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Modelling the impact of tensile and shear forces during the loop-forming process in knitting

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WAQAR IQBAL
YE-XIONG QI
YAMING JIANG

ABSTRACT – REZUMAT

Modelling the impact of tensile and shear forces during the loop-forming process in knitting

Knitting is a dynamic process during which the yarn simultaneously receives several mechanical forces such as tensile, shear and bending, especially when the new loop is drawn out of the old one by the needle hook. Many researchers analysed the factors mainly focusing on the tension variation during loop formation but seldom studied the impact of shearing force during new loop formation in detail. This paper presents an innovative method that introduces the shearing force as an important factor in the theoretical calculation model of forces in an integrated manner to understand the effect of tensile and shearing forces during a new loop-forming stage. It proves that the impact of shearing force acting along the yarn's cross-section is much more severe, which needs to be considered in the knitting machine design, knitting yarn selection and knitted products' quality control.

Keywords: *loop formation, tensile force, shearing force, modelling*

Modelarea impactului forțelor de tracțiune și de forfecare în timpul procesului de formare a ochiurilor de tricot

Tricotarea este un proces dinamic în timpul căruia firul este solicitat simultan de către mai multe forțe mecanice, cum ar fi forța de tracțiune, forța de forfecare și forța de îndoire, mai ales când noul ochi este creat prin cel vechi de cârligul acului. Mulți cercetători au analizat acești factori, concentrându-se în principal pe variația tensiunii în timpul formării ochiului în timpul procesului de tricotare, dar rareori au studiat în detaliu impactul forței de forfecare în timpul formării noului ochi. Această lucrare prezintă o metodă inovatoare care introduce forța de forfecare, ca un factor important în modelul de calcul teoretic al forțelor, într-o manieră integrată pentru a înțelege efectul forțelor de tracțiune și de forfecare în timpul unei noi etape de formare a ochiului. A fost demonstrat faptul că impactul forței de forfecare care acționează de-a lungul secțiunii transversale a firului este mult mai sever, ceea ce trebuie luat în considerare în proiectarea mașinii de tricotat, selecția firelor de tricotat și controlul calității produselor tricotate.

Cuvinte-cheie: *formarea ochiului de tricot, forța de tracțiune, forța de forfecare, modelare*

INTRODUCTION

Most researchers evaluated the effect of tension fluctuation in different zones of the knitting machines by using different theoretical or mathematical models. Those are useful for analysing the factors causing dynamic tension variation in various stages of the yarn movement over the contact point, yarn interaction with different elements of the knitting machine and finally, during the loop-forming process. The maximum value of tension is recorded. The exact degree of tension fluctuation during the loop-forming stage is still not precise. The magnitude of stress on the yarn rises in the knitting zone, and the degree of stress can be up to ten times higher than the stress at the entrance of the knitting system. The resultant bending deformation depends on the resistance of the yarn to the adhesive force, which acts on the moving part of the yarn in knitting. The resistance of the yarn to the loads relies on its viscoelastic properties. For example, since elastane yarns exhibit a lower elastic modulus, they offer lower resistance to the loads in knitting [1].

Textile yarns encounter different forces, including compression, bending and stretching forces. The mechanical properties of textile materials depend on factors such as strength, elasticity, extensibility, resilience, toughness, and stiffness. The mechanical properties are calculated from the load-deformation curves as the tensile, bending, shearing, and frictional forces under specific atmospheric conditions deform the fibres. The most commonly evaluated mechanical properties are the tensile properties because of the geometric shape and dimensions of fibres [2].

It is also worth considering that the yarn is bent during the knitting process into loops forming large curvatures, especially near the sinker and needle loops.

Plastic deformation can also occur due to the slippage of fibres or permanent extension of the fibres in the curved yarns [3]. According to the study's results, high-modulus yarns can withstand the bending stress of the knitting components. Thus, if simultaneous forces, i.e., tensile and bending forces, are applied to the yarn, some of the filaments are likely to fracture under the loading, which is less than the tensile strength of the yarn. This eventually decreases the strength of the knitted fabric. Hence, knitting tension must be lower than the tensile strength of the filament to avoid filament rupture [4]. Likewise, carbon fibre possesses ultimate tensile strength along its lengthwise direction, but the forces applied, such as; tension, compressive and shearing forces along the traverse direction, result in remarkable failure [5]. Manufacturing cotton knitted textiles with plated elastomeric yarns was done using a mathematical model to simulate dynamic stresses on yarns and knitting-in lengths. On a computer-aided measuring warp-knitting machine, the findings of the dynamic loads of yarns and lengths of knitting-in determined based on a computer simulation were validated experimentally. The computer simulation shows that feeding elastomeric yarn at a constant initial force results in different values of the pitch coefficient of knitting in the elastomeric yarn for a basic yarn. The pitch coefficient of knitting in the elastomeric yarn for a basic yarn refers to the angle of lifting the needles in the knitting zone. Knitting-in elastomeric yarns at 0.1 cN initial tension, a value of linear density expressed in dtex, will result in different lengths of knitting-in elastomeric yarn depending on the value of the angle of lifting the needles, and therefore various structural parameters of knitted fabrics and their characteristics [6].

The dynamic forces in yarns in the knitting zone for linear cams and cams of a composite linear-circular function contour with a circumference were analysed using a computer simulation and an experimental test [7]. Cams with an infinite height of needles growing in the knitting zone under constant tension (negative) feeding were the subjects of this study. The yarn-robbing back effect remained until the loop construction cycle was completed. Loop creation conditions were established at the stages of discontinuous robbing back in the knitting zone using a deterministic digital model of the knitting process. A linear cam with a descending angle of 50° and a rising angle of 30° was utilized as an example. The depletion of the yarn reserve on the needle that was previously raised and positioned beyond the maximum descending depth point determines the presence of the discontinuous phenomenon of yarn robbing back into the knitting zone. This effect arises when the needle rising point's horizontal coordinate value is smaller than the needle spacing. Depending on the parameter value and descending depth, maximum pressures in yarns in the knitting zone may be up to 2.2 times stronger than under continuous robbing back conditions [8].

Sometimes, the tensile strength of the textile materials is enough to be knitted while there is yarn breakage along its traverse direction. This implies that the yarn exhibits poor shear strength along its traverse direction. Previous studies investigated the effect of tension variation in the knitting zone. Still, they did not consider a difference in the impact of tensile and shear forces acting during the new loop formation. It is not true that the tensile forces are higher than the shear forces for the materials to be used for knitting. This paper contributes to a better understanding of the importance of this model, which will help in the selection of yarns for the knitting process, especially in the case of technical yarns and high-performance yarns.

MODELLING THE IMPACT OF TENSILE AND SHEAR FORCE

Model introduction and basic assumptions

The theoretical study indicates that several forces act simultaneously on the yarn during the new loop formation. The magnitude of the forces varies from point to point. The tensile and shear forces act simultaneously on the yarn while the new loop is drawn out. The effect of the shear force is amplified when there is an angular deflection in the yarn, which contributes to the yarn bending up to a certain limit. The needle hook takes the yarn down with the two ends supported by the sinkers. The wrapping angle and gauge play an essential role in such a condition for change in the degree of shearing and tensile forces. Previous researchers have put forward many models indicating significant differences in tensile force during the new loops.

An approximated technique has been introduced to study the tension fluctuation during the knitting loop formation. The results indicate that the tension rises as the needle reaches the maximum knitting position. Furthermore, the tension on the yarn increases as the yarn runs over verges [9–11]. A discrete probabilistic model for evaluating the dynamic forces in the knitting has been presented, showing that the maximum force is applied to the yarn in the knitting zone. Moreover, the cam design is essential in increasing the knitting force's magnitude. In contrast, the knocking-off depth of the needles is also associated with the coefficient of variation of forces in the yarn in the knitting zone [12]. The novelty of this paper is the study of the influence of simultaneous tensile and shear forces acting along the yarn's cross-section. The shear force's magnitude depends on the machine's gauge and yarn's wrapping angle.

The following notations are valid for the entire model as given in figures 1–4: S_1, S_2 – sinkers; M^{th} – needles; θ_M – total wrapping angle; T_M – output tension on the needle 'M'; T_{M-1} – input tension on the needle 'M'; $T_{M''}$ – TM^{th} force divided into vertical direction; $T_{M'}$ – TM^{th} force divided into horizontal direction; $T_{M'-1}$ – T_{M-1} force divided into horizontal direction; $T_{M''-1}$ – T_{M-1} force divided into vertical direction; C – bending length.

Some of the assumptions behind this model are:

- The angular deflection of the yarn caused by the needle is the wrapping angle.
- The friction between yarn and knitting elements is neglected.
- The yarn is even in diameter.

Wrapping angle

The yarn during knitting remains in contact with the different contact points and knitting elements until the final loop formation as shown in figure 1. The yarn is wrapped around different deflecting points along with the knitting elements of the machine. The Wrapping angle between the needle and yarn is indicated in figure 2. The wrapping angle varies instantaneously from point to point since knitting is a dynamic process where the tension fluctuates at each point. Therefore, a significant change exists between input and output tension. The input tension is denoted by ‘TM–1’ and ‘TM’ is the output tension on the needle ‘M’. The ‘a’ is the number of needles which come from the gauge of the machine. It is assumed that θ_M is the total wrapping angle formed by the M^{th} needle in the stage of maximum bent position. The ‘C’ indicates the total bending length of the yarn as a result of yarn deflection caused by the needle as represented in figure 3.

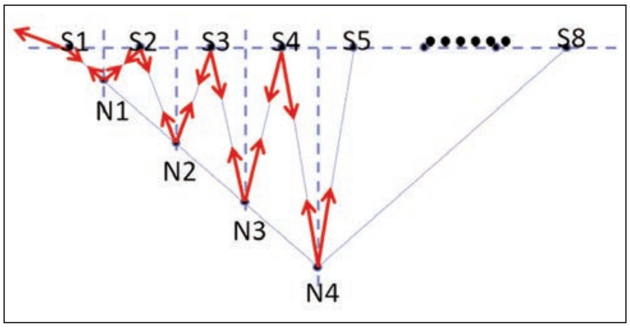

Fig. 1. Needles movement during loop formation

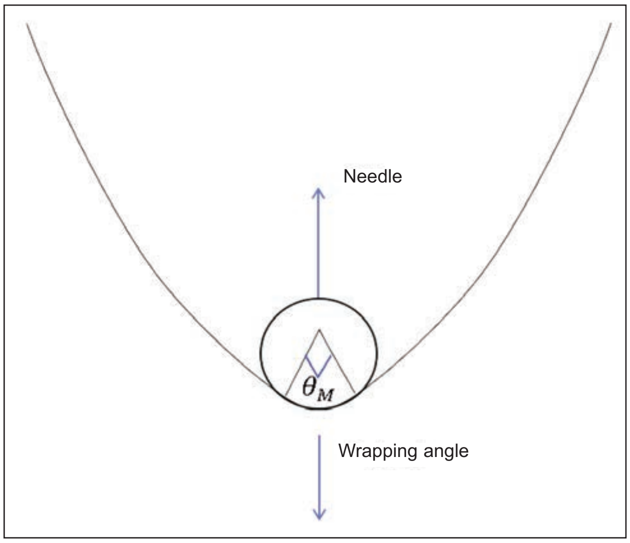

Fig. 2. Wrapping angle between needle and yarn

The wrapping angle can be calculated with the following equation 2 as derived from figure 2.

$$\tan\frac{\theta_M}{2} = \frac{\frac{a}{2} - R}{c} \tag{1}$$

$$\frac{\theta_M}{2} = \arctan\frac{\frac{a}{2} - R}{c} \tag{2}$$

Here, $\frac{\theta_M}{2}$ is the half-wrapping angle, R is the radius of the needle, and C is the bending length of the yarn.

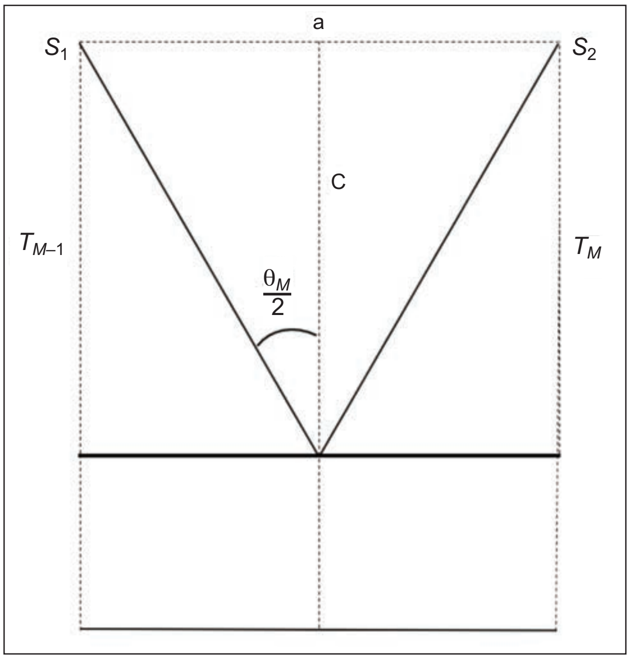

Fig. 3. Total wrapping angle when the needle carrying the yarn bends at maximum position

Shear and tensile forces

The change in input tension relies on the area of contact and the stresses over the contact surface. The increment in the input tension causes the stress build-up between the yarn and knitting elements, which leads to yarn flattening. As the yarn enters the knitting zone, the tension increases between the yarn and the knitting components while the yarn will be in a flattened state between the needle hooks. The impact of shear force along the yarn cross-section increases and can be severe to cause permanent deformation in the yarn [13]. The input and output tension is divided into horizontal and vertical components using trigonometric functions to calculate the impact of tensile and shear forces. The following equations represent the input tension. The horizontal component of input tension is indicated by equation 3:

$$T_{M-1} = T_{M''-1} \cdot \cos\frac{\theta_M}{2} \tag{3}$$

The vertical component of input tension is given by equation 4:

$$T_{M'-1} = T_{M''-1} \cdot \sin\frac{\theta_M}{2} \tag{4}$$

The horizontal component of output tension is shown in equation 5, while equation 6 indicates the vertical component of output tension.

$$T_M = T_{M''} \cdot \cos\frac{\theta_M}{2} \qquad (5)$$

$$T_{M'} = T_{M''} \cdot \sin\frac{\theta_M}{2} \qquad (6)$$

The tension fluctuation during the yarn movement throughout the yarn path is due to the yarn's contact with several contact points. The magnitude depends on the coefficient of friction (μ) and the wrapping angle (θ) of the yarn with the contact points. The final tension (T_0) of the yarn is obtained by multiplying the initial tension (T_i) of the yarn with a factor derived from the yarn wrapping angle (θ) and coefficient of friction (μ) between yarn and rod/pulley as follows:

$$T_0 = T_i e^{\mu\theta} \qquad (7)$$

Replacing T_0 by T_M, T_i by T_{M-1} and θ by θ_M, equation (7) becomes:

$$T_M = T_{M-1} e^{\mu\theta_M} \qquad (8)$$

$$T_M = T_1 e^{\mu\Sigma\theta_M} \qquad (9)$$

Here, $\Sigma\theta_M$ is the sum of the total wrapping angles of the Mth needles. By putting this value of TM from equation 9 into equation 8, we get:

$$T_{M-1} = \frac{T_1 e^{\mu\Sigma\theta_M}}{e^{\mu\theta_M}} \qquad (10)$$

Shear force

S_1 and S_2 are sinkers. As yarn stays over the sinkers and needle stretches the yarn downwards for loop formation as shown in figure 3. The shear force F_S acting from S_1 to S_2 for a loop drawing can be given as:

$$F_S = T_M \cos\frac{\theta_M}{2} + T_{M-1} \cos\frac{\theta_M}{2} \qquad (11)$$

$$F_S = \cos\frac{\theta_M}{2}\,(T_M + T_{M-1}) \qquad (12)$$

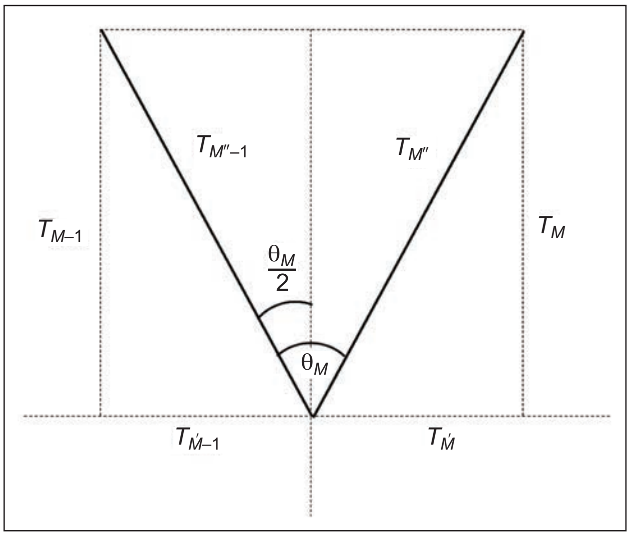

Fig. 4. Resolving input and output tension into vertical and horizontal components

By substituting the values of TM and TM-1 from equations 9 and 10 into equation 12, it follows:

$$F_S = \cos\frac{\theta_M}{2}\,(T_1 e^{\mu\Sigma\theta_M} + T_1 e^{\mu\Sigma\theta_M} \cdot e^{-\mu\theta_M}) \qquad (13)$$

$$F_S = \cos\frac{\theta_M}{2}\, T_1 (e^{\mu\Sigma\theta_M} + e^{M(\Sigma\theta_M - \theta_M)}) \qquad (14)$$

Tensile force

The yarn movement is dynamic in the knitting process. The tension increases gradually as the yarn moves over different contact points and knitting elements. Therefore, output tension T_M is higher than the input tension T_{M-1} because the coefficient of friction and wrapping angles of yarn with the other knitting elements increase. Then it is given as:

$$T_M \cdot \sin\frac{\theta_M}{2} > T_{M-1} \cdot \sin\frac{\theta_M}{2} \qquad (15)$$

If the frictional force is added, the movement of yarn is balanced in the knitting process. So, the following formula can be used. Evaluating equation 15 with the frictional and shear forces, it becomes:

$$T_M \cdot \sin\frac{\theta_M}{2} = T_{M-1} \cdot \sin\frac{\theta_M}{2} + \mu F_S \qquad (16)$$

Due to the unknown values of the friction coefficient, the following formula can be used:

$$F_T = T_M \cdot \sin\frac{\theta_M}{2} = T_1 \cdot e^{\mu\Sigma\theta_M} \cdot \sin\frac{\theta_M}{2} \qquad (17)$$

RESULTS AND DISCUSSION

The impact of shearing and tensile forces was calculated for 5 G, 7 G and 9 G knitting machines, as shown in figure 5. The results show that the tensile force decreases from 0.81 cN, 0.69 cN, and 0.58 cN with the increase of machine gauge of 5 G, 7 G and 9 G, respectively. Contrarily, the shear force increases from 5 cN, 5.6 cN, and 5.91 cN with the increase of machine gauge of 5 G, 7 G and 9 G, respectively. The results validated the theoretical analysis for the flat knitting machines with different gauges. The results agree with the theoretical analysis so that as the gauge of the machine increases, the number of needles increases by an inch. Thus, the wrapping angle of the yarn to sinker and knitting elements decreases. It is clear from the results that as the machine gauge increases, the influence of shearing force is more intense along the yarn cross-section. The wrapping angle decreases concerning the machine gauge increase. Since the wrapping angle becomes narrower, the needle hook acts like a cutting blade, which can cause yarn failure during knitting. Therefore, the shearing force's magnitude is higher than the tensile force's at the stage of new loop formation. Hence, the impact of shear force must be considered about tensile forces for higher gauge knitting machines. The higher degree of shear force can cause yarn failure no matter if the yarn exhibits higher tensile behaviour.

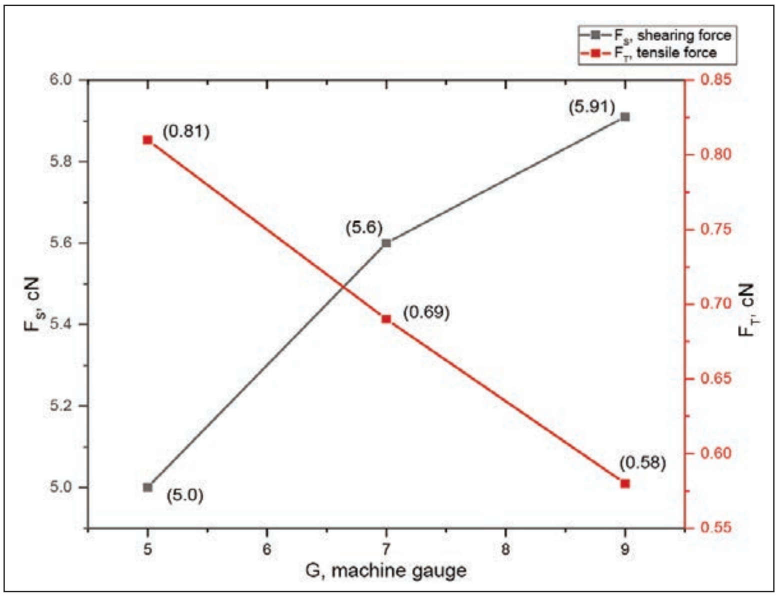

Fig. 5. Effect of gauge length on shear and tensile properties during knitting process

CONCLUSIONS

An approach to modelling the tensile and shearing force along the yarn cross-section provided the results, which are in good agreement with experimental tests. This indicates that the intensity of shear force is higher than that of tensile force. Moreover, the impact of shear force is more complex than the impact of tensile force acting on the yarn during the loop formation process. So, the perception of the only requirement for adequate tensile strength is invalid.

Sometimes, the materials do not exhibit enough tensile strength, but they own weak behaviour against the shear stress. The primary reason for their failure is the lack of shear strength rather than the lack of tensile strength. The machine's gauge plays a vital role in the variation of the magnitude of tensile and shear forces. Therefore, the shearing strength of the materials should be considered, along with the tensile strength.

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Authors:

WAQAR IQBAL, YE-XIONG QI, YAMING JIANG

School of Textile Science and Engineering, Tiangong University, Tianjin, 300387, China

Corresponding author:

YE-XIONG QI
e-mail: qiyexiong@tiangong.edu.cn

Does supplier management matter for supply chain performance? Evidence from the textile industry

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ASMA JAVED
QIAN LI
IKRAMUDDIN JUNEJO
FIZA ASHRAF MEMON
HASEEB-UR-REHMAN PAREKH
ZITA JÚLIA FODOR
MD BILLAL HOSSAIN

ABSTRACT – REZUMAT

Does supplier management matter for supply chain performance? Evidence from the textile industry

This study examines the impact of long-term relationships and vendor-managed inventory on supply chain performance and the mediating role of information sharing in Pakistan's textile industry. For testing the proposed hypotheses of the present study, the primary data was gathered with the help of a questionnaire from past studies via a convenience sampling strategy. Three hundred fifty questionnaires were distributed among the textile industry through the HR department of the concerned firm. However, only 330 cases were considered for data analysis after data clearing in SPSS version 25. Hence, the response rate is 94%. The data were analysed using SEM in Smart-PLS version 3. The results of hypothesis testing indicated the direct effect of long-term relationships and vendor-managed inventory, which was found to have a positive and significant impact on information sharing and supply chain performance in Pakistan's textile industry. Furthermore, the mediating effect of information technology between long-term relationships and vendor-managed inventory revealed a partial mediation effect on supply chain performance. The policymakers and top management of concerned firms should consider these variables for future strategies to get better supply chain performance.

Keywords: *supply chain performance, long-term relationship, information sharing, vendor-managed inventory, textile industry*

Impactul managementului furnizorilor asupra performanței lanțului de aprovizionare. Dovezi din industria textilă

Acest studiu își propune să examineze impactul relațiilor pe termen lung și al inventarului gestionat de furnizori asupra performanței lanțului de aprovizionare și al rolului de mediere al schimbului de informații în industria textilă din Pakistan. Pentru testarea ipotezelor propuse în studiul de față, datele primare au fost colectate cu ajutorul unui chestionar din studiile anterioare, printr-o strategie de eșantionare. Trei sute cincizeci de chestionare au fost distribuite industriei textile prin intermediul departamentului de resurse umane al firmei în cauză. Cu toate acestea, doar 330 de cazuri au fost luate în considerare pentru analiza datelor după ștergerea datelor în SPSS versiunea 25. Prin urmare, rata de răspuns este de 94%. Datele au fost analizate folosind SEM în Smart-PLS versiunea 3. Rezultatele testării ipotezelor au indicat efectul direct al relațiilor pe termen lung și al inventarului gestionat de furnizor, care s-a dovedit a avea un impact pozitiv și semnificativ asupra schimbului de informații și a performanței lanțului de aprovizionare, în industria textilă din Pakistan. În plus, efectul de mediere al tehnologiei informației între relațiile pe termen lung și inventarul gestionat de furnizor a evidențiat un efect parțial de mediere asupra performanței lanțului de aprovizionare. Factorii de decizie și managementul firmelor în cauză ar trebui să ia în considerare aceste variabile pentru strategiile viitoare, pentru a obține performanțe superioare în lanțul de aprovizionare.

