets in European Union: an empirical case study. In: Business, Management and Economics Engineering, 2021, 19, 1, 70–90, https://doi.org/10.3846/bmee.2021.13588

[12] Kocaarslan, B., Sari, R., Gormus, A., Soytas, U., *Dynamic correlations between BRIC and U.S. stock markets: The asymmetric impact of volatility expectations in oil, gold and financial markets*, In: Journal of Commodity Markets, Elsevier, 2017, 7, C, 41–56

[13] Chen, G.M., Firth, M., Rui, O.M., *Stock market linkages: evidence from Latin America*, In: Journal of Banking & Finance, 2002, 26, 6, 1113–1141

[14] Markowitz, H., *Portfolio selection*, In: The journal of finance, 1952, 7, 1, 77–91

[15] Spulbar, C., Trivedi, J., Birau, R., *Investigating abnormal volatility transmission patterns between emerging and developed stock markets: a case study*, In: Journal of Business Economics and Management, 2020, 21, 6, 1561–1592, https://doi.org/10.3846/jbem.2020.13507

[16] Spulbar, C., Birau, R., *Emerging research on monetary policy, banking, and financial markets*, In: IGI Global, USA, 2019, https://doi.org/10.4018/978-1-5225-9269-3

[17] Bodie, Z., Kane, A., Marcus,A.J., *Investments*, 4th Edition, McGraw Hill, 1999

[18] Phylaktis, K., Ravazzolo, F., *Stock market linkages in emerging markets: implications for international portfolio diversification*, In: Journal of International Financial Markets, Institutions and Money, 2005, 15, 2, 91–106

[19] Maldonado, R., Anthony, S., *International portfolio diversification and the inter-temporal of international stock market relationships 1957–1978*, In: Financial Management, 1981, 10, 54–63

[20] Eun, C.S., Sangdal, S., *International transmission of stock market movements*, In: Journal of Financial and Quantitative Analysis, 1989, 24, 241–256

[21] Ripley, D., *Systematic elements in the linkage of national stock market indices,* In: The Review of Economics and Statistics, 1973, 15, 356–361

[22] Panton, D.B., Parker, V.L., Joy, O.M., *Comovements of international equity markets: A Taxonomic approach*, In: Journal of Financial and Quantitative Analysis, 1976, 11, 415–432

[23] Spulbar, C., Birau, R., *Testing weak-form efficiency and long-term causality of the R.I.P.H emerging capital markets*, In: International Journal of Business Quantitative Economics and Applied Management Research, 2018, 5, 2, 1–19

[24] Arshanapalli, B., Doukas, J., *International stock market linkage: Evidence from the pre- and post-October 1987 period*, In: Journal of Banking and Finance, 1993, 17, 193–208

[25] Corhay, A., Rad, A., Urbain, J., *Long-run behavior of Pacific-Basin stock prices*, In: Applied Financial Economics, 1995, 5, 11–18

[26] Cheung, Y.L., Mak, S.C., *A Study of the international transmission of stock market fluctuation between the developed markets and the Asian-Pacific markets*, In: Applied Financial Economics, 1992, 2, 1–5

[27] Kwan, A.C.C., Ah-boon, S., Cotsomitis, J.A., The causal relationships between equity indices on world exchanges, Applied Economics, 1995, 27, 1, 33–37
[28] DeFusco, R.A., Geppert, J.M., Tsetsekos, G.P., *Long-run diversification potential in emerging stock markets*, In: Financial Review, 1996, 31, 343–363
[29] Korajczyk, R.A., *A measure of stock market integration for developed and emerging markets*, In: The World Bank Economic Review, 1996, 10, 2, 267–289
[30] Ghosh, A., Saidi, R., Johnson, K.H., *Who moves the Asia-Pacific stock markets – US or Japan? Empirical evidence based on the theory cointegration*, In: The Financial Review, 1999, 34, 159–170
[31] Tuluca, S.A., Burton, Z., *The effects of the Asian crisis on global equity markets*, In: The Financial Review, 2001, 36, 125–142
[32] Alam, N., Arshad, S., Rizvi, S.A., *Do Islamic stock indices perform better than conventional counterparts? An empirical investigation of sectoral efficiency*,In: Review of Financial Economics, Elsevier, 2016, 31, 108–114
[33] Plummer, M., Reid W.C., *Bond market development and integration in ASEAN*, In: International Journal of Finance & Economics, 2005, 10, 2, 133–142
[34] Hardouvelis, G., Malliaropulos, D., Priestley, R., *EMU and European Stock Market Integration*, In: The Journal of Business, 2006, 79, 1, 365–392
[35] Fabozzi, F., Gupta, F., Markowitz, H., *The Legacy of Modern Portfolio Theory*, In: The Journal of Investing, 2002, 11, 7–22, https://doi.org/10.3905/joi.2002.319510
[36] Bouri, E., Jain Anshul Biswal, P.C., Roubaud, D., *Cointegration and nonlinear causality amongst gold, oil, and the Indian stock market: Evidence from implied volatility indices*, In: Resources Policy, 2017, 52, 201–206
[37] Cheong, C.W., *A sectoral efficiency analysis of Malaysian stock exchange under structural break*, In: American Journal of Applied Sciences, 2008, 5, 1291–1295

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Classification of digital stitch lines in machine embroidery

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ABSTRACT – REZUMAT

Classification of digital stitch lines in machine embroidery

Despite the large application of the machine embroidery in textile and apparel design and high-tech clothing items, there is a lack of systematic arrangement of the digital stitch lines, used by embroidery machines and embroidery designers. Since 2010 information on embroidery stitch lines could be mostly found in the web sites of the embroidery machine manufacturers and software product manuals. However, in the instruction manuals the instruments for creating various embroidery objects are simply described without providing systematic information on the types of the stitch lines. Even more, different names of the stitch lines and different ways to achieve the same design are observed. Single authors offer their own classifications based entirely and logically on the stitches of the hand embroidery. Another group of authors relied on already developed techniques and strategies for digitizing stitches in various software products or took into account the final appearance of the stitch lines or their application. Our study aimed to develop a detailed and systematic classification of the digital stitch lines in the machine embroidery, which has not been presented in the literature.

Keywords: *machine embroidering, classification, digital stitch lines, textiles, textile systems*

Clasificarea liniilor digitale de coasere în broderiile realizate pe mașinile de brodat

În ciuda aplicării pe scară largă a broderiilor industriale în articolele de îmbrăcăminte uzuale și în cele de înaltă tehnologie, există o lipsă de dispunere sistematică a liniilor digitale de coasere, utilizate de mașinile de brodat și de proiectanții de broderie. Din 2010, informațiile despre liniile de coasere din broderii pot fi găsite în principal, pe site-urile web ale producătorilor de mașini de brodat și în manualele de produse software. Cu toate acestea, în manualele de instrucțiuni instrumentele pentru crearea diferitelor broderii sunt descrise simplist, fără a furniza informații sistematice despre tipurile de linii de coasere. În plus, sunt observate denumiri diferite ale liniilor de coasere și moduri diferite de a realiza același design. Anumiți autori oferă propriile lor clasificări bazate în întregime și în mod logic pe cusăturile utilizate în broderiile manuale. Un alt grup de autori s-a bazat pe tehnici și strategii deja dezvoltate pentru digitalizarea cusăturilor în diferite produse software sau au luat în considerare aspectul final al liniilor de coasere sau aplicația acestora. Studiul nostru a urmărit să dezvolte o clasificare detaliată și sistematică a liniilor digitale de coasere în broderiile realizate pe mașinile de brodat, care nu este prezentă în literatura de specialitate.

Cuvinte-cheie*: broderie realizată pe mașina de brodat, clasificare, linii digitale de coasere, textile, sisteme textile*

INTRODUCTION

The purpose of embroidery is to add an ornament to clothing, accessories, towels, bed linen, curtains, tablecloths, and other types of textile products. Very often, embroidery serves for advertising, used as logos, contains event information (for conferences, seminars, symposia), or sends different messages to people. The creation of embroidery was only manual for centuries, but with the Industrial Revolution, machine embroidery displaced on a large scale the hand embroidery. That is why embroidering can now be defined as a more sophisticated sewing process. Since 1980, when the first computer graphics of Wilcom minicomputer embroidery have been created, to date, the development of this group of textile machines has reached a high technological level [1]. Embroidery techniques are also used for the manufacturing of electronic textiles and conductive textile structures, allowing the connection between the textile system and electronic modules.

The research on the quality and application of embroidery is quite extensive. Several publications were dedicated to the accuracy of the shape and dimensions of the embroidery element [2–5]. A large area of research is dedicated to the ends-down of the embroidery machines and defects in the embroideries [6–12]. Another area of research involves the electronic textiles and high-tech clothing that are rapidly growing sectors in the textile and apparel industries. The embroideries are used as conductive systems, which are necessary for the best performing of the textile items and assuring their accuracy [13–20].

Despite the large application of the machine embroidery in textile and apparel design and high-tech clothing items, there is still a lack of systematic arrangement of the stitch lines, used by embroidery machines and embroidery designers. Our previous analysis [21] showed that the most comprehensive source of information on machine embroidery since 2010 could be found on the web sites of the leading embroidery machine's manufacturers and in the software manuals. Single authors [22] offer their own classifications based entirely and logically on the stitches of the hand embroidery, characterized by the application of a wide variety of techniques. However, in the machine-based embroidery, the needle passes only on one side of the fabric, and it is possible to obtain straight double lockstitches, typical for the lockstitch sewing machines, chain stitches and loose loops without knots. Another group of authors relied on already developed techniques and strategies for digitizing stitches in various software products to create machine embroidery designs [23]. Other authors took into account the final appearance of the stitch lines or their application [24].

The aim of our study was to develop and propose a general classification of the digital stitch lines for machine embroidery. The classification is based on the sequence of the stitch line formation, stitch line appearance, approaches for filling, and final application.

FORMATION OF STITCH LINES IN MACHINE EMBROIDERY

The principle of the embroidery machines' work is similar to that of the ordinary gripper sewing machine. The difference is that the fabric is embedded in an embroidery frame and moves into an XY plane after each needle puncture. There is no real change in the type of stitch or the way the needle and the graft threads cross, but the size and direction of the displacement before the needle punch can be controlled. This unified stitch, a point-to-point line, is the primary building block of the embroidery (figure 1). In addition, several building blocks can be stacked in a certain way to form a group of stitches, which in turn follow an arbitrary trajectory. The way of forming this combination of a small number of single stitches is inspired by hand embroidering.

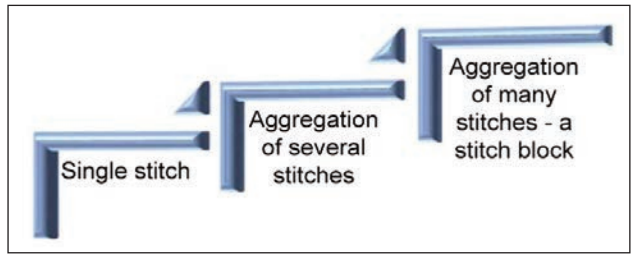

Fig. 1. Formation of the stitch lines in machine embroidery

When a significantly higher number of stitches are applied to form more sophisticated shapes (floral motifs, geometric patterns), then stitch blocks are used. Working with the stitch blocks, it is possible to define within the boundaries of an object: * the step and angle of the stitches, * the size of the motif itself, * the distance between the individual motifs in the XY-direction.

CLASSIFICATION OF STITCHES IN MACHINE EMBROIDERY

Figure 2 shows the proposed classification of the stitches in the machine embroidery: each stitch and

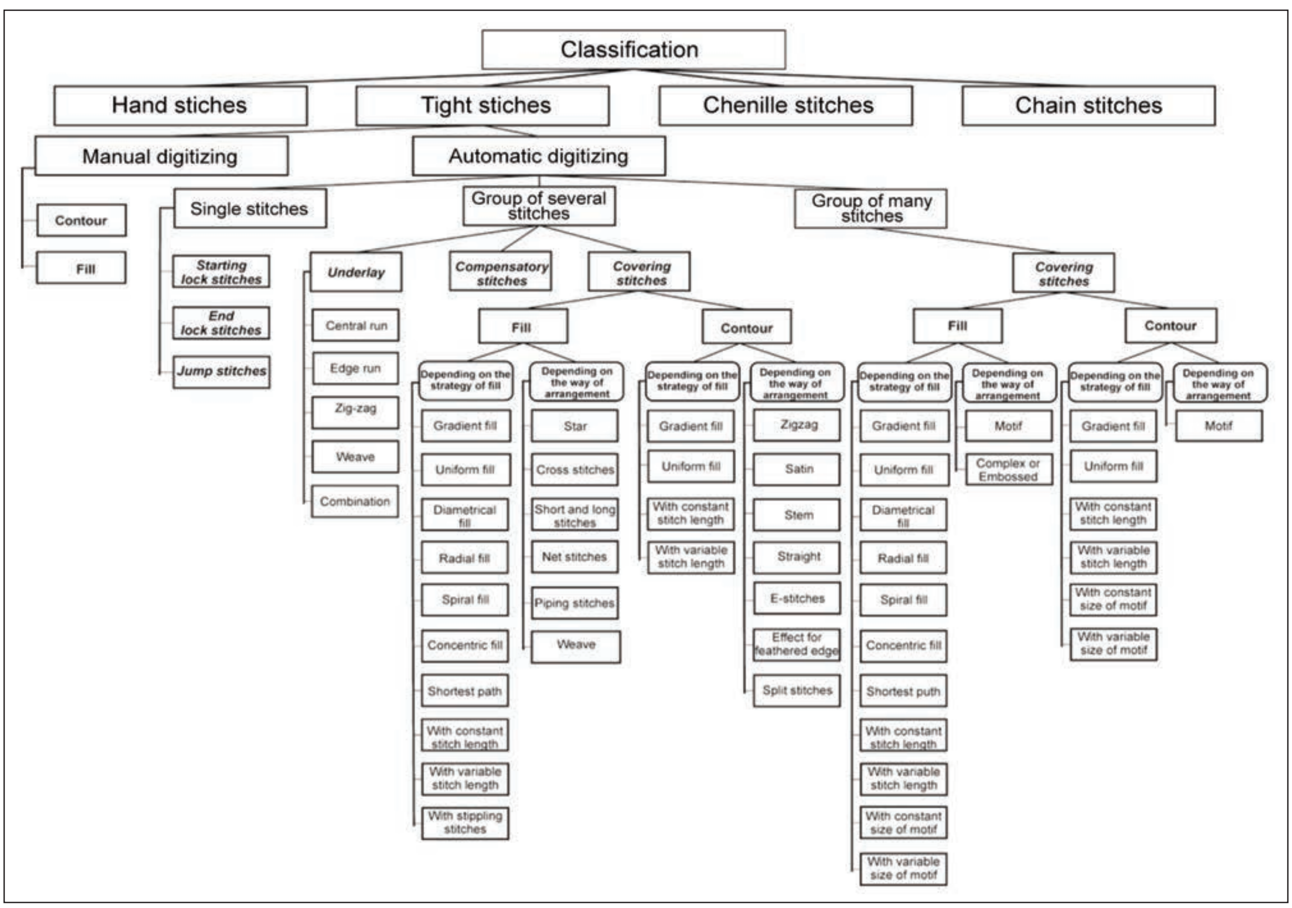

Fig. 2. Classification of the stitch lines in the machine embroidery

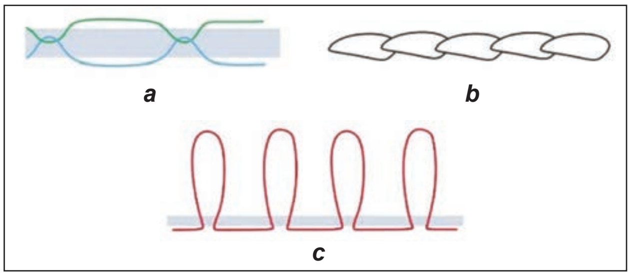

Fig. 3. Types of face covering stitches:
a – tight; *b* – chain stitch; *c* – loop

its place in the classification are discussed below. At this stage of development of the embroidery machines, the stitches that can be obtained are interlocking or tight (figure 3, *a*), imitating hand, chain stitches (figure 3, *b*) and those with loops (figure 3, *c*). The result of applying the last type of stitches is a Chenille embroidery (figure 4), which is less common and is made using special needles with a hook. Embroidery machines that form hand and chain stitches are also rarely used.
According to the digitization method of the embroidery, the stitch lines obtained from tight stitches can be divided into two groups: manual and automatic digitizing.

Manual digitizing

In manual digitizing, the contour and filling stitches are the two main stitch lines. The contour stitch (figure 5) outlines the delineation of the object. The filling stitch (figure 6) is a surface stitch used to fill the embroidered object, parts of it, or the background. There is no specific stitch, which can be indicated as a "filling stitch", as the user himself chooses each step and direction of the single stitch.

Automatic digitizing

In automatic digitization the embroidery object is firstly divided into single stitches, a group of stitches and blocks.

Single stitches

Figure 7 illustrates the single stitches in an embroidery detail. Two types of single stitches can be distinguished:

- Strengthening stitches. These stitches are placed at the beginning and the end of the stitch line, being: * Starting lock stitch and * End lock stitch.
- Jumping stitches. They assure the transition from one object to another with (or without) the formation of stitch lines. In the modern machines, the program automatically generates the jumping stitches, following the embroidery sequence and objects' start and end. They can be stitched from one point to another or in the form of a straight stitch with a set pitch.

Group of several stitches

In accordance with their application in the embroidery design, the stitch rows that are formed by groups of several stitches are divided into three groups: underlay stitches, compensatory stitches, and covering stitches. The underlay stitch lines play a crucial role in machine embroidery, as the quality of the embroidery obtained depends on them. They remain hidden beneath the surface of the embroidery but assure the stability, volume, density, accuracy, and clear image of the embroidery. Calculating the exact number and type of the underlay stitches and their respective density is an essential step in the process of digitization. The basic rule is that the direction of the underlay stitch line must be at a different angle from that of the outer covering stitch lines to balance the structure and prevent the single stitches from sinking. The underlay stitches are of different types, namely: * Central Run (figure 8): a straight lock stitch line with trajectory following the centerline of the object. It is applied to objects with a small width (columns) or in combination with other types of underlay stitches. * Edge Run (figure 9): a straight lock stitch line for outlining the contours of the object. It is used for objects of small width or in combination with other

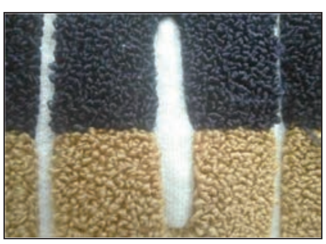

Fig. 4. Chenille embroidery

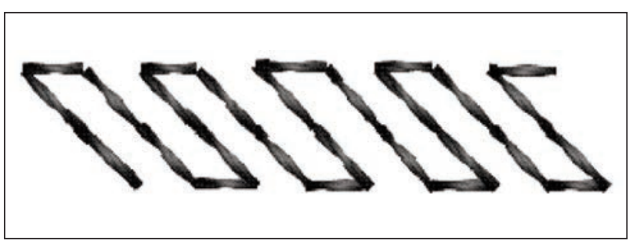

Fig. 5. Contour stitch

Fig. 6. Filling stitch

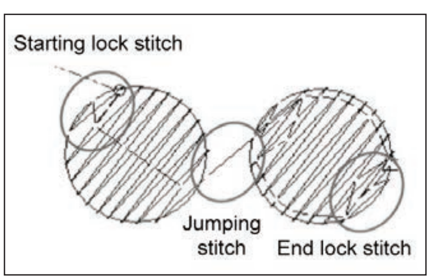

Fig. 7. Single stitches

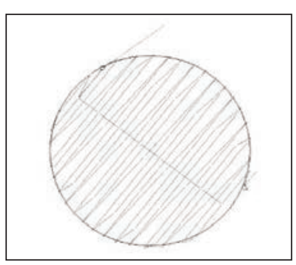

Fig. 8. Central run underlay stitch line

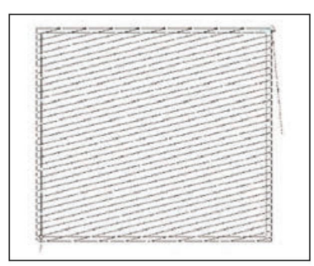

Fig. 9. Edge run underlay stitch line

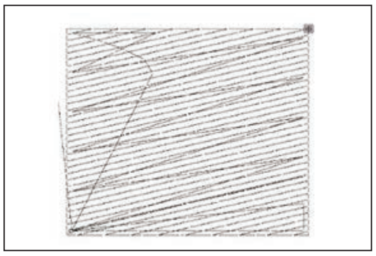

Fig. 10. Zigzag underlay stitch line

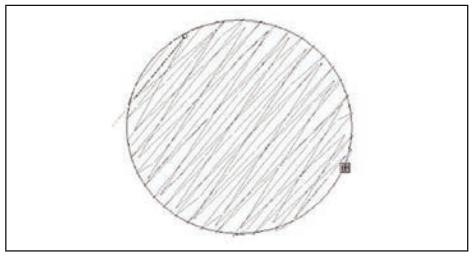

Fig. 11. Double Zigzag underlay stitch line

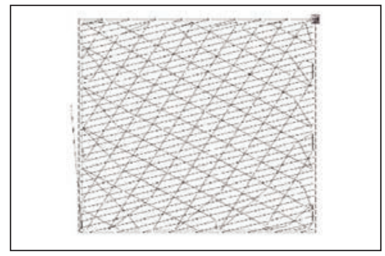

Fig. 12. Weave underlay stitch line

types of underlay stitches. * Zigzag (figures 10 and 11): it is particularly suitable for objects, made with covering stitches. It can also be used in combination with other underlay stitches. * Weave (figure 12): Similarly to the zigzag stitch, it is used in objects, where covering stitches are applied. Suitable for combination with other types of underlay stitches.

The second group of stitches is called "compensatory", because they serve to compensate for possible differences in the sizes of the virtual and real embroidered objects that result from the fabric deformation. For example, when embroidering on cotton fabrics, about 2% stitches are added, which should cover the difference in the size obtained.

The third group, called "covering" stitches, can be divided into two sub-groups, depending on their role in the embroidery and the way of arrangement of the stitches: fill covering stitches and contour covering stitches. The first sub-group involves the stitches that fill the objects in the embroidery. They are used for embroidering large-area objects. The fill covering stitches are stacked close to one another at a certain angle so that complete surface coverage can be achieved. The density of the stitches can vary to achieve a number of effects.

The fill covering stitches give the embroidery a flat appearance and have less shine than the satin stitch line, but they can fill areas of much larger size without producing a wavy surface, which could be the case with satin. The stitch line can be changed by varying the distance and alignment of the individual stitches, as well as the length of the stitch.

Depending on the strategy of filling, the fill covering stitches can be for: * Gradient fill (figure 13): the object is divided into different zones, filled in with different densities of the stitch lines. The distribution of the zones can be various, depending on the object and the design vision: * Uniform fill (figure 14): the density of the stitches has a constant value for the whole object; * Diametrical fill (figure 15): the strategy is to follow the contour (diameter) of the object; * Radial fill (figure 16): the stitch line goes from the center to the contour of the object (following the radius); * Spiral fill (figure 17): the covering stitches follow a spiral line; * Concentric fill (figure 18): the covering paths are concentric circumferences; * Shortest path: this strategy is based on finding the shortest path for covering the object with a specific geometry; * Fill with constant stitch length: the filling is carried out with a constant value of the step of the stitch line; * Fill with variable stitch length (figure 19): a variable value of the step of the stitch line is used, according to the stitch line's trajectory; * Fill with stipping stitches (figure 20): this strategy is borrowed

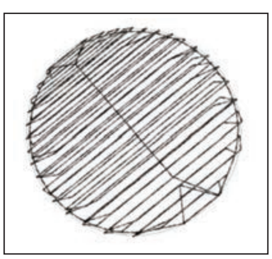

Fig. 13. Gradient fill (with weave)

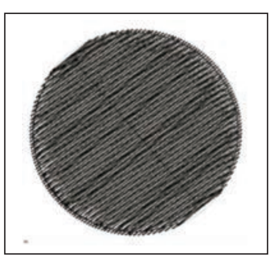

Fig. 14. Uniform fill (with weave)

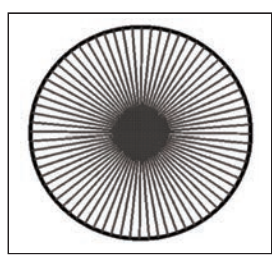

Fig. 15. Diametric fill

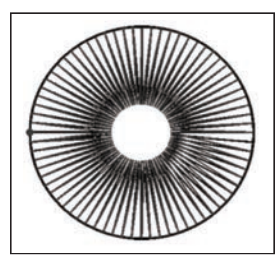

Fig. 16. Radial fill

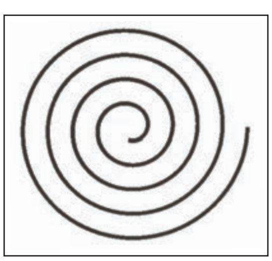

Fig. 17. Spiral fill

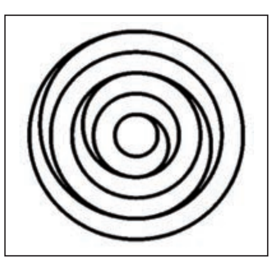

Fig. 18. Concentric fill

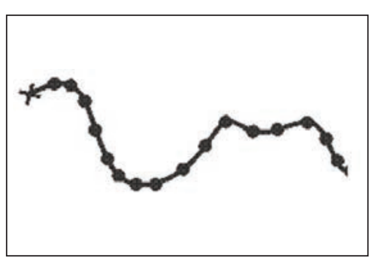

Fig. 19. Fill with variable stitch length

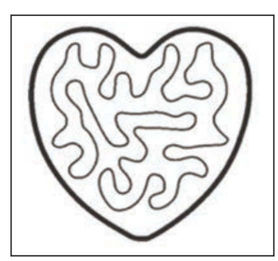

Fig. 20. Fill with stipping stitches

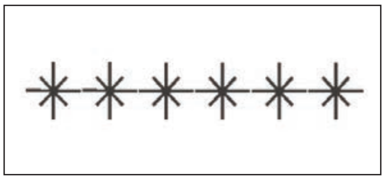

Fig. 21. Star stitch line

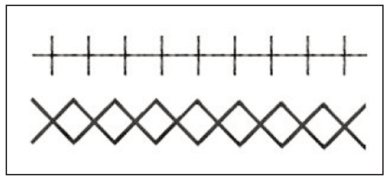

Fig. 22. Cross stitch line

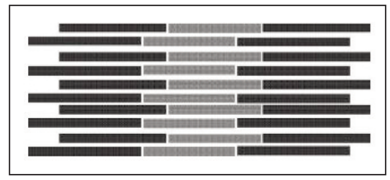

Fig. 23. Short and long stitch line

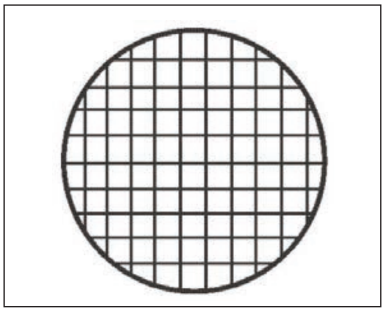

Fig. 24. Net stitch line

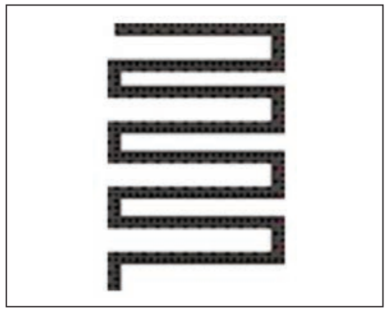

Fig. 25. Piping stitch line

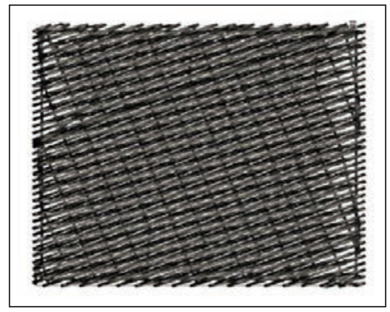

Fig. 26. Fill weave stitch line

from the quilting and is applied when layers of a textile system are joined together. It is usually performed with a running stitch line, so that the zones, divided by the stitch line to have approx. the same width.