Cuvinte-cheie: *performanța lanțului de aprovizionare, relație pe termen lung, schimb de informații, inventar gestionat de furnizor, industria textilă*

INTRODUCTION

A business model that supports the entire supply chain, such as vendor-managed inventory, maintains and manages inventory following retailer point-of-sale data [1]. Therefore, the suppliers ensure they have replacements in response to market demand and consumer purchasing patterns. Improving inventory utilisation by maximising its frequency by the supplier is an essential factor for the success of firms. In this context, enterprise resource planning is a crucial system that facilitates the management of critical resources to support business operations and enhance functionality. There are many benefits of enterprise resource planning (ERP). It is a financially efficient system that integrates diverse supply chain operations, including distribution, customer service, marketing and sales, production, and overall quality as perceived by the customer [2]. In this regard, by integrating fundamental business operations into a technology-driven system, one can guarantee the effective planning and allocation of resources at their designated locations [3].

The long-term relationship has the potential to generate community subsidies for supply chain partners, which cannot be ignored in today's competitive business environment [4]. For this, improving revenue through revenue competitiveness in the market can be achieved by implementing timely processes. Furthermore, this would promote operational efficiency through cost reduction, strategic collaboration and planning, joint ventures for innovative approaches, and sound decision-making to foster a positive relationship cycle for supply chain activities. Therefore, information sharing is the foundation of inter-business coordination, facilitating the seamless operation of technological developments [5]. To increase the supply chain's responsiveness, information sharing is utilized to render tactical data extremely valuable through technical expertise and strategic planning [6].

The textile industry is among the most ancient sectors of the global economy [7]. Pakistan's fashion and textile industry thrives due to the constant evolution of apparel and fashion trends [8]. This sector increased exports and contributed to the expansion of the Pakistani economy. In this connection, businesses must strengthen their supply chains by implementing contemporary, diverse planning, outsourcing, and distribution network strategies to gain a competitive edge. Additionally, it contributes to expanding a company's market share, customer satisfaction, and profits. The effect of effective supply chain management on the delivery of goods from factories is that it reduces both costs and delivery times while ensuring that final consumers receive high-quality products [9]. Within the textile industry of Pakistan, supply chain management is a concept that has been introduced previously. Regional rivals, including Vietnam, Bangladesh, China, Bangladesh, and Turkey, present serious competition in this industry. Compared to other regional competitors, conducting business in Pakistan entails a higher expenditure on the supply chain [10]. Due to the factors above, the textile industry in Pakistan is undergoing a critical period.

Many organizations have come to recognize the criticality of SCM in establishing a sustainable competitive edge for their products in fiercely competitive markets [11]. They have suggested that utilizing supply chain performance measurement as a foundation for enhancing overall supply chain efficiency could be beneficial in the long run. Previously, cost and visibility were identified as the primary challenges facing the textile industry in developing countries like Pakistan [12]. Therefore, various past studies reported comparable results, indicating that firm characteristics can influence the performance and practices of SCM [13, 14]. Similarly, one can infer from this that a single operational strategy must be revised to accommodate every feature of the supply chain. Within the contemporary supply chain environment, competition is increasingly emphasized.

Organizations strive to optimize performance by deploying accessible resources to enhance the supply chain process and gain a competitive advantage in the marketplace. Over recent decades, the textile industry in Pakistan has experienced a persistent decline that is attributable to a multitude of factors [15]. Industry performance will improve if the four tools are utilized effectively and accountability is maintained throughout the process. The characteristics mentioned above that impact the effectiveness and utility of SCM should have been considered in the present study.

The present study makes a few contributions to the field of knowledge. First, in the past, the direct effect of long-term relationships and vendor-managed inventory on supply chain performance was tested [16, 17]. However, in the present study, mediating role information sharing was introduced to validate research scholars' existing findings. Second, past studies mainly worked on the service sector [18], but the textile industry was studied using the variables stated in this study. Lastly, the textile industry managers responded to this study because the authors believe they provide a better understanding of studied variables compared to lower-level employees of firms [19].

Therefore, the objectives of the present study were to determine the direct impact of the direct effect of a long-term relationship and vendor-managed inventory on information sharing and supply chain performance and to examine the mediating role of information sharing regarding supply chain performance in the textile industry of Pakistan.

LITERATURE REVIEW AND HYPOTHESIS DEVELOPMENT

Theoretical framework

Resource-based view (RBV) is a theoretical framework that emphasizes an organization's internal resources and capabilities as sources of competitive advantage and superior performance [20]. The RBV model is considered a crucial resource for the supply chain. Regarding long-term relationships, these connections make building trust, commitment, and shared values-resources unique to each relationship-possible [21]. Furthermore, strategic planning increases the likelihood that partners will put effort into creating and sustaining relationship-specific resources, improving communication, cooperation, and data sharing. In addition, inventory that the vendors manage can be examined using RBV because a supplier's or vendor's capacity to keep track of their customers' inventory is an essential skill for a firm's success [22]. With this skill, the inventory is delivered more efficiently, there is better coordination throughout the supply chain process, and there are no chances of inventory stock-outs. The RBV model elaborates on the effects of information sharing on performance, an essential component of supply chain management [23].

Therefore, it can be said that the exchange of information is the most beneficial resource that could improve the process and performance of the supply chain. Coordination, responsiveness, and decision-making are all enhanced when parties in the supply chain share information and expertise [24].

Hypothesis development

Long term relationship

After extensive, long-term collaboration, cooperative and trusting relationships develop between companies and suppliers [25]. A recent study suggested that trust in the supply chain can improve efficiency and decision-making by encouraging open dialogue, exchanging relevant information, and pooling resources to address issues [26]. Another study revealed that suppliers maintain consistent and dependable business practices when parties commit to long-term partnerships [27]. Therefore, they are driven to meet quality standards consistently, deliver on time, and keep the agreed-upon service levels. However, a recent study concluded that because of this dependability, the supply chain operates more efficiently and faces fewer interruptions, and establishing long-term relationships could be a way to save costs. Positive outcomes cannot be ignored. Effective relations between suppliers and customers result in reduced costs, operational efficiency, and increased logistics [28].

Moreover, this effective relationship reduces procurement costs, increases the efficiency of the supply chain, and reduces the cost of holding inventory [29]. This is a win-win situation to mitigate supply chain risks, and it is beneficial for both parties to commit to a long-term partnership and combine their resources. Lastly, a study suggested that it is advisable to collaborate and share information in advance to reduce the impact of potential disruptions such as natural disasters, geopolitical events, or supplier capacity constraints on supply chain performance [30].

H1: Long-term relationships have a positive effect on supply chain performance.

H2: Long-term relationships have a positive effect on information sharing

Vendor Managed Inventory

A recent study confirmed that in the Vendor Managed Inventory (VMI), suppliers can assume control of their customers' inventory as part of their role in supply chain management [30]. In addition, in vendor management, the vendor represents the client by monitoring inventory, restocking as needed and making decisions. However, another study suggested that the bullwhip effect describes how shifts in demand are amplified as they make their way through the supply chain [31]. The key benefit would be VMI, where the supplier can directly access the customer's inventory or point-of-sale data, allowing them to acquire a more accurate picture of demand. In this regard, VMI mitigates the bullwhip effect, supply chains are more stable, and demand is less volatile, leading to improved efficiency and reduced costs. A study recommended that it is the responsibility of the vendor to keep an eye on inventory level and restock VIM as needed, and being able to anticipate changes in demand or supply disruptions allows for quicker responses [32]. Lastly, suppliers can modify the production and delivery schedules to ensure prompt replenishment of the customer inventory, and an increase in responsiveness can reduce lead times and improve customer service [33].

H3: Vendor-managed inventory has a positive effect on the supply chain performance.

H4: Vendor-managed inventory has a positive effect on information sharing.

Mediating role of information sharing

Complex and interdependent relationships characterize many supply chain activities. When partners effectively share information, it improves coordination and provides access to relevant, up-to-date data [34]. Improving supply chain performance is made possible through this coordination's ability to synchronize actions, streamline procedures, and avoid misalignments [35]. Sales projections, production schedules, and inventory levels are all easier to communicate in a partnership that lasts a long time. Effective planning and better forecasting improved the performance of the supply chain; consequently, the mismatch between demand and supply was eradicated [36]. In committed partnerships, asking each other how they are doing is customary. Both sides can monitor the other's evolution by using key performance indicators (KPIs) like product quality metrics, lead times, and on-time delivery rates. Each link in the supply chain is more likely to step up and do its part if everything is being tracked, which improves efficiency. Information exchange between suppliers and customers is crucial to Vendor Managed Inventory (VMI) [37]. The efficient flow of information enables a supplier to restock their inventory. Suppliers react faster to meet the demand level, removing supply hurdles, which is only possible with the effective exchange of information [38]. If suppliers are aware of trends in sales or when products are running low, they can proactively replenish their customers' inventory. There are fewer stockouts, shorter lead times, and better supply chain performance due to this replenishment responsiveness [39].

H5: Information sharing mediates the relationship between long-term relationships and supply chain performance.

H6: Information sharing mediates the relationship between vendor-managed inventory and supply chain performance.

METHODOLOGY

Data and procedure

A 'Primary' source provides the data for the study. Primary research consists of collecting data directly from respondents employed in the textile industry and to whom direct inquiries have been directed. The primary data is an information source from which the researcher gathers primary sources of information. It indicates that the researcher has collected data to pursue a particular study subject or objective. The information will be gathered from textile industry employees residing in Pakistan.

A convenience sampling strategy was utilized for this investigation. Non-probability sampling, which involves the random selection of individuals, is employed by researchers as a practical means of acquiring data. The sample size is determined from the entire population under study, as it is impracticable to include every employee in these industries (e.g., each factory has more than 1,500 workers). The participants in this research were personnel employed in the textile industry. Conducting studies with a sample size ranging from 30 to 500 respondents is deemed adequate and acceptable. Hence, 330 constitute our sample size in this study.

Scale development

Long term relationship was adopted from the study of Abbas and Kamal [40]. Four research items are "Last long-time relationship with a key supplier, Collaboration with a key supplier to improve quality in the long run, Long term alliance & Supplier as an extension".

Vendor Managed Inventory was taken from the research of Lee [17]. In this variable four items were considered "Your firm has built a VMI system infrastructure for continuous maintenance, your firm has improved work efficiency by using the VMI system, our firm has increased productivity by using the VMI system & Your firm has built an ERP system infrastructure for continuous maintenance".

Information sharing variable was considered from the study of Firmansyah and Siagian [41]. Research items were also four "Have an integrated information system with partners, Have an internally integrated information system, The relationship of information systems with suppliers & Communication systems with adequate suppliers".

Supply chain performance adopted from the study of Firmansyah and Siagian [41]. Four research items were "Delivery of orders as promised, Responsiveness in changing customer demand, Adjusting to the requested product specifications & The flexibility of product variety types".

Statistical procedure

In the present study, partial least squares structural equation modelling (PLS-SEM) is applied to test the proposed hypothesis using Smart-PLS software (version 3.3.2). This technique is acceptable when research scholars' objectives to test the proposed research model using existing theories and mediation effects are tested, as in the present study. We analysed the gathered data and reported as per recent guidelines.

RESULTS

Reliability and validity analysis

The purpose of reliability analysis is to determine whether or not the data was collected accurately [42]. Reliability is the degree to which random errors are absent; therefore, it measures dependable outcomes. It delineates the precision and validity of the experimental methodologies. In this instance, the reliability analysis determines Cronbach's alpha value, which is evident to yield significant results for the entire set of data. By applying the criterion established by: > 9 – Excellent, > 8 – Good, > 7 – Acceptable, > 6 – Questionable, > 5 – Poor, and < 5 – Unacceptable, the Cronbach's alpha values and composite reliability can be utilized to classify the reliability.

Table 1

RELIABILITY AND VALIDITY ANALYSIS

Name of variable	Item	Items loading	Cronbach's Alpha Value	Composite reliability	Variance Inflation Factor (VIF)
Long-Term Relationship	LTR1	0.786	0.854	0.902	0.697
	LTR2	0.809			
	LTR3	0.861			
	LTR4	0.880			
Information Sharing	IS1	0.857	0.880	0.918	0.736
	IS2	0.821			
	IS3	0.854			
	IS4	0.899			
Vendor Managed Inventory	VMI1	0.925	0.914	0.940	0.795
	VMI2	0.873			
	VMI3	0.887			
	VMI4	0.882			
Supply Chain Performance	SCP1	0.877	0.815	0.879	0.646
	SCP2	0.790			
	SCP3	0.727			
	SCP4	0.813			

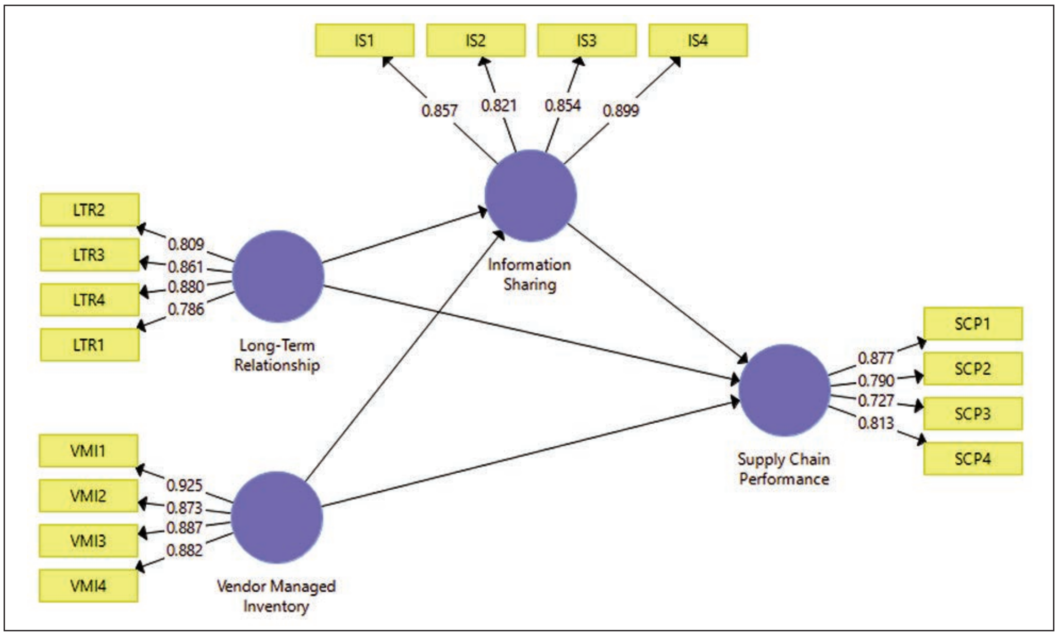

Fig. 1. Model fitness

A reliability rating of 0.70 or higher for Cronbach's Alpha and composite reliability indicates that the variable is trustworthy [43]. Based on the survey results indicating values exceeding the specified limit, it can be concluded that the data should be consistent. As demonstrated in table 1, our variables exhibit a high degree of dependability. Validity requires that the VIF value be equal to or greater than 0.50 [44]. It is evident that the VIF for all variables is equal to or greater than 0.50 (figure 1).

Hypothesis testing

Regression analysis aims to predict the value of the dependent variable by examining the values and impacts of the independent variables. Our research has involved the utilization of multiple independent variables; consequently, multiple regression analysis was employed in SmartPLS version 3. The beta values and t values are presented in table 2.

Therefore, the findings indicate that three factors (direct effects) – long-term relationship (β = 0.137, t-value = 2.007), information sharing (β = 0.260, t-value = 4.240), and vendor-managed inventory (β = 0.348, t-value = 0.348 – have a significant influence on the performance of the supply chain. Similarly, two factors – long-term relationship (β = 0.379, t-value = 7.657), and vendor-managed inventory (β = 0.427, t-value = 8.581) – have a significant influence on the performance of the supply chain in textile of Pakistan. Furthermore, the mediating

Table 2

PATH DIRECTIONS

Path directions	Value of Beta (Standard Coefficient)	Significance t-value	Results
Direct effects			
Long-Term Relationship → Information Sharing	0.379	7.657	Supported
Long-Term Relationship → Supply Chain Performance	0.137	2.007	Supported
Vendor Managed Inventory → Information Sharing	0.427	8.581	Supported
Vendor Managed Inventory → Supply Chain Performance	0.348	5.708	Supported
Information Sharing → Supply Chain Performance	0.260	4.240	Supported
Indirect effects			
Long-Term Relationship → Information Sharing → Supply Chain Performance	0.099	3.603	Supported
Vendor Managed Inventory → Information Sharing → Supply Chain Performance	0.111	3.814	Supported

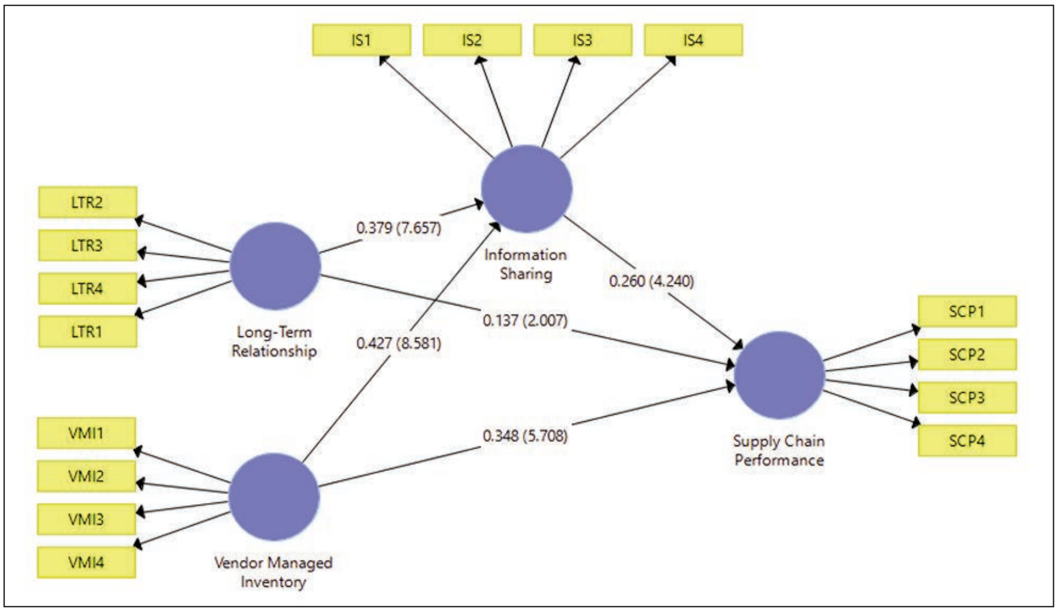

Fig. 2. Structural equation modelling

effect of information technology on the long-term relationship (β = 0.099, t-value = 3.603), and vendor-managed inventory (β = 0.111, t-value = 3.814) have a significant influence on the performance of the supply chain in textile of Pakistan. Hence, the partial mediation effect was confirmed (table 2 and figure 2).

DISCUSSION

In the present study, vendor-managed inventory has a more significant impact on supply chain performance in Pakistan's textile industry due to higher beta values for other variables. If the firm manages its inventory level better with the help of suppliers, then customers' needs can be fulfilled with greater profitability. In addition, various benefits can be driven, such as better inventory management, supplier coordination, and supply chain performance. Furthermore, the mediating effect of information sharing for the variable's long-term relationship and vendor-managed inventory confirmed better supply chain performance. These findings confirmed that better outcomes, such as trust level, resource support and commitment, can be achieved through long-term relationships. Lastly, the role of information sharing for vendor-managed inventory also recommended better and improved relationships for enhanced supply chain performance in the textile industry of Pakistan. Therefore, real-time decisions can be made, and improved supply chain performance must be addressed.

Prior researchers suggested that the influence of long-term relationships on supply chain performance is an essential factor that can be ignored [41]. Based on their findings, long-term relationships have a significant impact. Past study indicates that vendor-managed inventory significantly impacts the supply chain's performance [45]. Similarly, as market competition intensifies, industries must continue to hone their capabilities and monitor inventory, demand, and stock management to satisfy customer requirements. Therefore, prior scholars have reached the same conclusions as the present study, suggesting that VMI positively and significantly impacts supply chain performance in the long run. A previous study has demonstrated that information sharing had a substantial effect on supply chain performance [46]. They further stated that it is essential for the industry to maintain communication and information sharing with all stakeholders, such as suppliers, customers, and other partners involved in the supply chain process.

CONCLUSION

This study aims to examine the impact of long-term relationships and vendor-managed inventory on supply chain performance and the mediating role of information sharing in Pakistan's textile industry. The results revealed that all direct effects, including long-term relationships, vendor-managed inventory, and information sharing, positively and significantly impact information sharing and supply chain performance in Pakistan's textile industry. However, the unique finding of this study is that vendor-managed inventory has a more significant impact on supply chain performance for other variables. Furthermore, the mediating effect of information technology between long-term relationships and vendor-managed inventory revealed a partial mediation effect on supply chain performance. Lastly, vendors manage inventory with higher beta values as mediators concerning long-term relationships.

Theoretical contribution

The present study adopted the RBV resource-based view theory, which supported the conceptual framework. Long-term relationship findings suggested that commitment, timely information, resource support and shared values can be achieved. This theory is considered an external factor. In addition, RBV also confirmed in this study that managing inventory is significant in n many positive benefits, such as better inventory level, better customer satisfaction, and an improved position in the industry compared to competitors. Lastly, information sharing would help the textile industry in Pakistan with real-time information and timely decisions. This would also contribute to better visibility in the supply chain for better partners' performance as an internal factor in the long run.

Managerial implications

This research was considered significant for individuals employed in the textile industry and top management of the textile industry of Pakistan. Findings of this suggested that factors including vendor-managed inventory, information sharing, and long-term relationships significantly impact Pakistan's supply chain performance. Therefore, it is crucial for long-term relationships to sustain customers and cultivate positive relationships with them by ensuring the supply chain operates at peak efficiency.

Limitations and future research direction

Along with a few contributions, there are certain limitations as well. The research was limited to a sample size of 330 respondents. The sample size can be increased in the future to validate the present findings. This study was limited to only four factors. Still, other factors such as process integration, trust, collaborative planning, forecasting and replenishment, and warehouse management systems may be considered in the future. Due to time and resource constraints, our study employed non-probability convenience sampling. In contrast, prospective researchers may collect data through probability sampling.

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Authors:

ASMA JAVED[1], QIAN LI[1], IKRAMUDDIN JUNEJO[2,3], FIZA ASHRAF MEMON[3], HASEEB-UR-REHMAN PAREKH[3],
ZITA JÚLIA FODOR[4], MD BILLAL HOSSAIN[5]

[1]Department of Logistics Engineering and Management, School of Economics and Management,
Chang'an university, Xi'an, China
e-mail: asma.javed@chd.edu.cn, q.li@chd.edu.cn

[2]Department of Business Administration, University of Sindh, Thatta campus, Pakistan

[3]Department of Management Sciences, SZABIST University, Hyderabad Campus, Pakistan
e-mail: fizamemon2000@gmail.com, parekh840@gmail.com

[4]Institute of Economic Sciences, Hungarian University of Agriculture and Life Sciences,
Godollo-2100, Hungary
e-mail: fodor.zita.julia@uni-mate.hu

[5]Sustainability Competence Centre, Széchenyi Istvàn University,
9026, Győr, Hungary

Corresponding authors:

IKRAMUDDIN JUNEJO
e-mail: ikramuddin8022@yahoo.com

MD BILLAL HOSSAIN
e-mail: shohan_bd13@yahoo.com

Polydopamine nanocoating to use surface functionalization of polypropylene fabrics with a closed structure

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ABDURRAHMAN TELLI SAFIYE ARABACI

ABSTRACT – REZUMAT

Polydopamine nanocoating to use surface functionalization of polypropylene fabrics with a closed structure

In this study, an experimental investigation was conducted to explore polydopamine (PDA) nano-coating to use surface functionalization of polypropylene (PP) fabrics with a closed structure. Nanocoatings were made on polypropylene nonwoven fabric with the oxygen-induced polymerization method of dopamine (DA) at six different times. Uncoated control samples, coated samples and washed samples after coating were compared. A change in the solution towards a dark brown-black colour was observed during the experiment as the reaction time increased. Based on this finding, spectrophotometric measurements of samples were made. The lowest lightness and highest colour strength values were observed in fabric coated for 32 hours. In before and after washing SEM images, the formed nano-coating could be easily seen on this fabric (32 h). The nitrogen ratio indicating the presence of polydopamine was detected as 17.05%. After washing, it was observed that this high percentage decreased up to 1.35% but the nitrogen element was distributed homogeneously on the fabric surfaces from EDX mapping. FTIR analysis results confirmed that the PDA coating formed a bond with the polypropylene fabric and that these bonds continued after washing. Differently from uncoated fabric, extra bands and signals were observed in two different regions on the FTIR graph due to polydopamine. The results presented here may facilitate improvements in the surface activation of PP fabrics, which have a more closed structure for functionalization.