Depending on the way of the stitches arrangement, the fill covering stitches can be: * Star stitch line (figure 21): the stitch is borrowed from the hand embroidery; * Cross stitch line (figure 22): it is also typical for the hand embroidery; * Short and long stitch lines (figure 23): the alternation of short and long stitches creates a gradual overflow that has also root in the hand embroidery; * Net stitches (figure 24): these are new machine embroidery lines that form a net (mesh), 3D visual effects can be obtained using different dimensions of the squares; * Piping stitches (figure 25): a new stitch line, typical for the machine embroidery; * Weave (figure 26): a covering stitch line, also known as "tatami", used for large objects.

The second sub-group involves stitches, used for covering embroidery objects with a small width, up to 20 mm. They involve:

- Satin stitch line (figure 27): The satin (or column) stitch line is hugely suitable for lettering and contouring. The single stitches are stacked side by side, following an arbitrary line, always remaining perpendicular to the axis. Theoretically, it is suitable for objects smaller than 20 mm (in width), but practically they should be less than 12 mm. Otherwise, the stitches become loose and can be easily damaged. Designers use the satin to enhance the object's dimensions due to the better light reflection.
- Zigzag stitch line (figure 28): it differs from satin only in the density of the stitches.

Fig. 27. Satin stitch line

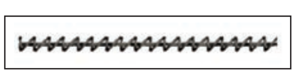

Fig. 28. Zigzag stitch line

- Stem stitch line: similar to satin but the embroidery path is at a certain angle concerning the single stitches.
- Straight stitch line: the straight lock stitch line usually consists of stitches of the same length, but through the software, the stitch length can be changed automatically when the shape of the contour is monitored. Different effects can be achieved by applying different stitching steps: the long stitches are shinier and smoother than the short ones that give a more rugged and tight embroidery look. The number of passes through an element can also vary to obtain thicker or thinner lines – single, double, or triple.
- E-stitches (figure 29): known as well as a "blanket stitch".
- Stitch line for feathered edge effect (figure 30): it creates a shading effect of the object, rough contours, and can be used for animal fur imitation.
- Split stitch line: it is similar to the stem stitch, with a more twisted appearance.

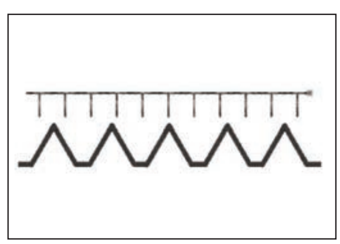

Fig. 29. E-stitches

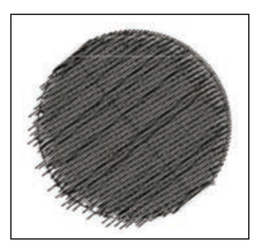

Fig. 30. Feathered edge effect

Group of many stitches (blocks)

The third group of automatically digitized embroidery stitch lines has the most complex organization of the stitches. The stitch lines form blocks and play the role of covering stitches, which form the contour of the embroidery objects or are used to fill them.

The fill covering stitches are again divided into two groups. Depending on the strategy of fill, the same types of blocks of stitches can be defined as for groups of several stitches: gradient fill, uniform fill, diametrical fill, radial fill, spiral fill, concentric fill, shortest path fill, and fill with constant stitch length and variable stitch lengths. Only the fill with stipping stitches is missing. Instead, two new possibilities appear: * Blocks of stitch lines, based on motifs, with constant size of the motif (figure 31) and * Blocks of stitch lines, based on motifs, with variable size of the motif (figure 32).

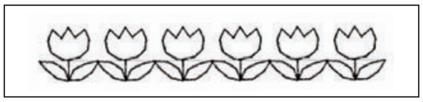

Fig. 31. Constant size motif filling

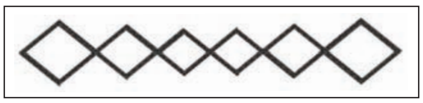

Fig. 32. Variable size motif filling

Depending on the way of arrangement, the blocks of fill stitches are: Motifs (figure 33): different motifs, organized in blocks, fill the surface of the object. Modern

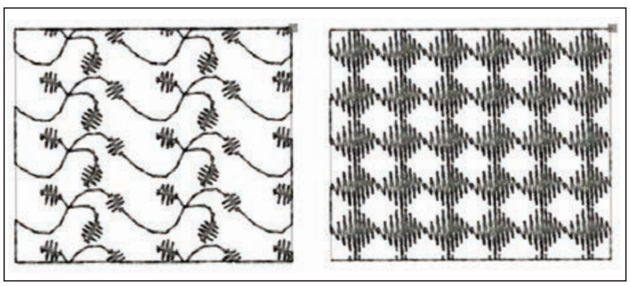

Fig. 33. Covering motifs

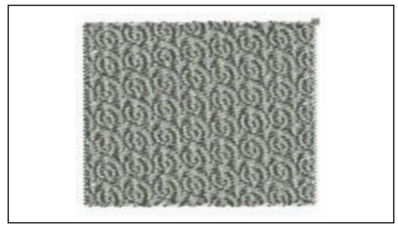

Fig. 34. Complex or emboss filling

software tools enable the creation of filling stitches in the form of smooth curved lines, resulting in the sense of increased contour and volume. Complex or embossed (figure 34): both the direction of the stitch rows and its density change horizontally and vertically. Thus, different visual effects are achieved.

Depending on the strategy of the fill, the contour covering stitch lines involve block stitches for gradient fill, uniform fill, stitch lines with constant and variable stitch length, as well as lines with constant or variable size of the motif, as in the case of fill covering stitches. It should be mentioned that some of patterns cannot be produced without stitching over existing stitches.

CONCLUSIONS

The proposed classification of the machine embroidery stitches allows a better understanding of the design abilities of different software products and embroidery machines. It helps both the learners and the experienced designers to orient in the possibilities for the creation of embroideries with a desired and unique look.

The classification can further be enlarged as the field of machine embroidering is among the fast-developing textile branches.

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REFERENCES

[1] Sofronova, D., *Opportunities of machine embroidery for creation of design interpretations*, In: Proceedings of 20th Int. Conf. of the FPEPM, Sozopol, Bulgaria, 2015, 272–278

[2] Juciene, M., Radaviciene, S., *Influence of embroidery threads on the accuracy of embroidery pattern dimensions*, In: Fibres & Textiles in Eastern Europe, 2012, 3, 92, 92–97

[3] Radaviciene, S., Juciene, M., Juchnevičienė, Ž., Čepukone, L., Vilumsone, A., Briedis, U., Baltina, I., *Analysis of shape nonconformity between embroidered element and its digital image*, In: Materials Science, 2014, 20, 1, 84–89

[4] Juchnevičienė, Ž., Juciene, M., Dobilaite, V., Saceviciene, V., Gulbiniene, A., *The Research on the Accuracy of the Geometrical Parameters of the Closed-Circuit Embroidery Element*, In: Materials Science, 2018, 24, 4, 453–549

[5] Juchnevičienė, Ž., Jucienė, M., Dobilaitė, V., Sacevičienė, V., Radavičienė, S., *Analysis on the Conformity between the Closed-Circuit Embroidery Elements of Different Widths and the Digitally Designed Elements*, Autex Research Journal, 2019, 250–256, https://doi.org/10.1515/aut-2018-0047

[6] Radaviciene, S., Juciene, M., Juchnevičienė, Ž., Čepukone, L., Kleveckas, T., Narviliene, V., *The influence of the properties of embroidery threads on buckling of fabric inside of the embroidered element*, In: Materials Science, 2012, 18, 4, 373–378

[7] Juciene, M., Radaviciene, S., Saceviciene, V., Adaškevicius, R., Petraitiene, S., *The research on surface non-uniformity of textile systems*, In: Int. Journal of Clothing Science and Technology, 2016, 28, 1, 36–46

[8] El-Kateb, S.N., *An investigation of factors affect ends-down rate in embroidery machine*, In: Journal of American Science, 2015, 11, 6, 39–42

[9] Kuo, C.F.J., Juang, Y., *A study on the recognition and classification of embroidered textile defects in manufacturing*, In: Textile Research Journal, 2016, 86, 4, 393–408
[10] Sofronova, D., Angelova, R.A., *Classification of the embroidery defects*, In: Proceedings of 21st Int. Conf. of the Faculty of Power Engineering and Power Machines, Sozopol, Bulgaria, 2016, 196–201
[11] Wei, B., Hao, K., Tang, X. S., Ding, Y., *A new method using the convolutional neural network with compressive sensing for fabric defect classification based on small sample sizes*, In: Textile Research Journal, 2018, 0040517518813656
[12] Angelova, R.A., Sofronova, D., Nikolova, V., *A case study on the defects in industrial manufacturing of embroidered textiles*, In: Journal of Multidisciplinary Engineering Science and Technology, 2016, 3, 12, 2458, 9403
[13] Mecnika, V., Hoerr, M., Krievins, I., Jockenhoevel, S., Gries, T., *Technical embroidery for smart textiles*, In: Materials Science. Textile and Clothing Technology, 2014, 9, 56–63
[14] Zhang, L., Wang, Z., Volakis, J.L., *Embroidered textile circuits for microwave devices*, In: Proceedings of the 2012 IEEE International Symposium on Antennas and Propagation, 2012, 1–2
[15] Radavičiene, S., Jucienė, M., Sacevičiene, V., Sacevičius, R., Otas, K., Investigation and assessment of photoluminescent embroidered elements, In: Int. Journal of Clothing Science and Technology, 2014, 26, 1, 38–47
[16] Åkerfeldt, M., Lund, A., Walkenström, P., *Textile sensing glove with piezoelectric PVDF fibers and printed electrodes of PEDOT: PSS*, In: Textile Research Journal, 2015, 85, 17, 1789–1799
[17] Wang, Z., Lee, L.Z., Psychoudakis, D., Volakis, J.L., *Embroidered multiband body-worn antenna for GSM/PCS/WLAN communications*, In: IEEE Transactions on Antennas and Propagation, 2014, 62, 6, 3321–3329
[18] Simorangkir, R.B., Yang, Y., Esselle, K.P., *Double-layer embroidery strategy for fabrication of textile antennas with improved efficiency*, In: 17th International Symposium on Antenna Technology and Applied Electromagnetics (ANTEM), 2016, 1–2
[19] Briedis, U., Valisevskis, A., Grecka, M., *Development of a smart garment prototype with enuresis alarm using an embroidery-machine-based technique for the integration of electronic components*, In: Procedia Computer Science, 2017, 104, 369–374
[20] Juchnevičienė, Ž., Briedis, U., Vališevskis, A., Jucienė, M., Dobilaitė, V., Sacevičienė, V., *Electrical conductivity of a closed-circuit embroidery element*, In: Proceedings of the Estonian Academy of Sciences, 2018, 67, 2, 158–164
[21] Sofronova, D., Angelova, R.A., *Analysis of the types of digital stitches in machine embroidery*, In: Proceedings of 22nd Int. Conf. of FPEPM, Sozopol, Bulgaria, 2017, 132–136
[22] Start, B., *Brokerage of embroidery capacity*, In: Eurostitch Magazine, 2001, 9, 48, 34–39
[23] Ripka, G., Mychko, A., Deyneka, I., *The analysis of machine embroidery stitches types classification*, In: Teka Komisji Motoryzacji i Energetyki Rolnictwa, 2014, 14, 2
[24] Chernenko, D.A., *Systematization of the design parameters of the automated embroidery and modeling of the deformation of the system “cloth-embroidery”*, PhD, Orel State Technical University, Russia, 2006, 120

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Open hole size effects on tensile properties of 3D braided composites

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ABSTRACT – REZUMAT

Open hole size effects on tensile properties of 3D braided composites

Owing to the excellent integrated structure, notch-insensitivity, delamination-free characteristics, 3D braided composites have a broad range of engineering applications. In this paper, the notch size effects on two types of 3D braided composites were experimentally examined. Style I incorporated 40% of longitudinal lay-in yarns. Style II was the pure braids. The Point Stress Criterion (PSC) was applied to predict the open-hole strength of 3D braided composites. It is found the 3D braided composites can keep higher proportion residual strength after involving the different circular hole sizes compared to plain woven laminates. The open-hole pure braided specimen shows better performance than that the braids with longitudinal yarns, the lay-in longitudinal yarns improve neither specimens' un-notched strength, nor the modulus. The predicted open-hole strength were compared with experimental results. The traditional analytical method can predict the open-hole strength of 3D braided composite to some extent. Under uniaxial tensile stress, the failure behaviour of two types of 3D braided specimens are different. For un-notched specimen, clear cracks usually show up on the Style II specimen, while it is not true for Style I coupon. For notched specimen, the crack of both notched specimens will propagate along the notch and finally render the specimen to fail.

Keywords: *3D braided composite, open-hole size, Point Stress Criterion, failure, strength prediction*

Influența dimensiunilor orificiilor asupra proprietăților de tracțiune ale compozitelor împletite 3D

Datorită structurii integrate excelente, insensibilității canelurilor, caracteristicilor fără exfoliere, compozitele împletite 3D au o gamă largă de aplicații inginerești. În această lucrare, efectele dimensiunii canelurilor au fost examinate experimental pe două tipuri de compozite împletite 3D. Tipul I a inclus 40% din firele de umplutură longitudinale. Tipul II a fost reprezentat de împletiturile propriu-zise. Point Stress Criterion (PSC) a fost aplicat pentru a preconiza rezistența orificiului deschis al compozitelor împletite 3D. Se constată că, compozitele împletite 3D pot păstra o rezistență reziduală proporțională mai mare după implicarea diferitelor dimensiuni ale orificiilor circulare în comparație cu țesăturile simple laminate. Proba împletită propriu-zisă cu orificii deschise prezintă performanțe mai bune decât cea împletită cu fire longitudinale, firele longitudinale de umplutură nu îmbunătățesc nici rezistența probelor și nici modulul. Rezistența preconizată a orificiilor deschise a fost comparată cu rezultatele experimentale. Metoda analitică tradițională poate preconiza într-o oarecare măsură rezistența orificiului deschis al compozitului împletit 3D. În condiții de tensiune uniaxială, comportamentul la deteriorare al celor două tipuri de probe împletite 3D este diferit. Pentru proba fără caneluri, fisurile clare apar de obicei pe proba tip II, dar nu apar pe proba tip I. Pentru proba cu caneluri, fisura ambelor probe se va propaga de-a lungul canelurii și, în cele din urmă, va duce la deteriorarea probei.

Cuvinte-cheie*: compozit împletit 3D, dimensiunea orificiului deschis, Criteriul de stres punctual, deteriorare, preconizarea rezistenței*

INTRODUCTION

Braided composites have gained considerable attention over the past years in a variety of applications, e.g. airframe spars, fuselage frames, rocket nose cones, ship propeller blades, engine nozzles, biomedical devices, etc. [1–3]. Compared to conventional unidirectional and woven laminate composites, the sustained interest in 3D braided composites can be attributed to the proven damage tolerance [4], delamination-free characteristics, and an ability to create net complex shape structures in a digitally controlled manner [5]. One of the most earlier studies of the structural properties of 3D braided composites was carried out by Gause and Alper [6]. In their study they evaluated a wide range of the static and dynamic mechanical properties of 3D braided composites including open hole static strength and tensile fatigue behaviour, they demonstrated that the 3D braided composites are notch (open hole) insensitive. Du and Ko [7] first examined 3-D braiding methods in the light of braid structures, followed by the development of geometric models for 3D braids using a unit cell approach. Portanova et al. [8, 9] examined the fatigue properties of un-notched 3D braided composites, it was found the residual fatigue life of 3D braided composite was sufficient to satisfy current composite damage tolerance design criteria.

One of the key considerations in the design of composite aircraft structures is the ability of the composite

to tolerate damage created during manufacturing, like drilling holes. It is an important issue for composite structure design to predict the open hole strength accurately. Lot of studies have been done on open-hole effects on laminated composite. Whitney and Nuismer [10, 11] proposed approximate solution to calculate the normal stress distribution adjacent to a circular hole in an infinite orthotropic plate was present in the form of polynomial. Norman and Anglin studied how open hole affects failure in 2D braided textile composite materials under tensile loading. They found un-notched tape equivalents are stronger than braided textiles but exhibited greater notch sensitivity. Notch strength could not be predicted using existing anisotropic theory for braided textiles. Damage initiation stress decreases with increasing braid angle [12]. Hwan and Tsai [13] studied the notched strengths of three kinds of braided composite plates with a centre hole, also point stress criterion (PSC) and average stress criterion (ASC) were applied to predict the strength of 2D braided composite plate with different sizes of the hole. Kohlman and Bail gave a notched coupon geometry method for tensile testing of 2D triaxial braid composites, which they claim the notch specimen is easier to fabricate [14].
Although many references with regard to hole size effects on laminates and notched strength prediction of laminated composites have been found and briefly introduced above, up to now, limited studies are available in the literature to study the effects of notch size on 3D braided composites. Accordingly, the objective of this study is to experimentally study the open hole sizes effects on 3D braided composites. The traditional analytical PSC criterion was also used to predict the open-hole strength of 3D braided composites

EXPERIMENTAL AND THEORETICAL METHODS

Material

HEXCEL AS4 6K carbon yarns are used as reinforced material, an epoxy system consisting of West System 105 resin and 209 curing agent (mix ratio = 3.68:1 by weight) was used as matrix material. According to the manufacturing datasheet, the properties of matrix and yarns are shown in table 1.

Table 1

PROPERTIES OF MATRIX AND CARBON FIBRE

Properties	Matrix	AS4-6k
Tensile modulus (GPa)	2.74	231
Tensile strength (MPa)	51	4447
Strain (%)	3.6	1.7
Density (g/m^3)	1.16	1.78

3D braided preforms were produced on a Cartesian four-step 3D braider. Two types of the braided preforms were fabricated. Style I incorporated 42% of longitudinal lay-in yarns (totally 129 yarns). Style II was the basic (1×1) pattern, with 124 yarns. The 3D braided preforms have a surface braiding angle of ±20°, and the actual cured braided specimen orientation is approximately ±18°, because of the compression in the closed mould during the curing process. The information of fabrics used in this paper are shown in table 2.
The dry preform was infused resin by RTM technology, a compressive mould was design for the sample manufacturing. Then, the fully cured composite in the shape of rectangular bar having 25.4 mm width was released from the mould. The volume fraction of the specimen was determined by measuring the density the coupon. For un-notched samples, the experimentally measured fibre volume fraction was 58% for Style I and 60% for Style II coupons.

Table 2

FABRICS USED AS REINFORCED IN THE 3D BRAIDED COMPOSITE

Fabric structure	No. of layers	No. of yarns	Dimension (mm)	Braiding angle (°)
Style I	4	129	25.4 by 3 ± 0.1 by 250	±20±1
Style II	5	124	25.4 by 2.9 ± 0.1 by 250	±20±1

The 3D braided composite are sensitive to the edge cutting for the cutting along the braiding direction will break the integrated characteristic of 3D braided specimen [15]. So all the preforms are fabricated with width closed to 25.4 mm, and thus avoid cutting from big panel. The different series of holes were drilled at the centre of the specimen using special CBN diamond core drill bits. The dimension of un-notched specimen is same with the notched one. For small hole sample preparation, the tab were bonded to the end of the coupon to avoid the sample break inside the clamps when do the test. While it is no need to bond the ta for large circular hole size specimen, it is already involved large stress concentration. The unit cells for Style I and Style II specimen are shown in figure 1. Photographs of cross-sectional areas of Style I 3D braided specimen were shown in figure 2.

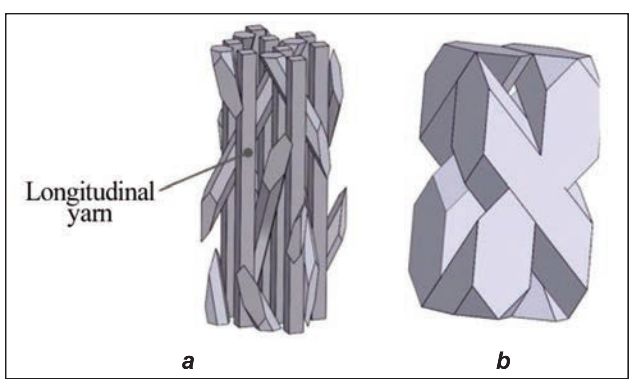
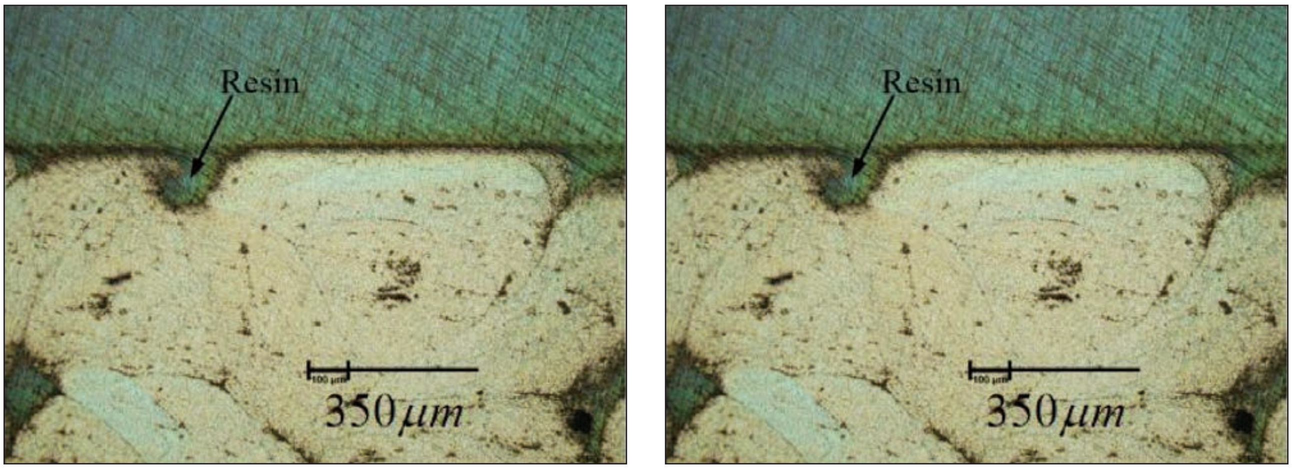


Fig. 1. Unit cell of 3D braided specimens:
a – Style I; *b* – Style II



a *b*

Fig. 2. Photographs of cross-sectional areas of 3-D braided composite: *a* – Style I; *b* – Style II

The yarn cross section of pure braids is usually more uniform than Style I with axial yarns. The Style I has more resin rich area in the interlacing area than Style II, resin rich areas usually appear on yarn interlacing area.

Testing method

The static un-notched tensile strength and notched are conducted according to the ASTM D3039 and ASTM D5766, respectively. For each group tests, 5 samples were tested to obtain the mean tensile strength, with cross-head moving rate of 2 mm/min. All the specimens were tested on a MTS servo-hydraulic mechanical testing unit under constant displacement rate of 2 mm/min. The test equipment and painted specimen were shown in figure 3.

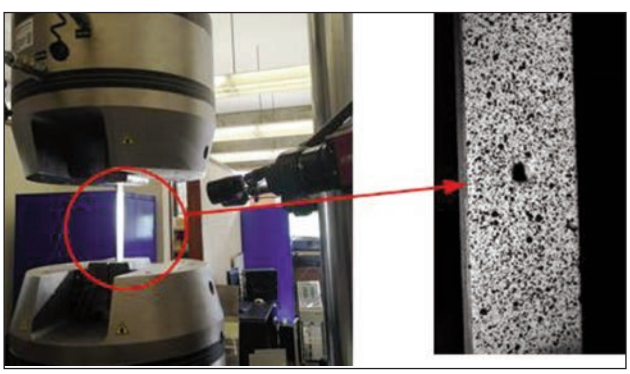


Fig. 3. The testing equipment

Notched specimen strength prediction

The 3D braided plate can be taken as orthotropic material. The notched tensile strength of the 3D braided composite were predicted following Point Stress Criterion (PSC) proposed by Whitney et al. [10, 11, 16], based on the stress distribution adjacent to the notch. In this criterion, failure is assumed to occur when the stress σ_y at some fixed distance (d_0) ahead of the notch becomes equal to the un-notched strength (σ_0) of the material. For a circular hole, the failure occurs according to the following equations:

$$\sigma_y(x,0)\big|_{x=R+d_0} = \sigma_0 \qquad (1)$$

For an infinite orthotropic plate containing a circular hole of radius R and subjected to uniform stress σ applied parallel to the y-axis at infinity, the normal stress (σ_y) along to the x-axis ahead of the hole can be expressed approximately by:

$$\sigma_y(x,0) = \frac{\sigma}{2}\left[2 + \left(\frac{R}{x}\right)^2 + 3\left(\frac{R}{x}\right)^4 - (K_T - 3)5\left(\frac{R}{x}\right)^6 - 7\left(\frac{R}{x}\right)^8\right], \quad x > R \qquad (2)$$

where K_T is the stress concentration factor for an infinite orthotropic plate [17]. The notched strength of an infinite width plate can be predicted by:

$$\sigma_N = 2\sigma_U / [2 + A^2 + 3A^4 - (K_T - 3)(5A^6 - 7A^8)] \qquad (3)$$

where σ_N, σ_U is the notched strength and un-notched tensile strength of the plate, respectively. The characteristic lengths d_0 = 1 were chosen, as suggested by Nuismer et al. [16]:

$$A = R / (R + d_0) \qquad (4)$$

RESULTS

This section presents results of the un-notched and notched tensile test of the specimens, also the comparison with the published 3D braided composite and laminates. The failure behaviour of notched and notched coupons of 3D braided composites were also observed.

Comparison with laminates

Figure 4 shows the stress-strain curve of the two types of un-notched samples up to failure, the stress-strain curve measured by DIC. The two types of braids show close strength and modulus, the adding axial yarn improve neither the modulus nor the strength. It is due to the adding yarn affect and volume fraction difference of the specimen. The natural behaviour of the lay-in yarn along the braiding direction in the preform is straight, whereas after the sample

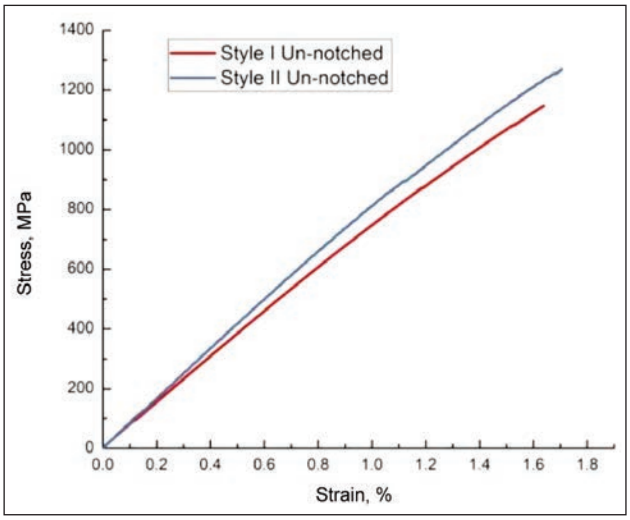


Fig. 4. Un-notched 3D braided composite quasi-static tension tests: stress vs. strain curves

cured in the compressive mould, the adding axial yarn may not straight, which should be observed using CT regeneration technology in the future. Also the adding in-lay yarn decreases the volume fraction of the coupon, as shown in figure 2. The DIC strain field of Style II sample with 5 mm hole at 50 KN was shown in figure 5. Figure 5 presents the shear strain ε_{xy}, longitudinal (loading direction) strain distribution ε_{yy} and transverse strain distribution ε_{xx}, respectively. It is found the existence of hole affect the strain distribution near the hole.