Keywords: *polypropylene, polydopamine, nonwoven, nano-coating, oxygen-induced polymerization*

Acoperirea cu nanoparticule de polidopamină pentru funcționalizarea suprafeței materialelor textile din polipropilenă cu structură închisă

În acest studiu, a fost efectuată o investigație experimentală pentru a explora acoperirea cu nanoparticule de polidopamină (PDA) pentru funcționalizarea suprafeței materialelor textile din polipropilenă (PP) cu structură închisă. Acoperirile cu nanoparticule au fost realizate pe nețesute din polipropilenă folosind metoda de polimerizare indusă de oxigen a dopaminei (DA) în șase timpi diferiți. Au fost comparate probele de control neacoperite, probele acoperite și probele spălate după acoperire. O schimbare a soluției către culoarea maro închis-negru a fost observată în timpul experimentului pe măsură ce timpul de reacție a crescut. Pe baza acestei constatări, au fost efectuate măsurători spectrofotometrice ale probelor. Cele mai scăzute valori de luminozitate și cele mai mari valori de rezistență a culorii au fost observate la materialul acoperit timp de 32 de ore. În imaginile SEM înainte și după spălare, învelișul nano format poate fi observat cu ușurință pe acest suport textil (32 de ore). Raportul de azot care indică prezența polidopaminei a fost detectat la 17,05%. După spălare, s-a observat că acest procent ridicat a scăzut până la 1,35% dar elementul azot a fost distribuit omogen pe suprafața materialului textil din cartografierea EDX. Rezultatele analizei FTIR au confirmat că învelișul PDA a format o legătură cu materialul textil din polipropilenă și că aceste legături au continuat după spălare. Spre deosebire de materialul textil neacoperit, s-au observat benzi și semnale suplimentare în două regiuni diferite pe graficul FTIR datorită polidopaminei. Rezultatele prezentate aici pot facilita îmbunătățiri în activarea suprafeței materialelor textile PP, care au o structură mai închisă pentru funcționalizare.

Cuvinte-cheie*: polipropilenă, polidopamină, nețesut, acoperire cu nanoparticule, polimerizare indusă de oxigen*

INTRODUCTION

Various functional properties can be imparted to textile materials by coating. In recent years, microcapsule applications have come to the fore to add lasting pleasant odours to fabrics. In these applications, durability against washing is still an unresolved research issue [1]. Nano-sized textile coatings have greater potential for the textile industry. For instance, it has been reported that better results were obtained in samples processed with nano-emulsion silicone softeners compared with micro and macro-emulsion silicone [2]. It was stated that the surface free energies and various structural properties of fabrics at nano-sized coatings changed compared to conventional size [3]. In a study where nano-sized zinc oxide was used to increase resistance to UV rays, a more effective UV radiation blockade was achieved compared to conventional size [4]. Especially with nanocomposite applications, various functional properties such as electromagnetic protection can be gained from fabrics [5]. In these applications, cross-linkers are generally used and the majority of these binders are harmful to the environment and workers [6]. There is a need for nanostructures and surface modification in closed-structure fabrics such as PES and PP, which are not moisture-absorbent. One of the outstanding applications for this purpose is the plasma technique. There are different types of this technique. It has been reported that it contributes to the fabric in terms of wrinkle resistance, drape ability and water repellency. These applications are currently expensive and negatively affect the mechanical properties of the fabric [7]. Surface activation has been studied over the last few decades because the majority of textile polymers have a closed chemical structure. Additional activation steps are required for functionalization.

Polypropylene (PP) fibres are preferred in many sectors due to their low density and cheap costs. PP has low surface energy due to its hydrocarbon chains, which results in poor wettability properties. Low adhesion properties create a disadvantage in dyeing, coating and use together with different materials. It restricts their use. For this reason, various surface treatments must be applied to these fibres to increase their surface energy [8]. Recently, research has been conducted on the preparation of polydopamine-coated complicated surfaces by polymerization of dopamine. Polydopamine (PDA) is a biopolymer synthesized by the oxidative self-polymerization of dopamine. It is estimated that surfaces functionalized with a PDA layer will be widely used in the coming years. The PDA layer can be used as an intermediate structure to anchor functional molecules on the surface through chemical bonds or other physical bonds [9–10]. There are a limited number of studies in the literature on the use of polydopamine in the textile industry [10–22]. It was reported in the literature that the oxidative polymerization of dopamine occurred mainly on the surface and in the amorphous regions of the textile fibres [23]. Previous studies have primarily concentrated on providing functional properties (hydrophobic character, self-cleaning, flame retardant, electrical conductivity) to cotton fabrics. In these studies, various nanoparticles such as silver and titanium dioxide were tried to be anchored to fabrics by applying polydopamine as an intermediate structure [12–13, 17, 19–21]. Liu et al. (2019) applied dopamine to the fabrics coated with Ag film. It was said that the antibacterial activity of the fabric and the laundering durability was enhanced. The developed fabrics showed more resistance against sodium sulphide corrosion with dopamine application [14]. Miao et al. (2022) developed a textile product by chemically depositing Ag particles on the textile surface using polydopamine as the binding layer. Researchers pointed out that this product can be used in the separation of oil/water mixtures and decomposition of the organic dyes under UV light [15]. Li et al. (2022) produced a superhydrophobic and conductive cotton fabric even after 18 cycles of accelerated washing through the PDA-assisted deposition of photocatalyst Ag/CdS [24]. Wang et al. (2023) produced a superhydrophobic coating providing functional properties such as self-cleaning, oil-water separation, oil sorption and flame retardancy. This nano-coating was achieved with polydopamine-boehmite modification. The boehmite particles were adhered to stainless steel mesh through polydopamine (PDA). Furthermore, cetylamine (CTA) with low surface energy and amino group was grafted onto PDA [18].

Literature reviews have indicated that there were no studies on the detailed performance of PDA nano-coating on polypropylene nonwoven fabrics. The objectives of this paper are to determine whether PDA nano-coating could be used for surface functionalization of polypropylene fabrics with a closed structure. For this aim, dopamine hydrochloride was preferred as the monomer. The oxygen-induced polymerization method of dopamine (DA) was used. The behaviour of nano-coating PP fabrics before and after washing was examined.

MATERIAL AND METHODS

In this study, polypropylene spunbond nonwoven fabrics with a weight of 35 grams per square meter, obtained from Teknomelt nonwoven company, were used. The fabric was washed with acetone to remove impurities before use in the experiment. Chemicals were obtained from Sigma-Aldrich Chemie GmbH in Germany. Dopamine hydrochloride (99 wt.%) and tris(hydroxymethyl)aminomethane (99 wt.%) were used without an additional purification step.

At first in the synthesis of polydopamine, 2 mg/ml dopamine hydrochloride as a monomer was dissolved in water. After this step, 1.2 mg/ml Tris(hydroxymethyl)aminomethane was added to the solution to stabilize of pH and mixed quickly. During this process, the solution, which was initially colourless and transparent, turned pale yellow with the oxidation of catechol to benzoquinone. After a homogeneous mixture was achieved, the fabric was left in the solution. Fabric in solution was starting to put to a continuous movement in the horizontal direction using a shaker. In this way, dopamine-melanin aggregates on fabric surfaces started to form under alkaline and stable environmental conditions as reported in the literature [10, 14, 16]. The self-polymerization reaction began to occur in the presence of atmospheric oxygen. The oxidative self-polymerization of dopamine was made six different times as powers of two ($2^0 = 1$, $2^1 = 2$, $2^2 = 4$, $2^3 = 8$, $2^4 = 16$, $2^5 = 32$ hours). As the reaction time increased, a gradual change in the solution colour towards dark brown-black was observed. PDA's natural colour becomes more evident as the layer thickness of the PDA increases successfully and the aggregates are observed more. Depending on the reaction time, this shows itself as a colour change [25–27]. The obtained coated samples were rinsed with cold water. Following this, samples were dried flat under standard atmospheric conditions. To determine the durability of the nano-coating, washing was carried out using sodium perborate for 30 minutes at 40 °C in the GyroWash Colour Fastness

Tester of James Heal according to EN ISO 105-C06. The A2S method was used for the experimental conditions.

Since the colour of the solution darkens with polymerization, spectrophotometric colour measurements (Minolta CM 3600 D Spectrophotometer and RealColor® software) were made on all samples. CIELab values of the fabrics were determined under standard D65 light. Among these values, lightness (L*) values were examined because it was thought that polymerization would be most successful as the darkness was increasing. In addition, colour strength values (K/S) were calculated using the percentage reflectance (%R) values at the 400 nm wavelength, where the maximum absorption of the colour in the dyes is found. The results obtained from uncoated control samples, coated samples and washed samples after coating (AW) were compared. Scanning electron microscopy (FEI Quanta 650 Field Emission SEM), energy dispersive spectrometer (EDX and mapping), FT-IR (Jasco FT/IR-6700) spectrum with ATR technique and static contact angle measurements for the surface wettability (Theta lite Contact Angle Measurement System) were used to examine and characterize the structure of the samples that were successful after colour measurements. Figure 1 shows the used methods as a schematic.

RESULTS AND DISCUSSION

Lightness (L*) results

The decrease in L* values indicates increasing darkness. Lightness (L*) values obtained at six different times are given in figure 2.

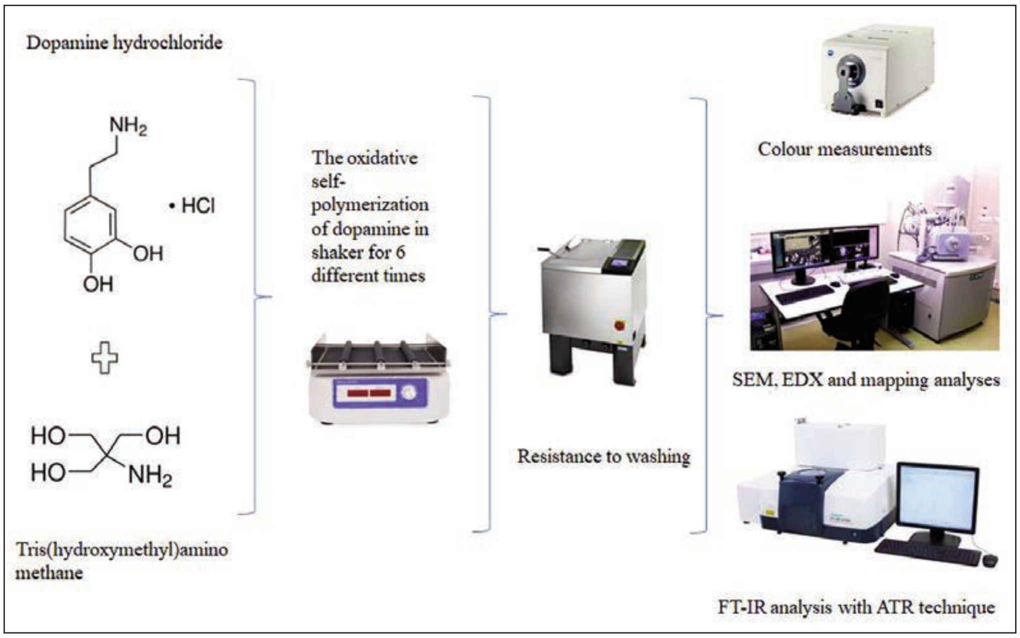

Fig. 1. The schematic representation of used methods

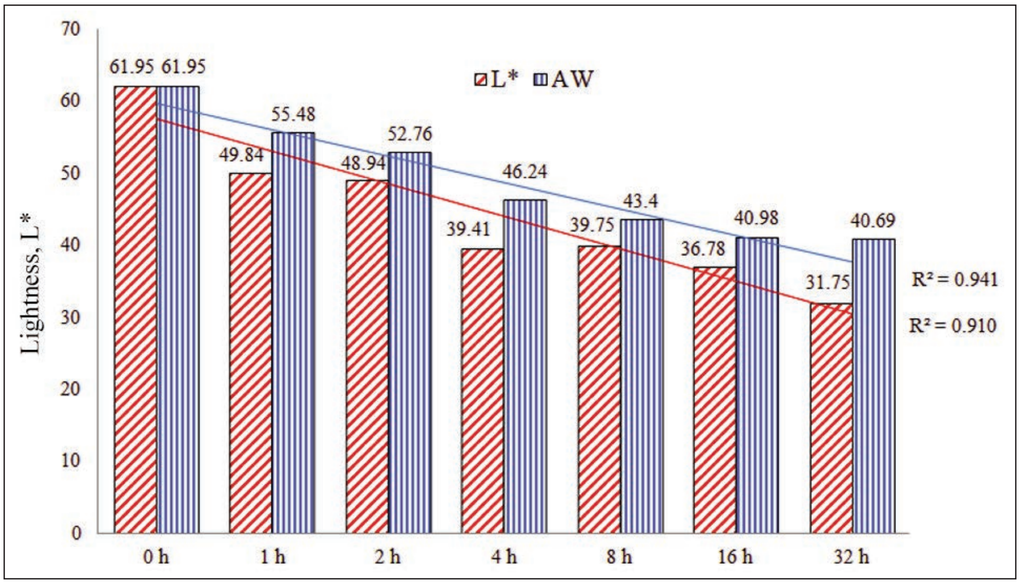

Fig. 2. Lightness (L*) values and changes after washing (AW)

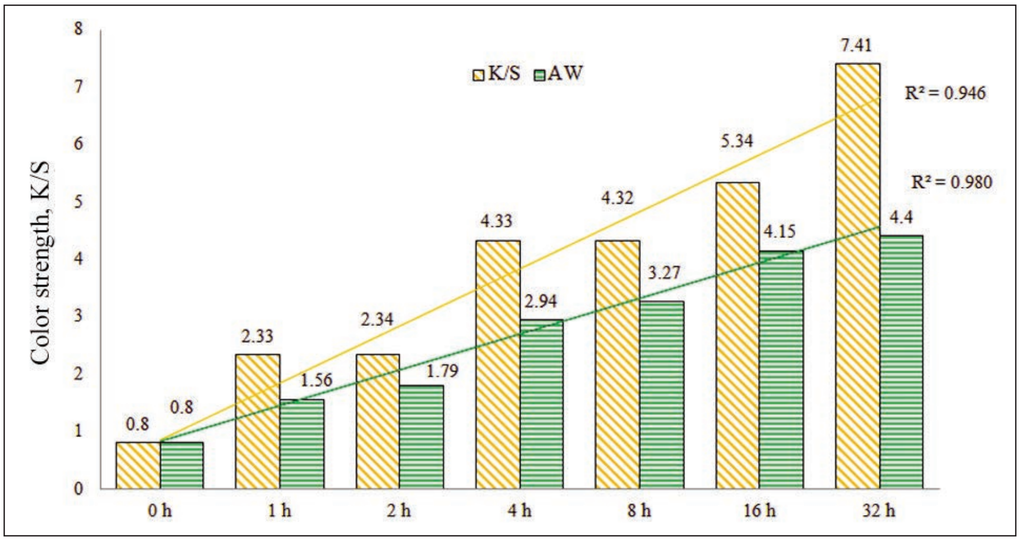

Fig. 3. Colour strength (K/S) values and changes after washing (AW)

A decrease in L* values was observed as the coating time increased, except for 8 hours. The lowest L* (L* = 31.75) were obtained in the coating applied for 32 hours. Similarly, after washing, the lowest L* (L* = 40.69) were measured in the coating applied for 32 hours. When the trend line of the coated fabrics was examined, high regression coefficients were observed for both lightness (R^2 = 0.910). After washing, significant and higher regression coefficients were seen in L* (R^2 = 0.941).

The colour strength (K/S) results

Fabrics with high cover factors have high K/S values. In this situation, it can be said that the increase in K/S values shows the success of coating. Colour strength (K/S) values obtained at six different times were presented in figure 3.

An increase in K/S values was observed as the coating time increased, except coated for 8 hours (figure 3). The highest K/S value (K/S = 7.41) was obtained in the coating applied for 32 hours. Similarly, after washing, the highest K/S value (K/S = 4.4) was measured in the coating applied for 32 hours. When the trend line of the coated fabrics was examined, high regression coefficients were observed for colour strength (R^2 = 0.946). After washing, significant and higher regression coefficients were seen in K/S (R^2 = 0.980).

Based on the results presented in figure 2 and figure 3, L* values and K/S values showed compatible results and it can be estimated that the most successful coating occurs in 32 hours which has the lowest L* and highest K/S. It was determined that washing removes the coatings to some extent at all application times. In washed samples, the darkest appearance, lowest lightness and highest colour strength values were measured in 32 hours. Before and after washing images of the coated (32 h) polypropylene fabric are shown in figure 4. It was seen that the coating applied for 32 hours was homogeneous and very close to black. But there was a significant colour fading with washing. For this reason, the study focused on 32 hours coated fabrics in subsequent processes.

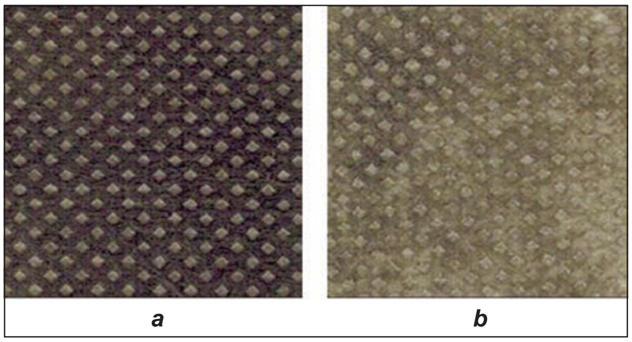

Fig. 4. Before and after washing images of the coated (32h) polypropylene fabric:
a – coated (32 h); *b* – washed

Presence of coatings in SEM images

To examine the presence of polydopamine nanocoating on the fabrics after the coating process and washing, images were taken at 10000x magnification on the SEM device. Compared to the uncoated control fabric in figure 5, the nanocoatings formed after the coating process can be easily seen on fabrics. It was seen that the polydopamine nanospheres remained on fabric surfaces after washing although its density decreased slightly.

Atomic percentages of elements in the EDX and Mapping

EDX analysis is used with SEM. Elements and percentage amounts on the surface can be analysed and mapped. The chemical composition results obtained from EDX analysis are given in table 1.

Polypropylene consists of methyl groups. For this reason, it contains only carbon and hydrogen elements. Since hydrogen could not be detected in the EDX analysis, it could be seen from table 1 that the structure of PP only consists of carbon. PP does not

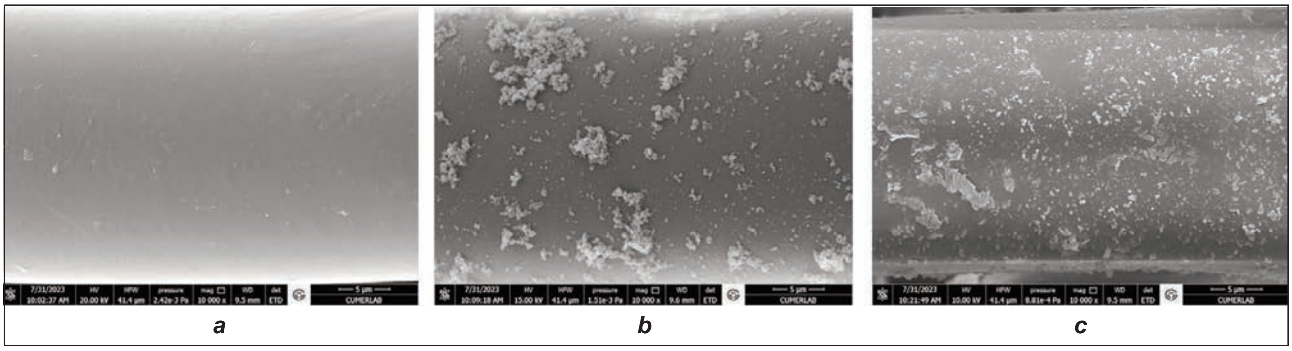
a b c

Fig. 5. SEM images of fabrics (10000x): *a* – uncoated control samples; *b* – coated samples (32 h); *c* – washed samples

contain a nitrogen element in its structure. In PP+PDA, 17.05% nitrogen content was detected thanks to PDA. After washing, it was observed that this high percentage decreased up to 1.35%. This situation is compatible with the colour change seen in the PP fabric after washing in figure 4. PDA continued its presence in the fabric although the rate decreased.

Table 1

CHEMICAL COMPOSITIONS IN FABRICS

Atomic %	C (carbon)	N (nitrogen)
PP	100*	-
PP+PDA	82.95	17.05
PP+PDA (AW)**	98.65	1.35

Note: *Hydrogen cannot be detected in EDX analysis; **AW: After Washing.

Additionally, before and after washing mapping of the coated PP fabrics was given in figure 6. In this figure, yellow colour for N and green colour for C were represented. According to figure 6, it was seen that the nitrogen element is distributed homogeneously on the surface of the PDA-coated polypropylene fabric. A similar appearance was obtained after washing. A homogeneous distribution continued after washing. The results confirmed that PDA coatings were successfully formed using the in-situ polymerization technique on PP fabric and remained valid after washing.

FT-IR results

Each type of bond absorbs energy of a specific frequency. In this way, bond types in an element can be determined using the FTIR spectrum. In figure 7, FTIR results of PP, PP+PDA and PP+PDA (AW) fabrics were presented as unified in a single graphic.