Figure 6 shows the comparison of measured mechanical properties of the un-notched 3D braided composite and notched with a hole of 5 mm and published results on 3D braided composite and lamination composites with plied angle (±20°). The four columns on left hand represent the 3D braided specimen; the right hand corresponds to laminates. It is found the tensile strength of the entire notched 3D braided composite is higher than that of laminated composites. It found the 3D braided composite at low braiding angle can contain damage better than laminates with similar plied angle. The 18-ply (0±20°) laminates [18] have the similar tensile strength with present results, after drilling the hole, the laminates can only keep 58% of the tensile strength, while the present both 3D braided composites can keep 74–79% of the tensile strength. This confirms that the 3D braided composites are less notch sensitive than laminated composites [4, 6]. The present two types of 3D braided specimen with or without longitudinal yarns shows similar modulus and failure strength under low braiding angle.

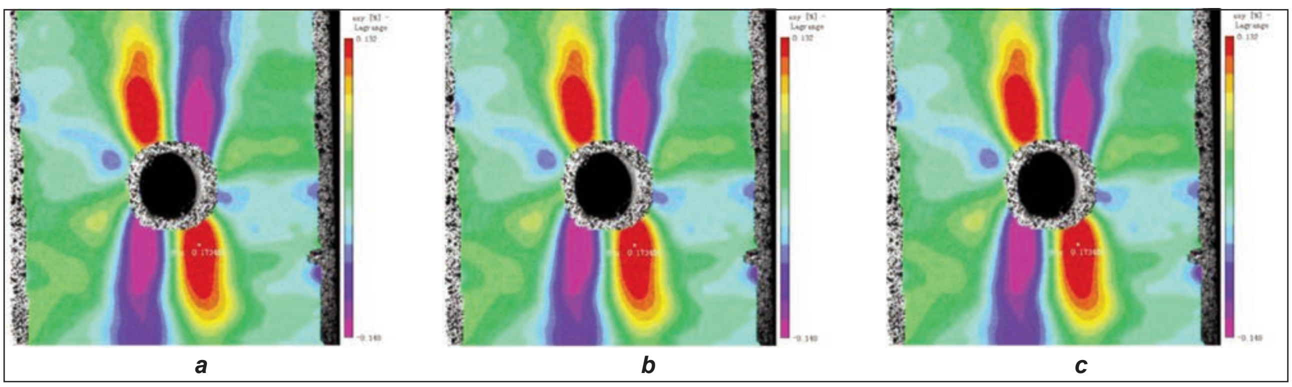


Fig. 5. DIC strain filed at 50 KN for Style II notched 3D braided specimen: *a* – ε_{xy}; *b* – ε_{yy}; *c* – ε_{xx}

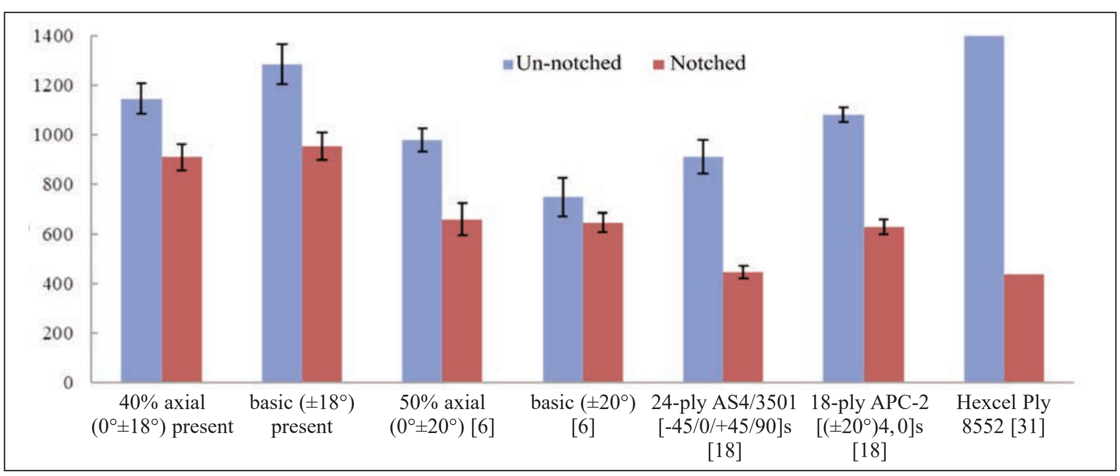


Fig. 6. Mechanical properties of the 3D braided composite and laminates

Hole size effects

Typical tensile load versus displacement curve of Style I and Style II 3D braided specimen are shown in figure 7. Although involving different hole size, the both braids still show similar slope, as talked before, the two types of braided composite have similar modulus and strength. The different series of hole sizes affect the failure strength and failure elongation significantly. As expected, the sample failed earlier when involved large size open circular hole. Table 3 summarized the tension strength with different hole size of 3D notched and un-notched braided composite. Each result was from five different specimens for 3D braided composite. σ_N is notched strength, σ_U is un-notched strength. The experimental results presented in table 3 clearly identify the size effects on 3D braided composites: an increase of the hole diameter from 2.8–11.2 mm result in a reduction in the strength of 44%.

Table 3

STRENGTH OF 3D NOTCHED AND UN-NOTCHED COMPOSITE

W (mm)	2R/W	2R (mm)	σ_N / MPa	STDV (MPa)	σ_N / σ_U
Style I σ_U = 1147 MPa E_x = 70.5 GPa	0.12	2.8	1006	68	0.87
	0.19	5	900	57	0.78
	0.31	7.85	670	49	0.58
	0.39	9.74	573	42	0.49
	0.45	11.2	500	43	0.46
Style II σ_U = 1287 MPa E_x = 75.2 GPa	0.12	2.8	1100	60	0.87
	0.19	5	970	45	0.77
	0.31	7.85	786	52	0.62
	0.39	9.74	674	45	0.53
	0.45	11.2	582	48	0.47
Laminates [19] σ_U = 581.2 MPa	0.05	1.0	532.2	-	0.88
	0.10	2.0	454.0	-	0.773
	0.20	4.0	388.8	-	0.639
	0.40	8.0	326.4	-	0.410
	0.50	10.0	321.8	-	0.318

The results were compared to plain woven laminates (V_f = 60%) [19], the both types of 3D braids show better performance. The laminates can only keep 32% of the un-notched strength when the hole diameter to width ratio is 0.5, while the both 3D braids can keep more than 46% of the original strength [19]. The final strength of 3D braided composites is also much higher than plain woven laminates. For woven laminates, the final open-hole strength is only 321 MPa, while the braids can retain more than 500 MPa of the strength.

The predicted notched value and comparison with experimental results are presented in figure 8, *a*. The hole size effects on different fibre architecture in the 3D braided composite are different. The pure braided composite can retain higher proportion of the notched strength than the specimen with axial yarn, with all series of circular hole size. The 3D braided composite having longitudinal yarns are sensitive to hole size, compared to pure braids. For un-notched strength prediction, the FGM were followed. It was found the predicted un-notched strength is quite close to the experimental value. For notched strength prediction, when the characteristic lengths d_0 is 1 [16], the traditional analytical method can predict the reduction trend of notched strength of 3D braided composite to some extent. However, to predict the open-hole strength of 3D braided composites accurately, the model needs to be modified and improved, more work need to done on this method.

The relation between the normalized notched strength and the ratio between the hole diameter is

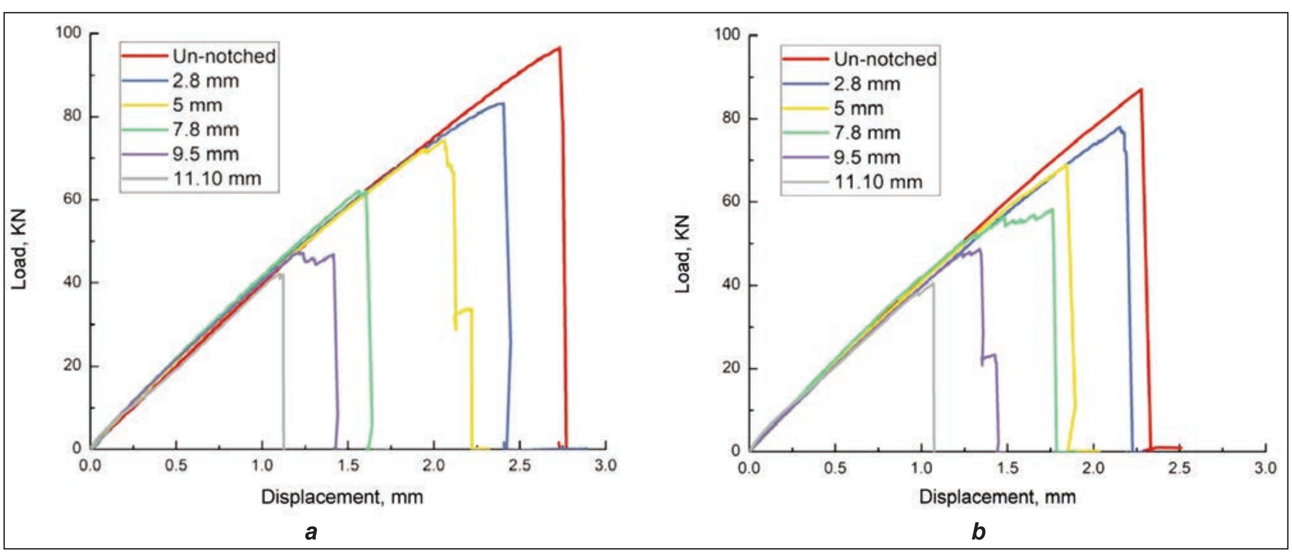


Fig. 7. Notched specimen Load vs Displacement curves: *a* – Style I; *b* – Style II

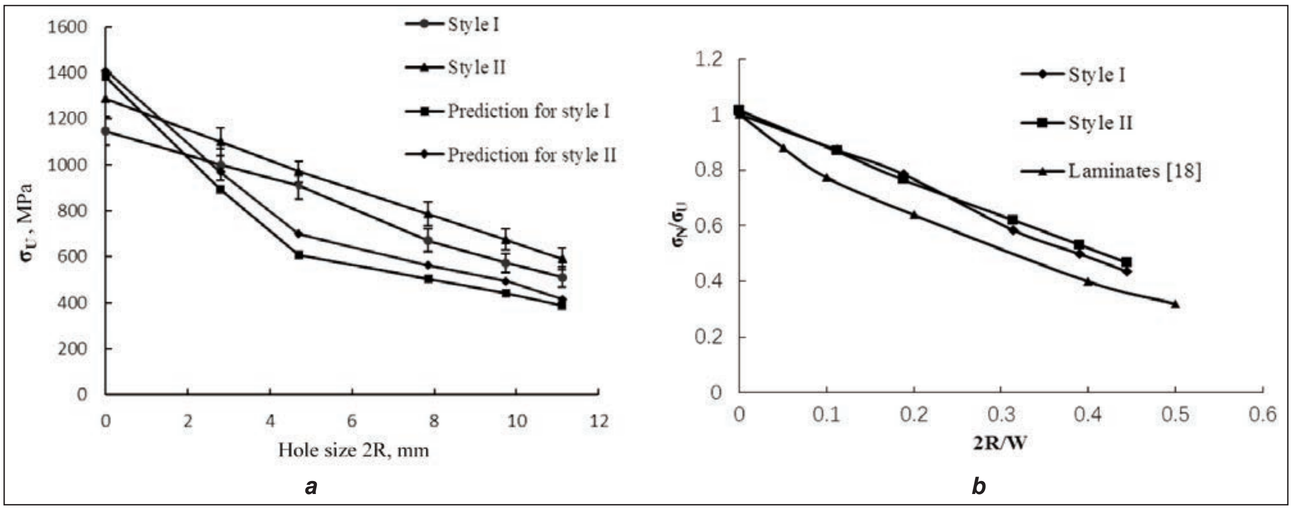


Fig. 8. Comparison of: *a* – the experimental and predicted notched strength of 3D braided composites; *b* – normalized notched strength versus hole size to width ratio

shown in figure 8, *b*. Also the data from paper was present to do the comparison with the 3D braided composite. As the open-hole size increases, the both braids lose strength in similar trend, the final notched strength of Style I is still lower than basic pattern. Compared to woven laminates, the both two types of 3D braided composites show better performance and higher notched strength than laminates. The 3D braids are less insensitive to the circular hole size compared to woven laminates.

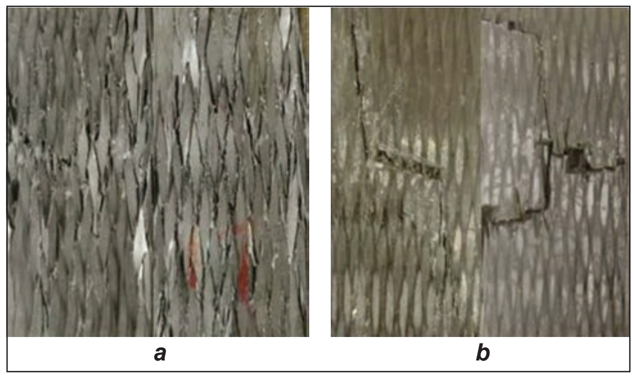


Fig. 9. Photographs of un-notched 3D braided specimens after the tensile tests: *a* – Style I; *b* – Style II

Failure behaviour

In this part, the failure behaviour of un-notched and notched specimens of 3D braided composites are presented. Figure 9 show the photographs of un-notched specimens for Style I and Style II after the tension test, respectively. The two types of un-notched 3D braided coupons perform different failure behaviour, fibre architecture in the 3D braided composite was found to play a significant role in the damage resistance of the composite. The pure braids tend to show clear cracks, while it is not true for the samples with longitudinal yarn, as shown in figure 9. It is mainly because the damage propagates the axial yarn direction. Figure 10 show the picture of the specimens with different hole size for Style I and Style II after tensile test. Compared with un-notched failure shape, the both notched specimen show consistent failure shape, failure always originated from the hole edge and along the braiding angle direction, finally rendering failure of the specimen, whereas clear crack still show up on pure braided coupons, but not for samples with axial yarn.

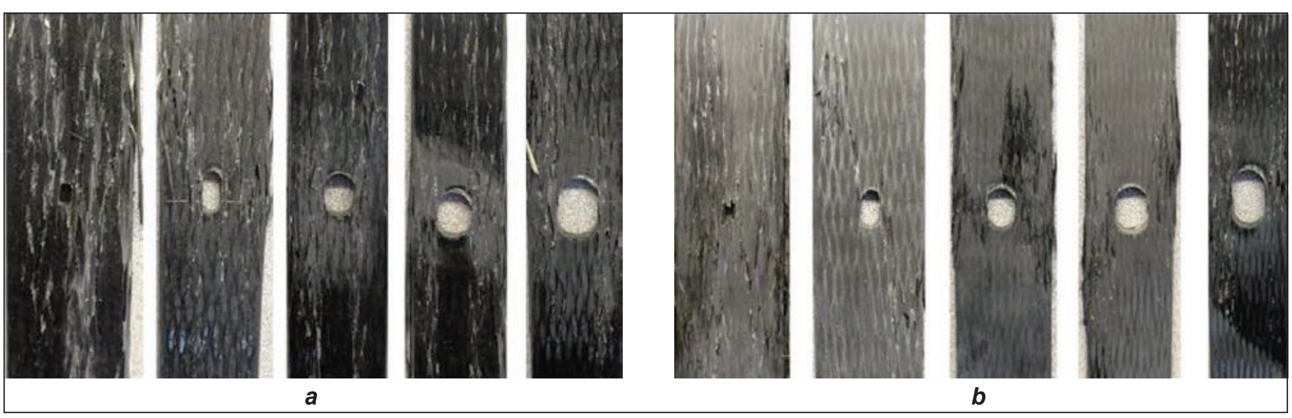


Fig. 10. Photographs of notched 3D braided specimens with different hole size after the tensile tests: *a* – Style I; *b* – Style II

CONCLUSIONS

In this paper, the notch size effects on two types of 3D braided composites were experimentally examined, the results were compared to plain woven laminated composites. It is found the 3D braided composites can keep higher proportion residual strength under tension loading after involving different series of open hole compared to laminates with same plied angle. The open-hole pure braids show better performance than that the braids with longitudinal yarns, the lay-in longitudinal yarns improve neither specimens' un-notched strength, nor the modulus. Considering the time consuming for the complex preform with axial yarn, the pure braids will be the right option for 3D braided structure design. The PSC criterion was applied to predict the open-hole strength of 3D braided composite, the predicted value were compared with experimental results. The traditional analytical method can predict the open-hole residual strength of 3D braided composite to some extent, more study should be done on this work in the future.

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REFERENCES

[1] Mouritz, A., Bannister, M., Falzon, P., Leong, K., *Review of applications for advanced three-dimensional fibre textile composites*, In: Composites Part A: Applied Science and Manufacturing, 1999, 30, 12, 1445–1461
[2] Shivakumar, K., Cozart, A., *Analysis of 3-D braided composite ablative rocket nozzle*, In: ASME 2002 Joint US-European Fluids Engineering Division Conference, American Society of Mechanical Engineers, 2002
[3] Bilisik, K., *Three-dimensional braiding for composites: A review*, In: Textile Research Journal, 2013, 83, 13, 1414–1436
[4] Dow, M., Dexter H., *Development of stitched, braided and woven composite structures in the ACT program and at Langley Research Center*, 1997
[5] Ko, F.K., *Three-dimensional fabrics for composites*, In: Textile Structural Composites, Elsevier Science Publishers, 1989, 129–171
[6] Gause, L., Alper, J., *Structural properties of braided graphite/epoxy composites,* In: Journal of Composites, Technology and Research, 1987, 9, 4, 141–150
[7] Du, G., Ko, F.K., *Unit cell geometry of 3-D braided structures*, In: Journal of Reinforced Plastics and Composites, 1993, 12, 7, 752–768
[8] Portanova, M., *Fatigue resistance of unnotched and post impact (+/–30 deg/0 deg) 3-D braided composites*, 1994
[9] Carvelli, V., Pazmino, J., Lomov, S., *Quasi-static and fatigue tensile behavior of a 3D rotary braided carbon/epoxy composite*, In: Journal of Composite Materials, 2012, 47, 25, 3195–3209
[10] Whitney, J., Nuismer, R., *Stress fracture criteria for laminated composites containing stress concentrations*, In: Journal of composite materials, 1974, 8, 3, 253–265
[11] Konish, H., Whitney, J., *Approximate stresses in an orthotropic plate containing a circular hole*, In: Journal of Composite Materials, 1975, 9, 2, 157–166
[12] Norman, T.L., Anglin, C., Gaskin, D., Patrick, M., *Effect of open hole on tensile failure properties of 2D triaxial braided textile composites and tape equivalents*, 1995
[13] Hwan, C.L., *Strength prediction of braided composite plates with a center hole*, In: Journal of Composite Materials, 2011, 45, 19, 1991–2002
[14] Kohlman, L., Bail, J., Roberts, G., Salem, J., Martin, R., Binienda, W., *A notched coupon approach for tensile testing of braided composites*, In: Composites Part A: Applied Science and Manufacturing, 2012, 43, 10, 1680–1688
[15] Macander, A.B., Crane, R.M., Camponeschi, E.T., *Fabrication and mechanical properties of multidimensionally (XD) braided composite materials*, In: Composite Materials: Testing and Design (Seventh Conference), ASTM International, 1986
[16] Nuismer, R., Whitney, J.M., *Uniaxial failure of composite laminates containing stress concentrations*, In: Fracture mechanics of composites, ASTM International, 1975
[17] Tan, S.C., *Stress concentrations in laminated composites*, 1994
[18] Hua, C.T., Chu, J.N., Ko, F.K., *Damage tolerance of three-dimensional commingled PEEK/carbon composites*, In: Composite Materials: Testing and Design (Tenth Volume), ASTM International, 1992
[19] Kim, J.K., Kim, D.S., Takeda, N., *Notched strength and fracture criterion in fabric composite plates containing a circular hole*, In: Journal of composite materials, 1995, 29, 7, 982–998

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Production and analysis of electrospun PA 6,6 and PVA nanofibrous surfaces for filtration

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ABSTRACT – REZUMAT

Production and analysis of electrospun PA 6,6 and PVA nanofibrous surfaces for filtration

Electrospun nanofibrous surfaces were produced by using two different polymers (PA 6,6 and PVA) at three different levels of polymer feeding rate (0.2, 0.6 and 1.0 ml/h, respectively) and three different levels of production time in electrospinning (5, 10 and 15 minutes, respectively) and the effect of polymer type, polymer feeding rate and production time was determined by analyzing unit weight and thickness of the nanofibrous membranes as well as fibre fineness and pore size distributions. The results showed that much finer fibres were produced by PA 6,6 polymer compare to PVA. The minimum average fibre fineness was 150.96 nm (by PA 6,6 polymer; 0.2 ml/h; 5 min.) while maximum fibre fineness was 243.43 nm (by PVA polymer; 0.6 ml/h; 15 min.). Similarly, the pore sizes of nanofibrous surfaces produced by PA 6,6 were smaller compare to the ones produced by PVA polymer. The results also indicated that coarser fibres were produced as the polymer feed rate and electrospinning time increased. In the second part of the work, composite structures were obtained by combining nanofibrous surfaces with PP non-woven material and their air permeability and filtration efficiency by using an aerosol having 0.2–0.33 mm diameter range were analyzed. The air permeability of PA 6,6 nanofibrous surfaces were much higher compare to the ones produced by PVA and quite high filtration efficiency (99.901 %) was obtained with PA 6,6 nanofibrous surfaces. Also, potential of these nanofibrous surfaces was evaluated by analysing chemical groups eliminated following their exposure to cigarette smoke which was chosen as a specific case study.

Keywords: *electrospinning, nanofibre, PA 6,6, PVA, nanofibrous surface, filtration*

Producția și analiza suprafețelor nanofibroase electrofilate din PA 6,6 și PVA pentru filtrare

Suprafețele nanofibroase electrofilate au fost produse prin utilizarea a doi polimeri diferiți (PA 6,6 și PVA) la trei niveluri diferite de viteză de alimentare a polimerului (0,2, 0,6 și respectiv 1,0 ml/h), precum și trei intervale diferite de timp de producție în electrofilare (5, 10 și respectiv 15 minute), iar influența tipului de polimer, vitezei de alimentare a polimerului și timpului de producție a fost determinate prin analiza greutății unitare și a grosimii membranelor nanofibroase, precum și prin finețea fibrelor și distribuția mărimii porilor. Rezultatele au arătat că fibrele mult mai fine au fost produse din polimerul PA 6,6 comparativ cu PVA. Finețea medie minimă a fibrelor a fost de 150,96 nm (din polimerul PA 6,6; 0,2 ml/h; 5 min.), în timp ce finețea maximă a fibrelor a fost de 243,43 nm (din polimerul PVA; 0,6 ml h; 15 min.). În mod similar, dimensiunile porilor suprafețelor nanofibroase produse din PA 6,6 au fost mai mici în comparație cu cele produse din polimerul PVA. Rezultatele au indicat, de asemenea, că fibrele grosiere au fost produse pe măsură ce viteza de alimentare a polimerului și timpul de electrofilare au crescut. În cea de-a doua parte a lucrării, structurile compozite au fost obținute prin combinarea suprafețelor nanofibroase cu material nețesut PP, iar permeabilitatea acestora la aer și eficiența de filtrare au fost analizate prin utilizarea unui aerosol cu un interval al diametrului de 0,2–0,33 mm. Permeabilitatea la aer a suprafețelor nanofibroase de PA 6,6 a fost mult mai mare în comparație cu cele produse din PVA și s-a obținut o eficiență de filtrare destul de ridicată (99,901%) cu suprafețe nanofibroase de PA 6,6. De asemenea, potențialul acestor suprafețe nanofibroase a fost evaluat prin analiza grupurilor chimice eliminate în urma expunerii lor la fumul de țigară, care a fost ales ca studiu de caz specific.

Cuvinte-cheie*: electrofilare, nanofibră, PA 6,6, PVA, suprafață nanofibroasă, filtrare*

INTRODUCTION

A filter media is utilised to purify air that contains solid particles (virus, mine dust etc.) or liquid particles (evaporated water, chemical solvents etc.), therefore filtration is mainly a seperation process. The main aim of such surfaces developed for filtration is to have pore sizes as minimum as possible while providing maximum filtration efficiency during use. As a result, including the finest possible fibres in a filtration media has been one of the important criteria for efficient removal of the particles. In conventional fibre production methods, however, the fibre fineness usually varies between 10–50 μm while it might be reduced down to 3–8 μm by meltblown technique [1]. However, not only the fibre fineness but also the pore size in a filter media matters as indicated above, i.e. mesh pore size must be small or thick mesh is required to remove ultrafine particles so that a filtration fan can blow the air with high pressure [2]. On the other hand, small particles such as between 0.04–0.4 μm, are known as the most difficult to get caught during filtration. Therefore, developing a porous filtration mesh surface being able to catch particles of 0.3 μm and below at high efficieny has been a challenging issue. As a result, development of filtration surfaces including very fine fibres and also being able to catch such a small particles is a need for better filtration. In this respect, electrospun nanofibre membranes, which can replace glass fibres and charcoal filters as functional nanofibre based filters or functional nanofibre combinations [3], gained an important potential and have been used in air filtration during last 20 years while a filtration market up to 700 billion USDollar in 2020 was estimated indicating the potential in this field [4,5]. In this respect, there is also a continuous search for new production perspectives for electrospun nanofibres in filtration. Production of nonwovens from short electrospun poymer nanofibre dispersion [6]; production of ultrafine (33 and 120 nm) polyamide 6 nanofibre membranes formed with needleless electrospinning [7] or fabrication of flexible and strong carbon nanofibre (CNF) membranes by electrospinning capable of efficiently rejecting NP of different sizes and materials such as Au, Ag, and TiO_2 from aqueous solution [8] can be given as examples.

Mainly PAN based nanofibre membranes produced by electrospinning is developed for ultrafiltration and nanofiltration [9, 10] while potential of other polymers have also been explored. Tsai *et al.* analyzed filtration performance of electrospun Polycarbonate, PU ve PEO nanofibre surfaces having 100–500 nm fibre fineness and tested for 300 nm NaCl aerosols by comparing with conventional meltblown fabrics [11]. They reported filtration efficiency (78%) of 3 g/m^2 electrospun PEO is equivalent to that of 100 g/m^2 of uncharged meltblown fabrics. Similarly, Ahn et al. studied the performance of electrospun PA6 nanofibre surfaces at different unit weights including fibres of 80-200 nm and reported surfaces of 5.75 g/m^2 and 10.75 g/m^2 exhibit HEPA level filtration efficiency [12]. Qin and Wang reported high filtration efficiency of electrospun PVA nanofibre surfaces with average fibre diameter of 200 nm and average porosity of 740 nm when tested with NaCl areosols of 0.6 μm [13]. On the other hand, Guibo et al., reported high filtration efficiency of electrospun PA6 surfaces, which have average fibre fineness of 177 ± 39 nm and porosity of 147.4 ± 42.9 nm, reaching up to 99,98% efficiency levels produced at different electrospinning production times [4]. Li and Gao compared filtration efficiency of electrospun PVA nanofibre membranes produced at different concentrations and electrospinning production times [14]. The average fibre fineness was 92 ± 21 nm while they used 75 ± 20 nm NaCl particles at 32 lt/min airflow reporting 99.95% efficiency. Similarly, Hung reported higher filtration performance of PEO nanofibre surfaces with fibre fineness of 100–400 nm for aerosols of 50–500 nm compared to the microfibre surfaces [15]. Regarding PEO nanofibrous membranes, the effect of nanofibre packing density and nanofibre layer thickness on filtration performance was studied as well by electrospinning these fibres on a microfibre substrate having mean PEO fibre diameter of 208 nm [16]. The results showed that the most penetrating particle sizes (MPPS) decreased with nanofibre packing density as the MPPS (NaCl aerosol size ranging from 50 to 480 nm) decreased from 140 to 90 nm when nanofibre packing density was increased from 3.9 to 36×10^{-3} while the effect of nanofibre layer thickness on MPPS is less prominent than that of nanofibre packing density.

On the other hand, Heikkila *et al.* studied filtration performance of different type of polyamides (PA 6, PA 6,6; PA 6,12; PA 6,14; PA 10,12 and PA 10,14) reporting that the finest fibres (120 ± 30nm) can be obtained by PA 6,6 polymer [17] while effect of electrospinning parameters (such as polymer solution concentration, voltage, tip-collector distance) on filtration performance of PA nanofibrous surfaces electrospun during 15, 30, 45 and 60 min was reported by Aliabadi [18]. There was a significant increase in filtration efficiency of surfaces electrospun at 30 min. compare to the ones produced at 15 min. while the difference was not significant between the surfaces produced at 30 min. and 45 min. The effect of electrospinning parameters such as polymer solution concentration, voltage, tip-collector distance and duration of electrospinning (18, 20, 22 and 24 min.) on filtration performance was also studied by Wei et al. by developing so-called “needleless double rings slit electrospinning” system producing PAN nanofibrous surfaces [19]. The results showed that mean pore diameter and its distribution increased as spinning time increase and filtration efficiency was above 99.9% for surfaces produced at 18 min. while filtration resistance increased dramatically when spinning time increased from 18 to 24 min. Similarly, Ahne et al. studied the effect of electrospinning parameters such as polymer solution concentration, voltage, tip-collector distance and duration of electrospinning (up to 30 min.) on filtration performance as well but producing cellulose acetate (CA) based nanofibres obtaining maximum filtration efficiency of 99.8% for samples obtained with deposition time of 30 min. while maximum filter quality factor was 0.05 Pa^{-1} for a filter corresponding to a CA concentration of 20 wt.%, a tip-to-collector distance of 12.5 cm, a voltage of 8 kV and a deposition time of 5 minutes [20]. The effect of electrospinning time on filtration performance of PAN nanofibrous surfaces was also studied showing that PAN deposition time during electrospinning affected the filter quality [21]. The results showed that shorter deposition time of PAN nanofibre mats yields a better quality factor. It was also observed that thickness uniformity of nanofibre mats was getting worse as the deposition time increased and therefore diminished filter quality. In another study, nylon nanofibre filters were fabricated with five different solution concentrations and five different electrospinning times (1, 1.5, 2, 3, and 4 h) to investigate the effect of fibre diameter, filter thickness, packing density and face velocity while a semi-empirical model was applied to predict $PM_{2.5}$ removal efficiency [22]. An air filter based on PVDF branched nanofibres having a basis weight of 1 g/m^2 with outstanding filtration efficiency (99.999%) to 0.26 µm sodium chloride particles under pressure drop of 126.17 Pa can be given as another interesting work in this field [23]. On the other hand, Daneleviciute-Vaisniene *et al.* produced electrospun PVA nanofibre membranes, but different from above works they analysed cigarette smoke filtration performance indicating that PVA surfaces were able to catch organic polar grups, ethers and carboxyl groups [24]. In this study, FT-IR analysis results of two layers (PP+PVA web) was compared with PP non-woven fabric layer itself after exposure to cigarette smoke filtration which would in fact need further confirmation including comparison of two identical structures.

Use of nanofibre webs also contributes significantly to remove small liquid drops in submicron range as well. Hajra et al. reported that small addition of nanofibres on the substrate of glass fibres effectively captures oil droplets of 210 nm diameter [25]. There are commercial two-layer composite nanofibre webs with supporting micron-fibre layer as dust filter bags capturing particles below 500 nm diameter size [26]. A pleated filter media prepared by nanofibres of 250 nm size wetlaid on a cellulose substrate of 10 mm fibre diameter is another example [27] while their potential for textile effluent treatment has also been studied [28]. A recent work by Shao et al. also show potential of composite nanofibrous membranes produced by electrospinning of polyvinyl chloride (PVC) nanofibres and polyamide-6 (PA6) nanofibres [29]. The removal efficiency was 98.75% for sodium chloride (NaCl) aerosol particles with a diameter of 0.3 µm as their performance was attributed to triboelectric effect between these two adjacent nanofibre membranes.

As cigarette smoke was chosen as a case study in this work, a brief discussion of some main findings in this field has also been included. Poisonuous chemicals in cigarette smoke is known as one of the main reasons for cancer and it is combination of over 4700 chemical compounds [30] including nicotin as well as poisonuous compounds like polycyclic aromatic hydrocarbons (PAHs) and N-nytrocamins [31]. IARC, on the other hand, indicates that 9 out of 50 chemicals in cigarette smoke are in Group 2A carcinogen category [32]. Therefore, an efficient filtration of cigarette smoke is a real need and a challenging issue. Today, generally natural/synthetic fibrous materials in tow form are used in cigarette filtres, by enhancing their filtration ability by additives or special chemical compounds that have been generally kept as a trade secret. The fibres used for cigarette filtres are mainly cellulose diacetate or PP, however, even use of silk fibres has been reported [33]. By adding Glycine to remove aldehites from cigarette smoke, or use of 3-aminopropylsyl groups binded by silica gel [34] or CGC substance obtained from *Ginkgo biloba* plant [35], or use of activated carbon within fibre tows [36] are examples for different approaches. It is also clear that maximising specific surface of fibres is advantageous for an efficient filtration, therefore fibres with specific cross-section, such as Y-cross-section, have also been used [37].

In the light of above works, electrospun nanofibre membranes were produced and their properties were analysed. During production of nanofibrous surfaces, two different polymers (PA 6,6 and PVA) were used. PA 6,6 was specificly chosen due to its high potential for finer fibre production while PVA was chosen mainly because of its common use in electrospinning for easy spinning conditions. Nanofibrous surfaces at different unit weights and thicknesses were electrospun at three different levels of polymer injection speed (0.2, 0.6 and 1.0 ml/h, respectively) and three different electrospinning times (5, 10 and 15 min., respectively).

MATERIAL AND METHOD

Production of nanofibre surfaces

Single needle electrospinning set up, that includes Matsusada AU30-DC (max. 30 kV) high-power supply and Newera Ne-300 polymer injection pump, was used for production of nanofibrous surfaces [38]. The conductivity of polymers was measured by Eutech conductivity tester while Brookfield DV-F viscosimeter was used for viscosity. During production, polymer fibres were collected as membrane form onto a PP non-woven surface. Main production parameters were summarised in table 1 and table 2, respectively.

Table 1

ELECTROSPINNING PARAMETERS

Polymer	Polymer concentration wt (%)	Solvent	Needle gauge (mm)	Distance between needle and collector (cm)	Voltage (kV)
PVA	10	Distilled water	0.7	10	20
PA 6,6	10	Formic acid			

Table 2

ELECTROSPUN NANOFIBROUS SURFACES PRODUCED IN THE WORK			
Polymer	**Sample code**	**Production time in electrospinning (min.)**	**Polymer feed rate (ml/h)**
PVA	PVA 5.02	5	0.2
	PVA 5.06		0.6
	PVA 5.1		1.0
	PVA 10.02	10	0.2
	PVA 10.06		0.6
	PVA 10.1		1.0
	PVA 15.02	15	0.2
	PVA 15.06		0.6
	PVA 15.1		1.0
PA 6,6	PA 5.02	5	0.2
	PA 5.06		0.6
	PA 5.1		1.0
	PA 10.02	10	0.2
	PA 10.06		0.6
	PA 10.1		1.0
	PA 15.02	15	0.2
	PA 15.06		0.6
	PA 15.1		1.0

Analysis of nanofibrous surfaces and their filtration performance

Following production of nanofibre membranes, average unit weights of surfaces were determined by testing 5 samples each. A digital micrometer (Kanon, EMS-150 model) with 0.01 mm accuracy was used for thickness measurement of the surfaces. SEM (Quanta, Feg 250) was used to analyse the fibre fineness and fineness variation within the nanofibre membranes together with Adobe Photoshop CS6. Additionally, pore sizes of nanofibre membranes were analyzed by Quanta Chrome tester according to ASTM F316-03 (2011). Following these main characterisation analyses, air permeability of the membranes were tested by Proser air permeability tester according to TS 391 EN ISO 9237:1999 at sample size of 5 cm^2 and pressure of 100 kPa. Certitest 8130 automatic filtration tester having liquid aerosol diameter range of 0.2–0.33 mm and 90–95 lt/min flow rate was used following EN 149:2001 to analyse filtration efficiency of the nanofibrous surfaces. Also, a basic test set up was used to simulate a simple cigarette smoke filtration (figure 1) as a specific case. In this set up, cigarette smoke was applied for each sample for 1 min. and following this, nanofibre surfaces are analyzed by FT-IR (Thermo iS10) to detect the chemical groups filtrated.

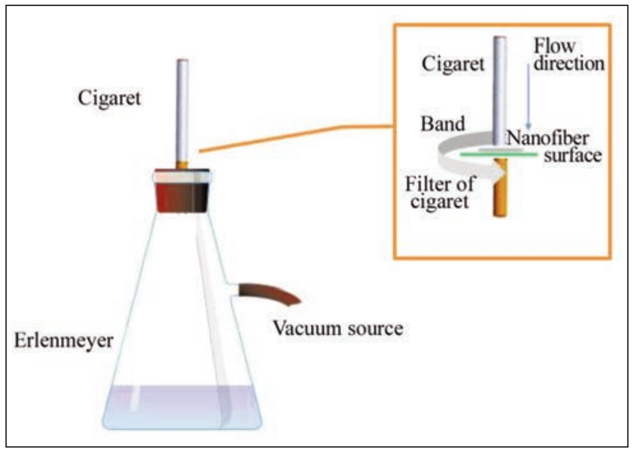


Fig. 1. The simple set-up used for cigarette smoke filtration

RESULTS AND DISCUSSIONS

Viscosity and conductivity of polymer solvents

The typical viscosity and conductivity results of the polymer solvents at 25°C were given below. The results showed that viscosity of both polymers was similar to each other while the conductivity of PA 6,6 polymer was higher (table 3).

Table 3

VISCOSITY AND CONDUCTIVITY VALUES OF POLYMER SOLVENTS		
Polymer solutions	**Viscosity (cP)**	**Conductivity (mS/cm)**
PVA	810.0	575
PA 6,6	800.8	658

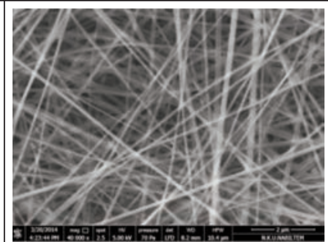
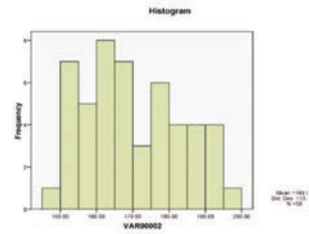
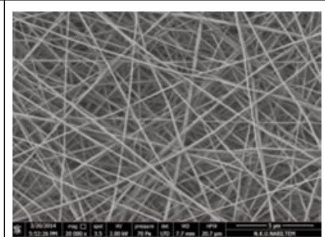
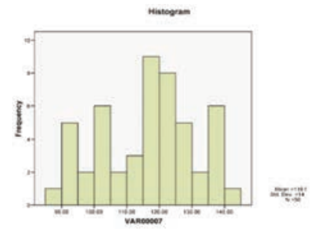
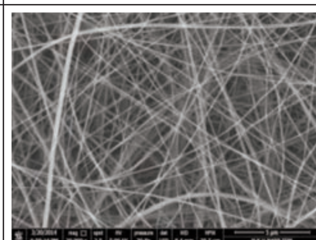
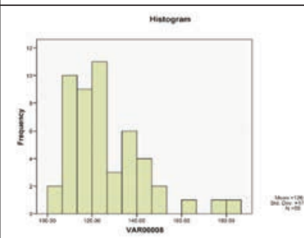
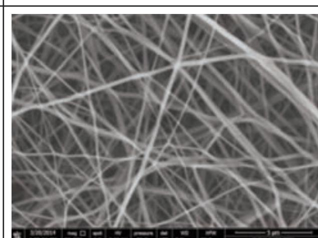
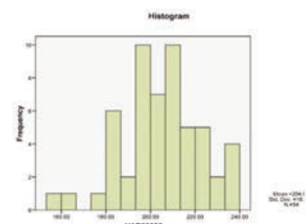
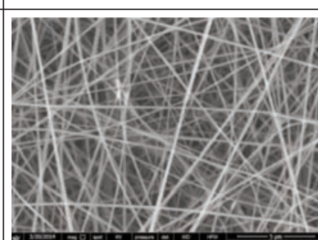
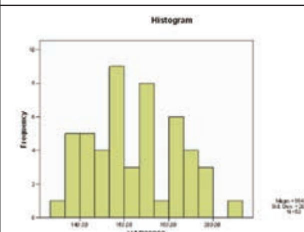
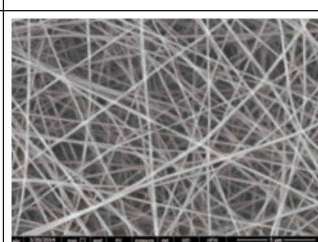
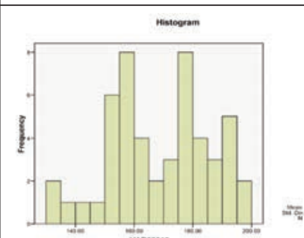
Characterisation of nanofibrous surfaces

The typical SEM images show that fibrous membranes were evenly produced by these two polymers (table 4). As the polymer feed rate increased during electrospinning, coarser fibres were produced as expected since the effect of polymer feed rate on fibre fineness is well-known as lower flow rates yielding fibres with smaller diameters [39, 40], although the increase in fibre fineness is more significant when PVA polymer was used (figure 2, *a*). The variation in fibre fineness also increased at higher polymer feeding rate. The effect of electrospinning time on fibre fineness was also analyzed as the results indicate that fibres get coarser as production time in electrospinning increases (figure 2, *b*). This is probably as a result of the decrease in conductivity when fibrous membrane surfaces get thicker on the collector during production in electrospinning.

Regarding the effect of electrospinning time on unit weight and thickness of fibrous mesh, the results were given by figure 3. These findings show that both unit weight and thickness values increase as the electrospinning time increases, as expected.

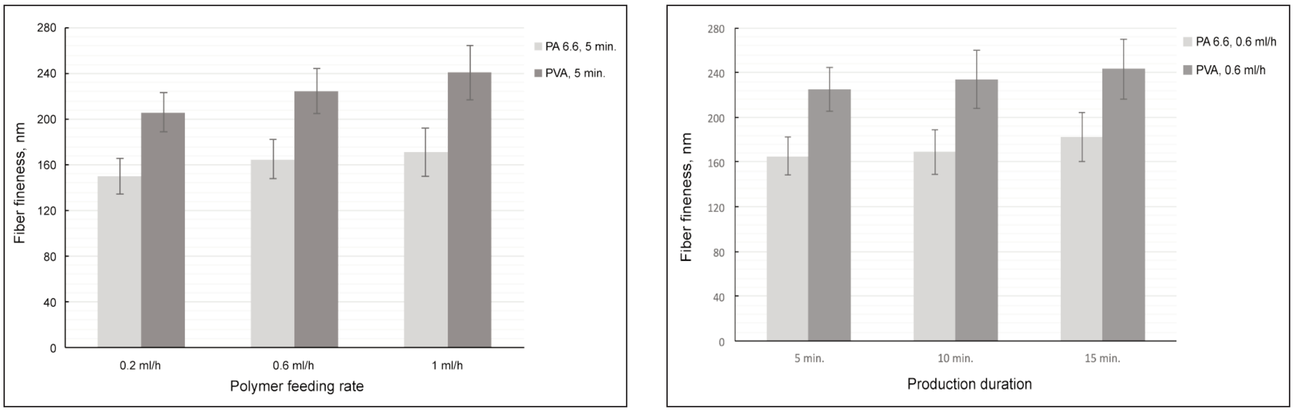
However, there is almost 95% increase in unit weight at 10 min. compare to 5 min. electrospinning time,

Table 4

TYPICAL EXAMPLES OF SEM IMAGES OF ELECTROSPUN NANOFIBROUS SURFACES AND THEIR FIBRE FINENESS DISTRIBUTIONS							
Sample code	**Diameter (nm)**					**Sem image**	**Fibre fineness distribution**
	N	**Min. (nm)**	**Max. (nm)**	**Mean (nm)**	**SD (nm)**		
PA 5.06	50	134.12	202.43	165.35	17.59		
PA 10.06	50	135.51	208.35	169.06	20.60		
PA 15.06	50	144.90	211.00	182.98	22.67		
PVA 5.06	50	180.34	273.87	225.39	20.53		
PVA 10.06	50	188.50	289.09	234.96	26.60		
PVA 15.06	50	192.08	265.56	243.43	27.57		

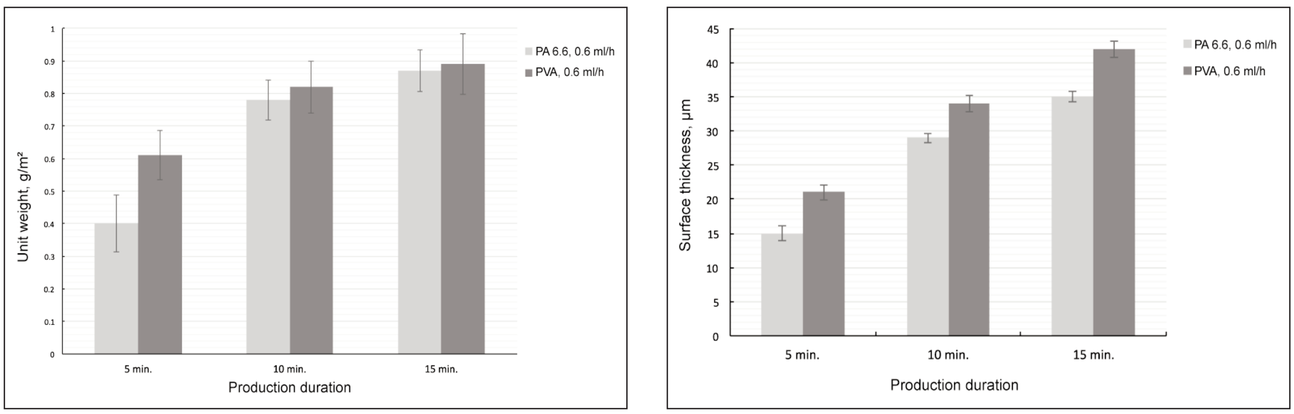
while the increase at 15 min. is much lower. This result can be attributed to the decrease in conductivity on collector surface due to the increase in fibre layer thickness as production continues. Similar findings were reported by Guibo et al. earlier during electrospinning of PA 6 polymer [4]. However, with PVA polymer, the increase in unit weight at 10 min. compare to 5 min. is % 71, i.e. much lower value compare to the results obtained by PA 6,6 polymer. That can be explained by lower conductivity of this polymer.

The typical porosity values of the nanofibrous surfaces produced by this work were also analysed by



a *b*

Fig. 2. The effect of: *a* – polymer feeding rate on fibre fineness; *b* – production time in electrospinning on fibre fineness



a *b*

Fig. 3. The effect of production time in electrospinning on unit weight (*a*) and thickness (*b*) of nanofibrous surfaces

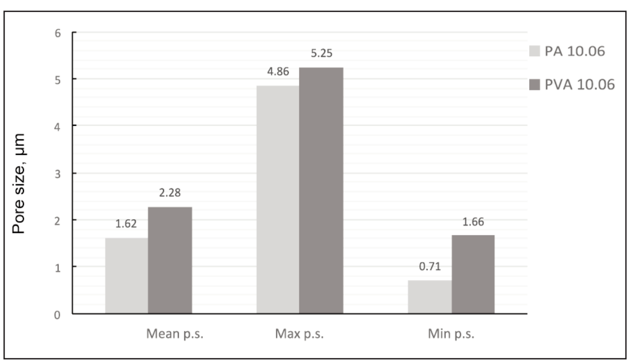


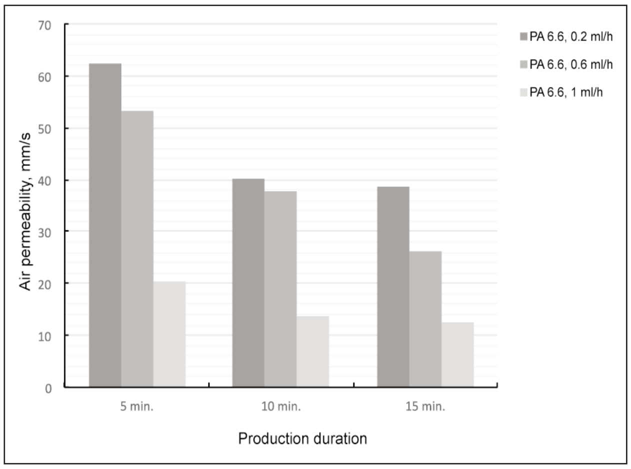
Fig. 4. Typical pore size distrubutions of electrospun nanofibrous surfaces

testing one sample type only to obtain a general idea (figure 4). The results show that nanofibrous surfaces produced by PA 6,6 have smaller pore size compare to PVA indicating their potential for better filtration performance. Smaller pore sizes with PA 6,6 nanofibrous surfaces is an expected result as surfaces with larger fibres would have larger holes [41].

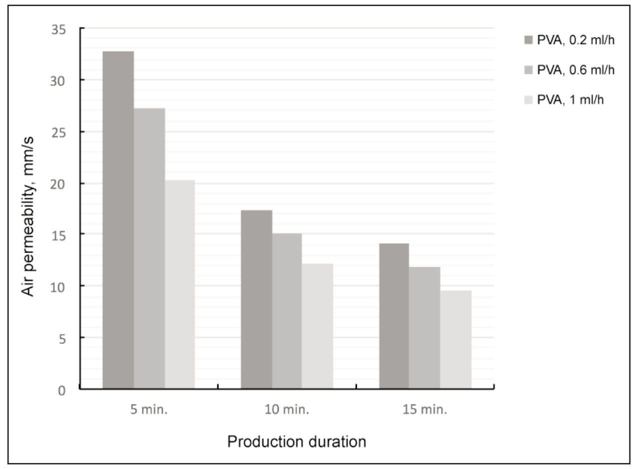
Filtration performance

The air permeability test results of PA 6,6 and PVA nanofibrous surfaces were given by figure 5. The test results showed that fibrous meshes with PA 6,6 polymer exhibit better air permeability performance, most probably owing to much finer fibres that these filter media contain. On the other hand, the results showed that air permability of structures decreased as electrospining time and polymer feed rate increased due to the increase in both thickness of mesh layer and its constituent fibres. Similarly, significant effect of spinning time on the filtration property of the nanofibre membrane, especially on filtration resistance was reported earlier [19]. However, it is worth noting that effect of production time was more significant when PVA polymer was used compare to PA 6,6.

Following air permability tests, the structures were also tested for liquid aerosol filtration efficiency. These tests were applied for PA 6,6 nanofibrous surfaces only as the filtration efficiency tests were failed during the test of PVA meshes probably due to their low tenacity and sensitivity for aerosols as well as their low air permeability as indicated by figure 5. Regarding PA 6,6 nanofibrous surfaces, the test results given by figure 6 indicate an increase in filtration efficiency as electrospinning time and feeding rate increases, as expected. It was reported earlier that longer fibre production time makes the fibrous media denser and has positive effect on filtration efficiency [42] also indicating an increase in filtration



a



b

Fig. 5. Air permeability test results of nanofibrous surfaces produced by: *a* – PA 6,6; *b* – PVA

efficiency by increase in spinning time [19]. The highest performance was obtained with the structures produced at 1.0 ml/h polymer feed rate and at 10 min. electrospinning time. However, the increase in efficiency of the structures produced at 5 min. and 10 min. was greater compare to the ones produced at 10 min. and 15 min.

Finally, the nanofibrous membranes were exposed to cigarette smoke by using filtration set up shown by figure 1. Then, FT-IR spectrums of nanofibrous structures produced by PA 6,6 and PVA polymers, given by figure 7 was analyzed in comparison with unexposed structures. Following filtration, regarding PA 6,6 membranes; the peak at 1713 cm^{-1} belong to (C=O) bonds indicating filtration of aldehit, kethon, carboxylic acids or esther functional groups while the peak at 1053 cm^{-1} indicates (C−O) bonds at primer alcohols, ethers or esters. For PVA nanofibrous membranes, however, peaks at 2917 cm^{-1}, 1707 cm^{-1} and 1600 cm^{-1} belonging to alkans, carbonyl groups and aromatic rings, respectively were oserved indicating aldehits, esthers, carboxyclic acides and kethons. As indicated earlier, cigarette smoke filtration performance of electrospun PVA nanofibre membranes was studied earlier as well indicating that PVA surfaces were able to catch organic polar grups, ethers and carboxyl groups [24], however FT-IR analysis results of two layers (PP+PVA web) was compared with only PP non-woven fabric layer itself after

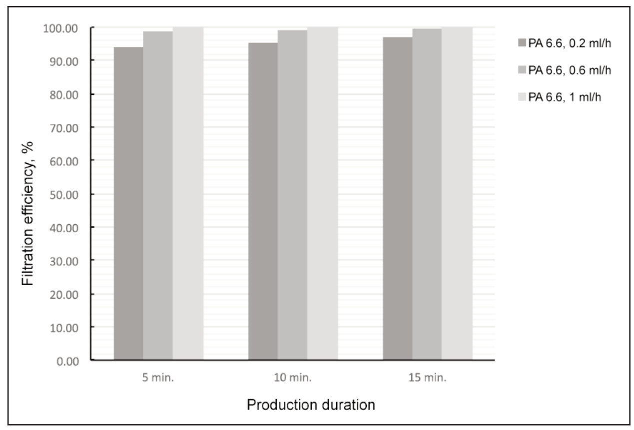
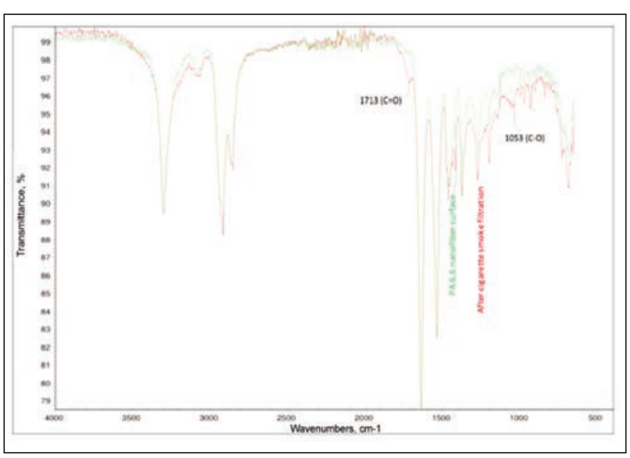
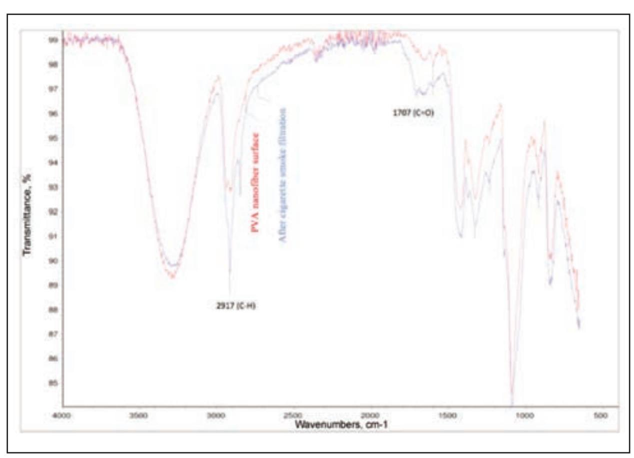


Fig. 6. Aerosol filtration efficiency of nanofibrous surfaces produced by PA 6,6



a



b

Fig. 7. FT-IR spectrum of: *a* – PA 6,6 nanofibrous structures; *b* – PVA nanofibrous structures before and after cigarette smoke filtration

exposure to cigarette smoke filtration. Therefore the results at figure 7 can be considered a further study by comparing results of two identical nanofibrous structures before and after smoke filtration.