In PP, CH3 stretching peaks at wavelengths of 2950.55 (asymmetric) and 2867.63 (symmetric) cm^{-1} and CH2 stretching peaks at wavelengths of 2916.81 (asymmetric) and 2837.74 (symmetric) cm^{-1} were observed. These peaks are the distinctive peaks in the FTIR graph of each polypropylene fabric. Four C-H stretching peaks were measured between wavelengths of 3000-2850 cm^{-1}. Since both methyl and methylene groups have two peaks in this range, the presence of four peaks means that both were present [28–29]. Additionally, two CH3 bending peaks were observed at wavelengths 1454.06 (asymmetric) and

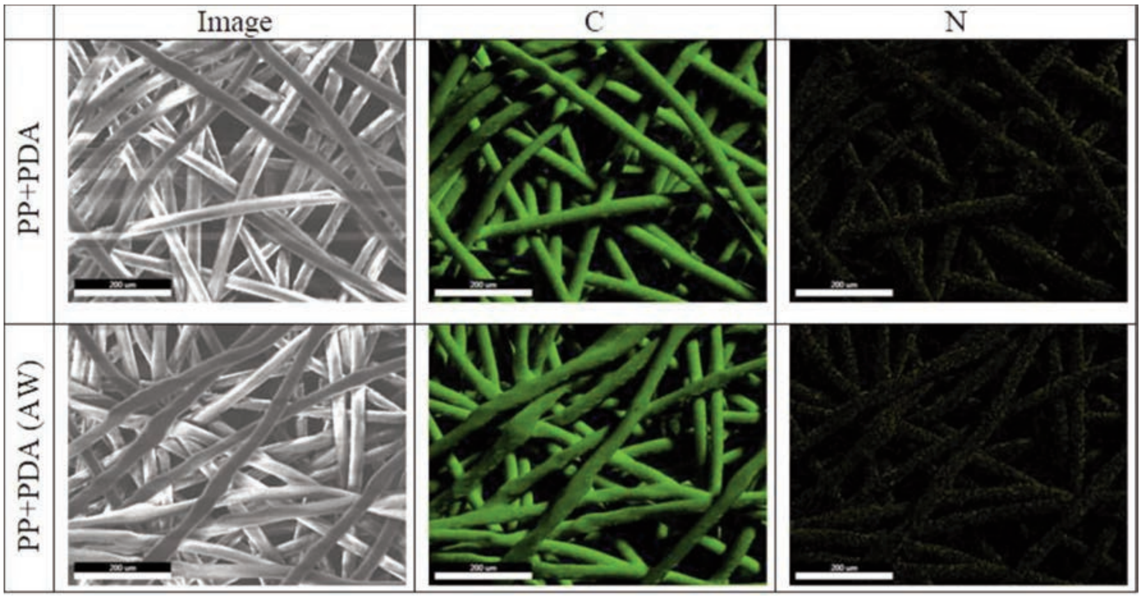

Fig. 6. Before and after washing mapping of the coated (32 h) PP fabric

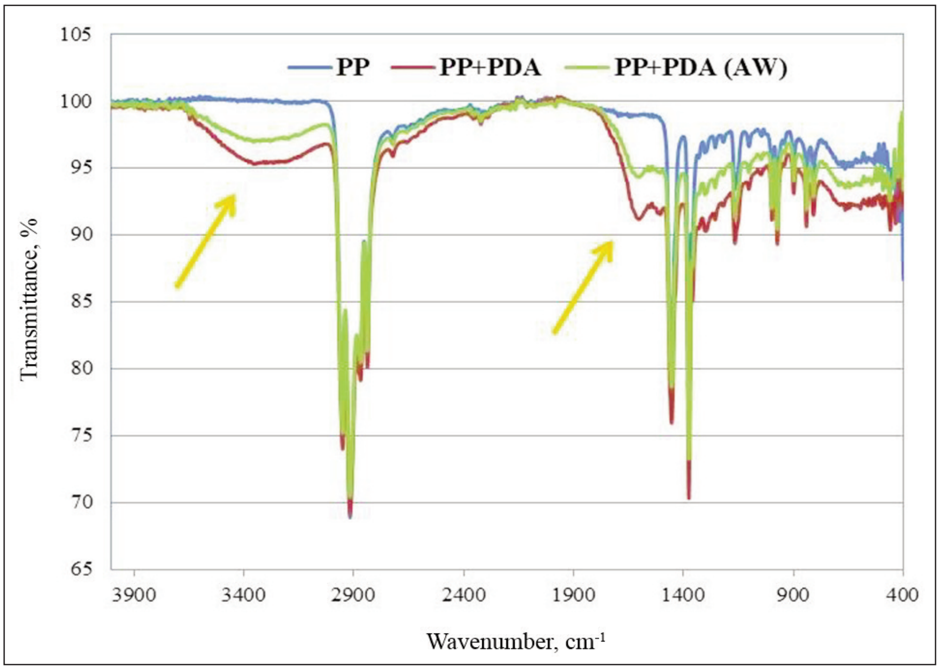

Fig. 7. FTIR results of PP, PP+PDA and PP+PDA (AW) fabrics

1375 (symmetric) cm^{-1} [29–31]. There were peaks with similar transmittance values at the same points in PP+PDA and PP+PDA (AW). However, differently from PP, the most striking result to emerge from the FTIR data is, that extra broad signals were observed in the two regions indicated by the arrows in figure 7 due to the presence of polydopamine.

The broad signals seen between the high wavelengths of 3600–3200 cm^{-1} originate from the catechol groups in the polydopamine structure. The presence of a broad signal at higher wavelengths indicates the presence of hydrogen bonds. If there is a very broad signal to the left of 3000 cm^{-1}, this is due to OH bonds. OH gives a broad signal due to its bond with hydrogen. Furthermore, symmetric N-H bond stretching (secondary amine) may occur at wavelengths of 3300±10. In figure 7, significant signals were detected at 3354.57 cm^{-1} in PP+PDA and 3355.53 cm^{-1} in PP+PDA (AW). Previous studies also emphasized that the signals in this region belong to (N-H) and (-OH) stretch vibrations in the dopamine structure [10, 32].

The other characteristic strong band was seen in the double bond region between wavelengths of 1650-1500 cm^{-1}. Signals were detected at 1602.56 cm^{-1} in PP+PDA and 1601.59 cm^{-1} in PP+PDA (AW). It was stated that these signals arise from the bending vibrations of the C=O double bond (COOH) of the carboxylic function, the aromatic C=C ring in the dopamine-quinone structure, and the C=N bond [10, 32]. When PP+PDA and PP+PDA (AW) were compared, the effect of washing was seen in the SEM images and EDX analysis results.

Transmittance values of specific peaks were found to be higher in PP+PDA (AW) fabric due to the slight decrease in nano-coating after washing. FTIR analysis results in figure 7 confirmed that the PDA coating formed bonds with the polypropylene fabric and these bonds continued after washing.

Surface wettability

The uncoated polypropylene (PP) fabric exhibited a high contact angle of 116 degrees, indicating a significant degree of inherent hydrophobicity. After coating the fabric with polydopamine (PDA), the contact angle was slightly reduced to 114 degrees. This minor decrease, however, fell within the margin of experimental error, suggesting that the PDA coating did not significantly alter the hydrophobic nature of the PP fabric. Thus, while the PDA coating modified the surface properties of the PP fabric, it did not drastically alter its overall hydrophobic nature. The proximity of the contact angles indicated that the PDA layer while affecting the surface chemistry did not significantly enhance the hydrophobicity of the already hydrophobic PP fabric (figure 8).

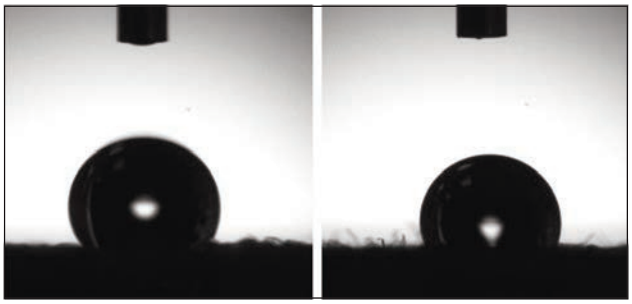

Fig. 8. Water contact angle results of PP and PP+PDA fabrics

CONCLUSIONS

In this study, polydopamine coatings six different times were made on polypropylene spunbond nonwoven fabric with the oxygen-induced polymerization method of dopamine (DA). This paper set out to compare the properties of uncoated control samples, coated samples and washed samples after polydopamine nano-coating. According to colour measurement results, the lowest lightness and highest colour strength values were observed in polypropylene fabrics coated for 32 hours. In SEM images, the formed nano coating after the coating process could be easily seen on the fabric. Although its density decreased slightly after washing, it was determined that polydopamine nanospheres remained on fabric surfaces. According to SEM EDX analysis results, the nitrogen content in PDA-coated PP fabrics was determined as 17.05%. After washing, it was observed that this high percentage decreased to 1.35%. This finding has shown that PDA continued its presence in the fabric although the rate decreased after washing. Furthermore, this study has shown that the nitrogen element was distributed homogeneously on the fabric surfaces before and after washing with EDX mapping of the coated fabrics. The other major finding was that FTIR analysis results confirmed that the PDA coating formed a bond with the polypropylene fabric and that these bonds continued after washing. Since there is no nitrogen in the polypropylene fabric structure, the presence of polydopamine could be detected. Extra bands and signals were observed in two different regions on the FTIR graph due to polydopamine. These were the broad signals in the high wavelengths of 3600–3200 cm^{-1} and peaks in the wavelengths of 1650–1500 cm^{-1} in the double bond region. Water contact angle results showed that the PDA coating did not significantly alter the hydrophobic nature of the PP fabric.

The SEM, EDX, Mapping and FTIR results of this research support the idea that the polydopamine (PDA) nanocoating intermediate layer, which enables the functionalization of fabrics to be carried out easier, better and more homogeneously with fewer chemicals, will be successful in PP fabrics. The evidence from this study suggests that PDA nano coating can be considered a sustainable alternative for surface activation of PP fabrics.

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Authors:

ABDURRAHMAN TELLI, SAFIYE ARABACI

Cukurova University, Faculty of Engineering, Department of Textile Engineering,
Balcalı Campus, 01330, Adana, Türkiye
e-mail: arabacisafiye84@gmail.com

Corresponding author:

ABDURRAHMAN TELLI
e-mail: atelli@cu.edu.tr

Improving sales performance management in textile and fashion companies: a case study of ASOS

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DANICA LEČIĆ-CVETKOVIĆ
JASNA PETKOVIĆ
VLADIMIR BURAZOR

TEODORA RAJKOVIĆ
JOVANA MIHAJLOV

ABSTRACT – REZUMAT

Improving sales performance management in textile and fashion companies: a case study of ASOS

Sales performance management is one of the key processes in companies from various industries. Improving business strategies through planning, analyzing, guiding and managing sales activities presents the overall aim of sales performance management for achieving companies' strategic business goals. The main objective of the paper is to present the application of a set of key performance indicators for improving online sales performance management in the textile and fashion industry. The characteristics of traditional and online sales, and their comparative analysis in companies from the textile and fashion industry, are presented. Also, the possibilities of implementing modern sales methods, techniques and information and communication technologies for improving online sales performance management are presented. The defined set of key performance indicators is applied to the example of one of the leading companies in online sales in the textile and fashion industry, the company ASOS. Based on the results, it can be concluded that four of the sales performance values of the ASOS are at a satisfactory level, while three should be ameliorated by implementing some of the recommendations for improvement presented in the paper.

Keywords: *textile and fashion industry, sales, management, key performance indicators, ASOS*

Îmbunătățirea managementului performanței vânzărilor în companiile textile și de modă: un studiu de caz al companiei ASOS

Managementul performanței vânzărilor este unul dintre procesele cheie în companiile din diverse industrii. Îmbunătățirea strategiilor de afaceri prin planificarea, analiza, îndrumarea și gestionarea activităților de vânzări prezintă scopul general al managementului performanței vânzărilor pentru atingerea obiectivelor strategice de afaceri ale companiilor. Obiectivul principal al lucrării este de a prezenta aplicarea unui set de indicatori cheie de performanță pentru îmbunătățirea managementului performanței vânzărilor online în industria textilă și de modă. Sunt prezentate caracteristicile vânzărilor tradiționale și online, precum și analiza lor comparativă în companii din industria textilă și de modă. De asemenea, sunt prezentate posibilitățile de implementare a metodelor, tehnicilor și tehnologiilor informației și comunicațiilor moderne de vânzare pentru îmbunătățirea managementului performanței vânzărilor online. Setul definit de indicatori cheie de performanță este aplicat pe baza unui exemplu al uneia dintre companiile lider în vânzări online din industria textilă și de modă, compania ASOS. Pe baza rezultatelor, se poate concluziona că patru dintre valorile performanței în vânzări ale companiei ASOS sunt la un nivel satisfăcător, în timp ce trei dintre acestea ar trebui îmbunătățite prin implementarea unor recomandări prezentate în acest studiu.

Cuvinte-cheie: *industria textilă și modei, vânzări, management, indicatori cheie de performanță, ASOS*

INTRODUCTION

The textile and fashion industry is one of the key pillars of global economic development. It represents an industry in which modern business conditions are highly volatile and turbulent. To thrive in such a business environment, companies in this industry have to invest in improving sales performance management. They need to apply adequate modern Information and Communication Technology (ICT) in their operations and regularly monitor and control the values of sales Key Performance Indicators (KPIs). The development of ICT has a crucial role in the development of the modern textile and fashion industry, particularly in the retail sector. To effectively manage products, sales and customer relationships, the application of contemporary and innovative ICT is necessary for sales management. KPIs represent the most important performances that need to be regularly monitored to gain insights into business outcomes across different segments. This paper focuses on KPIs for the improvement of sales management. The main objective of this paper is to present the application of a set of KPIs for the improvement of online sales performance management in the textile and fashion industry. This paper defines a set of the seven most important performance indicators for measuring online sales performance in companies from the textile and fashion industries. The set of KPIs is applied to real data from the company ASOS, which is exclusively engaged in online sales in this industry.

The paper is structured into four chapters. The first chapter presents the introduction of this manuscript, an overview of sales management in companies from the textile and fashion industry, focusing on two sales channels: traditional sales in physical stores and online sales via the Internet. A comparative analysis of these two channels is presented based on five criteria. In the same chapter sales methods and techniques to enhance sales performance management through the application of modern ICT are presented, as well as a literature review regarding performance indicators used in online sales management. The second chapter presents a set of defined KPIs with associated aimed values for the quantitative analysis of online sales performance in companies from the textile and fashion industry. In the third chapter results and discussion of an example of the application of a defined set of KPIs in one of the leading companies in the textile and fashion industry, company ASOS, is presented. Also, some recommendations for improving the online sales performance management for companies in the textile and fashion industry are present in this chapter. The conclusions and limitations of the study are presented in the fourth chapter.

Sales management in the textile and fashion industry

The fashion industry has undergone significant changes in the past few decades. Mass production has been replaced by small-batch production, with more fashion seasons, new trends, design flexibility, quality and product delivery. Until the end of the 20th century, the only way to purchase products was through physical retail stores. In the second half of the 1990s, a new method of trading emerged through the Internet – e-commerce. The Internet is considered “the fastest-growing phenomenon in modern history” [1]. It enables fast and intense communication, data exchange and improved development of all businesses by using different instruments of promotion propaganda with an impact on the consumer awareness of fashion brands [1, 2]. Table 1 presents a comparative analysis of traditional and online sales based on the five most important criteria selected from the literature review [3–8].

From table 1 it can be concluded that online sales have many advantages compared to traditional sales. Retailers consider the Internet as a tool to expand their target markets, gather data, facilitate communication with customers, promote products and reduce operating costs. With online sales and e-commerce development, geographical boundaries are erased, enabling customers to purchase products from brands whose physical stores do not exist nearby. Customers can easily access various types of information, about products, brands and companies. Research conducted by Ariffin et al. [9] indicates that time, product, financial, psychological and security risks have a negative impact on customers’ intentions to make online purchases, while social risk has an insignificant impact. Factors that can impact customers’ decision to purchase online include [10]: convenience, lower product prices, a wide selection of products and the risk of purchasing unsuitable items. These are the reasons why this paper examines the application of modern ICT in sales management and proposes a set of KPIs for its improvement in companies from the textile and fashion industry.

The application of modern ICT in sales management

The textile and fashion industry has been more slowly adopting online sales than other industries [11]. One of the main reasons is the challenge of shifting the experience of purchasing clothing in-store to the online form. This primarily refers to the need to see, touch and try on these products. However, by innovations and the application of ICT, this lack of sensory experience can be shifted into the online environment in several ways. The consulting agency “Alcimed” has identified 11 technologies as key technologies to ensuring agility and competitiveness in the fashion industry: Cloud Computing, Big Data,

Table 1

A COMPARATIVE ANALYSIS OF TRADITIONAL AND ONLINE SALES

Criteria	Traditional sales	Online sales
Location and accessibility	Physical locations, specific working hours, geographical limitations	Possibility to shop at any time and from any location
Delivery time and costs	Current delivery time, time spent on physically visiting a store, possible waiting times	Delivery time (ranging from a few days to several weeks), delivery costs (often paid by the customer)
Payment methods	Cash and checks, credit, debit and gift cards	Credit, debit and gift cards, PayPal, cryptocurrencies
Customer relations	More personalized relationships, seller advice, Email	Social media, applications, Email, Chatbots
Operational costs	Costs of rent, storage, employees, marketing, etc.	Costs of office rental, storage, employees, marketing, delivery, packaging, product returns, etc.

artificial intelligence, cybersecurity, tags, RFID technology, Internet of Things, robots, drones, additive manufacturing and virtual reality [12]. Customer Relationship Management (CRM) is an ICT solution with a basis that resides in information technology and customer data with a positive impact on the satisfaction and loyalty of a customer, increase in sales and profitability [13]. Product recommendation systems are innovative solutions that utilize historical customer data, their behaviour and the products they have chosen in previous purchases [14]. They help customers to make better decisions, reduce search efforts, find the most suitable product price and apply artificial intelligence technologies for visual detection and key product attributes. In fashion brand applications and websites, visual search is implemented using computer vision technologies. An image that presents an input and an output is an image with similar visual characteristics. Furthermore, the application of virtual fitting rooms and 3D virtual models in online sales reduces the rate of product returns. Chatbots are becoming increasingly popular for providing real-time customer service in online sales. They can be seen as user interfaces designed to enable users to communicate more intuitively with computers through natural language [15]. They represent virtual machines that interact with customers through “chatting”, answering inquiries, assisting users in navigating the store’s assortment and recommending clothing and fashion accessories that suit the most a particular customer.

Performance indicators for online sales management

Regardless of selling products traditionally in retail stores, online shops or through a combination of both, companies in the textile and fashion industry need to define, measure and monitor a set of adequate KPIs to effectively perform sales performance management. Performance management presents the product of specific tools designed to monitor organizational performance [16]. Performance indicators present the results of performance measurement, usually presented through numbers (showing the quantity – how much) and measurement units (giving a meaning – what) [17]. KPIs present indicators that focus on the organizational performance critical for the current and future success of the organization [18]. KPIs are applied in companies to ensure the correct direction of the business and the achievement of organizational objectives [19]. The topic of performances and performance indicators in the textile and fashion industry is presented in various papers. Indicators for evaluating sustainable performance in the textile industry are identified in [20], while environmental and financial performance indicators used to measure environmental performance in the Brazilian textile industry are presented in Lucato et al. research [21]. An assessment of the competitive indicators in textile companies in the Republic of Serbia is presented in Miletić et al. research [22], while Awan et al. [23] examine the impact of leadership on employee performance in textile exporting companies in Pakistan. Two indicators, the variation of the test fabric thickness and the variation of the mass for the simulation friction process for outerwear products are determined by Hristian et al. [24], while Apaydın Avşar and Belgin [25] analyze technical efficiency and changes in the productivity of the Turkish textile industry using Textile Firms Technology Change Index (TCI), Technical Efficiency Change Index (TECI) and Total factor Productivity Index (TFPI). Detailed analysis and literature review of the application of KPIs in the textile and fashion industry are presented in Rađenović et al. research [26]. Based on the literature review presented in this chapter, it can be concluded that there are articles that present the use of performance indicators in the textile and fashion industry, but there are no articles that have presented a set of KPIs for online sales performance analysis in the textile and fashion industry. Based on the aforementioned, the applications of the defined set of KPIs on real data of the company from the textile and fashion industry for performance analysis presented in this paper will fill this gap.

MATERIAL AND METHOD

Material

The main focus of this paper is to define a set of relevant and the most important, i.e. key performance indicators in online sales management. The set of seven KPIs is presented in table 2. The criteria used for selecting the set of seven KPIs [27, 28]: simplicity and relevance (KPIs must be easy to use, clear and understandable for the company, as well as important for the company’s business), cost-effectiveness (collection of data and detailed analysis should not expensive), measurability, availability and validity (KPIs can be measured based on the existence of real and valid data), comparability (obtained results of KPIs can be used for the comparison with results of other companies from the similar branch), reliability and consistency (conclusions and decisions can be made based on the obtained results). These KPIs can be applied as a tool for measuring online sales performance in companies from the textile and fashion industry but can also be applied to companies in any industry, as well as for the improvement of sales performance and gaining a competitive advantage.

Method

KPIs presented in table 2 are explained in the following.

KPI 1. Add-To-Cart Rate (ATC): measures the percentage of website visitors that add at least one product to their cart during their visit (table 2, row no. 1). The aimed value for this KPI is to be as high as possible. According to Dynamics yield [29], the average value for this indicator is 7.8%.

KPI 2. Shopping Cart Abandonment Rate (SCA): measures the percentage of a visitor to the website

Table 2

KPIS FOR MEASURING ONLINE SALES PERFORMANCE IN COMPANIES FROM THE TEXTILE AND FASHION INDUSTRY

KPIs		KPIs formulas	KPIs aimed values
1	KPI ATC	$ATC = \frac{VAC}{TV} \cdot 100\ (\%)$ •ATC – Add-to-Cart rate [%]; •VAC – Number of visits where at least one product was added to the cart within a specific period [1]; •TV – Total number of visits to the website within a specific period [1].	as high as possible, average = 7.8%
2	KPI SCA	$SCA = \left(1 - \frac{TT}{VAC}\right) \cdot 100\ (\%)$ •SCA – Shopping Cart Abandonment Rate [%]; •TT – Total number of completed transactions within a specific period [1]; •VAC – Number of visits where at least one product was added to the cart within a specific period [1].	as low as possible, average = 69.99%
3	KPI ATS	$ATS = \frac{TTS}{TV}$ (time unit) •ATS – Average Time on Site [time unit]; •TTS – Total time spent on the website within a specific period [time unit]; •TV – Total number of visits to the website within a specific period [1].	as high as possible, average = 54 sec
4	KPI BR	$BR = \frac{SPV}{TV} \cdot 100\ (\%)$ •BR – Bounce Rate [%]; •SPV – Number of single-page visits on the website within a specific period [1]; •TV – Total number of visits to the website within a specific period [1].	$40 \geq BR \geq 20$
5	KPI RLR	$RLR = \frac{LRR}{TR} \cdot 100\ (\%)$ •RLR – Revenue Loss Rate per Return Products [%]; •LRR – Loss revenue due to returned products within a specific period [value unit]; •TR – Total sales that present the revenue achieved within a specific period [value unit].	as low as possible, average = 16.5%
6	KPI WCR	$WCR = \frac{TT}{TV} \cdot 100\ (\%)$ •WCR – Website Conversion Rate [%]; •TT – Total number of completed transactions within a specific period [1]; •TV – Total number of visits to the website within a specific period [1].	as high as possible, average = 3.32%
7	KPI ATV	$ATV = \frac{TR}{TT}$ (value unit) •ATV – Average Transaction Value [value unit]; •TR – Total sales revenue within a specific period [value unit]; •TT – Total number of completed transactions within a specific period [1].	as high as possible, average = 85.60 £

that adds products to the shopping cart but does not complete the purchasing process for various reasons (table 2, row no. 2). The aimed value of the KPI SCA is to be as low as possible. According to Baymard Institute [30], the average value for this indicator is 69.99%.

KPI 3. Average Time on Site (ATS): measures the average length of time visitors spend on the website (table 2, row no. 3). The observed period can be a day, month or year. The aimed value of the KPI ATS is to be as high as possible. According to Contentsquare [31], the average value for this indicator across all industries is 54 sec.

KPI 4. Bounce Rate (BR): presents the percentage of visitors that leave the website after viewing only one page (table 2, row no. 4). Since this rate range for the retail sites should be between 20% and 40% [32], the aimed value of this indicator is to be within that range.

KPI 5. Revenue Loss Rate per Return Products (RLR): presents the revenue loss rate per returned product within a specific period (table 2, row no. 5). This KPI is applied in both online and traditional sales, but it is particularly significant in online sales. According to the National Retail Federation [33], the average value for this indicator is 16.5%.

KPI 6. Website Conversion Rate (WCR): presents the percentage of website visitors that take a desired action on site and is significant for companies that sell online through a website (table 2, row no. 6). The aimed value is to be as high as possible. According to Dynamics yield [29], the average value for this indicator is 3.32%.

KPI 7. Average Transaction Value (ATV): presents the average amount a customer spends on a single purchase. This KPI is calculated by dividing the total value of all transactions within the observed period (total revenue) by the number of completed transactions during the same observed period (table 2, row no. 7). The aimed value is to be as high as possible. According to Dynamics yield [29], the average value for this indicator is 109 $, i.e. 85.60 £.

RESULTS AND DISCUSSION

The set of KPIs presented in the previous chapter has been applied to real data from ASOS, one of the most successful companies exclusively engaged in online sales of products from the textile and fashion industry. ASOS is a British company founded in London in 2000. Based on data from 2022, ASOS has 84% brand awareness in the UK [34]. The entire business is based on online sales, without any traditional stores. Through its online store, ASOS offers more than 850 brands, including 17 owned by ASOS, such as Topshop, Topman, Miss Selfridge, ASOS Design, Collusion, etc. [35]. It delivers its products to 195 countries from distribution centres located in the UK, US and Europe. An analysis of ASOS sales management results was conducted for the business year 2022. Data on business results are observed from the annual report of ASOS company for the period from August 31st, 2021, to August 31st, 2022 [36] and quantitative analysis was conducted. Also, additional data required to calculate some of the KPIs that were not presented in the ASOS annual report are accessed from reports available at Guesswork [37] and Guesswork [38]. The data in the ASOS annual report [36], as well as additional reports [37, 38], were presented in total for the observed period without classifying data for seasons, type of brands, type of products, as well as customer profiles. Data were selected from mentioned reports and quantitative analysis was conducted for the defined set of KPIs. The data from reports used to calculate a defined set of KPIs are quite large, displayed in long figures and, for this reason, only aimed and calculated values of KPIs will be presented in table 3.

Figure 1 presents graphically calculated and aimed values per every KPI.

KPI 1. Add-To-Cart Rate (ATC): The calculated value of the KPI ATC for the year 2022 in ASOS company is 11%. It can be concluded that the value of this KPI in 2022 is at a satisfactory level (above 7.8%), although there should be a striving for improvement. The value of this KPI provides the company's management with answers to important questions, such as whether the products and their prices meet visitor expectations, whether the website provides a good user experience, whether the marketing strategy is successful, etc. The value of this KPI can be improved by implementing a product recommendation system that utilizes artificial intelligence to proactively suggest products to users. These suggestions can include substitutes for the originally aimed products if their sizes are out of stock or other products that can complement their outfit. Additionally, another way to increase the value of this KPI is to create a "sense of urgency" or artificial "shortage" by presenting products available in limited quantities to customers. The functionalities of the shopping website also have a role in increasing the value of this KPI. Each product should have an adequate description and high-quality images from different angles with zoom options and be presented on models. All the mentioned factors will significantly contribute to improving the user experience and increasing the possibility of users adding products to their shopping carts.

KPI 2. Shopping Cart Abandonment Rate (SCA): The calculated value of KPI SCA in ASOS company in 2022 is 70.09%. The aimed value of KPI SCA is to be as low as possible. It can be concluded that the value of this KPI for ASOS company in 2022 is high and slightly above the average value of 69.99%. Relating to various aspects of service quality in sales and issues that can appear, some of the reasons why the value of this KPI is high are: inadequate delivery times and delivery options – customers expect a reasonable delivery timeframe, costs and delivery options; unexpected additional costs – that are often

Table 3

RESULTS AND AIMED VALUES OF KPIS FOR MEASURING ONLINE SALES PERFORMANCE IN ASOS COMPANY (FROM AUGUST 31ST, 2021, TO AUGUST 31ST, 2022)

KPIs		KPIs results	KPIs aimed values
1	KPI ATC	11%	as high as possible, average = 7.8%
2	KPI SCA	70.09%	as low as possible, average = 69.99%
3	KPI ATS	308 sec	as high as possible, average = 54 sec
4	KPI BR	36.86%	40 ≥ BR ≥ 20
5	KPI RLR	1.97%	as low as possible, average = 16.5%
6	KPI WCR	3.29%	as high as possible, average = 3.32%
7	KPI ATV	39.48£	as high as possible, average = 85.60 £

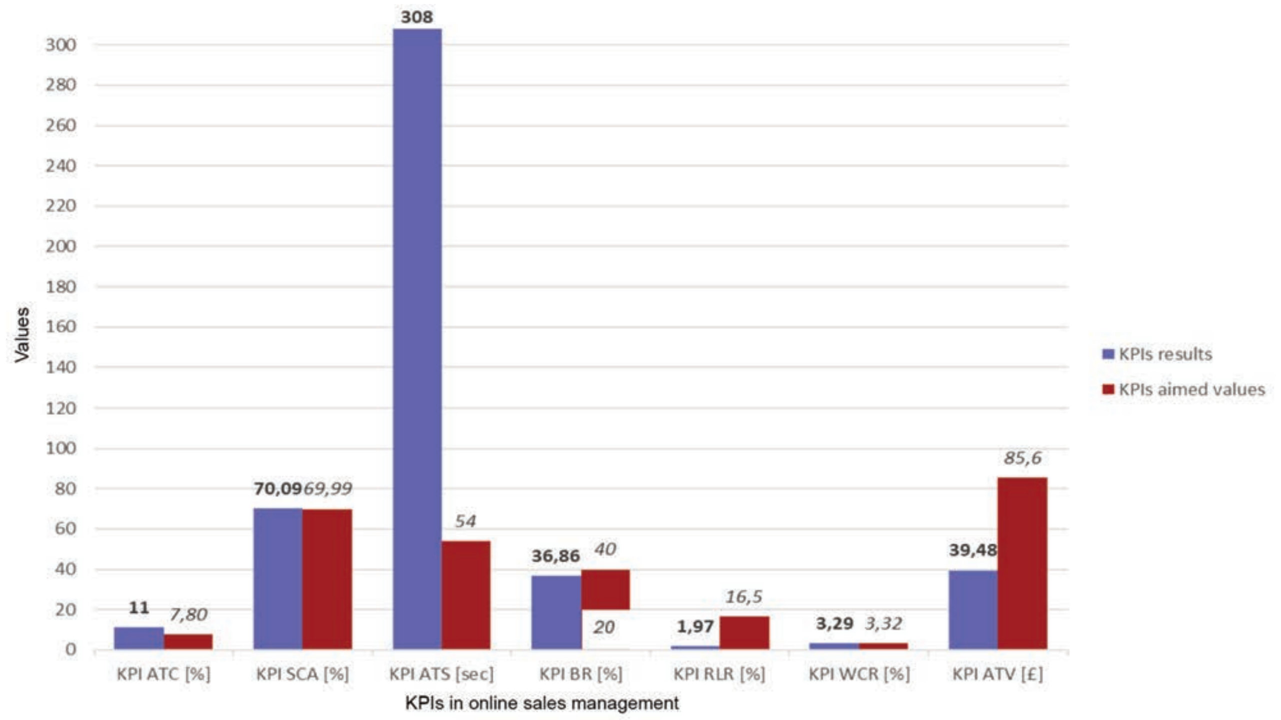

Fig. 1. Results and aimed values of KPIs for measuring online sales performance in ASOS company

presented only after the customer adds an item to the cart, thus all costs need to be displayed transparently; online shopping requires creation of an account or registration – the option for visitors and single-time customers to complete their purchase without creating an account needs to be provided; poor user interface and website performance – customers prefer a platform with easy navigation and optimal page loading speed; lack of trust in platform security – a clear and visible display of security certificates during the purchasing and payment process will improve level of customers' trust in the platform and payment security; inadequate return policy – the ability to easily and conveniently return items purchased in online shopping is essential; inadequate payment options – online shopping and payment have to be fast, easy and convenient, so it is important to offer multiple payment options.

KPI 3. Average Time on Site (ATS): based on the data available from the report, this KPI is calculated for the period from March to May 2023. The calculated value of KPI ATS in ASOS company during that period is 308sec. Considering that the objective for the KPI ATS is to be as high as possible, it can be concluded that the value of this KPI in 2022 is at a satisfactory level (above 54 sec). A high value of KPI ATS indicates that visitors are interested in the brand and the products it sells, while a low value implies that the content is not tailored to the target audience or that the website is not sufficiently user-friendly. However, a long time spent on the website or a high value of KPI ATS does not always necessarily indicate a positive outcome. If the high value of this KPI is caused by users not being able to find the information and products they are interested in or not being able to complete their desired purchase, it indicates that the user experience is not at a high level and the possibility of creating a purchase is lower.

KPI 4. Bounce Rate (BR): the KPI BR utilizes data available for July 2022. The calculated value of KPI BR for the ASOS website for 2022 is 36.86%. The aimed value of KPI BR is to be within the range of 20% to 40%, so the observed value for this KPI for the ASOS company in July 2022 is at a satisfactory level. There are multiple reasons why the value of this KPI can be high, which also present issues to be addressed. The most important are: website speed – prolonged page loading time is one of the common reasons why visitors leave the website after viewing only one page; website design – a good design that is simple, neat and consistent in terms of fonts, colours and layout helps visitors to perceive the brand more seriously, while a poor design generates mistrust among visitors; website optimization for all device types – the website should be responsive and optimized for all types of devices; intrusive advertisements – ads should not be placed in automatic search locations such as a menu, search fields or content areas of the website.

KPI 5. Revenue Loss Rate per Return Products (RLR): The calculated value of KPI RLR for 2022 is 1.97%. The observed value for this KPI for the ASOS company in 2022 is at a satisfactory level since the aimed value of KPI RLR is much lower than the average value (16.5%). Returning products purchased online, as previously stated, is one of the main disadvantages of online sales compared to traditional sales, caused by the inability to try, touch and see the product. Therefore, it is essential to provide a detailed product description, a size chart, as well as information about the height and weight of the model wearing the product in the image to help customers assess the appropriate size more easily. Another reason for returning products is dissatisfaction with the product's quality. Additionally, returns occur when the product does not meet the customers' standards or if there is some type of manufacturing defect.

KPI 6. Website Conversion Rate (WCR): The calculated value of KPI WCR in 2022 is 3.29%. The objective of every company is to achieve a higher value for the KPI WCR. Considering that ASOS operates exclusively in online sales, the observed value of this KPI for the year 2022 is slightly below the average value of 3.32% and is not at a satisfactory level, indicating the need for improvement in sales using websites. The KPI WCR is used as a benchmark value that indicates whether the customer experience is at an acceptable level. Conversion rates by online channels provide insights to make informed decisions on which sales channel requires specific enhancements, thereby stimulating sales growth.

KPI 7. Average Transaction Value (ATV): The calculated value of KPI ATV for the year 2022 is 39.48 £. The observed value is not at a satisfactory level since the aimed value for the KPI ATV is to be as high as possible and the average value is 85.60 £. A low value may suggest that customers are purchasing fewer products or products with lower prices, prompting a need to reassess prices or implement new sales strategies to encourage higher spending. There are various ways to increase the value of this KPI and overall sales revenue. One technique is Up-Selling, which aims to reconsider what the customer has already decided and show them that by spending a little more money, they can observe a higher-quality product. Another technique is Cross-Selling, where customers are recommended products that complete, add value to or upgrade the product they already intend to purchase. In online sales, both techniques can be implemented through recommendation systems and chatbots. A third technique is loyalty programs, which enable the retention and reward of existing customers while attracting new ones and it can be increased by creating an artificial "shortage". Additionally, providing a good shopping experience through a user-friendly and functional online website is essential.

Concisely, based on the previous analysis and discussion of the values of KPIs of the ASOS company for the year 2022, it can be concluded that the values of four KPIs (KPI 1 ATC, KPI 3 ATS, KPI 4 BR, KPI 5 RLR) are at a satisfactory level and that the values of three KPIs (KPI 2 SCA, KPI 6 WCR, KPI 7 ATV) are not at a satisfactory level. Although ASOS company apply some of the mentioned techniques of online sales, as well as the application of modern ICT technologies, according to the observed results for all these KPIs, it can be concluded that some improvements to increase their values should be implemented. Some recommendations for improving the online sales performance management for companies in the textile and fashion industry are:

- Optimizing the website or sales application to be functional, user-friendly, easy to navigate and fast, with a substantial number of product images from different angles.
- Implementing Up-Selling techniques aimed at showing customers that by spending slightly more money, they can acquire higher-quality products.
- Applying Cross-Selling techniques, where customers are presented with products that complement, add value to or enhance the product they already intend to purchase.
- Introducing loyalty programs to reward and incentivize loyal customers for each purchase.
- Enabling virtual search through the application of artificial intelligence, allowing customers to find items they want to purchase based on self-created images or images from the Internet.
- Implementing Chatbots to facilitate virtual communication between companies and customers, assisting them through conversational interactions, answering their queries, aiding in product selection and making personalized recommendations.
- Applying adequate KPIs for continuous monitoring of sales performance.

CONCLUSION

The textile and fashion markets today are characterized by rapid changes in trends and demands, a wide range of products, short product life cycles and demand-driven supply chains that focus on real-time information sharing and quick response to customer demands. To thrive in such a business environment, companies from the textile and fashion industry have to continuously monitor sales KPI values and apply modern sales methods, techniques and approaches based on ICT to enhance their business strategies and overall performance. This paper proposes a set of seven KPIs that can effectively improve sales performance management. In this paper are presented some of the methods, techniques and approaches of online sales and strategies based on the application of contemporary ICT technologies for enhancing online sales, as well as recommendations for the improvement of online sales performance management in companies from the textile and fashion industry. The set of KPIs defined in this paper was applied to sales annual results of ASOS company, one of the leading companies in online sales in the textile and fashion industry, for the year 2022. Based on the results, it can be concluded that four of ASOS online KPIs are at a satisfactory level, but three KPIs can be ameliorated.

There are some limitations of the study presented in this paper. The first limitation is that the set of KPIs for online sales performance analysis is defined based on available data from reports of ASOS company as the most important ones for this study, but some additional indicators could also be defined. The second limitation is that the data for online sales in reports of ASOS company are summed data for all accomplished online sales during the observed period, without classification on seasons, type of brands, type of products and customer profiles, which limits the detailed analysis by the specified types or profiles. The third limitation is that the analysis is limited to the data of one company from the textile and fashion industry. The fourth limitation is the absence of KPIs benchmarking with other similar studies in the textile and fashion industry.

The first direction of future research of the authors of this paper is to apply the defined set of KPIs to other companies from the textile and fashion industry and conduct comparative analyses of their online sales performance. The second direction for future research is the application and comparative analysis of defined KPIs in companies from other industries.

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Authors:

DANICA LEČIĆ-CVETKOVIĆ, JASNA PETKOVIĆ, VLADIMIR BURAZOR,
TEODORA RAJKOVIĆ, JOVANA MIHAJLOV

University of Belgrade, Faculty of Organizational Sciences, Jove Ilića 154, 11010, Belgrade, Serbia
e-mail: danica.lecic-cvetkovic@fon.bg.ac.rs, jasna.petkovic@fon.bg.ac.rs, drvburazor@gmail.com,
mihajlov.jovana98@gmail.com

Corresponding author:

TEODORA RAJKOVIĆ
e-mail: teodora.rajkovic@fon.bg.ac.rs

Effect of alkali treatment on physical and mechanical properties of Cattail and Kenaf fibres

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REZIG SANA
BEN MLIK YOSR
JAOUADI MOUNIR
KHOFFI FOUED
MSAHLI SLAH

ABSTRACT – REZUMAT

Effect of alkali treatment on physical and mechanical properties of Cattail and Kenaf fibres

NaOH treatment is widely used for natural fibre extraction. However, the different treatment conditions produce fibres with other characteristics. The present work aims to study the effect of alkali treatment conditions on Kenaf bast and Cattail stem fibres' properties. Two conditions at two different levels were selected. They are soaking time (2 and 4 hours) and alkali treatment temperature (80 and 120°C). Untreated Kenaf and Cattail fibres were used as control samples. The NaOH process occurred due to the decline in the fineness of Cattail and Kenaf fibres. SEM micrographs of treated fibres showed a clear surface with rectangular pits for Cattail fibres and dissociation of the technical fibre. Best tensile strength obtained for Kenaf fibres for 80°C and under 4 hours. However, a temperature of 120°C and a duration of 4 hours confirmed the best results in terms of lignin removal, proved by IR spectra. Also, X-ray diffractograms suggested that the crystallinity index increases with the highest conditions. The properties of Kenaf bast fibres are found to be superior to Cattail fibres. Characteristic ranges of Cattail and Kenaf fibres after alkaline treatment can be resumed respectively as the diameter of (205–496) and (66–162 μm), the linear density of (31–48) and (14–22 tex), tenacity of (6–8) and (13–17 cN/tex), elongation of (2.6–3.3) and (3–6.2%), lignin ratio of (20.7–23.7) and (15.13–22.6%), alpha-cellulose of (50.2–55.6) and (53–59%), and crystallinity of (43.9–58.6) and (55.4–66.3%). Findings showed that Kenaf bast fibres are found to be great resistant and thinner than Cattail fibres and compared to other fibres.

Keywords: *Cattail fibre, Kenaf fibre, NaOH process, physical properties, mechanical properties*

Efectul tratamentului alcalin asupra proprietăților fizice și mecanice ale fibrelor de papură și chenaf

Tratamentul cu NaOH este utilizat pe scară largă pentru extracția fibrelor naturale. Cu toate acestea, condițiile diferite de tratament produc fibre cu caracteristici diferite. Lucrarea de față își propune să studieze efectul condițiilor de tratare cu alcalii asupra proprietăților fibrelor liberiene de papură și chenaf. Au fost selectate două condiții la două niveluri diferite, și anume timpul de impregnare (la 2 și 4 ore) și temperatura tratamentului alcalin (80°C și 120°C). Fibrele de papură și chenaf netratate au fost utilizate ca probe de control. Procesul NaOH a avut ca rezultat o scădere a fineței fibrelor de papură și chenaf. Micrografiile SEM ale fibrelor tratate au evidențiat o suprafață clară cu caneluri dreptunghiulare pentru fibrele de papură și disocierea fibrei tehnice. Cea mai bună rezistență la tracțiune a fost obținută în cazul fibrelor chenaf la o temperatură de 80°C și o durată de până la 4 ore. Cu toate acestea, o temperatură de 120°C și o durată de 4 ore au confirmat cele mai bune rezultate în ceea ce privește îndepărtarea ligninei, dovedită cu ajutorul spectrelor IR. De asemenea, difractogramele de raze X au sugerat că indicele de cristalinitate crește la cele mai ridicate niveluri de temperatură. Proprietățile fibrelor chenaf sunt superioare fibrelor de papură. Intervalele caracteristice ale fibrelor de papură și chenaf după tratamentul alcalin pot fi reluate, și anume: diametrul de (205–496) și respectiv (66–162 μm), densitatea liniară de (31–48) și (14–22 tex), tenacitatea (6–8) și (13–17 cN/tex), alungirea de (2,6–3,3) și (3–6,2%), raportul de lignină de (20,7–23,7) și (15,13–22,6%), alfa-celuloză de (50,2–55,6) și (53–59%) și cristalinitatea de (43,9–58,6) și (55,4–66,3%). Rezultatele au arătat că fibrele de chenaf sunt foarte rezistente și mai subțiri decât fibrele de papură sau față de alte tipuri de fibre.

Cuvinte-cheie*: fibră de papură, fibră chenaf, proces NaOH, proprietăți fizice, proprietăți mecanice*

INTRODUCTION

Biocomposites reinforced with Natural Fibres (NFs) have increased widely. In addition, such composites can be used for various applications such as automotive, marine, military, and sports equipment, in industrial and home applications [1]. Moreover, NFs have many advantages especially since they are eco-friendly, non-hazardous, and degradable. NFs can be provided by plants, animals, and minerals. Considering NFs from plants, fibre quality depends on the plant growth region (climate, soil, etc), the position of the fibre in the plant, variety, etc [2]. Besides, extraction methods and processing parameters also have an impact on the final properties of NFs [3]. Among the processes reported in the extraction of NFs, the alkali treatment is the most used method, due to its simplicity and cost-effectiveness [4]. Research on the extraction process using NaOH treatment confirms the enhancement of mechanical, physical, and thermal properties of composite materials reinforced with NFs [5]. Alkali treatment contributes to the removal of non-cellulosic compounds like lignin and hemicelluloses [6]. So, it reduces the amorphous region and increases the crystallinity index [7], resulting in the modification of mechanical characteristics, roughness, and thermal stability. In addition, it was proved that the NaOH process is efficient in getting the best quality fibre because of the disturbance of the hydrogen bond in the chemical structure which increases the roughness and eliminates the percentage of binding material like hemicellulose and lignin content [8].

Several efforts have been made to study many properties of the stem fibres [9]. Some fibres have not been enough developed and, at some times, few researchers have explored their various morphological, mechanical, physical, and chemical analyses [10]. Cattail stem fibres are considered one of these categories. Considering the no availability of data on the characterization of the effect of extraction parameters on the Cattail stem fibre quality, this study was undertaken to fill this gap. To explore all stem fibres and investigate their properties, especially for reinforcing bio-composite materials, it is essential to study these unknown characteristics of less-considered fibres like Cattail.

First, this study focuses on analysing the effect of NaOH alkali duration and temperature with a concentration of 20 g/l on Cattail fibres. Second, a comparison was carried out between the characteristics of extracted cattail stem fibre, a recently discovered plant, with another fibre widely discussed in the literature, which is the Kenaf bast fibre. In addition, there is no relative information related to the effect of the duration and temperature of alkali treatment on the properties of the Cattail stem fibres. The properties of fibres were carefully observed and compared with untreated raw fibres. Therefore, physical, chemical, and morphological characteristics will make foundations for future investigations on the valorisation of these fibres for potential sources in reinforcing bio-composites for different applications.

EXPERIMENTAL

Materials

Cattail plants (figure 1, *a*), also called Typha, were collected from the local river in Moknine, Tunisia. Kenaf (figure 1, *b*), also called Hibiscus Cannabinus, was cultivated in an experimental field in a semi-arid region in Tunisia.

Fig. 1. Plants of: *a* – Cattail; *b* – Kenaf

The procedure of fibre extraction

Extraction of the Kenaf and Cattail Stem fibres was conducted at NaOH concentrations of 20 g/l at 80 and 120°C for 2 and 4 hours. After completion of the alkaline treatment, fibres were washed several times in hot water, and pH was neutralized by using dilute acetic acid, rinsed in water, and dried under ambient conditions. For the extraction, 5 g of Cattail or Kenaf was extracted using a Mathis LABOMAT and the liquor ratio was equal to 1/40.

So, five tests were conducted for each fibre, composed of 4 alkali treatment test conditions (1, 2, 3, 4) and a non-treated test (NT) as shown in table 1. The untreated test presented fibres manually extracted without NaOH for both Kenaf (KNT) and Cattail (CNT), used as control samples. Alkali treated tests for Cattail (C1, C2, C3, C4) and Kenaf (K1, K2, K3, K4) were codified as presented in table 1.

Characterization

SEM Analysis

The morphology (longitudinal and cross-section views) of Cattail and Kenaf fibres were examined using a scanning electron microscope (SEM) Hitachi S-2360N.

Physical, chemical and mechanical properties

To determine the diameter of Cattail and Kenaf fibres, an optic microscope (Leica) was used following the French standard NF G 07-004 (1983). Also, the linear density of Cattail and Kenaf fibres was measured using the gravimetric method using the ISO 1973 (1995) standard. Besides, Alpha-cellulose content and lignin fraction were measured using the TAPPI

Table 1

EXTRACTION CONDITIONS AND CODED TESTS FOR CATTAIL AND KENAF FIBRES

Test	Extraction conditions			Code	
	NaOH (g/l)	Temperature (°C)	Duration (h)	Cattail	Kenaf
1	20	80	2	C1	K1
2	20	80	4	C2	K2
3	20	120	2	C3	K3
4	20	120	4	C4	K4
NT	-	-	-	CNT	KNT

standard method T 203 cm-09 and T222 om-11 respectively. Finally, mechanical properties were determined with an LLOYD dynamometer according to the NF G07-002, 50 tests were carried out to determine the maximum strength that fibre can support and the corresponding strength and elongation.

FTIR analysis

The functional groups present in Cattail and Kenaf fibres and their unique chemical bonds were found by Perkin Elmer Spectrum 100 FT-IR, connected to an ATR Mode. The sample was analysed in the wavelength range of 500–4500 cm^{-1} at 25°C.

X-Ray diffraction study

The amorphous and crystalline phase of the Cattail and Kenaf fibres were analyzed using X-ray diffraction X'P ERT Pro model (1967) by PANalytical with cu kα ($\lambda = 1.5406$ °A) as a radiation source with an accelerating voltage of 40 kV. The crystallinity index (CI) was calculated using the following equation:

$$CI\ \% = 100 \times \frac{(AC)}{(AT)} \tag{1}$$

where *AC* presents areas of crystalline peaks and *AT* the total area of amorphous and crystalline peaks.

RESULTS AND DISCUSSION

Morphology of Cattail and Kenaf fibres

The effect of NaOH treatment conditions on Cattail and Kenaf fibres was discussed in figures 2 and 3 through SEM images. Impurities around the raw fibres are highly clear in figure 2 (CNT) and figure 3 (KNT) due to the existence of non-cellulosic compounds. Moreover, it was determined from the longitudinal of CNT and KNT, many rectangular indentations on the surface. This observation was also followed by other studies on lignocellulosic fibres like Typha Australis [11] and Catalpa bignonioides fibres [12]. When the fibre underwent treatment for 2 h at 80°C, defibrillation of both Kenaf and Cattail did not occur but there was a removal of some parts of impurities. With raising the duration (2 h to 4 h), impurities are well eliminated for Cattail fibres, but it was still present in Kenaf fibres. Although some percentage of impurities was seen, defibrillation started to take place, as shown in figure 2 (C2) and figure 3 (K2). However, in the case of Cattail fibres SEM micrographs of longitudinal views in figure 2, show some rectangular pits on the surface of Cattail fibres which can be explained by the removal of fatty substances formed by Tyloses as reported by other researchers working on Borassus fruit fibres [13]. Destruction of these rectangular entities begins when accelerating temperature to 120°C as followed in figure 3 (C3). Moreover, figure 2 (C4) and figure 3 (K4) depict that the defibrillation process can be accelerated with both higher temperature and duration of alkali treatment (120°C and 4 h).