CONCLUSIONS

In this work, 18 different nanofibrous surfaces were produced by PVA and PA 6,6 polymers by electrospinning at three different levels of polymer feeding rate (0.2; 0.6 and 1.0 ml/h, respectively) and three different levels of electrospinning time (5, 10 and 15 min., respectively). These structures were analysed in terms of fibre fineness distrubition, membrane thickness and unit weight. Then, selected nanofibrous surfaces were analysed for their pore size distributions, air-permeability, aerosol filtration efficiency. In addition to that, they were tested on a simple set-up to analyse their cigarette smoke filtration potential that was chosen as a specific case.

The results show that much finer fibres were produced by PA 6,6 polymer compare to PVA polymer. The pore sizes of PA 6,6 membranes were smaller in comparison to PVA membranes as well. During electrospinning process, much coarser fibres were produced as the polymer feed rate and electrospinning time increased reducing air-permeability of these nanofibrous surfaces as expected. The minimum average fibre fineness was 150.96 nm produced by using PA 6,6 polymer at 0.2 ml/h polymer feed rate and 5 min. production time while maximum average fibre fineness was 243.43 nm produced by using PVA polymer at 0.6 ml/h and 15 min. The air permeability of PA 6,6 nanofibrous surfaces were much higher compare to the ones produced by PVA. Aerosol filtration efficiency test results showed quite high efficiency (99.901 %) can be obtained with PA 6,6 nanofibrous surfaces (electrospun at 1ml/h and 10 min.) indicating that PA 6,6 nanofibrous surfaces have potential for such applications. The test results also showed that filtration efficiency increased as polymer feed rate and electrospinning time increased. On the other hand, the cigarette smoke tests carried out in this work showed that mainly PA 6,6 membranes can filtrate carboxylic acids and primer alcohols while PVA membranes can filtrate alkans.

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REFERENCES

[1] Nataraj, S.K., Yang, K.S., Aminabhavi, T.M., *Polyacrylonitrile-Based Nanofibres a State of the Art Review*, In: Progress in Polymer Science, 2012, 37, 487–513
[2] Ramakrishna, S., Fujihara, K., *An Introduction to Electrospinning and Nanofibres*, World Scientific Publishing, USA, 2005
[3] Sundarrajan, S., Tan, K.L., Lim, S.H., Ramakrishna, S., *Electrospun Nanofibres for Air Filtration Applications*, In: Procedia Engineering, 2014, 75, 159–163
[4] Guibo, Y., Qing, Z., Yahong, Z., Yin, Y., Yumin, Y., *The Electrospun Polyamide 6 Nanofibre Membranes Used As High Efficiency Filter Materials*, In: J. of Applied Polymer Science, 2013, 128, 1061–1069
[5] Ustun, A., *Nanofibre Production for Air Filtration*, MSc Thesis, Denizli Pamukkale University, Natural&Applied Science Institution, Turkey, 2011
[6] Langner, M., Greiner, A., *Wet-Laid Meets Electrospinning: Nonwovens for Filtration Applications from Short Electrospun Polymer Nanofibre Dispersions*, In: Macromol. Rapid Commun, 2016, 37, 351−355
[7] Yan, S., Yu, Y., Ma, R., Fang, J., *The Formation of Ultrafine Polyamide 6 Nanofibre Membranes with Needleless Electrospinning for Air Filtration*, In: Polym. Adv. Technol., 2019, 30, 1635–1643
[8] Faccini, M., Borja, G., Boerrigter, M., Martín, D., Crespiera, S. M., Vázquez-Campos, S., Aubouy, L., Amantia, D., *Electrospun Carbon Nanofibre Membranes for Filtration of Nanoparticles from Water*, In: J. of Nanomaterials, 2015, Article ID 247471, https://doi.org/10.1155/2015/247471
[9] Yoon, K., Kim, K., Wang, X., Fang, D., *High Flux Ultrafiltration Membranes Based on Electrospun Nanofibrous PAN Scaffolds and Chitosan Coating*, In: Polymer, 2006, 47, 2434–2441
[10] Menkhaus, T.J., Varadaraju, H., Zhang, L., Schneiderman S., *Electrospun Nanofibre Membranes Surface Functionalized with 3-Dimensional Nanolayers As An Innovative Adsorption Medium with Ultra-High Capacity and Throughput*, In: Chem. Commun., 2010, 46, 3720–3722
[11] Tsai, P.P., Schreuder-Gibson, H., Gibson, P., *Different Electrostatic Methods for Making Electrect Filters*, In: Journal of Electrostatics, 2002, 54, 333–341
[12] Ahn, Y.C., Park, S.K., Kim, G.T., Hwang, Y.J., Lee, C.G., Shin, H.S., Lee, J.K., *Development of High Efficiency Nanofilters Made of Nanofibres*, In: Current Applied Physics, 2006, 6, 6, 1030–1035
[13] Qin, X., Wang, S., *Filtration Properties of Electrospinning Nanofibres*, In: Journal of Applied Polymer Science, 2006,102, 1285–1290
[14] Li, J., Gao, F., *Needleless Electrospun Nanofibres Used For Filtration of Small Particles,* In: Express Polymer Letters, 2013, 7, 8, 683–689
[15] Hung, C., *Experimental Investigation and Theoretical Analysis on Air Filtration of Sub-micron Aerosols by Nanofibre Filter*, PhD Thesis, Hong Kong Polytechnic University, Hong-Kong, 2010
[16] Leung, W.W., Hung, C., Yuen, P., *Effect Of Face Velocity, Nanofibre Packing Density And Thickness On Filtration Performance Of Filters With Nanofibres Coated On A Substrate*, In: Seperation and Purification Technology, 2010, 71, 30–37

[17] Heikkila, P., Taipale, A., Lehtimaki, M., Harlin, A., *Electrospinning of Polyamides with Different Chain Compositions for Filtration Application,* In: Polymer Engineering and Science, 2008, 48, 1168–1176
[18] Aliabadi, M., *Effect of Electrospinning Parameters on the Air Filtration Performance Using Electrospun Polyamide-6 Nanofibres*, In: Chem. Ind. Chem. Eng. Q., 2017, 23, 4, 441−446
[19] Wei, L., Zhang, H., Qin, X., *Fabricated Narrow Diameter Distribution Nanofibre For An Air Filtration Membrane Using A Double Rings Slit Spinneret*, In: Textile Research Journal, 2019, 89, 6, 936–947
[20] Ahne, J., Li, Q., Croiset, E., Tan, Z., *Electrospun Cellulose Acetate Nanofibres For Airborne Nanoparticle Filtration*, In: Textile Research Journal, 2019, 89, 15, 3137–3149
[21] Zhang, Q., Welch, J., Park, H., Wu C., Sigmund, W., Marijnissen, J.C.M., *Improvement In Nanofibre Filtration By Multiple Thin Layers Of Nanofibre Mats*, In: J. of Aerosol Science, 2010, 41, 230–236
[22] Bian, Y., Wang, S., Zhang, L., Chen, C., *Influence Of Fibre Diameter, Filter Thickness, And Packing Density On PM2.5 Removal Efficiency Of Electrospun Nanofibre Air Filters For Indoor Applications*, In: Building and Environment, 2020, 170, 106628
[23] Zaarour, B., Tina, H., Zhu, L., Jin, X., *Branched Nanofibres With Tiny Diameters For Air Filtration Via One-Step Electrospinning*, In: J. of Industrial Textiles, 2020, 1–13
[24] Daneleviciute-Vaisniene, A., Katunkis, J., Buika, G., *Electrospun PVA Fibres for Gas Filtration Applications*, In: J. of Fibres&Textiles in Eastern Europe, 2009, 17, 40–43
[25] Hajra, M.G., Mehta, K., Chase, G.G., *Effects of Humidity, Temperature and Nanofibres on Drop Coalescence in Glass Fibre Media*, In: Serp. Purif. Technol., 2003, 20, 79–98
[26] Emig, D., Klimmek, A., Raabe, E., *Dust filter bag containing nano non-woven tissue*, US Patent 6,395,046 B1, 2002
[27] Grafe, T.H., Graham, K.M., *Polymeric Nanofibres and Nanofibre Webs: A New Class of Nonwovens*, International Non-wovens Technical Conference, Atlanta-USA, 2002
[28] Khanmohamadi, S., Gharehaghaji, A.A., Hoseini, S.A., *Study on the Performance of Nanofibrous Filters For Colored Effluent Treatment*, International Innovative Textile Congress (Icontex2011), İstanbul-Turkey, 20–22 October 2011
[29] Shao, Z., Jiang, J., Wang, X., Li, W., Fang, L., Zheng, G., *Self-Powered Electrospun Composite Nanofibre Membrane for Highly Efficient Air Filtration*, In: Nanomaterials, 2020, 10, 1706
[30] Zhang, D., Tao, Y., Gao, J., Zhang, C., et. al., *Pycnogenol® in Cigarette Filters Scavenges Free Radicals and Reduces Mutagenicity and Toxicity of Tobacco Smoke in Vivo.,* In: Toxicol. and Industrial Health, 2002, 18, 215–224
[31] Hoffmann, D., Hoffmann, I., *The Changing Cigarette: 1950–1995,* In: J. Toxicol. Environ. Health, 1997, 50, 307–364
[32] Şeker, F.A., *Determination of Some Polycyclic Aromatic Hydrocarbons in Filter Tar of Turkish Cigarettes,* In: J. Sep. Sci., 2005, 28, 2370–2373
[33] Tian, B.Z., Chen, P., Chen, J., Bai, L., *Blocking and Filtering Effect of Bombyx Mori Silkworm Silk Fibre Filter Tips Against Mainstream Smoke of Cigarettes*, In: Materials and Design, 2009, 30, 2289–2294
[34] Koller, K.B., Wrenn, S.E., Houck, W.G., Paine, J.B., *Cigarette Filter*, US Patent No 6,595,218 B1, 2003
[35] King, B., *Is the "CGC" Cigarette Filter Additive a Solution for China's Tobacco-induced Disease Problem?,* In: Toxicological & Environmental Chemistry, 2012, 94, 3–6
[36] Pauly, J.L., Rees, V., O'Connor, R., *Philip Morris Clinical Study of Carbon Filtered Cigarettes Challenged by Nondisclosure Issues*, In: Nicotine & Tobacco Research, 2009, 11, 1245–1246
[37] Collazo, H., Crow, W.A., Gardner, L., Phillips, B.L., Dyer, W.M., *Aerodynamic Diameter Measuremet of Cellulose Acetate Fibres from Cigarette Filters,* In: Inhalation Toxicology, 2002, 14, 247–262
[38] Dönmez, S., *Production of Nanofibrous Webs for Air Filters By Electrospinning Process*, MSc Thesis, Tekirdağ Namık Kemal University, Natural & Applied Science Institution, Turkey, 2016
[39] Patanaik, A., Anandjiwala, R.D., Rengasamy, R.S., Ghosh, A., *Nanotechnology in Fibrous Materials*, In: Textile Progress, 2007, 39, 2, 67–120
[40] Andrady, A.L., *Science and Technology of Polymer Nanofibres*, Jonh Wiley&Sons, USA, 2008
[41] Zhang, X., Chase, G.G., *Solid Aerosol Filtration by Electrospun Pyrrolidene Fibre Mats and Dependence on Pore Size*, In: J. Textile Eng. Fashion Techno., 2017, 1, 5, 180–187
[42] Matulevicius, J., Kliucininkas, L., Martuzevicius, D., Krugly, E., Tichonovas, M., Baltrusaitis, J., *Design and Characterization of Electrospun Polyamide Nanofibre Media for Air Filtration Applications*, In: Journal of Nanomaterials, 2014, Article ID 859656

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Investigation of the effects of antibacterial finishing on some mechanical properties of cotton sheet fabrics

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ABSTRACT – REZUMAT

Investigation of the effects of antibacterial finishing on some mechanical properties of cotton sheet fabrics

In this article, it is aimed to determine the effect of the antibacterial finishing process applied to bed linen fabrics, which are widely used in the market, on some mechanical properties of the fabric. Antibacterial finishing process was applied to the fabric produced for this purpose under operating conditions and wrinkle strength, tear strength and abrasion resistance levels were made on these fabrics. Measurements were made before and after antibacterial finishing. The resulting results were evaluated among themselves and processed in SPSS (Statistical Package for Social Sciences) 21.0 program. Since the number of processed data is less than 50 according to greige fabric and antibacterial treated fabric measurements, it has been tested with Shapiro-Wilk analysis. The homogeneity of the test variances of the data was done with Levene homogeneity test. Tear strength, creasing angle and abrasion resistance test results are focused on how scientifically meaningful the effects of process parameters and interactions on fabric properties are in accordance with statistical analysis. As a result of the analysis, it was revealed that the results obtained from the tear strength, wrinkle angle and abrasion resistance tests were statistically significant and as a result, the antibacterial process parameters negatively affect the wrinkle strength, tear strength of the cotton fabric; it was found to affect the wear resistance positively.

Keywords: *antibacterial textiles, medical textiles, greige fabric, wrinkle test, tear test, abrasion level*

Analiza influenței finisării antibacteriene asupra unor proprietăți mecanice ale țesăturilor din bumbac

În acest articol, s-a urmărit determinarea influenței procesului de finisare antibacteriană aplicat țesăturilor pentru lenjeria de pat, care sunt utilizate pe scară largă pe piață, asupra unor proprietăți mecanice ale țesăturii. Procesul de finisare antibacteriană a fost aplicat țesăturiilor produse pentru acest domeniu de utilizare, iar rezistența la șifonare, rezistența la rupere și rezistența la abraziune au fost determinate pentru aceste țesături. Măsurătorile au fost efectuate înainte și după finisarea antibacteriană. Rezultatele au fost evaluate și prelucrate în programul SPSS 21.0 (Pachetul statistic pentru științe sociale). Deoarece numărul datelor prelucrate este mai mic de 50, în funcție de determinările efectuate pe țesătura crudă și pe țesăturile tratate antibacterian, acestea au fost testate cu analiza Shapiro-Wilk. Omogenitatea variațelor de testare a datelor a fost realizată cu testul de omogenitate Levene. Rezistența la rupere, unghiul de șifonare și rezultatele testelor de rezistență la abraziune sunt axate pe cât de semnificativă din punct de vedere științific este influența parametrilor procesului și interacțiunile asupra proprietăților țesăturii, în conformitate cu analiza statistică. Ca rezultat al analizei, s-a demonstrat că datele obținute din testele de rezistență la rupere, unghiul de șifonare și rezistența la abraziune au fost semnificative din punct de vedere statistic și, prin urmare, parametrii procesului antibacterian influențează negativ rezistența la șifonare și rezistența la rupere a țesăturii de bumbac; s-a constatat că influențează pozitiv rezistența la abraziune.

Cuvinte-cheie*: textile antibacteriene, textile medicale, țesătură crudă, test de rezistență la șifonare, test de rezistență la rupere, nivel de abraziune*

INTRODUCTİON

Hospital beds in the hospital environment used like bed sheets, bedspreads and pillows microorganisms placed between textile structures damage to the textile product itself and the user can give. In this study; After giving general information about woven fabric, factors affecting fabric characteristics hospital infections, after antibacterial finishing treatment applied to bed linen fabrics used in the hospital, it was investigated how the fabric affects the wrinkle strength, tear strength and abrasion resistance properties of cotton fabric. Odor and color change in textile products where bacteria reproduce and loss of quality and performance [1]. Many researchers have done studies for the effectiveness of bacteria in fabrics. Isys AG was used in antibacterial dispersion fabrics containing silver ions. Cotton/Polyester blends are used to combine the water absorbency and natural properties of cotton and the durability of polyester. In addition, with this mixture, along with the price advantage of polyester, a decrease in product price is observed. Such sheets can be used longer. They show similar properties with 100% cotton fabric antimicrobially [2]. It is the application of the finishing agent that will change the properties of use or appearance, dissolved/ homogeneously dispersed in a liquid to the fabric [3]. Perelshtein et al. [4] revealed excellent antibacterial activity against Ag-fabric *Escherichia coli* (gram-negative) and *Staphylococcus aureus* (gram-positive) cultures. Balakumaran et al. [5] investigated AgNP-coated cotton fabrics exhibited broad-spectrum antibacterial activity against all tested pathogens. HR-SEM micrographs of cotton fabrics coated with AgNPs exhibited a rough surface, and the presence of nanoparticles on the cotton surface was also observed and demonstrated the importance of developing this method. The treated cotton fabric *Escherichia coli* and *Staphylococcus aureus* bacterial reduction efficiency resulted in good quantitative and qualitative antimicrobial activity. They showed excellent resistance to biodegradation caused by soil microflora. They also demonstrated the high durability of antimicrobial activities obtained even after 20 wash cycles; where *E. coli* and *S. aureus* achieved a 99.1% and 98.7% reduction in the number of bacteria, respectively [6]. The antibacterial fabric with 758 mg/kg silver nanoparticles on surface cotton was highly effective in killing test bacteria and had excellent water resistance [7]. It is a simple and inexpensive procedure to prepare antibacterial cotton fabric using silver nanoparticles (AgNPs) and biodegradable GT. To investigate the effectiveness of antibacterial power, different concentrations of GT (2, 4 and 6 g/l) were applied, together with a constant amount of Ag (5%; based on the weight of dry GT used in solutions). The effects of *E. coli* and *Staphylococcus aureus* cotton fabric on their physical, mechanical and biological properties and the presence of a small amount of composite structure AgNP were sufficient to increase the antibacterial activity of fabrics compared to only GT treated fabric [8]. Kittinaovarat et al. made to use glycosal and chitosan in a single-stage finishing process in order to give antibacterial efficacy with durable press performance to cotton fabrics. The Glyoxal process provided good wrinkle-resistant properties and fair antibacterial activity on the finished fabrics, but there was a decrease in the tensile strength of the finished fabrics. Added to the combination of this system, chitosan gave similar results in wrinkle-resistant and antibacterial properties, as did glycosal on finished fabrics. The advantage of chitosan in the combination of glycosal and chitosan system was that it did not adversely affect the breaking strength [9]. The coating of Ag NPs on cotton fabric showed excellent antibacterial properties and washing resistance, after 50 consecutive wash cycles for *S. aureus* and *E. coli*. Bacterial reduction rates (BR) versus *E. coli* remained above 95% [10]. QingBo Xu et al. investigated L-cysteine (Cys) and silver nanoparticles (Ag NPs) that were successfully bonded to cotton fabric surfaces. Bacterial reduction rates (BR) efficacy for scherichia *E. coli* and *S. aureus* reached 100%. After 50 consecutive wash cycles, bacterial reduction rates (BR) against *E. coli* and *S. aureus* were kept above 97% [11].

MATERİAL

It is decided to use the most woven cotton cloth foot sheet which antibaterial %100 cotton plan fabrics in the hospitals for use in the experiments. The fabric is woven in a Picanol air-jet weaving machine with a width of 240 cm. Burning, desizing, bleaching, optical bleaching and calendering processes were carried out in the operating environment, respectively. The substance called Isys AG is a silver-containing dispersion, a textile finishing product with a bacteriostatic effect. K A good antibacterial activity was observed against the MRSA isolate in the fabric, and it was observed that the fabric showed a weak antibacterial activity against the *E.coli* isolate. No antibacterial activity of the fabric against other 4 bacteria was observed. The effectiveness of antibacterial activity will decrease depending on the type of chemical substance that has antibacterial effect, the duration of its activity on the fabric, and physical factors such as washing and wear. In general, antibacterial termination was found to be effective against MRSA and *E. coli*, which are common isolates of hospital infections.

METHOD

In the research, it was aimed to compare the greige fabric with the antibacterial fabric by making measurements in terms of wrinkle strength, tear strength and abrasion resistance. Within the scope of the research, data collected as warp and weft in terms of wrinkle and tear strength of greige fabric and antibacterial treated fabric and data collected in terms of abrasion resistance were processed into SPSS (Statistical Package for Social Sciences) 21.0 program. Since the number of processed data is less than 50 according to greige fabric and antibacterial treated fabric measurements, it has been tested with Shapiro-Wilk analysis. The homogeneity of the test variances of the data was done by Levene homogeneity test. 111 g/m^2 of greige plain woven fabric 30 warp per cm every warp 740 tour per m, 26 weft per cm and weft yarn 600 tour/m. The pre-finishing of our woven cotton fabric was carried out in the dyehouse environment. In the laboratory, the physical properties of the fabric before and after processing were measured and compared.

Test results were recorded in SPSS (Statistical Package for Social Sciences) 21.0 program. Since the number of processed data is less than 50 according to greige fabric and antibacterial treated fabric measurements, it has been tested with Shapiro-Wilk analysis. The homogeneity of the test variances of the data was done by Levene homogeneity test. iSys AG is sensitive to over 40ºC and cold; Permanent changes occur at temperatures close to the freezing point. Thanks to its nano-sized silver content, the antimicrobial property, which is very well achieved with iSys AG, is obtained and this process is done in scarfs. Prepare 10.0g/l iSys MTX, 0.5 g/l iSys AG, 20.0 g/l TUBINGAL HWS, 0.5 g/l KOLLASOL CDO at pH 5.5. Pick-up 100% Drying is fixed at 120ºC veC and 170ºC, fix for 30 seconds Tests on the fabric were checked by processing and processed fabric samples. 6 different bacterial isolates (MRSA) ATCC 43300, *Enterococcus faecalis* ATCC 29212, *Streptococcus pneumoniae* ATCC 49619, *Escherichia coli* ATCC 25922, *Klebsiella pneumoniae* ATCC 700603 ve *Pseudomonas aeruginosa* ATCC 27853) in the microbiology laboratory were apliciated. AATCC 147 diffusion method and AATCC 100 are quantitative analysis methods [12]. In AATCC 147, diffusion test method, pre-prepared bacterial concentrations are poured into the medium and then 25 mm diameter sample fabrics are placed. After the sample fabrics are kept at 37°C for 24 hours, the effectiveness of the sample fabric is determined by measuring the diameter formed around the fabric (inhibition zone diameter).

In the Agar Diffusion Method, which is a quantity method, the antibacterial activity of antimicrobial treated fabrics can be observed and comments can be made about the effectiveness (Palamut et al.). Tear strength tests of sample fabrics were carried out in the ElmaTear Digital Tear Strength Meter in accordance with the TS EN ISO 13937-1 standard. Test samples are 100 +/– 2 mm long and 75 +/– 2 mm wide. 20 +/– 0.5 mm notch is opened from the lower middle part of the sample. 5 different experiments are carried out in the direction of weft and warp and the average of these values is given as the average tear strength [13]. Determination of the abrasion resistance of the sample fabrics was made 15 times from two different fabrics that had undergone antibacterial treatment for Martindale crease angle test based on TS EN ISO 12945-1 standard. The numbers in table 1 are the arithmetic mean of the different number of measurements as per the standard. Fabric creasing angle was measured separately for weft and warp direction. In samples measured for both weft and warp direction; half of the sample was measured with the fabric side facing the fabric and the other half with the fabric opposite.

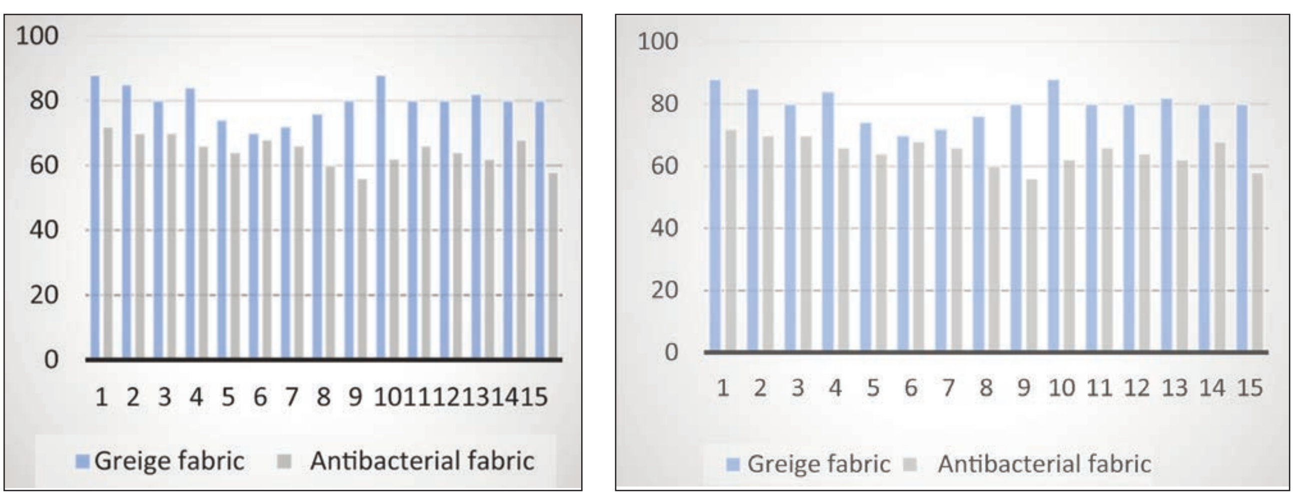
Table 1

WRINKLE ANGLE TESTS FOR GREIGE FABRIC AND ANTIBACTERIAL FABRIC (ISO 2313)

Samples	Greige fabric (degree)		Antibacterial fabric (degree)	
	Warp	Weft	Warp	Weft
1	62	88	42	72
2	66	85	50	70
3	60	80	44	70
4	58	84	40	66
5	64	74	40	64
6	68	70	44	68
7	63	72	42	66
8	60	76	40	60
9	60	80	38	56
10	60	88	38	62
11	52	80	42	66
12	55	80	44	64
13	58	82	40	62
14	54	80	36	68
15	54	80	44	58

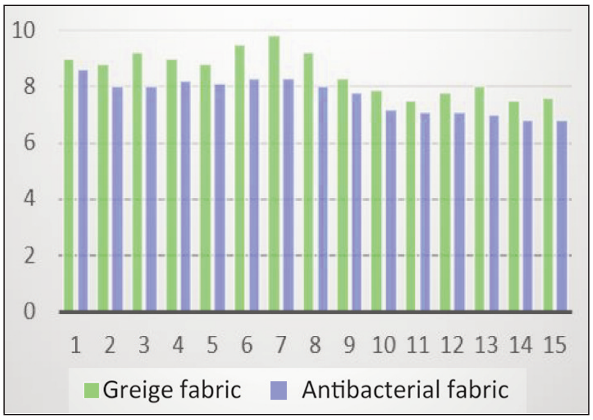
Tear strength test results applied to antibacterial treated and untreated fabrics are shown in table 2. Each value in table 2 is the arithmetic mean of 5 different tear strengths. As seen in table 1, after the antibacterial finishing process, there was a decrease in the creasing strength (angle) of both warp and weft direction.

Comparing Greige fabric and antibacterial finishing fabric wrinkle testin figure 1, it is clearly seen that antibacterial fabrics affect negatively wrinkle angle. After the antibacterial finishing process, the tear strength decreased in both warp and weft directions (table 2 and figure 2). There was an increase in abrasion resistance after antibacterial finishing (table 3).

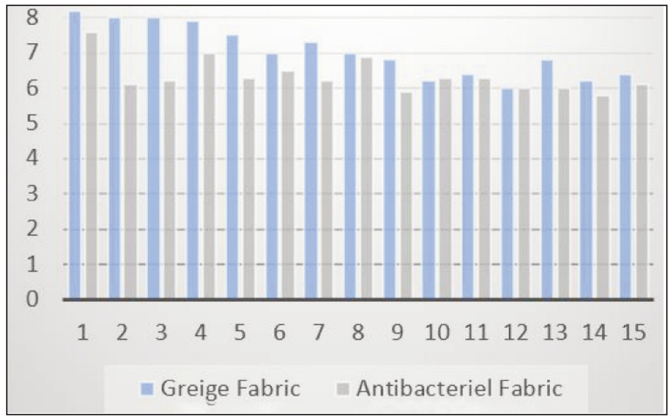


a *b*

Fig. 1. Greige fabric and the antibacterial finishing fabric are compared with wrinkle test:
a – Wrinkle test warp direction; *b* – Wrinkle test weft direction



a



b

Fig. 2. Greige fabric and the antibacterial finishing fabric are compared with the creasing strength levels: *a* – tear streght with warp direction; *b* – tear streght with weft direction

Table 2

TEAR STRENGTH TEST RESULTS (TS EN ISO 13937-1)

Samples	Greige fabric (N)		Antibacterial fabric (N)	
	Warp direction	**Weft direction**	**Warp direction**	**Weft direction**
1	9.0	8.2	8.6	7.6
2	8.8	8.0	8.0	6.1
3	9.2	8.0	8.0	6.2
4	9.0	7.9	8.2	7.0
5	8.8	7.5	8.1	6.3
6	9.5	7.0	8.3	6.5
7	9.8	7.3	8.3	6.2
8	9.2	7.0	8.0	6.9
9	8.3	6.8	7.8	5.9
10	7.9	6.2	7.2	6.3
11	7.5	6.4	7.1	6.3
12	7.8	6.0	7.1	6.0
13	8.0	6.8	7.0	6.0
14	7.5	6.2	6.8	5.8
15	7.6	6.4	6.8	6.1

Table 3

MARTINDALE ABRASION RESISTANCE TEST RESULTS (TS EN ISO 12947-1)

Samples	Greige fabric (Tour)	Antibacterial fabric (Tour)
1	18150	19750
2	19050	19650
3	18100	19800
4	18800	19900
5	18250	19850
6	18300	19350
7	19050	19450
8	19000	19400
9	19100	19450
10	18900	19400
11	19000	19500
12	18850	19450
13	18850	19450
14	18950	19750
15	18900	19800

Martindale Abrasion and Pilling gauge test on the sample fabrics was made in accordance with the TS EN ISO 12947-1 standard (table 3).

The results of greig and antibacterial fabric abrasion clearly show that the antibacterial process contributes greatly to the greig fabric in terms of abrasion in figure 3.

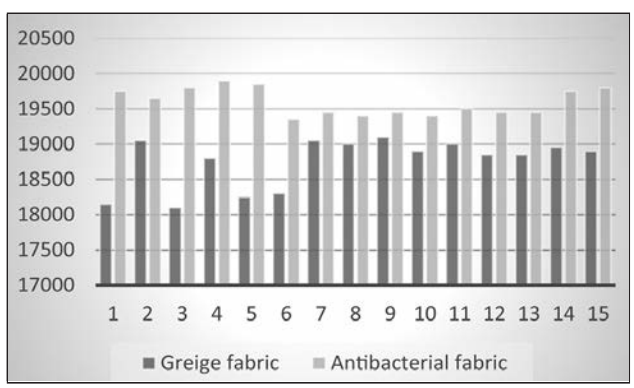


Fig. 3. Asbrasion resistance levels of the greige fabric and the antibacterial treated fabric are compared

In table 4, the normality and homogeneity assumptions of the data distributions obtained from the processes applied to the greige fabric and antibacterial treated fabrics were examined. The results of Shapiro-Wilk statistic scores of both fabrics are not significant compared to $p > 0.05$, it is concluded that all score distributions meet the normality assumption, that is, normal distribution. According to Levene homogeneity test results, it is concluded that test variances according to $p > 0.05$ are distributed homogeneously, that is, they meet the assumption of homogeneity. It is seen that the distribution of the

Table 4

SHAPIRO-WILK NORMALITY TEST AND LEVENE HOMOGENEITY TEST, *p<0.05							
Group	Fabric	Group	Shapiro-Wilk			Levene Homogeneity Test	
			Statistic	sd	p	F(1-28)	p
Wrinkle strength (wrinkle angle)	Greige fabric	Warp	0.969	15	0.838	10.201	0.282
		Weft	0.936	15	0.331	0.000	0.988
	Antibacterial treated fabric	Warp	0.928	15	0.254	1.201	0.282
		Weft	0.971	15	0.866	0.000	0.988
Tear strength (N)	Greige fabric	Warp	0.923	15	0.217	1.615	0.214
		Weft	0.927	15	0.243	1.816	0.156
	Antibacterial treated fabric	Warp	0.888	15	0.062	1.615	0.214
		Weft	0.945	15	0.456	1.816	0.156
Martin deal abrasion resistant test (number of tours)	Greige fabric	Greige fabric	0.917	15	0.202	1.865	0.063
	Antibacterial treated fabric	Antibacterial fabric	0.896	15	0.142	1.865	0.063

points obtained from the data is continuous data and at the level of equal intervals.

The sampling of these two fabrics is independent of each other, the dependent variables are measured at the range or ratio scale level, and the assumptions of normality and homogeneity meet the parametric test assumptions.

According to table 1, after the antibacterial finishing process, the shrinkage strength (angle) decreased in both warp and weft direction. According to table 2, after the antibacterial finishing process, the tear strength decreased in both warp and weft direction. According to table 3, there was an increase in the abrasion resistance after antibacterial finishing.

In table 5, the wrinkle strength levels of greige fabric and antibacterial treated fabric are compared in terms of warp. Wrinkle strength (angle) in terms of warp of greige fabric ($\overline{X}$ = 59.60 degree) and crease strength (angle) in terms of warp to antibacterial treated fabric ($\overline{X}$ = 41.60 degree), $t_{(14)}$ = 14.91, It is seen that there is a significant difference according to p = 0.000 < 0.05. After the greige fabric is treated with antibacterial, it is seen that the creasing strength (angle) decreases in terms of warp, that is, the decrease of this angle is perceived as a negative result. In this respect, in order to reduce the creasing angle, the greige fabric should be treated with antibacterial in terms of warp.

Table 6 is examined, it is seen that in terms of weft, the greige fabric and the antibacterial finishing fabric are compared with the creasing strength levels. $t_{(14)}$ = 8.9, between the crease strength ($\overline{X}$ = 79.93 degre) in terms of weft of the greige fabric and the crease resistance ($\overline{X}$ = 64.80 degre) in terms of weft to the antibacterial treated fabric It is seen that there is a significant difference according to p = 0.000 < 0.05. After the greige fabric is treated with antibacterial, it is seen that the creasing strength (angle) decreases in terms of weft, that is, the reduction of this angle is perceived as a negative result. In this respect, in order to reduce the creasing angle, the greige fabric should be treated with antibacterial in terms of weft.

Table 5

PAIRED-SAMPLE T-TEST RESULTS REGARDING THE DIFFERENCE BETWEEN LEVELS OF WRINKLE STRENGTH IN TERMS OF GREIGE FABRIC AND ANTIBACTERIAL TREATED FABRIC , *p<0.05							
Parameter	Warp direction	No.	Mean	S	t	sd	p
Wrinkel strength	Greige fabric	15	59.60	4.60	14.91	14	0.000*
	Antibacterial treated fabric	15	41.60	3.40			

Table 6

DIFFERENCES BETWEEN WEFT CREASING STRENGTH (ANGLE) OF GREIGE FABRIC AND ANTIBACTERIAL TREATED FABRICS							
Parameter	Weft direction	No.	Mean	S	t	sd	p
Wrinkel strength	Greige fabric	15	79.93	5.27	8.97	14	0.000*
	Antibacterial treated fabric	15	64.80	4.59			

Table 7

T-TEST RESULTS REGARDING THE DIFFERENCE BETWEEN TEAR STRENGTH LEVELS IN TERMS OF RAW WARP DIRECTION AND ANTIBACTERIAL TREATED FABRIC WARP, *p < 0.05							
Parameter	**Warp direction**	**No.**	**Mean**	**S**	**t**	**sd**	**p**
Tear strength	Greige fabric	15	8.53	0.77	10.16	14	0.000*
	Antibacterial treated fabric	15	7.69	0.62			

Table 8

T-TEST RESULTS REGARDING DIFFERENCE BETWEEN TEAR STRENGTH LEVELS IN TERMS OF GREIGE FABRIC AND ANTIBACTERIAL TREATED FABRIC, *p < 0.05							
Parameter	**Weft direction**	**No.**	**Mean**	**S**	**t**	**sd**	**p**
Tear strength	Greige fabric	15	7.05	0.74	4.41	14	0.001*
	Antibacterial treated fabric	15	6.35	0.48			

Table 9

T-TEST RESULTS REGARDING THE DIFFERENCE BETWEEN THE ABRASION RESISTANCE STRENGTH LEVELS OF GREIGE FABRIC AND ANTIBACTERIALLY TREATED FABRIC, *p < 0.05							
Parameter	**Fabric type**	**No.**	**Mean**	**S**	**t**	**sd**	**p**
Abrasion resistant strength	Greige fabric	15	18750.00	355.57	7.03	14	0.000*
	Antibacterial treated fabric	15	19596.67	193.16			

As seen in figure 2, antibacterial treatment negatively affected the tear strength of Greige fabric and antibacterial finish fabric tear strength results.

According to table 7, the tear strength levels of the greige fabric and the antibacterial treated fabric are compared in terms of warp. Between tear strength mean ($\bar{X}$ = 8.53 N) of warp in terms of warp and tear strength mean ($\bar{X}$ = 7.69 N) of antibacterial treated fabric in terms of warp $t_{(14)}$ = 10.16, It is seen that there is a significant difference according to p = 0.000 < 0.05. After the greige fabric is treated with antibacterials, it is seen that the tear strength (Newton) decreases in terms of warp, that is, the decrease in this weight is perceived as a negative result. It is seen that antibacterial finishing process negatively affects the weft tear strength.

In table 8, the tear strength levels of the greige fabric and the antibacterial treated fabric are compared in terms of weft. $t_{(14)}$ = 4.41, between the tear strength ($\bar{X}$ = 7.05 newton) in terms of weft of the greige fabric and the tear strength ($\bar{X}$ = 6.35 newton) in the antibacterial treated fabric It is seen that there is a significant difference according to p = 0.001 < 0.05. After the greige fabric is treated with antibacterials, it is seen that the tear strength (newton) decreases in terms of weft, that is, the decrease in this weight is perceived as a negative result. It is seen that the antibacterial finishing process negatively affects the warp tear strength.

According to table 9, the abrasion resistance levels of the greige fabric and the antibacterial treated fabric are compared. Abrasion resistance strength (number of tours) of greige fabric ($\bar{X}$ = 18750.00) and abrasion resistance (number of tours) of fabric treated with antibacterials ($\bar{X}$ = 19596.67) $t_{(14)}$ = 7.03, p = 0.000 < 0.05 It is seen that there is a significant difference. It is seen that the abrasion resistance (number of turns) increases after the greige fabric is treated with antibacterial. In this respect, it is seen that the antibacterial process has a positive effect on fabric abrasion resistance.

After antibacterial finishing, there was a decrease in the creasing strength (angle) of both warp and weft direction. In other words, sheets with antibacterial finishing are wrinkled more. Wrinkle angle of flexible fabrics is higher. Since the antibacterial finishing process reduces fabric flexibility, it negatively affected the creasing angle of the treated fabric. In addition, the antibacterial finishing process creates extra weight on the fabric, and the wrinkle angle may be adversely affected after the applied force. As a result of Sema Palamutcu et al. 2008 project, it was observed that the fabric tear strength decreased after antibacterial treatment [14]. These results support the results of our thesis. There was an increase in abrasion resistance after antibacterial finishing. In other words, sheets with antibacterial finishing are less and hard to wear. We can say that there is an increase in the abrasion resistance since the chemical surface is coated with an antibacterial finishing process.

CONCLUSİONS

A good antibacterial activity was observed against the MRSA isolate in the fabric, and it was observed that the fabric showed a weak antibacterial activity against the *E. coli* isolate. The effectiveness of the antibacterial activity will decrease, depending on the type of chemical substance that shows antibacterial effect, the duration of its activity on the fabric, the physical factors such as washing and tearing.

After the antibacterial finishing process, the wrinkle strength (angle) of warp and weft direction decreases, so these sheets become more wrinkled. Wrinkle angle of flexible fabrics is higher. Since the antibacterial finishing process reduces fabric flexibility, it negatively affected the creasing angle of the treated fabric. In addition, the antibacterial finishing process creates extra weight on the fabric and the wrinkle angle may be adversely affected after the applied force.

After the antibacterial finishing process, the tear strength decreased in both warp and weft directions. In other words, sheets with antibacterial finishing treatment can be torn more easily. The tear strength of flexible fabrics is higher as the yarns can slip more easily over each other. Since the antibacterial finishing process reduces fabric flexibility, a reduction in tear strength occurred.

In the conclusion of Huriser Balcı's thesis study in 2006, the characteristics that antibacterial process parameters negatively affect cotton fabric; tensile tensile, tear strength, creasing properties, water and sweat fastness [15]. As a result of Sema Palamutçu et al. 2008 project, the decrease in fabric tear strength after antibacterial treatment supports the study [14]. There was an increase in abrasion resistance after antibacterial finishing. An improvement has been observed in this regard. It can be said that there is an increase in the abrasion resistance since the chemical surface is coated with antibacterial finishing process. Wrinkle strength, tear strength; the positive effect was the abrasion resistance. Along with the antibacterial process applied in the studies to be carried out, it should definitely be evaluated in decreases in the mechanical properties besides the feature to be gained to the fabric.

The studies that can be done in the next periods are mentioned respectively. Comparison can be made with different chemical structured antibacterial finishing agents by applying finishing to fabrics of different weaving types. Relationships between different mechanical properties such as tensile strength, seam strength, bursting strength can be examined by antibacterial finishing.

Antibacterial finishing process; chemical properties such as fastness and sensory properties such as attitude and touch can be examined.

REFERENCES

[1] Akaydin, M., Kalkanci, M., *Hastane Giysisi Olarak Kullanılan Kumaşların Antibakteriyel Özellikleri Üzerine Bir Araştırma*, In: SDU J. Sci., 2014, 9, 1, 20–34

[2] Ünal, H., *Development Of Disposable Hydrophilic And Antibacterial Polypropylene Nonwoven Sheet*, Yüksek Lisans Tezi, İstanbul Teknik Üniversitesi Fen Bilimleri Enstitüsü, Tekstil Mühendisliği Anabilim Dalı, 2009

[3] Tomasino, C., *Chemistry & Technology of Fabric Preperation & Finisihin,* North Carolina State University Publication, Raleigh, 1992

[4] Perelshtein, L., Applerot, G., Perkas, N., Guibert, G., Mikhailov, S., Gedanken, A., *Sonochemical coating of silver nanoparticles on textile fabrics (nylon, polyester and cotton) and their antibacterial activity*, In: Nanotechnology, 2008, 19, 24

[5] Balakumarana, M.D., Ramachandrana, R., Jagadeeswarib, S., Kalaichelvana, P.T., *In vitro biological properties and characterization of nanosilver coated cotton fabrics – An application for antimicrobial textile finishing,* In: International Biodeterioration & Biodegradation, 2016, 107, 48–55

[6] Haytham, M.M., Mahmoud, I., Hassanb, S., *Characterization and antimicrobial properties of cotton fabric loaded with green synthesized silver nanoparticles*, In: Carbohydrate Polymers, 2016, 151, 841–850

[7] Thanh, N.V.K., Phong, N.T.P., *Investigation of antibacterial activity of cotton fabric incorporating nano silver colloid*, In: APCTP – Asean Workshop on Advanced Materials Science and Nanotechnology (AMSN08), 15–21 September 2008

[8] Mohammadi, M.R., *Production of cotton fabrics with durable antibacterial property by using gum tragacanth and silver,* In: International Journal of Biological Macromolecules, 2018, 109, 476–482

[9] Kittinaovarat, S., Kantuptim, P., Singhaboonponp, T., *Wrinkle resistant properties and antibacterial efficacy of cotton fabrics treated with glyoxal system and with combination of glyoxal and chitosan system,* In: Journal of Applied Polymer Science, 2006, 100, 2, 1372–1377

[10] Xu, Q.B., Xie, L.J., Diao, H., Li, F., Zhang, Y.Y., Fu, F.Y., Liu, X.D., *Antibacterial cotton fabric with enhanced durability prepared using silver nanoparticles and carboxymethyl chitosan,* In: Carbohydrate Polymers, 2017, 177, 187–193

[11] Xu, Q., Gu, J., Zhao, Y., Ke, X.T., Liu, X.D., *Antibacterial cotton fabric with enhanced durability prepared using L-cysteine and silver nanoparticles,* In: Fibers and Polymers, 2017, 18, 2204–2211

[12] Ramachandran, T., Rajendrakumar, K., Rajendran, R., *Antimicrobial Textiles an Overview*, IE (I) Journal TX, 2004, 84

[13] Özdil, N., *Kumaşlarda Fiziksel Kalite Kontrol Yöntemleri*, In: Tekstil ve Konfeksiyon Araştırma – Uygulama Merkezi Yayini, 2016, 167

[14] Palamutcu, S., Şengül, M., Devrent, N., Keskin, R., *Tekstil Ürünlerinde Antimikrobiyal Etkinlik Belirleme Testleri,* VII. Ulusal Ölçübilim Kongresi, 30 Ekim –1Kasım, 2008

[15] Balci, H., *Akıllı (Fonksiyonel) Tekstiller, Seçilmiş Kumaşlarda Antibakteriyel Apre Ve Performans Özellikleri*, Yüksek Lisans Tezi, Çukurova Üniversitesi Fen Bilimleri Enstitüsü, Tekstil Müh. Anabilim Dali, 2006

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A new perspective in e-learning training toolkit development for advanced textile research centres in Morocco and Jordan

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ABSTRACT – REZUMAT

A new perspective in e-learning training toolkit development for advanced textile research centres in Morocco and Jordan

This paper presents an overview of training/learning tools for advanced textile research centres in Morocco and Jordan. Within the Erasmus+ FOSTEX project, the main courses necessary for the training of researchers and students enrolled in master's or doctoral programs in Morocco and Jordan and who will work within the advanced research centres have been identified and selected. Starting from good European practices on learning, teaching, research and testing services, several courses have been structured that offer knowledge on international conformity certification, standardization, quality management, testing/inspection, labelling, integration of technical specifications, testing physical-mechanical, colour resistance testing, tests specific to instrumental analysis and development of advanced materials. In order to improve the skills of human resources (research staff, masters and doctoral students), the Erasmus+ FOSTEX consortium has developed an extensive toolkit of learning-training, thematic workshops and services appropriate to the equipment purchased by partners in Morocco and Jordan for research centres in the field of advanced textiles.

Keywords: *research, advanced materials development, testing, standardization, e-learning, training*

O nouă perspectivă în dezvoltarea setului de intrumente de formare e-learning pentru centrele de cercetare în domeniul textilelor avansate din Maroc și Iordania

Această lucrare prezintă o vedere de ansamblu a instrumentelor de formare/învățare pentru centrele cercetare în domeniul textilelor avansate realizate în Maroc și Iordania. În cadrul proiectului Erasmus+ FOSTEX au fost identificate și selectate principalele cursuri necesare pentru formarea cercetătorilor şi studenților înscriși în programe de masterat sau doctorat din Maroc și Iordania şi care vor lucra în cadrul centrelor de cercetare avansată. Pornind de la bunele practici europene privind învățarea, predarea, activitatea de cercetare și serviciile de testare, au fost structurate mai multe cursuri care oferă cunoștințe despre certificarea de conformitate internaţională, standardizare, managementul calității, testare/inspecție, etichetare, integrarea specificațiilor tehnice, testare fizico-mecanică, testarea rezistentei culorii, teste specifice analizei instrumentale și dezvoltarea materialelor avansate. Pentru a îmbunătăți abilitățile resurselor umane (personal de cercetare, masteranzi și doctoranzi), consorțiul Erasmus+ FOSTEX a dezvoltat un set de instrumente de învățare-formare extins, ateliere tematice și servicii adecvate echipamentelelor achiziționate de partenerii din Maroc și Iordania pentru centrele de cercetare în domeniul textilelor avansate.

Cuvinte-cheie: *cercetare, dezvoltarea materialelor avansate, testare, standardizare, e-learning, formare*

INTRODUCTION

In the Erasmus+ FOSTEX project, tremendous work was to develop the courses modules in the framework of the learning toolkit, taking into account the particularities of the advanced centres established in Jordan and Morocco such as the equipment purchased in the framework of the Erasmus+ FOSTEX project, services proposed, and background of the human resources involved in the advanced textile centres created or updated. Starting from the best practices database containing the examples of learning, teaching (courses), dissemination, quality testing, standardization, equipment acquisitions, educational, and research projects, were developed and provided a set of courses (toolkit) about international conformity certification, standardization, quality management, inspection vs. testing of the textiles (protective textile testing, washing fastness, colour fastness testing, tensile strength testing), instrumental analysis, colour management and communication, integration of textile testing result into technical specifications, environmental legislation and advanced composites development based on plasma, 3D printing, polymeric matrix, fibres, nonwoven, knitted structures and micro/nanoparticles for functionalization. In addition, based on the final list of equipment purchased by partners from Jordan and Morocco was provided an adequate selection of services and thematic workshops usefully to be developed. In order to deliver attractive courses in the context of the Covid-19 crisis, have been used formal or informal teaching/

learning methods in the virtual classroom established using dedicated software for meeting applications.
The proposed courses, services and workshops aim to improve the knowledge, to foster the collaboration in research [1, 2] or educational projects between EU and Moroccan and Jordanian universities in the advanced textiles sector and to co-create innovation and training network that will continue to produce sustainable results after the end of the project.
The knowledge about advanced textile materials must be permanently updated with advanced knowledge from other disciplines (physics, chemistry, mechanics, biology, and electronics). To increase the students' attention and perception and to attract them to learn about new materials was very important to prepare an adequate interactive presentation mixing the slides, images, exercises, sound and videos. In addition, the knowledge level can be improved by seminars, workshops, e-learning and training, as well as real practice in laboratories. However, for upgrading or development of new research centres (Jordan, Morocco) are very important the infrastructure and human resources qualifications, as well as the continuous learning.
This paper contains an overview of the international conformity certification, labelling and technical specifications, quality management, environmental legislation and inspection/testing (physico-mechanical testing, colour fastness testing and the testing suite provided by a large group of instrumental analyses).

INTERNATIONAL CONFORMITY CERTIFICATION

Conformity represents compliance with standards, rules, or laws. Conformity assessment involves a set of processes that show your product, service or system meets a standard's requirements. CASCO Committee (ISO's Committee on Conformity Assessment) develops standards and addresses issues related to conformity assessment (figure 1).
The main forms of conformity assessment are testing, certification and inspection.
Textile testing is the determination of one or more of the textile product's characteristics and is usually performed by a laboratory. CASCO has developed several standards that laboratories can follow to help ensure that their results can be trusted. Inspection describes the regular checking of a product to make sure it meets specified criteria. Firefighters' PPE, for example, need regular inspections to ensure they are safe for use (ISO/CD 23616).
Certification is a useful tool to add credibility by demonstrating that your product or service meets your customers' expectations. For some industries, certification is a legal or contractual requirement. However, ISO does not perform certification and does not issue certificates. CASCO has produced some standards related to the certification process, which are used by certification bodies. Certification is certifying that the product, service or system in question meets specific requirements. Certification is also known as third-party conformity assessment [3, 4]. For example, companies and organizations are certified to management system standards (ISO 9001). In this way, get visible that the organization has a quality management system implemented. CE marking (European conformity certification) signifies that the EEA (European Economic Area) products have been assessed to meet high safety, health, and environmental protection requirements. CE marking is a part of the EU's harmonization legislation. CE marking on the textile product is a declaration that the product meets all the legal requirements for CE marking and can be sold throughout the EEA. This also applies to products made in other countries that are sold in the EEA.
Benefits of the CE marking:
- Businesses know that products bearing the CE marking can be traded in the EEA without restrictions;
- Consumers enjoy the same level of health, safety, and environmental protection throughout the entire EEA.

Certificate of Conformity (CoC), also named Certificate of Compliance, is a mandatory document necessary for Customs clearance of exports to many countries around the globe.
CoC is a document certified by a competent authority that the supplied good or service meets the required specifications.
CoC shows that the goods being exported comply with the relevant technical regulations and national,

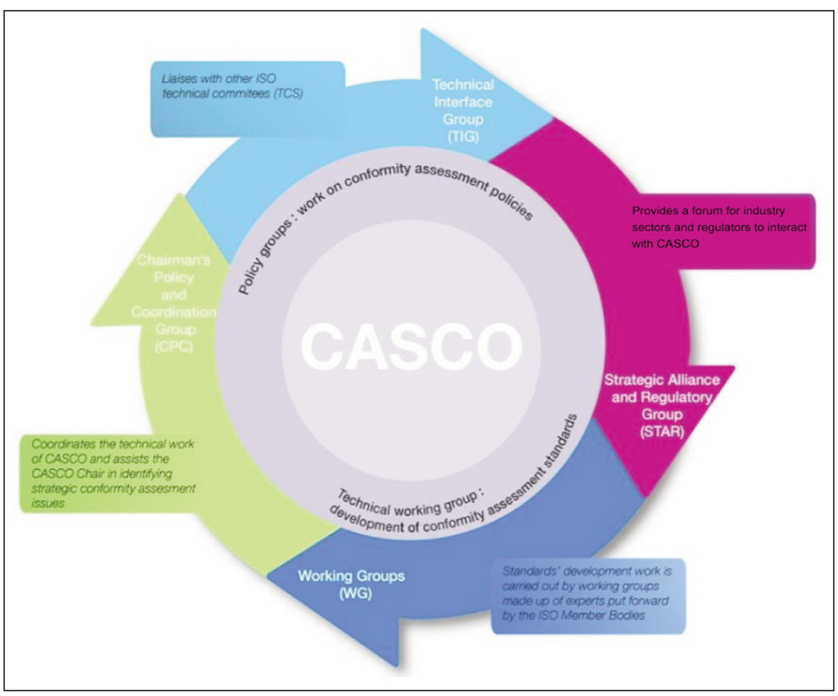

Fig. 1. Structure of CASCO (Source: www.iso.org)

regional or international standards of import, protecting citizens' health, safety, and the environment from substandard imported goods and giving them the assurance they need in their local market.

Certification ≠ Approval (Organizations such as Underwriters Laboratories, TÜV Rheinland, NTA Inc, and CSA International test the products according to standard procedures and declare that the product is compliant with the standard).

The technical documentation contain the information on the design, manufacture and all the details necessary to demonstrate the product conforms to the applicable requirements [5].

In case of the manufacturer, the certification is required as evidence or proofs that products or services meet regulations, standards or other requirements before placing the product on the market.

QUALITY MANAGEMENT AND ADVANCED MATERIALS TESTING

Quality management/Quality assurance

Quality management [6, 7] is providing confidence that quality requirements are achieved. Quality control is a "part of quality management focused on fulfilling quality requirements".