So, the main observation was that the obtained fibres were more and more clean and rougher with increasing NaOH conditions treatment. As it will be confirmed in the ATR-FTIR analysis reported in the next part, alkaline treatment dissolves majorly lignin, and hemicellulose. Therefore, defibrillation occurs when raising temperature and duration of the process and the ultimate fibres appear. This can be more revealed by the presence of some holes and grooves on the fibre surface which confirmed the dissociation of one fibre to smaller ones. Cross-section micrographs in figure 2 (C4) and figure 3 (K4), proved that Kenaf and Cattail fibres are formed by several single fibres called ultimate fibres linked together by non-cellulosic materials.

Physical properties of Cattail and Kenaf fibres

Variations in diameter and linear density were reported in figure 4. Raw materials show the highest diameter, due to the presence of impurities and non-cellulosic materials. Even after alkali treatment, Cattail fibres showed a big fibre diameter compared to raw

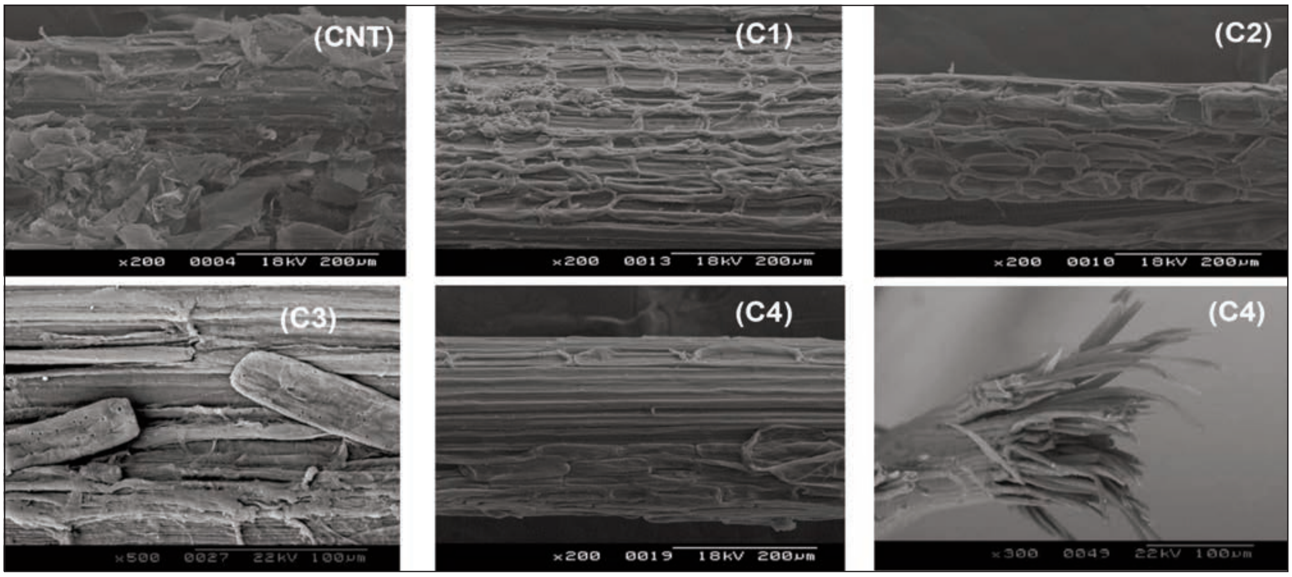


Fig. 2. SEM micrographs of a longitudinal view of Cattail fibres under different treatment conditions (CNT), (C1), (C2), (C3), (C4) and cross-section for (C4)

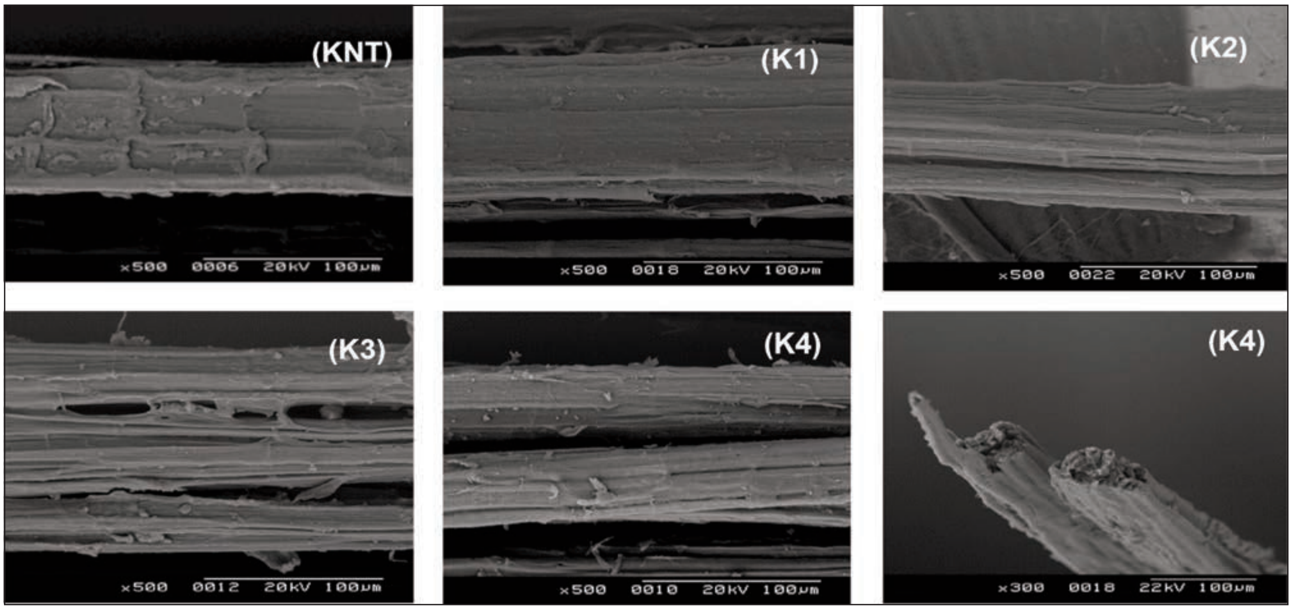


Fig. 3. SEM micrographs of a longitudinal view of Kenaf fibres under different treatment conditions (KNT), (K1), (K2), (K3), (K4), and cross-section for (K4)

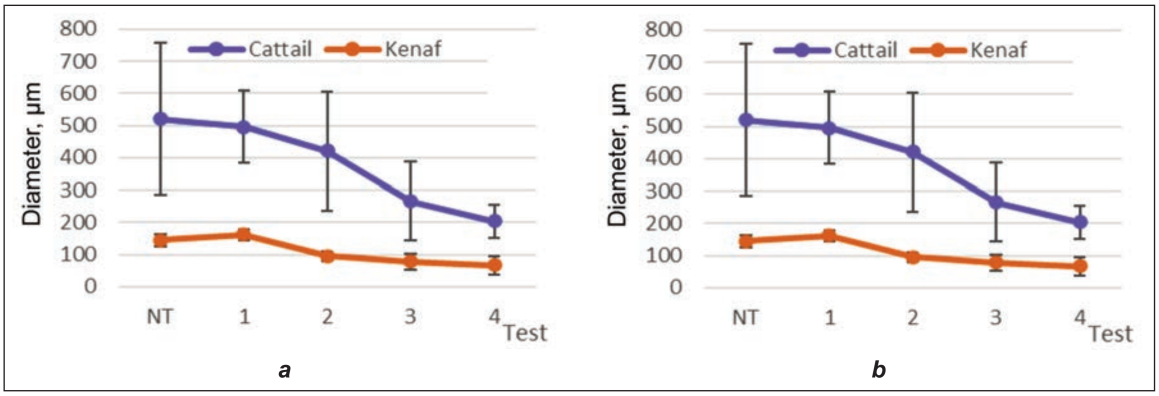
Kenaf fibres. In addition, (KNT) established thinner fibres with 13 tex and 150 µm whereas Cattail NaOH treated fibres showed 31 tex and 205 µm for (C4). Due to sodium hydroxide, the fineness of obtained fibres is enhanced which confirms the removal of foreign compounds from both Cattail and Kenaf surface fibres. In fact, (KNT) and (CNT) have an average diameter of 145 and 520 µm respectively. After alkali treatment, the diameter decreased, and the best results were obtained after 4 hours at 120°C showing a reduction of 54 and 60% for (K4) and (C4) respectively. The decrease in fibre diameter can be explained by the NaOH treatment reaction.

Generally, kenaf and cattail fibres like other lignocellulosic fibres, presented technical fibre bundles, which are formed by the association of ultimate fibres as shown in the SEM cross-section in figure 2 (C4) and figure 3 (K4). After alkali treatment, the partial removal of non-cellulosic materials especially lignin as shown in the figure 6, favours the defibrillation of the technical fibre. This separation resulted in bundles of fibre with reduced diameter [14]. Besides, linear density proved that the extraction process at 80°C for both Kenaf and Cattail showed fibres larger than the one extracted manually after 2 or 4 hours of treatment. As the diameter, the best linear density was reported for (K4) and (C4). This may be clarified by the dissociation of technical fibre to smaller ones by reduction of the fraction of binding materials.

Reduction in fibre diameter was reported due to the removal of non-cellulosic materials from the Kenaf and Cattail out layers. This investigation was reported also for Bamboo fibres [15]. The decrease in fibre diameter increases the length/diameter ratio which can improve the adhesion of Kenaf and Cattail fibres with polymer matrix and certainly would ameliorate the mechanical properties of resulted composite materials [16–19].

Mechanical properties of Cattail and Kenaf fibres

Variations in Tenacity and Elongation were reported in figure 5. Before alkali treatment, tenacity was equal to 5 and 14 cN/tex for CNT and KNT respectively.



a

b

Fig. 4. Properties of Cattail and Kenaf fibres:
a – variation of diameter; *b* – variation of linear density for different conditions

After the chemical process, the best improvement for cattail fibres was considered at 120°C for 4 hours. Sodium hydroxide treatment enhances the mechanical properties of NFs. In addition, due to the removal of microvoids and a decrease in non-cellulosic compounds, the stress transfer between ultimate fibres increases and tenacity improves [20]. However, the best results for Kenaf fibres were obtained at 80°C for 4 hours. When the Temperature increased to 120°C, although tenacity increased and presented the best results as the duration increased as well for Cattail fibres, the tenacity of K3 reduced after 2 hours compared to (K1) and (K2) and continued the reduction after 4 hours to reach 13 cN/tex for (K4). This may be attributed to the excessive treatment conditions which can damage kenaf strength. NaOH begins to integrate into internal molecules of Kenaf fibres when it reaches a higher temperature and soaking time [21]. This difference in mechanical behaviour may also be explained later by the difference in chemical composition between Kenaf and Cattail fibres presented by high lignin levels for Cattail fibres.

Considering the elongation, alkaline treatment, led to decreased elongation rates for Kenaf fibres. This phenomenon is very clear after the first condition of treatment with a reduction of 64% for (K1) compared to (KNT). When alkali duration and temperature increased, elongation rates were between 2.54% and 3.34%. These investigations were in contrast to those of Cattail fibres. The first condition (C1) shows an enhancement of 27% compared to (CNT). When boosting soaking time (4h) for Cattail fibres, elongation rises slightly to reach 6.2%. However, further increments in temperature and duration led to reduced elongation rates to reach 3.01% for (C4) like Kenaf fibres. The same results were reported in the case of Okra bast and corn husk fibres [22]. Removal of non-cellulosic compounds leads to smaller microfibril angles, which promotes easy reorientation of fibrils along the direction of tensile force. As a result, there is a better distribution of the load which enhances the tensile strength of fibres and decreases their elongation, especially for kenaf. Moreover, the elongation percentage was affected by lignin content. Some researchers suggested that an increase in lignin fraction enhances the extension ability of natural fibres, which confirms the elongation decreases. This is supported by other research on cattail fibres showing that the fibres extracted from the leafiran variety of cattail (with 26% of lignin) presented higher elongation than kenaf fibre (with 17% of lignin) [23].

Chemical composition

Chemical constituents of the fibre, especially cellulose fraction affect the mechanical properties of the composite material reinforced with natural fibre. The concept of NaOH treatment was to eliminate non-cellulosic compounds like lignin, hemicellulose, wax, and pectin to obtain the best mechanical properties. Figure 6 depicted that before alkali treatment, the lignin ratio was highest for cattail fibres at about 30% compared to 22% for kenaf fibres. Best results were obtained for 120°C after 4 hours showing a reduction of 32% and 30% for (C4) and (K4) respectively. Alkali treatment confirmed modification of chemical constituents by enhancing alpha-cellulose content by 22 and 27%, the best results for (C4) and (K4) respectively. These results in turn would increase tensile strength in the using of these fibres for composite reinforcement. Removal of the lignin fraction increases the alpha-cellulose fraction.

ATR-FTIR analysis

Figure 7 illustrates the spectra for Cattail and Kenaf fibres with NaOH and without NaOH treatments. Overall, curves show that untreated and treated fibres have differences in terms of band intensity. Considering KNT and CNT fibres, FTIR spectra showed clear bands at 3353 cm^{-1}, 2902 cm^{-1}, 1726 cm^{-1}, 1625 cm^{-1}, 1417 cm^{-1}, 1316 cm^{-1}, 1230 cm^{-1}, 1025 cm^{-1} and 894 cm^{-1}. In addition, the first band at around 3353 cm^{-1} is related to hydroxyl OH stretching of alpha-cellulose. Besides, the second band at 2902 cm^{-1} is associated with C-H stretching jointed to CH_2 and CH attesting to the existence of cellulose, and hemicellulose. The band at 1726 cm^{-1} is attributed to pectin and hemicellulose and the band at 1625 cm^{-1} is connected to the presence of lignin. The next band was observed at 1417 cm^{-1} confirming the CH stretching of lignin. Another peak at

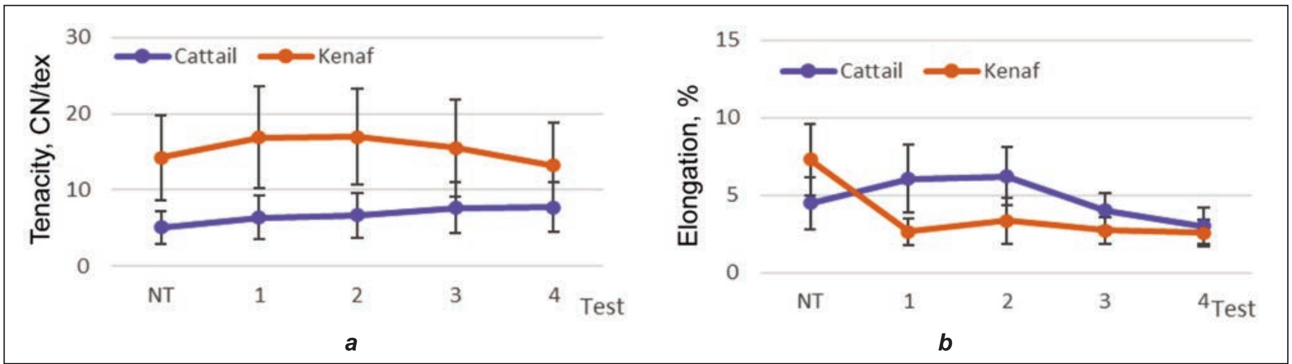


Fig. 5. Properties of Cattail and Kenaf fibres:
a – variation of tenacity; *b* – variation of elongation for different conditions

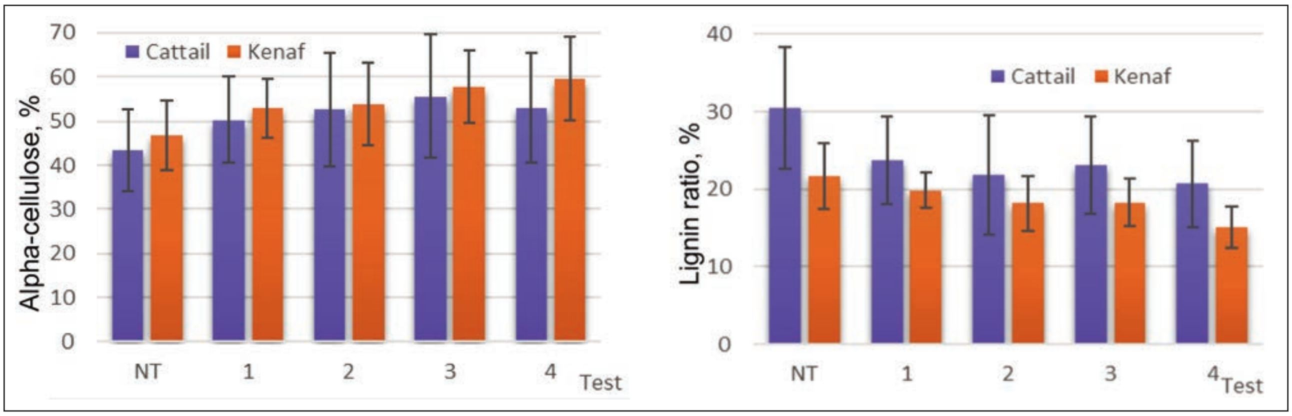


Fig. 6. Variation of Lignin ratio and alpha-cellulose for different conditions of Cattail and Kenaf fibres

1316 cm^{-1} jointed to the hemicellulose fraction was detected. Moreover, the spectra confirm the presence of lignin at 1230 cm^{-1} with vibrations of C=O and O-C-O groups. Another band at around 1025 cm^{-1} indicated cellulose by the asymmetric stretching of O-C-O ester groups. Finally, a band at 894 cm^{-1} was found for both (KNT) and (CNT) indicating cellulose existence by the C-OH group [24]. After the NaOH process, it was clear that chemical constituents and vibrations were affected majorly by the duration of the treatment. In addition, some bands were attenuated or dismissed especially for (K2), (K4), (C2), and (C4). A clear attenuation of the band around 1625 cm^{-1} was observed for (K1), (K2) and (K3). The same band disappeared for (C2), (C4), and (K4). Besides, the bands at 1417 cm^{-1}, 1316 cm^{-1}, and 1230 cm^{-1} were no longer detectable for (C2), (C4), and (K4). This confirms that the removal of some portion of lignin and hemicellulose was more affected by the duration of treatment. This can be assumed that a longer soaking time, will remove binding materials and increase cellulose, especially for cattail fibres.

X-Ray analysis

The X-ray diffractogram of cattail and Kenaf fibres was represented in figure 8, showing four main diffraction peaks for both Cattail and Kenaf at 2Theta angles of approximately 15°, 16°, 22,5° and 35°corresponding to (101) (101-), (002) and (040) lattice planes, respectively [14]. The crystallinity index of untreated and treated fibres was calculated using equation 1 and results are summarized in table 2. Overall, Kenaf fibres have higher crystallinity compared to Cattail fibres which was expected since they have lower lignin content (figure 6). Moreover, after alkaline treatment, crystallinity rises by 14% and 6% for (C1) and (K1) respectively. Besides, with further increase in NaOH conditions, crystallinity augments and becomes equal to 58.6% and 66.34% for (C4) and (K4) respectively like the crystallinity of other fibres, for example, hemp (56%), kenaf (62.9%), and kusha (65.18%) as reported by Ravindra et al. [25]. This may be explained by the removal of some portion of amorphous materials like lignin, which ameliorates the packing of cellulose.

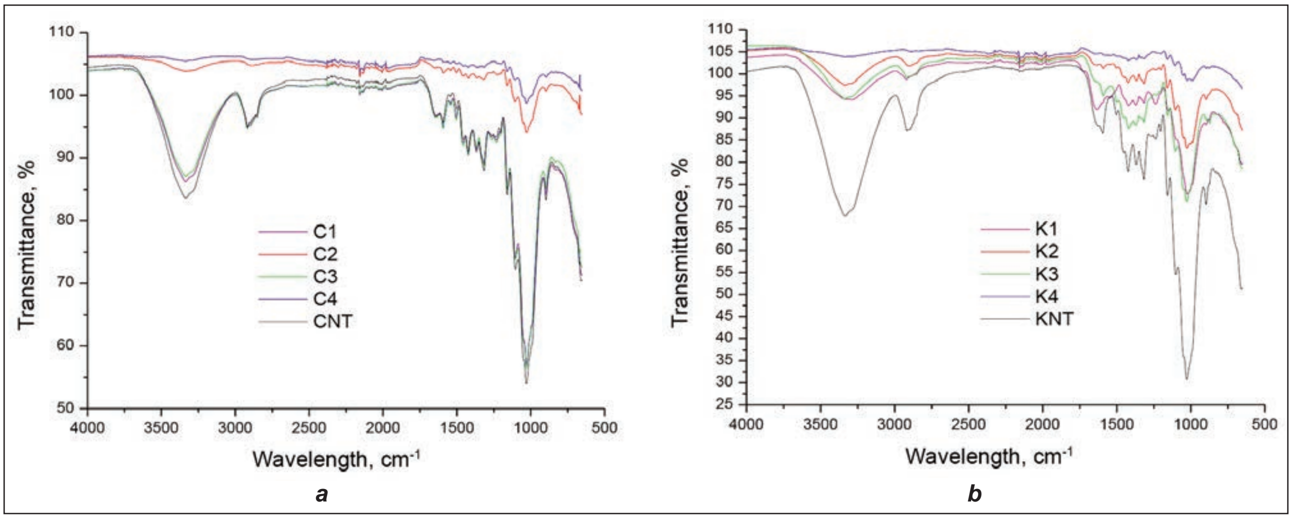


Fig. 7. ATR-FTIR Spectra analysis for: *a* – Cattail fibres; *b* – Kenaf fibres

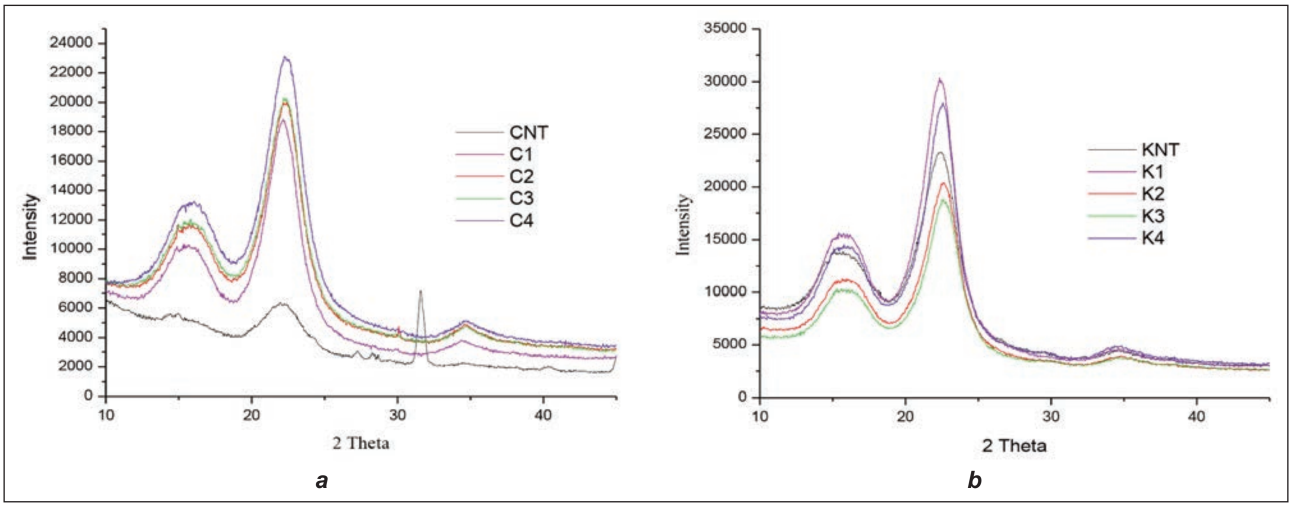


Fig. 8. X-ray diffraction pattern of: *a* – Cattail fibres; *b* – Kenaf fibres for different conditions

Table 2

CRYSTALLINITY INDEX OF CATTAIL AND KENAF FIBRES FOR THE DIFFERENT COMBINATIONS

	CNT	**KNT**	**C1**	**K1**	**C2**	**K2**	**C3**	**K3**	**C4**	**K4**
Crystallinity (%)	38.54	52.42	43.86	55.39	53.25	60.3	56.5	59.4	58.6	66.34
CV (%)	12.4	10.96	15.46	10.48	14.78	12.45	16.45	13.14	17.82	11.45

CONCLUSION

Biodegradable lignocellulosic fibres are currently performed to reinforce composite materials thanks to their low cost, low density, and high performance. Research on novel fibres and the necessity to valorise the existent biomass is very interesting. In this study, Cattail and Kenaf fibres were extracted and characterized. Alkaline treatment led to the removal of amorphous compounds like lignin, pectin, and hemicellulose as reported in FT-IR analysis and chemical composition. The experimental work shows that diameter and linear density decreased after all treatment conditions and thinner properties were observed for Kenaf fibres. Mechanical properties confirmed better results after alkaline treatment and the best results were obtained for (C4) and (K3). X-ray findings confirmed enhancement in the crystallinity index for both Kenaf and Cattail. From SEM micrographs, impurities were removed from the surface of fibres and the obtained fibres show a structure of composite fibre formed by several ultimate fibres. Even though the properties of Cattail fibres are found to be generally inferior to Kenaf fibre, this study suggests the possibility of introducing these fibres in the field of industry. Work is in progress to investigate the relationship between microstructure and mechanical properties. Also, the need to study the thermogravimetric behaviour to identify the thermal stability of the obtained fibres will be more needed to complete this study to make a reliable comparison between Kenaf and Cattail fibres quality. So, more research and work must be done to provide its characteristics to state the appropriate application like reinforcing bio composite, etc.