Quality assurance (QA) [8, 9] is used to prevent defects in products manufactured when delivered to customers and can be achieved through inspection. Inspection is the process of measuring, examining, and testing the product /service characteristics and comparing the testing results with specified requirements to determine conformity [10].

Testing

Testing [11] is a part of quality assurance -inspection, being an activity developed to measure the quality of the product characteristics.

To prepare a high-quality set of requirements specifications for products it is mandatory to verify the product's technical characteristics by testing the product in accredited laboratories.

We need to test the mechanical, chemical or electrical properties of the product to evaluate the quality of the product's characteristics and to answer if the product has the performance (numerical values of the parameters tested) in line with the technical requirements and specifications.

These numerical values of the parameters (mechanical or chemical, electrical) obtained by testing are useful in production, purchasing and claims.

The testing activity can be performed during product development to assure that the quality meets expectations. The results of the tests are useful in identifying the appropriate parameters that should be improved/optimised in production. The testing results following the European and international standards (ISO) can be used to certify that your product meets the expected requirements. In addition, the test results can also help resolve complaints seeking damages.

Physico-mechanical testing

Tensile strength testing can be performed through 2 methods grab and strip using standards ISO 13934 and ISO 13935.

The standard ISO 13934 is used for the determination of mechanical properties of textiles using mainly tensile testing machines, e.g. tensile properties, seam tensile properties, tear properties, seam slippage.

Tensile properties (maximum force or elongation at maximum force) of the textiles (woven structures) can be investigated by 2 methods:

- Strip method (ISO 13934-1:2013) allows determination of maximum force and elongation [12];
- Grab method (ISO 13934-2:2014) allows the determination of maximum force [13].

ISO 13935 is used for the determination of seam maximum force of sewn seams when the force is applied perpendicularly to the seam. Tensile properties (seam maximum force of sewn seams when the force is applied perpendicularly to the seam) can be investigated using 2 methods:

- Strip method (ISO 13935-1:2014) allows determination of maximum force to seam rupture [14];
- Grab method (ISO 13935-2:2014) allows determination of maximum force to seam rupture [15].

Colour fastness testing

Colour fastness represents the resistance of the colour of textiles to the different agents (figure 2) to which these materials may be exposed during manufacture and wearing.

The most used colour fastness tests in textile industry are:

- Colour fastness to perspiration (ISO 105-E04:2013) [16];
- Colour fastness to wash (ISO 105-C10:2006, ISO 105-C06:2010) [17, 18];
- Colour fastness to light: daylight (ISO 105-B01:2014) [19];
- Colour fastness to artificial light (ISO 105-B02:2014) [20];
- Colour fastness to water (ISO 105-E01:2013) [21];

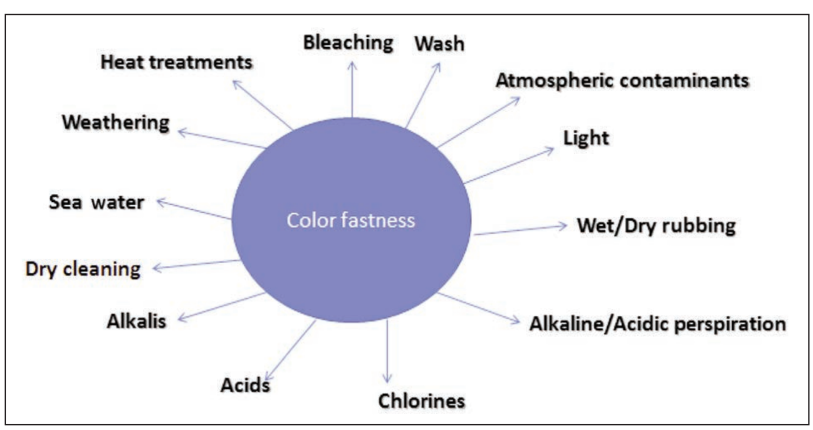

Fig. 2. Types of colour fastness testing

- Colour fastness to rubbing (ISO 105-D02:2016, ISO 105-X16:2016, ISO 105-X12:2016) [22–24];
- Colour fastness to hot pressing (ISO 105-X11: 1994) [25].

Instrumental analysis

Analytical instrumentation is crucial to molecular biology, medicine, geology, food science, or materials science [26–29]. For each classical or instrumental analysis method are defined the adequate qualitative and quantitative methods [30–32].

- A qualitative method provides information about the identity of atomic/molecular species and functional groups of the sample.
- A quantitative method provides numerical information about the relative amount of one or more components.

Then qualitative and quantitative analysis can be performed, often with the same instrument and may use light interaction, heat interaction, electric fields or magnetic fields [33–35]. Instrumental analysis methods may be elemental or molecular analysis using qualitative and quantitative methods (tables 1 and 2) [36–38].

Some of the presented methods can be used in the investigation of the textile materials, additional micro/nanoparticles present on the textile surface [35]. Below are presented the main applications of instrumental methods [31, 33–35] (elemental and molecular analysis):

Elemental analysis

- **Atomic absorption spectrometry (AAS)**

Qualitative analysis of the AAS method is not used routinely for qualitative analysis, since with most instruments; it is only possible to test for one element at a time.

Quantitative analysis of the AAS method is a very accurate and sensitive method for the quantitative investigation of metals and metalloids down to absolute amounts as low as picograms for some elements. It cannot be used directly for the determination of non-metals.

- **X-ray fluorescence (XRF)**

The XRF method's qualitative analysis is useful for elements with atomic numbers greater than 4, including metals and non-metals. For qualitative analysis, no sample preparation is required, and the method is generally non-destructive.

Quantitative analysis of the XRF method is used extensively for the quantitative determination of elements in alloys and mineral samples, particularly of elements with high atomic weights. Sample preparation is elaborate for quantitative analysis.

- **Atomic emission spectrometry (AES), Optical emission spectrometry (OES)**

Qualitative analysis in the case of the AES method is an almost comprehensive method for qualitative elemental analysis for metals, metalloids, and non-metals except for some permanent gases. Its sensitivity range is good, varying from ppb to percent levels. It has the advantage that many elements can be

Table 1

INSTRUMENTAL METHODS OF ANALYSIS [32]

Method	Qualitative		Quantitative	
	Elemental	**Molecular**	**Elemental**	**Molecular**
Atomic absorption spectrometry	No	No	Yes	No
Atomic emission spectrometry	Yes	No	Yes	No
Capillary electrophoresis	Yes	Yes	Yes	Yes
Electrochemistry	Yes	Yes	Yes	Yes
Gas chromatography	No	Yes	No	Yes
ICP-mass spectroscopy	Yes	No	Yes	No
Infrared spectroscopy	No	Yes	No	Yes
Ion chromatography	Yes	Yes	Yes	Yes
Liquid chromatography	No	Yes	No	Yes
Mass spectroscopy	Yes	Yes	Yes	Yes
Nuclear magnetic resonance	No	Yes	No	Yes
Raman spectroscopy	No	Yes	No	Yes
Thermal analysis	No	Yes	No	Yes
UV/VIS spectrophotometry	Yes	Yes	Yes	Yes
UV absorption	No	Yes	No	Yes
UV fluorescence	No	Yes	No	Yes
X-ray absorption	Yes	No	Yes	No
X-ray diffraction	No	Yes	No	Yes
X-ray fluorescence	Yes	No	Yes	No

Table 2

ANALYTICAL CONCENTRATION RANGES FOR COMMON INSTRUMENTAL METHODS [32]					
Technique	**Destructive**	**Ultratrace (<1 ppm)**	**Trace (1 ppm – 0.1%)**	**Minor (0.1% – 10%)**	**Major (>10%)**
X-ray diffraction	No	No	No	Yes	Yes
Nuclear magnetic resonance	No	No	Yes	Yes	Yes
X-ray fluorescence	No	No	Yes	Yes	Yes
Infrared spectroscopy	No	No	Yes	Yes	Yes
Raman spectroscopy	No	No	Yes	Yes	Yes
UV/VIS spectrometry	No	No	Yes	Yes	Yes
Colorimetry	No	Yes	Yes	Yes	No
Molecular fluorescence spectrometry	No	Yes	Yes	Yes	Yes
Atomic absorption spectrometry	Yes	Yes	Yes	Yes	No
Atomic emission spectrometry	Yes	Yes	Yes	Yes	Yes
Atomic fluorescence spectrometry	Yes	Yes	Yes	No	No
ICP-mass spectrometry	Yes	Yes	Yes	Yes	No
Organic mass spectrometry	Yes	Yes	Yes	Yes	Yes
GC-MS	Yes	Yes	Yes	Yes	Yes
LC-MS	Yes	Yes	Yes	Yes	Yes
Potentiometry	No	Yes	Yes	Yes	Yes
Voltammetry	No	Yes	Yes	Yes	Yes
Gas chromatography	May be	Yes	Yes	Yes	Yes
High-performance liquid chromatography	May be	Yes	Yes	Yes	Yes
Ion chromatography	May be	Yes	Yes	Yes	Yes
Capillary electrophoresis	No	Yes	Yes	Yes	Yes
Thermal analysis	Yes	No	No	Yes	Yes

detected simultaneously. However, the spectral overlap is the major limitation.

Quantitative analysis in the case of the AES method is used extensively to determine elements in concentrations from percent levels down to ppb. Liquids, slurries, and solids can be analysed using the appropriate instrumentation.

Molecular analysis

- **Nuclear magnetic resonance (NMR) spectroscopy**

Qualitative analysis in the case of the NMR method is used to investigate the structure of molecules. NMR identifies the number and type of protons and carbon atoms in organic molecules (e.g., among aromatic, aliphatic, alcohols, and aldehydes)

Quantitative analysis of the NMR method is useful at percentage concentration levels, but trace levels (ppm) are becoming attainable with reasonable accuracy.

- **Infrared (IR) spectroscopy**

Qualitative analysis in the IR method identifies organic functional groups present in molecules, including groups containing heteroatoms: O, S, N, Si, halides. The conventional spectrometers systems have been replaced by Fourier transform IR (FTIR) instrumentation.

Quantitative analysis of the IR method is used routinely for the quantitative analysis of organic compounds, particularly at percentage concentration levels.

- **Fourier-transform infrared spectroscopy (FTIR)**

FTIR is a spectroscopic technique used to obtain an infrared spectrum of absorption or emission of a solid, liquid or gas. FTIR spectrometer collects high-spectral-resolution data over a wide spectral range. The theory is based on the fact that different elements absorb light at different frequencies. FTIR is used because it can produce an interferogram within a second. FTIR analysis method uses infrared light to scan test samples and observe the organic, polymeric, or inorganic materials' chemical properties.

- **UV and visible (UV/VIS) spectrophotometry**

Qualitative analysis UV/VIS of the organic or inorganic reagents is used for specific tests for many elements or compounds by forming a compound that absorbs specific wavelengths. The products may or may not be coloured. For compounds that are coloured, the analysis may be carried out visually (colorimetric analysis by eye), but a spectrometer is more accurate. The interaction of UV and visible radiation with matter can provide qualitative identification of molecules and polyatomic species, including ions and complexes. Qualitative information is usually obtained by observing the UV/VIS spectrum, the absorption of UV and visible radiation as a function of

Table 3

SPECTROMETRY USING UV AND VISIBLE LIGHT [32]		
Spectrometry using UV and Visible Light		
Function	**Analytical field**	**Analytical application**
Atomic spectroscopy		
Absorption of UV/VIS radiation	Atomic absorption spectrometry (AAS)	Quantitative elemental analysis
Emission of UV/VIS radiation	Flame photometry, Auger electron spectroscopy (AES)	Qualitative and quantitative multi-element analysis
Emission of UV/VIS radiation	Atomic fluorescence spectroscopy (AFS)	Quantitative elemental analysis of ultra-trace concentrations (sub-ppb)
Molecular spectroscopy		
Absorption of UV/VIS radiation	UV/VIS molecular absorption spectroscopy, spectrophotometry	Qualitative and quantitative determinations of aromatic and unsaturated organic compounds, including natural products; direct and indirect quantitative determination of inorganic ions, organic molecules, and biochemicals
Emission of UV/VIS radiation	Molecular fluorescence, molecular phosphorescence	Detection of small quantities (<ng) of certain aromatic compounds and natural products, analysis of gels and glasses, determination of organic and inorganic species by "tagging."

wavelength by molecules (tables 3 and 4). The principle is based on the fact that:

I. Frequency absorbed or emitted by a molecule and the energy of radiation are related by:

$$\Delta E = hv \qquad (1)$$

II. The amount of energy required depends on the difference in energy (equation 2) between the energy of the ground state ($E0$) and the energy of the excited state ($E1$) of the electrons.

$$\Delta E = E1 - E0 = hv \qquad (2)$$

Table 4

WAVELENGTHS = F (RADIATION TYPE) [32]			
Unit	**Symbol**	**Length (m)**	**Type of radiation**
Angstrom	Å	10^{-10}	X-ray
Nanometre	nm	10^{-9}	Ultraviolet/ visible (UV/VIS)
Micrometre	µm	10^{-6}	Infrared (IR)
Millimetre	mm	10^{-3}	IR
Centimetre	cm	10^{-2}	Microwave
Meter	m	1	Radio

Quantitative analysis UV/VIS is a sensitive and selective method developed for most elements and many functional groups. It is used extensively in routine analysis of water, food, beverages, industrial products, etc. In general, spectrometers UV/VIS often operates with wavelengths from 800 to 200 nm (UV radiation has wavelengths from 400 to 200 nm; respective VIS (visible light) have wavelengths from 800 to 400 nm). Quantitative measurements by UV/VIS spectrometry are essential in environmental monitoring, industrial process control, including food and beverage manufacturing, pharmaceutical quality control, and chemistry. Quantitative information can also be obtained by studying the absorption or emission of UV and visible radiation by molecules or polyatomic species. The emission of radiation by molecules may occur in several ways (fluorescence and phosphorescence) following the molecule's excitation. In addition, concentrations of solutions can be measured using UV/VIS absorption spectrometry or fluorescence spectrometry.

- **X-ray diffraction (XRD)**

Qualitative analysis in the XRD method is used for the measurement of crystal lattice dimensions and to identify the structure and composition of all types of crystalline inorganic and organic materials.

Quantitative analysis in the XRD method is used to determine percent crystallinity in polymers, the composition of mixtures, mixed crystals, soils, and natural products.

- **X-ray absorption spectroscopy**

Qualitative analysis in the X-ray absorption reveals the contours and location of high atomic weight elements in the presence of low atomic weight matrixes or holes in the interior of solid samples (voids).

- **Gas chromatography (GC)**

Qualitative analysis in the case of the GC method can separate the components of complex mixtures of gases or volatile compounds.

Quantitative analysis in the case of the GC method is an accurate method for quantitative analysis based on the peak area and comparison with standards. Quantitative analysis is used extensively in organic, environmental, clinical, and industrial analysis.

- **Thermal analysis (TA)**

Qualitative analysis in the TA method is used to identify inorganic and some organic compounds using small quantities of samples. It is also used to identify phase changes, chemical changes on heating, the heat of fusion, melting points, boiling points, drying

Table 5

LIST OF SAMPLE TYPES AND PROPERTIES EXAMINED BY THERMAL ANALYSIS METHOD [32]							
Properties	Samples						
	Chemicals	Elastomers	Explosives	Soils	Plastics	Textiles	Metals
Identification	x	x	x	x	x	x	x
Quantitative composition	x	x	x	x	x	x	
Phase diagram	x	x	x		x		x
Thermal stability	x	x	x		x	x	
Polymerization	x	x			x	x	
Catalytic activity	x						x
Reactivity	x	x			x	x	x
Thermochemical constants	x	x	x	x	x		x
Reaction kinetics	x	x	x		x	x	x

processes, decomposition processes, and compounds' purity (table 5).
Quantitative analysis in the TA method can be used for the quantitative determination of the components of an inorganic sample, particularly at high concentration levels (table 5).

- **Differential scanning calorimetry (DSC)**

DSC monitors the difference in temperature between a sample and a reference material as a function of time and temperature in a specified atmosphere.
Quantitatively measures heat absorbed or released by a material undergoing a physical or chemical change. DSC is not temperature-dependent; DSC is used for quantitative measurements of ΔH and heat capacity. Information obtained Glass transition, melt and phase-change temperatures, heats of reaction, heat capacity, crystallinity, aging, degradation, and thermal history (table 6).

Table 6

DSC METHOD APPLICATIONS	
Applications	DSC method
Compositional analysis	x
Curing studies	x
Glass transition	x
Heat of reaction	x
Oxidative stability	x
Corrosion	x
Creep	-
Stress relaxation	-
Thermal stability	x
Viscoelastic properties	x
Protein denaturation	-
Shrinkage	x

TECHNICAL SPECIFICATIONS INTEGRATION AND LABELING

A technical specification document defines the requirements for a textile material or final product.

Technical specifications integration and testing role

The testing activity is important to verify the product properties or develop the technical specifications sheet that should provide:

- the minimum requirements for the mechanical, physical and chemical properties of the products that your company purchases or produces;
- ensure that the quality of your products meets your expectations/your customers' expectations;
- prevent miscommunication between the producer, supplier, purchaser and retailer;
- to ensure that the customers are satisfied and you will not receive complaints.

Complications may occur when the product properties are not described in sufficient detail. However, it is impossible to detect the defects (durability, shrink, fade in use) visually when we buy a product.
The textile product should have several performance indicators and should be able to confer:

- Fire safety;
- UV protection;
- Friction resistance;
- Chemicals resistance and to contain allowed chemicals and not prohibited, according to the REACH (Registration, Evaluation, Authorization and Restriction of Chemicals).

In REACH [37,38] are presented the requirements for chemicals that are allowed or prohibited from use in your products.
Usually, consumers or textile specialists cannot see or feel if textile products contain harmful substances, but chemical analyses can identify the presence of prohibited chemical substances.
The absence of the harmfully chemical can be certified by:

- STANDARD 100, ECO PASSPORT and MADE IN GREEN by OEKO-TEX® [37] certify that your products guarantee that they do not contain any chemical compounds known to be harmful.
- OEKO-TEX* certify that your products comply with the requirements of REACH, the EU law regulating chemicals, and the substances on the SVHC (Substances of Very High Concern) list [38].

Safety requirements

In the EU, the General Product Safety Directive (GPSD) [40, 41] regulates all products and the manufacturers and distributors carry the responsibility not to bring products on the market, which present a health or safety hazard towards or property when used in the manner intended. There are many safety issues, such as fire, fall accidents, choking, chemical content, etc. The requirements and the testing methods of the textile products are given in the standards. For example, the requirement for protective clothing is focused on health and ergonomics aspects, design, comfort, cleaning/washing, the size used for pattern design of the protective clothing.

Health and ergonomic requirements for protective clothing (ISO 13688:2013) [42] specify that the protective clothing:

- should not affect the health or hygiene of the user;
- the textile fabrics should not release toxic, carcinogenic, mutagenic, allergenic, toxic to reproduction or otherwise harmful substances;
- materials should be selected to minimize the environmental impact of the production and disposal of protective clothing;

Each layer of material of the protective clothing shall comply with the following requirements:

- all metallic materials which could come into prolonged contact with the skin (e.g. studs, fittings) shall have a release of nickel of less than 0,5 μg/cm^2 per week;
- protective clothing material shall have a pH value in the interval 3.5–9.5;
- Carcinogenic Azo colorants should not be used.

Design requirements consist in:

- using the adequate design of protective clothing that facilitate its correct positioning on the user and shall ensure that it remains in place for the foreseeable period of use, taking into account ambient factors, together with the movements and postures that the wearer could adopt during the course of work or other activity;
- using adequate adjustment systems or adequate size ranges shall be provided to enable protective clothing to be adapted to the morphology of the user.

Comfort requirements

The protective clothing shall provide users with a level of comfort consistent with the level of protection required against the hazard, the ambient conditions, the level of the user's activity, and the anticipated duration of use of the protective clothing.

- Cleaning/washing requirements
- Size requirements

Product labelling

Product labelling is necessary for selling part, offering the consumers information about product type, performance parameters and usage conditions.

How can we decide the performance of the product?

- Overall, the consumers and textile specialists cannot see or feel the performance of a textile.
- The manufacturer can evaluate the performance characteristics of a product by testing.
- The purchaser should obtain the documentation of the successful fulfilment of any applicable requirements.

Why it is necessary to specify the requirements on the product label?

- A labelling system can help to inform the consumer of the requirements that the products have fulfilled.
- Specification requirements will inform the consumer of the quality and properties of the product.

Several integrated labelling solutions are available:

- **Test the parameters of your products** and **use a label with a hangtag** after successful completion of testing in accredited laboratories.
- A **hangtag informs the consumer** that the requirements of the product complied with and assures the standard of quality.
- A **hangtag with a barcode** [43] (figure 3), will enable the consumer to receive informative videos on smartphones about the characteristics of your product.
- **Brand protection** by use anti-counterfeit features for brand protection based on advanced UV inks and yarn, laser yarn, glow-in-the-dark yarn, micro text prints, and watermarks to ensure the authenticity of your products and reduce the risk of counterfeit.

Fig. 3. Barcode hangtag [41]

In addition, the product that has a green label must comply with environmental policy goals (climate change, resource use and sustainable consumption and production) and a better environment according to the GPP (Green Public Procurement) [44–47].

GPP approaches include also restricting hazardous substances in textiles, or requiring operators to demonstrate that timber has been sustainably sourced. EU GPP specifies relevant production methods for some product and service groups, including electricity, textiles and food. Labels and GPP criteria are useful reference points, as they are based on scientific information and life-cycle assessment of the materials and substances found in the covered products and services. Green labels (Eco-labels and Green stickers) are labelling systems for consumer products [46, 47, 48]. Green label is officially recognized as a method for companies to make:

- transparent environmental declarations;
- claims about their products such as materials used (natural, recycled, eco-friendly), the energy consumption in the manufacturing process.

In the EU, the EU Ecolabel, established in 1992, has the scope to encourage businesses to market products and services that are kinder to the environment [48–50]. EU Ecolabel covers 34 products and services including paper, textiles, cleaning products, lubricants, appliances, home and garden products and tourist accommodation. On many textile products, we can be recognized the OEKO-TEX® label provided by OEKO-TEX® which is an organization that has several members: 18 independent research and test institutes in the field of textile and leather ecology in Europe and Japan with contact offices in more than 60 countries. The partner institutes develop test methods and limit values, which form the basis for the standards (STANDARD 100 by OEKO-TEX®, MADE IN GREEN by OEKO-TEX® and LEATHER STANDARD by OEKO-TEX®) for labelling or product certification according to STeP by OEKO-TEX® (Sustainable Textile & Leather Production), ECO PASSPORT by OEKO-TEX® (chemical certification).

CONCLUSIONS

This paper offers some definitions, examples and practical applications of the international conformity certification, labelling and technical specifications, quality management, environmental legislation and inspection/testing (physico-mechanical testing, colour fastness testing and instrumental analysis). For example, these courses about instrumental analysis succinctly presented by applications, are very usefully for engineers and researchers, specialized in the textiles field, to have a global overview of the tests that can be performed on the textile materials and how to request adequate tests to obtain quickly the information about the textile materials (e.q. presence of the other contaminants on the textile surface or of the micro/nanoparticles). In conclusion, the courses modules developed were successfully delivered and the feedback was very positive from the students and researchers.

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REFERENCES

[1] Biesta, G., Allan, J., Edwards, R., *The theory question in research capacity building in education: Towards an agenda for research and practice*, In: British Journal of Educational Studies, 2011, 59, 3, 225–239

[2] Prakash, Y., Charwak, B., Kumar, P.V., *Textile industry in new India: challenges and opportunities*, In: International Journal of Indian Culture and Business Management, 2020, 21, 4, 435–458

[3] *Certification*, Available at: https://www.iso.org/certification.html [Accessed on April 2020]

[4] *COC – Certificate of Conformance*, Available at: www.labhut.com/education-centre/dissolution-accessories/coc-certificate-of-conformance-vs-coa-certificate-of-analysis.html [Accessed on April 2020]

[5] *The 'Blue Guide' on the implementation of EU products rules 2016*, European Commission, 2016/C 272/01

[6] ISO 9001:2015 – *Quality management systems – Requirements*

[7] ISO 9000:2015 – *Quality management systems – Fundamentals and vocabulary*

[8] Morris, A.S., *Measurement and calibration requirements for quality assurance to ISO 9000*, Wiley, 1997

[9] *Quality assurance vs. control,* Available at: https://asq.org/quality-resources/quality-assurance-vs-control [Accessed on April 2020]

[10] ISO/IEC 17000:2020, *Conformity assessment – Vocabulary and general principles*

[11] ISO/IEC 17025:2017, *General requirements for the competence of testing and calibration laboratories*

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

[13] ISO 13934-2:2014, *Textiles – Tensile properties of fabrics. Part 2: Determination of maximum force using the grab method*

[14] ISO 13935-1:2014, *Textiles – Seam tensile properties of fabrics and made-up textile articles. Part 1: Determination of maximum force to seam rupture using the strip method*

[15] ISO 13935-2:2014, *Textiles – Seam tensile properties of fabrics and made-up textile articles. Part 2: Determination of maximum force to seam rupture using the grab method*

[16] ISO 105-E04:2013, *Textiles – Tests for colour fastness. Part E04: Colour fastness to perspiration*

[17] ISO 105-C10:2006, *Textiles – Tests for colour fastness. Part C10: Colour fastness to washing with soap or soap and soda*
[18] ISO 105-C06:2010, *Textiles – Tests for colour fastness. Part C06: Colour fastness to domestic and commercial laundering*
[19] ISO 105-B01:2014, *Textiles – Tests for colour fastness. Part B01: Colour fastness to light: Daylight*
[20] ISO 105-B02:2014, *Textiles – Tests for colour fastness. Part B02: Colour fastness to artificial light: Xenon arc fading lamp test*
[21] ISO 105-E01:2013, *Textiles – Tests for colour fastness. Part E01: Colour fastness to water*
[22] ISO 105-D02:2016, *Textiles – Tests for colour fastness. Part D02: Colour fastness to rubbing: Organic solvents*
[23] ISO 105-X16:2016, *Textiles – Tests for colour fastness. Part X16: Colour fastness to rubbing: Small areas*
[24] ISO 105-X12:2016, *Textiles – Tests for colour fastness. Part X12: Colour fastness to rubbing*
[25] ISO 105-X11:1994, *Textiles – Tests for colour fastness. Part X11: Colour fastness to hot pressing*
[26] Holler, F.J., Skoog, D.A., Crouch, S.R., *Chapter 1. Principles of Instrumental Analysis* (6th ed.), Cengage Learning, 2007, 9
[27] Skoog, D.A., Hollar, F.J., Crouch, S.R., *An Introduction to Ultraviolet-Visible Molecular Absorption Spectrometry. Principles of Instrumental Analysis*, 6th ed, Harayana: Thomson, 2007, 336–337
[28] Skoog, D.A., Holler, F.J., Crouch, S.R., *Principles of instrumental analysis*, Cengage learning, 2017
[29] Lanigan, K.C., *Teaching analytical method development in an undergraduate instrumental analysis course*, In: Journal of Chemical Education, 2008, 85, 1, 138
[30] Willard, H.H., Merritt Jr, L.L., Dean, J.A., Settle Jr, F.A., *Instrumental methods of analysis*, 1988
[31] Pungor, E., Horvai, G., *A practical guide to instrumental analysis,* CRC Press, 1994
[32] Robinson, J.W., Frame, E.S., Frame II, G.M., *Undergraduate instrumental analysis*, CRC Press, 2014
[33] Rouessac, F., Rouessac, A., *Chemical analysis: modern instrumentation methods and techniques*, John Wiley & Sons, 2013
[34] Morris, A.S., *Measurement and instrumentation principles*, 2001
[35] Morris, A.S., Langari, R., *Measurement and instrumentation: theory and application*, Academic Press, 2012
[36] Riley, W.F., McConnell, K.G., Dally, J.W., Dally, J., Dally, J., *Instrumentation for engineering measurements,* Wiley, 1993
[37] Johnson, C.D., *Process control instrumentation technology,* Pearson, 2014
[38] Perry, D.R., Appleyard, H.M., Cartridge, G., Cobb, P.G.W., Coop, G.E., Lomas, B., Ritchie, G.G., Taylor, C., Welch, M.J., Farnfield, C.A., *Identification of textile materials*, 1985
[39] *REACH*, Available at: ec.europa.eu/environment/chemicals/reach/reach_en.htm [Accessed on April 2020]
[40] *Understanding REACH*, Available at: https://echa.europa.eu/regulations/reach/understanding-reach [Accessed on April 2020]
[41] *OEKO-TEX*, Available at: www.oeko-tex.com [Accessed on April 2020]
[42] *Candidate List of substances of very high concern for Authorisation*, Available at: echa.europa.eu/candidate-list-table [Accessed on April 2020]
[43] *Directive 2001/95/EC of the European Parliament and of the Council on general product safety*, European Commission
[44] ISO 13688:2013, *Protective clothing – General requirements*
[45] *Barcode-Hashtag*, Available at: sourcing-media.hktdc.com/product-original/Barcode-Hangtag [Accessed on April 2020]
[46] *Green Public Procurement (GPP)*, Available at: ec.europa.eu/environment/gpp/index_en.htm [Accessed on April 2020]
[47] *Report – Textiles Technical Background Report, Green Public Procurement*, European Commission, 2011
[48] *EU green public procurement criteria for textiles products and services*, European Commission
[49] *Buying green!, A handbook on green public procurement*, 3rd Edition, Contract № 071201/2014/692772//SER/ENV.F.1, European Commission and ICLEI – Local Governments for Sustainability, 2014
[50] *Guidance on the implementation/application of directive 2015/29/EC on unfair commercial practices,* European Commission

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Design and development of experimental models for textile structures integrated in wound dressings applied in curative therapy of inflammatory skin diseases, using specific instruments of descriptive statistics

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ABSTRACT – REZUMAT

Design and development of experimental models for textile structures integrated in wound dressings applied in curative therapy of inflammatory skin diseases, using specific instruments of descriptive statistics

Wound dressing is a key factor of the wound management system, having as main objective the stimulation of the healing process for a variety of inflammatory skin diseases. To maximize the therapeutic effects, innovative medical devices with integrated drug delivery system become of real interest during the last decade. For the realization of the optimal woven fabrics used as a substrate for various active principles, such as propolis and cinnamon essential oil, the multivariate linear regression analysis was used to elaborate the conceptual models on the basis of which the experimental models of the textile supports were designed. Using as input data the characteristics of the selected yarns (breaking force, elongation at break, torsion/twist, hygroscopicity), one can predict the structural parameters of the woven fabrics (raw materials, yarn density, lengths of the underlaps) and also the assembly and adjusting parameters for the machinery from weaving preparation and weaving sectors (advance and height of the drum, reed width, drawing-in, input/output of the gripper, cross unevenness reed, stationary in maximum open lease, the moment of the grippers opening, impulse time, the moment of the shaft smoothening, etc.). The validation of the elaborated conceptual models it was confirmed by the registered yields in the range of 88–96 %, during the weaving process.