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Authors:

REZIG SANA, BEN MLIK YOSR, JAOUADI MOUNIR, KHOFFI FOUED, MSAHLI SLAH

University of Monastir, Laboratory of Textile Engineering LGTEX, 5070, Ksar Hellal, Tunisia

Corresponding author:

REZIG SANA
e-mail: rezig.sana@yahoo.fr

Assessing the quality level of the technical fabrics intended for protective equipment for firefighters by determining synthetic indicators

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EMIL CONSTANTIN LOGHIN
IONUȚ DULGHERIU
LILIANA HRISTIAN
LILIANA BUHU
MANUELA AVĂDANEI
SAVIN DORIN IONESI

ABSTRACT – REZUMAT

Assessing the quality level of the technical fabrics intended for protective equipment for firefighters by determining synthetic indicators

The paper aims to highlight the quality level of technical fabrics by determining synthetic indicators based on durability and comfort functions, which can subsequently be used for modelling the physico-mechanical properties and selecting the most suitable fabrics to meet the requirements of a specific field of use. The study was conducted on two groups of technical fabrics with different compositions (Kevlar and Nomex), intended to manufacture firefighter protective equipment (jackets). Quality indicators represent numerical expressions of the quality level of a product or the relative expression of a certain characteristic, obtained by comparing it to a reference value (norm, standard, model). Quality indicators are converted into grades $I \in [0,1]$, where conventionally, a grade of 0 represents an inadequate product/non-quality, and a grade of 1 represents a superior quality level. The synthetic indicators determined in this study express the quality level of a product through the prism of categories/subcategories of quality characteristics representative of evaluating the comfort and durability functions specific to the groups of fabrics intended for the manufacture of protective equipment. Based on the values obtained for the synthetic indicators, a ranking of fabric variants is made according to the importance of durability and comfort characteristics. Thus, optimal fabric variants from each group can be highlighted, and solutions for improving the quality level for other variants can be proposed.

Keywords: *synthetic indicators, durability characteristics, comfort characteristics, Nomex fabrics, Kevlar fabrics*

Aprecierea nivelului calitativ al țesăturilor tehnice destinate echipamentelor de protecție pentru pompieri prin determinarea indicatorilor sintetici

Lucrarea și-a propus să evidențieze nivelul calitativ al țesăturilor tehnice, prin determinarea indicatorilor sintetici, pe baza funcțiilor de durabilitate și confort, care pot fi folosiți ulterior pentru modelarea proprietăților fizico-mecanice și pentru selectarea celor mai adecvate țesături privind satisfacerea cerințelor unui anumit domeniu de întrebuințare. Studiul a fost efectuat pe două grupe de țesături tehnice din compoziții diferite (Kevlar și Nomex), destinate confecționării echipamentelor de protecție pentru pompieri (jachete). Indicatorii calității reprezintă expresiile numerice ale nivelului calității unui produs sau expresia relativă a unei anumite caracteristici, obținută prin raportarea la valoarea de referință (normă, standard, model). Indicatorii calității sunt convertiți în calificative, $I \in [0,1]$, unde convențional, prin calificativul 0 se reprezintă un produs necorespunzător/noncalitate, iar prin calificativul 1 se reprezintă nivelul calitativ superior. Indicatorii sintetici determinați în cadrul acestui studiu exprimă nivelul calității unui produs prin prisma unor categorii/subcategorii de caracteristici de calitate reprezentative pentru evaluarea funcțiilor de confort și durabilitate specifice grupelor de țesături destinate confecționării echipamentelor de protecție. Pe baza valorilor obținute pentru indicatorii sintetici se realizează o ierarhizare a variantelor de țesături în funcție de gradul de importanță al caracteristicilor de durabilitate și confort. Astfel, pot fi evidențiate variantele optime de țesături din fiecare grupă și pot fi propuse soluții de îmbunătățire a nivelului calității pentru celelalte variante.

Cuvinte-cheie: *indicatori sintetici, caracteristici de durabilitate și confort, Nomex, Kevlar*

INTRODUCTION

In general, when creating firefighter protective equipment (jackets), fabrics that meet the highest levels of protection and comfort are sought, despite their high costs. Most companies use fabrics made from aramid fibres, which dominate the sector, as they offer high levels of mechanical tensile strength and durability while being completely flame-resistant. For these reasons, a range of technical fabrics necessary for the manufacture of firefighter protective equipment has been developed using blends of the latest meta-aramids and para-aramids with comparable effectiveness and protection at reasonable prices [1–3]. Depending on the application, the choice between Kevlar and Nomex is one of the requirements for comfort and protection, which can be used in the seven layers that make up firefighter protective equipment. Kevlar is much more resistant to abrasion than Nomex and is therefore used in a higher concentration percentage in firefighter protective equipment [4–6]. Nomex is a softer-feeling fibre and is used to a greater extent in everyday clothing articles due to the greater comfort it offers the wearer [7–9]. Simple weave structures such as plain or twill, as well as some of their derivatives like rip-stop and twill, are most commonly used for the outer fabric of firefighter protective equipment due to their exceptional tear resistance and increased tensile strength [10–12]. Nomex provides heat and flame resistance to the protective equipment, while Kevlar offers flexibility, comfort, and breathability [13–15]. Kevlar has been extensively utilized in the production of advanced composites in aerospace, military, marine, and sports sectors due to its mechanical properties, thermal stability, and high energy absorption properties [16–18]. Nomex®, manufactured by DuPont, is made of aramid fibres and is lightweight with high tensile strength and heat resistance (degrading at 480°C) [19–20]. Its high breathability and low water vapour resistance make it suitable for use as an outer layer. Fabrics face complex demands in fire situations [21–26]. The fabric's performance in these situations is related to comfort, time, warmth, durability, and other specific appearance features [27–30]. The performance of firefighter protective clothing is primarily based on the thermophysical properties of the materials used in their construction [31–36].

EXPERIMENTAL PART

Materials and methods

The experimental matrix included twelve samples from two groups of technical fabrics with different compositions, intended for the manufacture of firefighter protective equipment, whose characteristics are presented in table 1.

Group A of fabrics contains six articles, coded K1, K2, K3, K4, K5, and K6, made from yarns composed of Kevlar fibres, balanced in fineness with $Nm_{warp} = Nm_{weft}$ and density $P_{warp} = P_{weft}$, with plain and twill weave structures.

Group B of fabrics contains six articles, coded N1, N2, N3, N4, N5, and N6, made from yarns composed of Nomex fibres, balanced in fineness with $Nm_{warp} = Nm_{weft}$ and density $P_{warp} = P_{weft}$, with plain and twill weave structures.

The fibrous composition, properties of the component fibres, structural parameters of the fabrics, mechanical and physical properties of the yarns, as well as finishing treatments, influence the quality characteristics regarding the durability and physiological comfort of firefighter protective equipment. To highlight the influence of the weave structure on certain surface characteristics of the fabrics in the studies conducted within this work, the weave structure was expressed by the warp floating for the warp yarns F_{warp} and the weft floating for the weft yarns F_{weft}. The intersection between a warp yarn and a weft yarn is called a binding point, so the weave structure contains the set of all binding points with a warp or weft effect in the longitudinal or transverse direction. The floating size, like the binding segment, has a minimum value of $F = 1$, which is specific to the plain weave structure.

Due to its unique properties such as high strength-to-weight ratio and greater modulus, Kevlar fibre has become very popular as reinforcement in composite materials, and its application has increased considerably. Kevlar® is an example of a para-aramid fibre, while Nomex® is considered a meta-aramid. The key difference between meta and para-aramid is that

Table 1

CHARACTERISTICS OF TWELVE SAMPLES OF TECHNICAL FABRICS WITH DIFFERENT COMPOSITIONS

Group/ Composition	**Article code**	**Yarn count $Nm_{warp} = Nm_{weft}$**	**Technological density, (yarns/10 cm) $P_{warp} = P_{weft}$**	**Mean flotation F**	**Type of bonding**
Group A/Kevlar	K1	68/2	265	2	Twill $D\frac{2}{2}/$
	K2	54/2	260	2	Twill $D\frac{2}{2}/$
	K3	48/2	290	1.5	Twill $D\frac{2}{1}/$
	K4	60/2	280	1.5	Twill $D\frac{2}{1}/$
	K5	68/2	285	1	Plain
	K6	60/2	275	1	Plain
Group B/Nomex	N1	64/2	270	2	Twill $D\frac{2}{2}/$
	N2	60/2	260	2	Twill $D\frac{2}{2}/$
	N3	48/2	370	1.5	Twill $D\frac{2}{1}/$
	N4	56/2	360	1.5	Twill $D\frac{2}{1}/$
	N5	56/2	355	1	Plain
	N6	68/2	350	1	Plain

meta-aramid has a semi-crystalline molecular structure, while para-aramid is crystalline. Fabrics woven from Nomex® fibres are used in applications requiring good textile properties, good dimensional stability, and excellent heat resistance. Fabrics woven of Nomex® fibre have good resistance to many chemicals and are highly resistant to most hydrocarbons and many other organic solvents.

The database used in this study was obtained by quantifying the physical-mechanical properties of the two groups of fabrics using standardized methods and evaluated through a series of indices determined directly on the measuring apparatus or by calculation. In determining the synthetic indicators of the two groups of technical fabrics intended for the manufacture of firefighter protective equipment, a series of representative characteristics reflecting durability were selected: tensile strength, Pr (daN); fabric tenacity, τ (cN/tex); puncture resistance, T (N); work of mechanical deformation at rupture, W_s (N·m); and flexural stiffness, R (mg·cm). In determining the synthetic indicators reflecting physiological comfort, the following representative characteristics were selected: air permeability index, I (kg/m^2·h); relative elongation at break, ε (%); thermal conductivity coefficient, λ (kcal/m·h·°C); vapour permeability coefficient, μ (g/m^2·h) and fabric mass, M (g/m^2).

The representative characteristics used in calculating the synthetic indicators of durability and comfort were selected using the correlation method. Tensile properties tests of the fabrics were conducted on the Honsfield electronic dynamometer, according to SR EN ISO 2062. Analysis of fabric behaviour during wearing indicates that they are subjected to simple or repeated uniaxial or biaxial stretching stresses. The level of these stresses can be close to the breaking limit or may have low, insignificant values, so the designer must anticipate the behaviour under such stresses. This can be appreciated by determining indices derived from the stress-strain diagram. The behaviour under the bending stress of fabrics is structurally determined by the transfer of fibre-yarn-fabric properties, influenced by mechanical and chemical processing processes, and is expressed by the bending length and flexural stiffness. In this study, we used the values obtained for the flexural stiffness of the two groups of fabrics, determined according to the ASTM D1388-18 standard.

Protective equipment for firefighters must be designed to ensure conditions of comfort (being permeable to air and vapours, impermeable to water and toxic substances), of operation (comfortable, resistant, easy to wear), but also to contribute to the prevention of accidents and occupational illnesses.

The mass of the fabrics was determined according to the SR EN 12127:2013 standard, which allows for comparative evaluation, essential for the intended use of the fabric.

Air permeability was determined in accordance with the EN ISO 9237:1995 standard, which for fabrics intended for clothing must ensure comfort conditions during wearer activity.

Experimental values for determining the thermal conductivity coefficient, vapour permeability coefficient, and air permeability index for the two groups of fabrics were obtained through standardized methods, depending on treatment parameters (temperature, pressure, and speed) and material characteristics.

The quality level of the two groups of technical fabrics intended for the manufacture of protective equipment is assessed by determining synthetic quality indicators based on comfort and durability functions.

Quality indicators are numerical expressions of the quality level of a product. A quality indicator must meet a series of conditions:

- it should be simple, so that the calculation method, expression, and meaning are easy to understand;
- it should be relevant to ensure the most accurate description of the actual quality level;
- it should be verifiable so that it can be recalculated anytime based on the method used.

The quality index is a relative expression of a specific characteristic, obtained by comparing it to a reference value (norm, standard, model).

The index can be converted into a rating $I \in [0,1]$, where conventionally, a rating of 0 represents an inadequate product/non-quality, and a rating of 1 represents a superior quality level.

To determine the indices, it is necessary to apply methods for evaluating quality characteristics. Specific methods for the textile industry include:

- measurement with known precision using standardized means;
- expertise conducted through sensory analysis by specialists in the field;
- sociological evaluation based on survey questionnaires addressed to potential users.

In the study, quality characteristics representative of evaluating the comfort and durability functions specific to the groups of fabrics intended for the manufacture of protective equipment were measured. The expertise method was applied to assess the importance of the characteristics expressing the functions of the analysed products. Quality indicators can be simple, synthetic, or global based on the level of complexity. The emphasis of the study was on evaluating the quality level of the analyzed textile surfaces through synthetic and global indicators. The synthetic indicator expresses the quality level of a product through the prism of categories/subcategories of quality characteristics.

The algorithm for calculating the synthetic indicator is as follows:

1. Select representative characteristics.
2. Obtain the sample consisting of representative samples (n).
3. Measure the characteristics using standardized methods.
4. Determine the preferred direction of increase/decrease for each characteristic, depending on the product's purpose.

5. Report the obtained values for each characteristic on a unique scale within the interval [0;1].
6. By reporting, the degree of utility U_i is obtained depending on the preferred direction of increase/decrease of the quality characteristic values, as follows:
   - for the preferred direction of increase in characteristic values (positive characteristic), U_i is calculated using the following relationship:

$$U_i = \frac{x_i - x_{min}}{x_{max} - x_{min}} \quad (1)$$

   - for the preferred direction of decrease in characteristic values (negative characteristic), U_i is calculated using the following relationship:

$$U_i = \frac{x_{max} - x_i}{x_{max} - x_{min}} \quad (2)$$

   - the hierarchy of quality characteristics based on the coefficient of significance (degree of importance) is calculated using the following relationship:

$$\gamma_i = \left(100/\sum_{j=1}^{m} R_{ij}\right) / \left(\sum_{i=1}^{n}\left(100/\sum_{j=1}^{m} R_{ij}\right)\right) \quad (3)$$

where R_{ij} = 1 represents the rank assigned to the characteristic considered the most important (with maximum score); R_{ij} = n represents the rank assigned to the characteristic considered the least important (with minimum score); n is the number of characteristics i = 1, ..., n; m is the number of experts j = 1, ..., m.

To establish the significance coefficient, the expertise method was applied. The ranks corresponding to the quality characteristics were evaluated by a team of six specialists in the textile field. Based on the evaluations, the experts fill out survey sheets assigning different ranks to the quality characteristics. The consistency of opinions among experts is verified using the following relationship:

$$W = \sum_{i=1}^{n}\left(\sum_{j=1}^{m} R_{ij} - R_{ij}\right)^2 / \left[m^2 \cdot (n^3 - n)/6\right] \quad (4)$$

where:

$$R_{ij} = \left(\sum_{i=1}^{n}\sum_{j=1}^{m} R_{ij}\right) / 6 \quad (5)$$

The verification of agreement among experts is conducted based on the χ^2 test, where the test statistic is calculated using the following relationship:

$$\chi^2 = W \cdot m(n-1) \quad (6)$$

If $\chi^2_{calc} > \chi^2_{\nu-1,\alpha=0.05}$, it follows that the opinions of the experts are in agreement (W is significant).

For $W \geq 0.8$, the significance coefficient γ_i is determined using the following relationship:

$$\gamma_i = \left(100/\sum_{j=1}^{m} R_{ij}\right) / \left(\sum_{i=1}^{n} 100/\sum_{j=1}^{m} R_{ij}\right) \quad (7)$$

The hierarchy of characteristics is determined based on the criterion of decreasing values of γ_i.The representative values must satisfy the condition $\gamma_i > 1/n$ [37–40]. Calculation of the synthetic indicator using the relationship:

$$Is = \sum_{i=1}^{n} U_i \cdot \gamma_i \quad (8)$$

Synthetic indicators express the quality level of a product through the prism of categories/subcategories of quality characteristics considered to be representative of a product.

RESULTS AND DISCUSSIONS

According to the steps in the workflow algorithm, the following are calculated:

- Synthetic durability indicators $Is_{1-gr.A}$ and $Is_{1-gr.B}$ for Group A and Group B of fabrics, respectively.
- Comfort indicators $Is_{2-gr.A}$ and $Is_{2-gr.B}$ for Group A and Group B of fabrics intended for the manufacture of firefighter protective equipment.

The calculation of the synthetic durability indicator for the fabrics in Group A (Kevlar)

Selection of representative characteristics:

- tensile strength, *Pr* (daN);
- fabric tenacity, τ (cN/tex);
- puncture resistance, *T* (N);
- work of deformation at rupture, W_s (N·m);
- flexural rigidity, *R* (mg·cm).

The average values of durability characteristics for the fabrics in Group A (Kevlar) are presented in table 2.

Table 2

AVERAGE VALUES OF DURABILITY CHARACTERISTICS FOR THE FABRICS IN GROUP A (KEVLAR)

Group/ Composition	Article code	Tensile strength *Pr* (daN)	Fabric tenacity τ (cN/tex)	Puncture resistance *T* (N)	Mechanical work W_s (N·m)	Flexural rigidity *R* (mg·cm)
Group A/ Kevlar	K1	79.03	16.70	1539.72	6.247	52.92
	K2	77.76	16.15	1487.52	6.065	50.86
	K3	72.47	12.00	1224.64	3.287	58.85
	K4	71.59	15.34	1342.78	3.849	54.66
	K5	87.05	20.77	1380.58	6.393	62.44
	K6	85.24	18.60	1420.51	5.919	58.85
Min		**71.59**	**12.00**	**1224.64**	**3.287**	**50.86**
Max		**87.05**	**20.77**	**1539.72**	**6.393**	**62.44**

The preferred direction of variation for durability characteristics has been adopted as follows:

- positive characteristics: *Pr* (daN), τ (cN/tex), *T* (N) and W_s (N·m);
- negative characteristics: *R* (mg·cm).

The values obtained for each characteristic are reported on a single scale in the interval [0;1] as shown in table 3; the degree of utility U_i based on the preferred direction of increase/decrease of the quality characteristic values was determined as follows:

- For the preferred direction of increasing the values of the characteristic (positive characteristic), U_i is calculated using the relationship:

$$U_i = \frac{x_i - x_{min}}{x_{max} - x_{min}} \tag{9}$$

- For the preferred direction of decreasing the values of the characteristic (negative characteristic), U_i is calculated using the relationship:

$$U_i = \frac{x_{max} - x_i}{x_{max} - x_{min}} \tag{10}$$

The values of the synthetic durability indicator for the fabrics in Group A (Kevlar) are presented in table 3. To calculate the indicator $Is_{1-gr.A}$, the values of the importance degree of durability characteristics presented in table 4 were required. The importance degree of durability characteristics was evaluated using the expert method (table 5).

The consistency of expert opinions was checked using the relationship:

$$W = \sum_{i=1}^{n}\left(\sum_{j=1}^{m} R_{ij} - R_{ij}\right)^2 / \left[m^2 \cdot (n^3 - n)/6\right] = \tag{11}$$

$$= \frac{25960}{36 \cdot \frac{(125-5)}{6}} = 36$$

From a statistical point of view, the agreement of expert opinions is verified using the test, where the χ^2 test statistic is calculated using the relationship:

$$\chi^2 = W \cdot m(n-1) \tag{12}$$

If $\chi^2_{calc} > \chi^2_{\nu-1,\alpha=0.05}$, it follows that the expert opinions are in agreement (*W* is significant). So, from a statistical perspective, $\chi^2_{calc} = 720 > \chi^2_{tab}$, the expert opinions are in agreement (*W* is significant). The ranking of characteristics is based on the criterion of decreasing values of γ_{ij}, as presented in table 5.

The calculation of the synthetic durability indicator for the fabrics in Group B (Nomex)

The average values of durability characteristics for fabrics in Group B (Nomex) are presented in table 6. To calculate the indicator $Is_{1-gr.B}$, the values of the importance degree of durability characteristics presented in table 7 were required. The importance degree of durability characteristics was evaluated using the expert method (table 5).

The ranking of durability characteristics for fabrics in Group B was conducted similarly to fabrics in Group A, according to table 5. This method of calculation allows for drawing direct conclusions based on the quality indicators: the closer the indicator value is to 1, the higher the quality it represents. The synthetic indicator $Is_{1-gr.A}$ includes all the characteristics that are reflected in the durability of the analysed fabrics, as observed from the experimental data for fabrics in Group A (Kevlar). Article K5, characterized by $Nm_{warp} = Nm_{weft} = 68/2$, $P_{warp} = P_{weft} = 285$ yarns/10 cm plain weave, with floating $F = 1$, has the highest value of the synthetic indicator $Is_{1-gr.A} = 0.889$. This is justified by the fact that the utility of positive characteristics for tensile strength, fabric tenacity, and mechanical work of rupture deformation has the maximum value, indicating a higher quality level, except for puncture resistance, which is 0.5. Also, the utility of the negative characteristic for bending stiffness has the maximum value, indicating a higher quality level.