Keywords: *virtual model, multivariate regression, cumulative probabilities, multiple correlation coefficient, biomaterial, structural parameters, woven fabrics*

Design și realizare de modele experimentale pentru structuri textile destinate pansamentelor pentru terapia curativă a afecțiunilor inflamatorii ale pielii utilizând instrumente specifice statisticii descriptive

Pansamentul este un factor cheie al sistemului de management al rănii, având ca obiectiv principal stimularea procesului de vindecare pentru o gamă largă de afecțiuni cutanate inflamatorii. Pentru maximizarea efectelor terapeutice, în ultimul deceniu au fost dezvoltate o serie de dispozitive medicale neinvazive, prevăzute cu sisteme de eliberare controlată a medicamentului. Pentru obținerea țesăturilor optime folosite ca substrat pentru depunerea diferitelor principii active, precum propolisul și uleiul esențial de scorțișoară, a fost folosită analiza de regresie liniară multivariată cu ajutorul căreia au fost elaborate modelele conceptuale, care au stat la baza proiectării modelelor experimentale de suporturi textile. Folosindu-se ca date de intrare caracteristici ale firelor utlizate (sarcina și alungirea la rupere, torsiunea/răsucirea, higroscopicitatea), au fost predicționați parametrii structurali ai țesăturilor (materii prime, desime, lungimile segmentelor de legare), precum și parametrii de montare și reglaj ai utilajelor din preparația țesătoriei și a țesătoriei (avans și înălțime tambur, lățime în spată, năvădire, intrare/ieșire greifer, denivelare traversă de spate, staționare în rost maxim deschis, momentul deschiderii greiferelor, durata impulsului, momentul nivelării ițelor etc.). Validarea modelelor conceptuale elaborate a fost confirmată prin obținerea în timpul țeserii a unor randamente situate în intervalul 88–96 %.

Cuvinte-cheie: *model virtual, regresie multivariată, probabilități cumulate, coeficient de corelație multiplă, biomaterial, parametri structurali, țesături*

INTRODUCTION

Although the human skin possesses high regenerative and reparative abilities, it is constantly exposed to multiple forms of injury [1]. Dermatological pathology affects all ages: from birth (neonatal dermatology), childhood (paediatric dermatology), adulthood and older adulthood (geriatric dermatology).

Wound management is a complex process having as main objective the acceleration of the healing process, simultaneously with obtaining satisfactory results from a cosmetic point of view, respectively the healing of the tissue injury with minor scarring.

The dressing is a special class of medical textiles, being very well known as the vital role of the wound dressing in the healing processes of the skin injury, due to multiple functionalities in dermal application, not just with a protective role on the skin condition against the external environment, but also with a therapeutic role [2, 3].

In comparison with the traditional dressings that have the major disadvantage of strong adhesion to the wound surface and of causing pain or even additional damage at the removal moment, this study is intended to develop innovative dressings by functionalization with emulsion or hydrogel of the appropriate textile substrates, thus obtaining high performances in terms of low adhesion to the wound surface and an optimal hydration level due to the high content of water from the emulsion or hydrogel [4].

The optimal selection of the textile substrates and of the therapeutic agents used for the functionalization represents the key factor in the manufacturing process of the dressings which, in order to be considered ideal, must meet the following requirements: it must be sterile, non-toxic and non-allergenic, must provide protection against bacterial infections, should maintain a temperature and humidity level favourable for healing; should increase the epidermal cell migration to promote the angiogenesis and the connective tissue synthesis; has to allow the exchange of gases between the injured skin area and the environment [5, 6]. In order to obtain this, raw materials based on cotton, acetate, Lenpur and cotton blended with Rayon were selected and analysed from the physical-mechanical characteristics' point of view [7]. The obtained results were used to design four conceptual models of textile structures which serve as substrates for the functionalized wound dressings with application in curative therapy of inflammatory skin diseases.

MATERIALS AND METHOD

Using the well-known methods of regression analysis, the engineering characteristics of the textile biomaterials designed for wound dressings used in the curative therapy of various skin diseases were predicted. For this purpose, multiple experiments were carried out to determine the values of the breaking force, elongation at break, torsion/twist and hygroscopicity, for five variants of yarns obtained from various raw materials and with different linear density (table 1).

Table 1

YARNS SUBJECTED TO EXPERIMENTS

Yarn variant	Identification data	
	Raw material type	**Yarn count/Fineness**
V1	100% acetate	130 dtex × 1
V2	100% cotton	200 dtex × 2
V3	100% Lenpur	300 dtex × 1
V4	100% cotton	165 dtex × 2
V5	80% cotton/ 20% Rayon+ZnO	147 dtex × 2

The calculation of the distribution parameters was realized based on a specialized program which allows calculating the mean, the median, the mode, the standard deviation, the percentile values, the skewness and the kurtosis. The results of the statistical analysis revealed a variation coefficient less than 11% for all the evaluated characteristics, the mean of the data set being representative (therefore, the populations are homogenous) and the interquartile deviation demonstrating that there's no data variability. The whiskers are drawn from the smallest to the largest detected value, being situated within the limits of 1.5 "box" lengths; extreme cases situated at a distance larger than a length of 3 "boxes" were not recorded. More than that, the obtained values for kurtosis indices demonstrate that the maximum possible limit (1.96) has not been reached for any of the variants. In fact, there is no case of the distribution going out of the theoretical normality.

For the development of the conceptual model for textile biomaterials integrated in wound dressings for curative therapy of inflammatory skin diseases, the multiple linear regression analysis was used.

For the prediction of the main engineering characteristics, the following steps were taken:

I. *Identification of dependent and independent variables* (customized for each model).

Y is the elongation at break of the support, X_1 – the linear density of the warp system, X_2 – the linear density of the weft system, X_3 – the torsion/twist of the warp system, X_4 – the torsion/twist of the weft system; X_5 – the hygroscopicity of the warp system; X_6 – the hygroscopicity of the weft system; X_7 – the elongation at break of the warp system, X_8 – the elongation at break of the weft system; X_9 – the tensile strength of the warp system, X_{10} – the tensile strength of the weft system.

II. *Determination of conceptual models of multivariate regression* – multiple regression equations for 10 predictors of type:

$$\ddot{Y} = B_0 + B_1 * X_1 + B_2 * X_2 + ... + B_n * X_n \qquad (1)$$

where: B_0 is the constant of the model and $B_1, ..., B_n$ are the unstandardized regression coefficients calculated for each independent variable separately.

III. *Construction of the cumulative probability graphs for the standard residual notes and band graphs*.

The studied conceptual models are highlighted in table 2.

The graphs of the cumulative probabilities for the standard residual notes and the band graphs are represented in figures 1 and 2 for all four conceptual models developed during this research.

From the obtained data based on the statistical analysis, the results are below:

- The standard error of the predicted dependent variable (elongation at break support), for any of the four conceptual models demonstrates that the maximum standard deviation of the elongation at break is 3%, if the independent variables value is known.
- The standard deviations of the unstandardized regression coefficients highlight the prediction variation interval: e.g. for the unstandardized breaking

Table 2

STUDIED CONCEPTUAL MODELS			
Conceptual model	**Predictors identification**		**Regression equations**
	Weft system	**Warp system**	
CM1 75%/25% cotton/acetate	V1 100% acetate	V2 100% cotton	Elongation at break = –148.472 + 1.362 * linear density V1 – 0.365 * linear density V1 – 0.446 * torsion V1 – 0.050 * twist V2 + 22.155 * hygroscopicity V1 + 8.755 * hygroscopicity V2 – 9.149 * breaking force V1 + 6.520 * breaking force V2 + 0.610 * elongation at break V1 – 0.473 * elongation at break V2
CM2 62%/38% cotton/Lenpur	V3 100% Lenpur	V2 100% cotton	Elongation at break = 95.3 + 0.15* linear density V3 + 4.7 * hygroscopicity V2 + 0.62 * breaking force V2 + 3.7* elongation at break V3 – 0.171 * linear density V2 – 0.1 * torsion V3 – 0.1 * twist V2 + 1.458 * hygroscopicity V3 – 7.32 * breaking force V3 + 0.7 * elongation at break V2
CM3 100% cotton	V4 100% cotton	V2 100% cotton	Elongation at break = 122.94 + 0.01* linear density V4 + 3.68 * hygroscopicity V2 + 4.38 * breaking force V2 + 1.61* elongation at break V4 + 0.03 * linear density V2 + 0.02 * twist V4 – 0.002 * twist V2 – 11.26 * hygroscopicity V4 –12.26 * breaking force V4 – 2.23 * elongation at break V2
CM4 95%/5% cotton/Rayon+ ZnO	V5 80%/20% cotton/Rayon+ ZnO	V2 100% cotton	Elongation at break = 245.34 – 0.26 * linear density V2 – 2.27 * hygroscopicity V2 + 4.282* breaking force V2 – 0.58 * elongation at break V2 – 0.02 * twist V2 – 0.22 * linear density V5 – 0.007 * twist V5 – 8.70 * hygroscopicity V5 + 6.58 * breaking force V5 – 2.40 * elongation at break V5

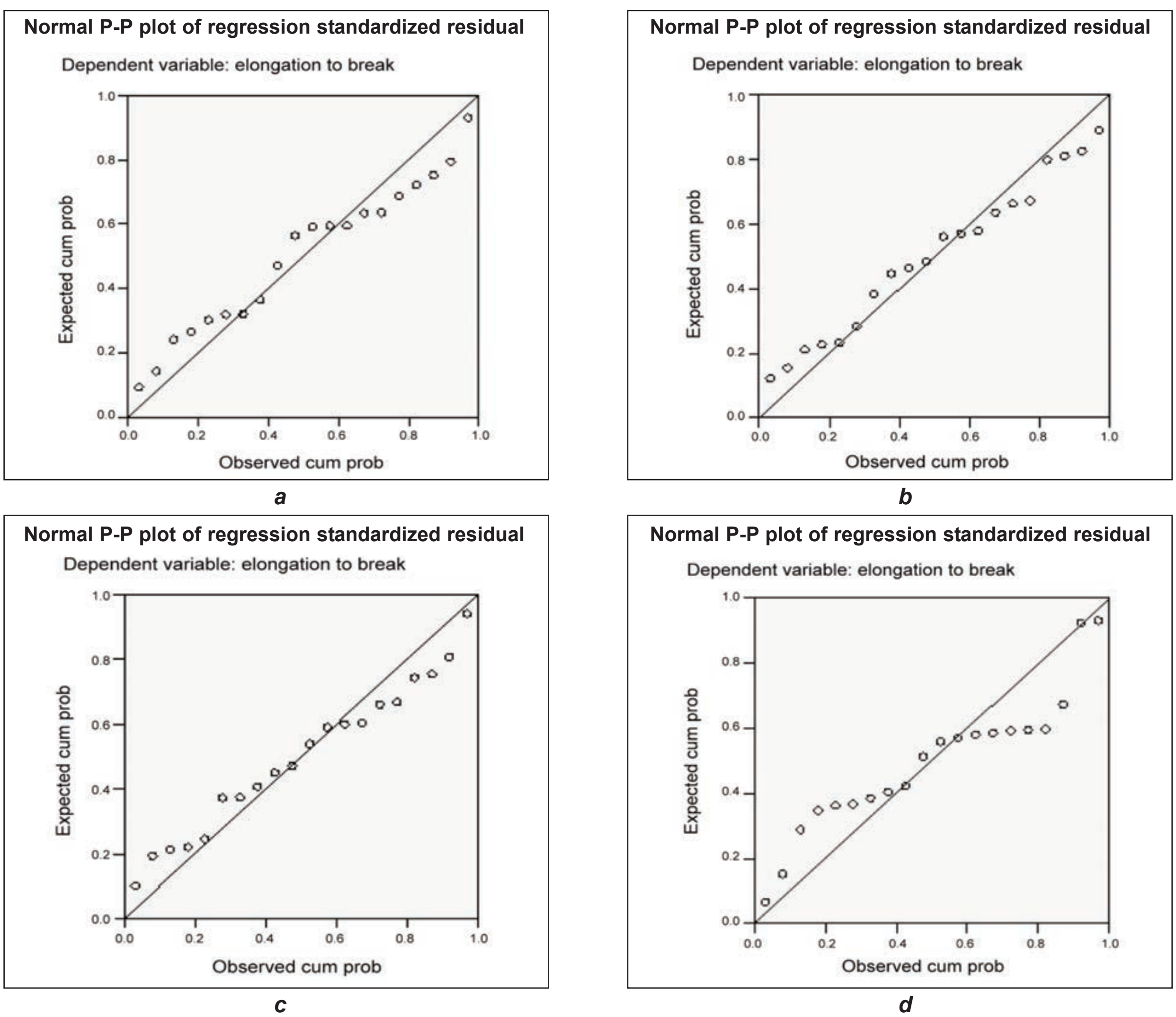


Fig. 1. Graphical representation of the standardized residual distribution compared to the normal distribution for: *a* – CM1; *b* – CM2; *c* – CM3; *d* – CM4

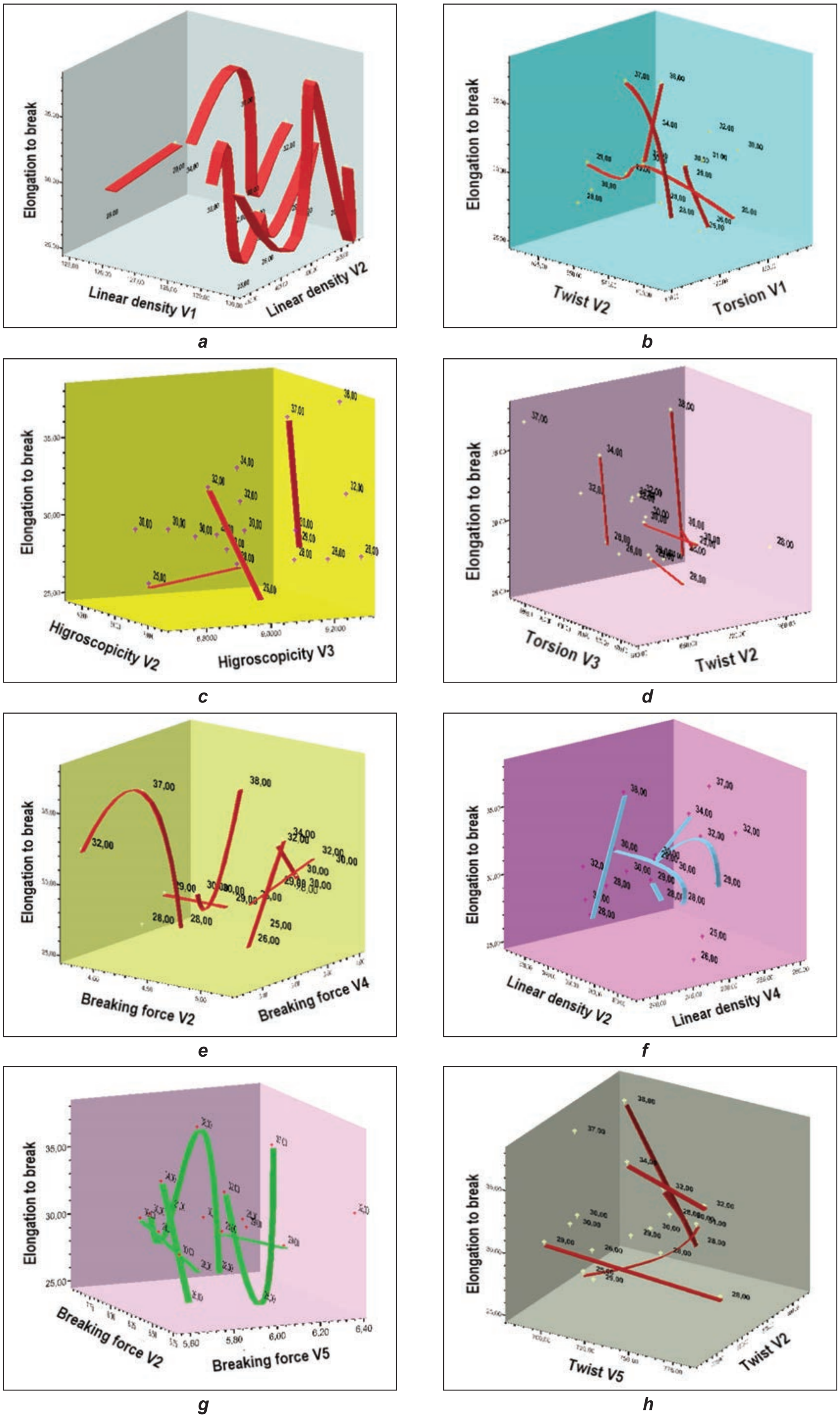


Fig. 2. Graphical representation of the elongation at break of the support depending of:
a – linear density of the yarns (V1 and V2) – for CM1; *b* – torsion (V1) and twist (V2) – for CM1; *c* – hygroscopicity (V3 and V2) – for CM2; *d* – torsion (V3) and twist (V2) – for CM2; *e* – breaking force (V4 and V2) – for CM3; *f* – linear density (V4 and V2) – for CM3; *g* – breaking force (V2 and V5) – for CM4; *h* – twist (V2 and V5) – for CM4

force coefficient, the standard deviation is of maximum 11.5, a fact explained by the assembly and adjusting parameters of the technological flow used during the spinning process and by the non-uniformity of the fibre in terms of length and diameter, etc.

- The variant analysis shows, with an error probability of 5%, that the model explains significantly much of the variation of the dependent variable. The values of the note F demonstrate that the explained variation by the model is significantly higher than the residual one, and so, the developed model is efficient in prediction. The average deviation of the conceptual model from reality is about 2%, more or less. Still, other specific factors of the technological flow must be taken into account to accurately predict the values of the dependent variable.
- The points corresponding to the cumulative probabilities obtained from the regression model follow those of the normal curve, so the developed conceptual model is valid. The scores predicted according to the above equations were estimated, because the correlation between the variables is not perfect, and the more error, the lower the correlation between the variables (the points of the correlation graph being farther from the regression line). So, for certain values of the dependent variable (depending on the variant of the conceptual model), it tends to overestimate or underestimate the reality.
- Band type graphics highlight the probable evolution of the elongation at break of the support (dependent variable) in accordance with predictive variables (Lagrange interpolation 3rd order).
- These findings highlighted after analysing the resulted information from the statistical calculation served as a basis from which to start the design for the experimental models of woven textile structures used as dressings in the curative therapy of various skin diseases [8–10].

RESULTS

Specific design parameters (fibre composition and yarn count for warp and weft systems, density of yarns on weft direction and the weave pattern) related to each variant of the structure, coded EM1 – EM4, are presented in table 3.

The weave pattern programming scheme is presented in figure 3.

During the entire technological process, the yarns used to obtain the textile structures EM1 – EM4 presented an appropriate behaviour; no unusual phenomena were reported and the registered yields were similar to those from the weaving preparation (at warping, drawing-in, reeding). During the weaving process, the obtained yields were situated in the range of 88–96 %, the stationary, mainly due to the warp yarns (a regular situation for a weaving machine for cotton and cotton type yarns), and so, for a theoretical BRO of 13800, the lowest obtained value was 12185, which corresponds to a yield of at least 88.3%.

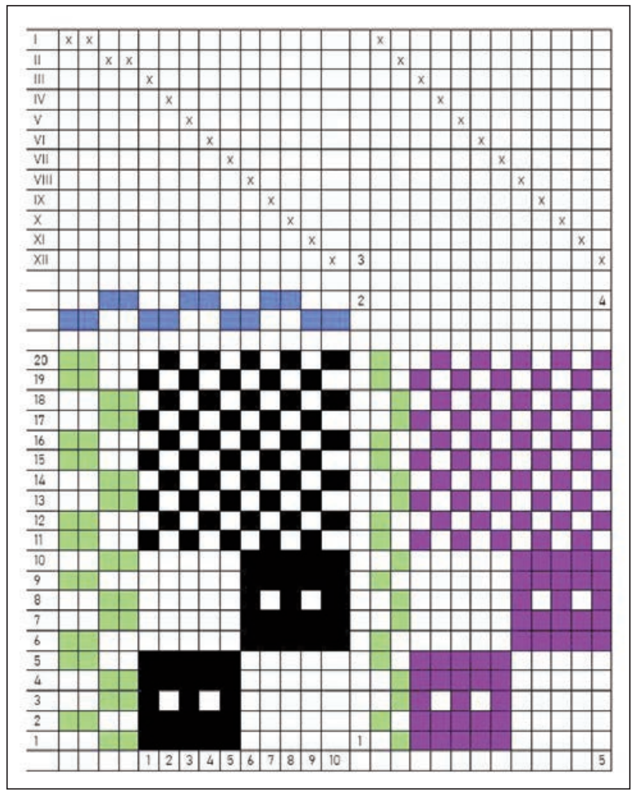
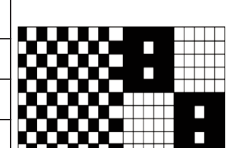


Fig. 3. The weave pattern programming scheme for experimental models of textile structures EM1 – EM4: *1* – weave pattern; *2* – reeding; *3* – drawing-in; *4* – sinkers linkage; *5* – the card

Table 3

SPECIFIC DESIGN PARAMETRES						
Textile support	**Parameters**					**Weave pattern**
	Fibre composition (%)		**Linear density (dtex)**		**Weft yarn density (yarns/10 cm)**	
	Weft	**Warp**	**Weft**	**Warp**		
EM1	100% cotton	100% acetate	200 dtex × 2	130 dtex × 1	365	
EM2	100% cotton	100% Lenpur	200 dtex × 2	300 dtex × 1	285	
EM3	100% cotton	100% cotton	200 dtex × 2	165 dtex × 2	260	
EM4	100% cotton	80%/20% cotton/Rayon+ZnO	200 dtex × 2	147 dtex × 2	270	

CONCLUSIONS

The elaborated conceptual models based on the multivariate linear regression analysis allowed the designing of the experimental models for textile structures integrated in wound dressings that have been applied in curative therapy of inflammatory skin diseases.

The regression equations allowed the prediction of the structural parameters (yarn density, raw materials, lengths of the underlaps) and assembly and adjusting parameters for the machinery from weaving preparation and weaving sectors (advance and height of the drum, reed width, drawing-in, input/output of the gripper, cross unevenness reed, stationary in maximum open lease, the moment of the grippers opening, impulse time, the moment of the shaft smoothening, etc.).

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REFERENCES

[1] Takeo, M., Lee, W., Ito, M., *Wound Healing and Skin Regeneration*, Cold Spring Harbor Perspectives in Medicine, 2015, http://doi.org/10.1101/cshperspect.a023267

[2] Rajendran, S., *Advanced Textiles for wound Care,* 2nd Edition, Woodhead Publishing, 2018

[3] Subtirica, A.I., Banciu, C.A., Chivu, A.A.-M., Dinca, L.C., *Nanofibres made from biocompatible and biodegradable polymers, with potential application as medical textiles*, In: Industria Textila, 2018, 69, 1, 55–58, http://doi.org/10.35530/IT.069.01.1502

[4] Simoes, D., Miguel, S.P., Ribeiro, M.P., Coutinho, P., Mendonca, A.G., Correia, I.J., *Recent advances on antimicrobial wound dressing: A review*, In: European Journal of Pharmaceutics and Biopharmaceutics, 2018, 127, 130–141, https://doi.org/10.1016/j.ejpb.2018.02.022

[5] Kellie, G., *Developments in nonwovens for wound dressings*, Uzun, M. Eds., Advances in technical Nonwovens, Woodhead Publishing, 2016, 443–472

[6] Ehterani, A., Salehi, M., Farzamfar, S., Vaez, A., Samadian, H., Sahrapeyma, H., Mirzaii, M., Ghorbani, S., Goodarzi, A., *In vitro and in vivo study of PCL/COLL wound dressing loaded with insulin-chitosan nanoparticles on cutaneous wound healing in rats model*, In: Int. j. Biol. Macromol., 2018, 1, 117, 601–609, 2018, https://doi.org/10.1016/j.ijbiomac.2018.05.184

[7] Chirilă, L., Constantinescu, G.C., Danila, A., Popescu, A., Constantinescu, R.R., Săndulache, I.-M., *Functionalization of textile materials with bioactive polymeric systems based on propolis and cinnamon essential oil*, In: Industria Textila, 2020, 71, 2, 186–192, http://doi.org/10.35530/IT.071.02.1793

[8] Lungu, O., *SPSS 10.0*, 2007, 44–65

[9] Levesque, R., *SPSS Programming and Data Management,* 4th Edition, Chicago, 2007

[10] Weinberg, S.L., Abramowitz, S.K., *Data Analysis for the Behavioral Sciences Using SPSS,* 2002

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