Table 3

VALUES OF THE SYNTHETIC DURABILITY INDICATOR FOR THE FABRICS IN GROUP A (KEVLAR)

Group/ Composition	**Article code**	**Positive**	**Positive**	**Positive**	**Negative**	**Negative**	$Is_{1-gr.A}$
		***Pr* (daN)**	**τ (cN/tex)**	***T* (N)**	**W_s (N·m)**	***R* (mg·cm)**	
Group A/ Kevlar	K1	0.481	0.317	1.000	0.863	0.178	0.553
	K2	0.399	0.357	0.834	0.567	0.000	0.428
	K3	0.057	0.000	0.000	0.106	0.690	0.170
	K4	0.000	0.040	0.375	0.000	0.328	0.160
	K5	1.000	1.000	0.495	1.000	1.000	**0.889**
	K6	0.883	0.994	0.622	0.992	0.690	**0.828**

Table 4

VALUES OF THE IMPORTANCE DEGREE OF DURABILITY CHARACTERISTICS OF GROUP A (KEVLAR)

Degree of importance	***Pr* (daN)**	**τ (cN/tex)**	***T* (N)**	**W_s (N·m)**	***R* (mg·cm)**
γ_i	0.19	0.23	0.22	0.15	0.21

Table 5

RANKING OF CHARACTERISTICS OF GROUP A (KEVLAR)

Characteristics / Experts	*Pr* (daN)	τ (cN/tex)	*T* (N)	W_s (N·m)	*R* (mg·cm)	$\sum_{i=1}^{n} R_{ij}$
E1	5	3	4	2	1	15
E2	4	2	1	5	3	15
E3	1	4	2	3	5	15
E4	2	3	4	5	1	15
E5	1	3	2	4	5	15
E6	2	1	4	5	3	15
$\sum_{j=1}^{m} R_{ij}$	19	15	16	23	17	90
$100/\sum_{j=1}^{m} R_{ij}$	5.26	6.67	6.25	4.35	5.88	28
γ_{ij}	0.19	0.23	0.22	0.15	0.21	1.0
Rank	4	1	2	5	3	15.0
$\sum_{j=1}^{m} R_{ij} - R_{ij,n}$	5041	5625	5476	4489	5329	$\sum_{i=1}^{n}\left(\sum_{j=1}^{m} R_{ij} - R_{ij}\right)^2$

Table 6

AVERAGE VALUES OF DURABILITY CHARACTERISTICS FOR FABRICS IN GROUP B (NOMEX)

Group/ Composition	**Article code**	***Pr* (daN)**	**τ (cN/tex)**	***T* (N)**	**W_s (N·m)**	***R* (mg·cm)**
Group B/ Nomex	N1	35.05	5.13	674.17	4.068	52.92
	N2	34.89	5.18	642.21	4.039	50.86
	N3	33.27	4.38	538.33	4.051	58.85
	N4	32.86	4.32	524.16	4.04	52.66
	N5	37.24	9.01	706.67	3.339	62.75
	N6	36.58	8.83	716.85	3.348	58.64
Min		**32.86**	**4.32**	**524.16**	**3.34**	**50.86**
Max		**37.24**	**9.01**	**716.85**	**4.07**	**62.75**

Table 7

VALUES OF THE IMPORTANCE DEGREE OF DURABILITY CHARACTERISTICS OF GROUP B (NOMEX)

Group/ Composition	**Article code**	**Positive**	**Positive**	**Positive**	**Positive**	**Negative**	$Is_{1-gr.B}$
		***Pr* (daN)**	**τ (cN/tex)**	***T* (N)**	**W_s (N·m)**	***R* (mg·cm)**	
Group B/ Nomex	N1	0.500	0.173	0.779	0.960	0.827	0.623
	N2	0.463	0.183	0.613	1.000	1.000	0.624
	N3	0.094	0.013	0.074	0.977	0.328	0.254
	N4	0.000	0.000	0.000	0.962	0.849	0.323
	N5	1.000	1.000	0.947	0.000	0.000	0.628
	N6	0.849	0.962	1.000	0.012	0.346	**0.676**

At Article K4 in Group A, characterized by $Nm_{warp} = Nm_{weft} = 60/20$, $P_{warp} = P_{weft} = 280$ yarns/10 cm, diagonal $D\frac{2}{1}/$, with floating $F = 1.5$, the lowest value of the synthetic indicator $Is_{1-gr.A} = 0.160$ was obtained. This is justified by the fact that the utility of positive characteristics for tensile strength and mechanical work of rupture deformation has the minimum value. Additionally, fabric tenacity and puncture resistance have values lower than 0.4, closer to the lower limit, indicating a lower quality level. Moreover, the utility of the negative characteristic for bending stiffness has a value lower than 0.4, indicating a lower quality level.

At Article N6 in Group B (Nomex), characterized by $Nm_{warp} = Nm_{weft} = 68/2$, $P_{warp} = P_{weft} = 350$ yarns/10 cm, plain weave, with floating $F = 1$, the highest value of the synthetic indicator $Is_{1-gr.B}$ = 0.676 was obtained. This is justified by the fact that the utility of positive characteristics for tensile strength, fabric tenacity, and puncture resistance, except for the mechanical work of rupture deformation, is close to the maximum value, indicating a higher quality level. However, the utility of the negative characteristic for bending stiffness has a value lower than 0.4, close to the lower limit, indicating a lower quality level.

At Article N3 in Group B, characterized by Nm_{warp} = Nm_{weft} = 48/2, P_{warp} = P_{weft} = 370 yarns/10 cm, diagonal $D\frac{2}{1}/$, with floating F = 1.5, the lowest value of the synthetic indicator $Is_{1-gr.A}$ = 0.254 was obtained. This is justified by the fact that the utility of positive characteristics for tensile strength, fabric tenacity, and puncture resistance is at the minimum value, indicating a lower quality level, except for the mechanical work of rupture deformation. However, the utility of the negative characteristic for bending stiffness is close to the upper limit, indicating a higher quality level.

Among the analysed characteristics, the team of experts considered that fabric tenacity best reflects the durability of the fabrics, assigning it the highest weight for assessing the quality level of fabric assortments needed for the production of firefighting equipment.

Calculating the synthetic physiological comfort indicator for fabrics in Group A (Kevlar)

According to the steps within the algorithm, synthetic comfort indicators $Is_{2-gr.A}$ and $Is_{2-gr.B}$ are calculated for each group of fabrics.

Selection of representative characteristics:

- Air permeability index, I (kg/m^2·h)
- Relative elongation at break, ε (%)
- Thermal conductivity coefficient, λ (kcal/m·h·°C)
- Vapor permeability coefficient, μ (g/m^2·h)
- Fabric mass, M (g/m^2)

The average values of comfort characteristics for fabrics in Group A (Kevlar) are presented in table 8. The preferred direction of variation for physiological comfort characteristics has been adopted as follows:

- positive characteristics: I (kg/m^2·h) and ε (%);
- negative characteristics: λ (kcal/m·h·°C), μ (g/m^2·h) and M (g/m^2).

The values obtained for each characteristic are reported on a single scale in the interval [0;1] in table 9. The degree of utility U_i depending on the preferred direction of increase/decrease of the quality characteristic values was determined as follows:

- for the preferred direction of increasing the values of the characteristic (positive characteristic), U_i is calculated using the relationship:

$$U_i = \frac{x_i - x_{min}}{x_{max} - x_{min}} \quad (13)$$

Table 8

AVERAGE VALUES OF COMFORT CHARACTERISTICS FOR FABRICS IN GROUP A (KEVLAR)

Group/ Composition	**Article code**	**Air permeability index I (kg/m^2·h)**	**Relative elongation at break ε (%)**	**Thermal conductivity coefficient λ (kcal/m·h·°C)**	**Vapour permeability coefficient μ (g/m^2·h)**	**Fabric mass M (g/m^2)**
Group A/ Kevlar	K1	35.4	7.3	0.044	4.28	147
	K2	24.2	6.8	0.047	4.22	160
	K3	34.5	7.6	0.052	4.35	156
	K4	32.8	7.8	0.048	4.42	180
	K5	33.6	5.4	0.053	4.75	162
	K6	34.2	5.6	0.050	4.68	174
Min		**24.2**	**5.4**	**0.044**	**4.22**	**147**
Max		**35.4**	**7.8**	**0.053**	**4.75**	**180**

Table 9

VALUES OF THE SYNTHETIC COMFORT INDICATOR FOR THE FABRICS IN GROUP A (KEVLAR)

Group/ Composition	**Article code**	**Positive**	**Positive**	**Negative**	**Negative**	**Negative**	$Is_{2-gr.A}$
		I (kg/m^2·h)	**ε (%)**	**λ (kcal/m·h·°C)**	**μ (g/m^2·h)**	**M (g/m^2)**	
Group A/ Kevlar	K1	1.000	0.792	1.000	0.887	1.000	**0.939**
	K2	0.000	0.583	0.667	1.000	0.606	0.561
	K3	0.920	0.917	0.111	0.755	0.727	0.694
	K4	0.768	1.000	0.556	0.623	0.000	0.586
	K5	0.839	0.000	0.000	0.000	0.545	**0.296**
	K6	0.893	0.083	0.333	0.132	0.182	0.341

- for the preferred direction of decreasing the values of the characteristic (negative characteristic), U_i is calculated using the relationship:

$$U_i = \frac{x_{max} - x_i}{x_{max} - x_{min}} \qquad (14)$$

The values of the synthetic comfort indicator $Is_{2-gr.A}$ for fabrics in Group A (Kevlar) are presented in table 9. For the calculation of the indicator $Is_{2-gr.A}$, the values of the importance degree of comfort characteristics presented in table 10 were required. The importance degree of durability characteristics was evaluated using the expert method (table 11).

The consistency of expert opinions was checked using the relationship:

$$W = \sum_{i=1}^{n} \left(\sum_{j=1}^{m} R_{ij} - R_{ij} \right)^2 / \left[m^2 \cdot (n^3 - n)/6 \right] = \qquad (15)$$

$$= \frac{25960}{36 \cdot \frac{(125-5)}{6}} = 36$$

From a statistical point of view, the agreement of expert opinions is verified using the test, where the χ^2 test statistic is calculated using the relationship:

$$\chi^2 = W \cdot m(n-1) \qquad (16)$$

So, from a statistical perspective, $\chi^2_{calc} > \chi^2_{\nu-1,\alpha=0.05}$, the expert opinions are in agreement (W is significant). The ranking of characteristics is based on the criterion of decreasing values of γ_{ij}, as presented in table 11.

Calculating the synthetic physiological comfort indicator for fabrics in Group B (Nomex)

The average values of physiological comfort characteristics for fabrics in Group B (Nomex) are presented in table 12. The values of the synthetic comfort indicator $Is_{2-gr.B}$ for fabrics in Group B (Nomex) are presented in table 13. For the calculation of the indicator $Is_{2-gr.A}$, the values of the importance degree of comfort characteristics presented in table 10 were required. The importance degree of durability characteristics was evaluated using the expert method (table 11).

The ranking of comfort characteristics for fabrics in Group B was conducted similarly to fabrics in Group A, according to table 4. From the analysis of the values obtained for the synthetic comfort indicators $Is_{2-gr.A}$ and $Is_{2-gr.B}$, the following aspects can be deduced:

- The synthetic indicator $Is_{2-gr.A}$ includes all the characteristics that are reflected in the comfort of the analysed fabrics, as observed from the experimental data for fabrics in Group A (Kevlar). Article K1, characterized by $Nm_{warp} = Nm_{weft} = 56/2$, $P_{warp} = P_{weft} = 365$ yarns/10 cm, diagonal $D\frac{2}{2}/$, with floating $F = 2$, has the highest value of the synthetic indicator $Is_{1-gr.A} = 0.939$. This is justified by the fact that the utility of positive characteristics for the air permeability index has the maximum value, and the relative elongation at break is close to the upper limit, indicating a higher quality level.

Table 10

VALUES OF THE IMPORTANCE DEGREE OF COMFORT CHARACTERISTICS OF GROUP A (KEVLAR)

Degree of importance	**I (kg/m^2·h)**	**ε (%)**	**λ (kcal/m·h·°C)**	**μ (g/m^2·h)**	**M (g/m^2)**
γ_i	0.22	0.18	0.19	0.21	0.20

Table 11

RANKING OF CHARACTERISTICS OF GROUP A (KEVLAR)

Characteristics / **Experts**	**I (kg/m^2·h)**	**ε (%)**	**λ (kcal/m·h·°C)**	**μ (g/m^2·h)**	**M (g/m^2)**	$\sum_{j=1}^{m} R_{ij}$
E1	1	2	3	4	5	15
E2	3	4	1	5	2	15
E3	4	5	3	1	2	15
E4	1	4	5	2	3	15
E5	2	3	4	1	5	15
E6	5	2	3	4	1	15
$\sum_{i=1}^{n} R_{ij}$	16	20	19	17	18	90
$100/\sum_{j=1}^{m} R_{ij}$	6.25	5.00	5.26	5.88	5.56	28
γ_{ij}	0.22	0.18	0.19	0.21	0.20	1
Rank	1	5	4	2	3	15
$\sum_{j=1}^{m} R_{ij} - R_{ij,n}$	5476	4900	5041	5329	5184	$\sum_{i=1}^{n} \left(\sum_{j=1}^{m} R_{ij} - R_{ij} \right)^2$

Table 12

AVERAGE VALUES OF PHYSIOLOGICAL COMFORT CHARACTERISTICS FOR FABRICS IN GROUP B (NOMEX)

Group/ Composition	**Article code**	**Air permeability index I (kg/m^2·h)**	**Relative elongation at break ε (%)**	**Thermal conductivity coefficient λ (kcal/m·h·°C)**	**Vapour permeability coefficient μ (g/m^2·h)**	**Fabric mass M (g/m^2)**
Group B/ Nomex	N1	26.30	21.90	0.056	5.45	217
	N2	30.60	22.70	0.054	5.32	214
	N3	28.80	25.30	0.059	5.73	220
	N4	27.40	26.80	0.057	5.66	230
	N5	29.10	17.60	0.063	6.17	292
	N6	32.20	16.30	0.060	5.81	288
Min		**26.30**	**16.30**	**0.054**	**5.32**	**214**
Max		**32.20**	**26.80**	**0.063**	**6.17**	**292**

Table 13

VALUES OF THE SYNTHETIC COMFORT INDICATOR FOR FABRICS IN GROUP B (NOMEX)

Group/ Composition	**Article code**	**Positive**	**Positive**	**Negative**	**Negative**	**Negative**	**$Is_{2-gr.B}$**
		I (kg/m^2·h)	**ε (%)**	**λ (kcal/m·h·°C)**	**μ (g/m^2·h)**	**M (g/m^2)**	
Group B/ Nomex	N1	0.000	0.533	0.778	0.847	0.962	0.611
	N2	0.729	0.610	1.000	1.000	1.000	**0.870**
	N3	0.424	0.857	0.444	0.518	0.923	0.624
	N4	0.186	1.000	0.667	0.600	0.795	0.630
	N5	0.475	0.124	0.000	0.000	0.000	**0.128**
	N6	1.000	0.000	0.333	0.424	0.051	0.386

Additionally, the utility of the negative characteristics, such as the thermal conductivity coefficient and fabric mass, has maximum values. Moreover, the vapour permeability coefficient has a value greater than 0.8, close to the upper limit, indicating a higher quality level.

- At Article K5 in Group A, characterized by Nm_{warp} = Nm_{weft} = 68/2 and P_{warp} = P_{weft} = 285 yarns/10 cm, plain weave, with floating F = 1, the lowest value of the synthetic indicator $Is_{2-gr.A}$ = 0.296 was obtained. This is justified by the fact that the utility of positive characteristics for relative elongation at break is at the minimum value, indicating a lower quality level. Additionally, the utility of negative characteristics, such as the thermal conductivity coefficient and vapour permeability coefficient, has minimum values. Moreover, the fabric mass has an average value, indicating a lower quality level.
- At Article N2 in Group B (Nomex), characterized by Nm_{warp} = Nm_{weft} = 60/2, P_{warp} = P_{weft} = 260 yarns/10 cm, diagonal $D\frac{2}{2}/$, with floating F = 2, the highest value of the synthetic indicator $Is_{2-gr.B}$ = 0.870 was obtained. This is justified by the fact that the utility of positive characteristics, such as the air permeability index and relative elongation at break, is close to the upper limit, indicating a higher quality level. Additionally, the utility of negative characteristics, such as the thermal conductivity coefficient, vapour permeability coefficient, and fabric mass, has maximum values, indicating a higher quality level.
- At Article N5 in Group B, characterized by Nm_{warp}= Nm_{weft} = 56/2, P_{warp} = P_{weft} = 355 yarns/10 cm, plain weave, with floating F = 1, the lowest value of the synthetic indicator $Is_{1-gr.A}$ = 0.128 was obtained. This is justified by the fact that the utility of positive characteristics, such as the air permeability index and relative elongation at break, is close to the lower limit, indicating a lower quality level. Additionally, the utility of negative characteristics, such as the thermal conductivity coefficient, vapour permeability coefficient, and fabric mass, has minimum values, indicating a lower quality level.
- Among the analysed characteristics, the team of experts considered that the air permeability index best reflects the comfort of the fabrics, assigning it the highest weight for assessing the quality level of fabric assortments needed for the production of firefighting equipment.

CONCLUSIONS

In conclusion, it is noted that the highest values for the synthetic durability indicators of fabrics, both in Group A (Kevlar) and Group B (Nomex), were obtained for fabrics with a plain weave structure,

$Is_{1-gr.A}$ = 0.889, Art. K5 and $Is_{1-gr.B}$ = 0.676, Art. N6, while the lowest values were obtained for fabrics with a diagonal $D\frac{2}{1}/$ structure, $Is_{1-gr.A}$ = 0.160, Art. K4 and $Is_{1-gr.B}$ = 0.254, Art. N3.

The highest values for the synthetic comfort indicators of fabrics, both in Group A (Kevlar) and Group B (Nomex), were obtained for fabrics with a Diagonal $D\frac{2}{1}/$ structure, $Is_{2-gr.A}$ = 0.939, Art. K1 and $Is_{2-gr.B}$ = 0.870, Art. N2 respectively, while the lowest values were obtained for fabrics with a plain weave structure, $Is_{2-gr.A}$ = 0.296, Art. K5 and $Is_{2-gr.B}$ = 0.128, Art. N5.

Fabrics with a Plain weave structure provide better stability of the yarns in the woven structure, regardless of the fibre composition. However, it should be noted that the raw materials used in the production of firefighting equipment must have special characteristics, which Kevlar and Nomex fibres fulfil, thus ensuring the performance of activities involving risk factors of thermal, chemical, biological, mechanical, physical, or electrical nature and have direct influences on the health and life of the individual performing a certain activity.

The values of the synthetic indicators determined based on durability and comfort functions can be used subsequently for modelling the physical-mechanical properties and for selecting the most suitable fabrics to meet the requirements of a particular field of use.

Articles in each group where the value of both the synthetic durability indicator and the synthetic comfort indicator is close to the maximum, indicating a superior quality level, can be considered reference elements. Therefore, articles, where the value of both the synthetic durability indicator and the synthetic comfort indicator is minimal, can have their quality improved by modifying structural parameters (such as fineness, technological density, and weave type), with the high-quality article from each group serving as a reference. This approach allows for finding optimal operating conditions in a short time and with reduced material costs compared to laboratory research.

The choice of raw material for making firefighter suits is a meticulous and rigorous process, considering that this equipment must provide maximum protection under extreme conditions.

By calculating the synthetic durability indicators for the fabrics from Group A (Kevlar), manufacturers can select plain weave fabrics, such as: Art. K5 ($Is_{1-gr.A}$ = 0.889) and Art. K6 ($Is_{1-gr.A}$ = 0.828), to be used in the outer layer of the protective jacket for firefighters, because through their structural characteristics (fineness, technological density, type of weave) and the values of durability assessment properties, they offer good resistance to cuts and abrasions, as well as thermal protection.

Diagonal $D\frac{2}{2}/$ weave fabrics, namely Art. K1 ($Is_{1-gr.A}$ = 0.553) and Art. K2 ($Is_{1-gr.A}$ = 0.428), can be used for the collar and cuff areas. These areas can be reinforced with Kevlar fabric to prevent fire penetration and provide additional protection against heat.

Additionally, $D\frac{2}{1}/$ weave fabrics, namely Art K3 ($Is_{1-gr.A}$ = 0.170) and Art. K4 ($Is_{1-gr.A}$ = 0.160), can be used for the shoulder and elbow areas as an additional layer of protection to provide better protection against impact and heat.

Based on the obtained values of the synthetic comfort indicators for the fabrics from Group A (Kevlar), manufacturers can select Diagonal $D\frac{2}{1}/$, weave fabrics, such as: Art K1 ($Is_{2-gr.A}$ = 0.939) and Art. K2 ($Is_{2-gr.A}$ = 0.561), to be used in the elbow and knee areas in the case of pants, as an additional layer of protection.

Diagonal $D\frac{2}{1}/$ weave fabrics, namely Art. K3 ($Is_{1-gr.A}$ = 0.694) and Art. K4 ($Is_{1-gr.A}$ = 0.586), can be used for the pocket area. This area can be reinforced with Kevlar fabric to prevent the penetration of fire and water, providing additional protection against heat and for the radio/phone.

Plain weave fabrics, namely Art. K5 ($Is_{1-gr.A}$ = 0.296) and Art. K6 ($Is_{1-gr.A}$ = 0.341), can be used for the shoulder and collar areas as an insulation layer to keep heat away and protect against extreme temperatures.

By calculating the synthetic durability indicators for the fabrics from Group B (Nomex), manufacturers can select plain weave fabrics, such as: Art. N6 ($Is_{1-gr.B}$ = 0.676) and Art. N5 ($Is_{1-gr.B}$ = 0.628), to be used in the outer layer of the jacket, providing a barrier against flames and intense heat.

Diagonal $D\frac{2}{2}/$ wave fabrics, namely Art. N1 ($Is_{1-gr.B}$ = 0.623) and Art. N2 ($Is_{1-gr.B}$ = 0.624), can be used for the protective hood, which covers the head, neck, and sometimes shoulders, often made of Nomex to protect these sensitive areas from exposure to fire and heat.

Diagonal $D\frac{2}{1}/$ wave fabrics, namely Art. N3 ($Is_{1-gr.B}$ = 0.254) and Art. N4 ($Is_{1-gr.B}$ = 0.323), can be used for the collar and cuff areas. These areas can be reinforced with Nomex fabric to prevent fire penetration and provide additional protection against heat.

Based on the obtained values of the synthetic comfort indicators for the fabrics from Group B (Nomex), manufacturers can select Diagonal $D\frac{2}{2}/$ weave fabrics, such as Art. N2 ($Is_{2-gr.B}$ = 0.870) and Art. N1 ($Is_{2-gr.B}$ = 0.611), to be used in the making of base clothing, worn under the main suit, which can be made from Nomex to provide additional protection at the skin level.

Diagonal $D\frac{2}{1}/$ weave fabrics, namely Art. N3 ($Is_{1-gr.B}$ = 0.624) and Art. N4 ($Is_{1-gr.B}$ = 0.630), can be used for making full suits to provide complete protection.

Plain weave fabrics, namely Art. N5 ($Is_{1-gr.B}$ = 0.128) and Art. N6 ($Is_{1-gr.B}$ = 0.386), can be used in the inner layers including lining to ensure additional protection and enhance the comfort of the firefighter.

Based on the obtained values of durability and comfort synthetic indicators, manufacturers ensure that the selected materials used in various areas of firefighter protective equipment meet the highest safety and performance standards, thereby protecting the lives of those on the front lines of firefighting efforts.

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Authors:

EMIL CONSTANTIN LOGHIN, IONUȚ DULGHERIU, LILIANA HRISTIAN, LILIANA BUHU,
MANUELA AVĂDANEI, SAVIN DORIN IONESI

"Gheorghe Asachi" Technical University of Iasi, Faculty of Industrial Design and Business Management,
29 D. Mangeron, 70050, Iasi, Romania

Corresponding author:

SAVIN DORIN IONESI
e-mail: savin-dorin.ionesi@academic.tuiasi.ro

The durable hydrophobic and antibacterial polyester textile coating with ZnO/Zn(OH)$_2$/starch/stearic acid composite

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PHIPHOP NARAKAEW
SIWAT THUNGPRASERT
SAMROENG NARAKAEW
WIPANOOT BAISON
THEERAPORN PROMANAN
PAKORN SANTAKIJ
SUKEE SUKDEE
CHAINET CHANOGKUN
KANJANA RUTTANATEERAWICHIEN
APHIRUK CHAISENA
PIYAPORN KRACHODNOK

ABSTRACT – REZUMAT

The durable hydrophobic and antibacterial polyester textile coating with ZnO/Zn(OH)$_2$/starch/stearic acid composite

Herein, we prepare the antibacterial and hydrophobic polyester weaved textile using ammonium hydroxide (NH_4OH) hydrolysis and dip-coating method which can be fabricated zinc oxide (ZnO)/zinc hydroxide $Zn(OH)_2$)/starch/stearic acid (STA) composite on the textile surface. Phase identification, surface morphology, and chemistry of the composite were revealed by Raman spectroscopy and SEM/EDX techniques. The durable hydrophobic and antibacterial properties were investigated by water contact angle measuring, and against gram-negative Escherichia coli and gram-positive Staphylococcus aureus bacterium as per the colony count method according to the AATCC 100 antibacterial test method. Raman spectrum result shows the modified polyester textile sample surface, not only ZnO crystallized in the hexagonal wurtzite structure but also $Zn(OH)_2$, starch, and STA composite is included. SEM images confirmed a smooth surface of the treated fibre before washing due to using STA as a second coating agent. Despite the composite being peeled out from the surface fibre after 5 washing cycles, the finished polyester woven textile is good durable water-repellent. Moreover, good durable antibacterial activity against Staphylococcus aureus strains after 20 washing cycles. The colour differences and the whiteness index of the treated polyester textile after 20 repeated washing were not significantly changed.

Keywords: *ZnO/Zn(OH)$_2$/starch/STA composite, antibacterial activity, hydrophobic effects, coating, polyester textile*

Învelișul textil durabil hidrofob și antibacterian din poliester cu compozit ZnO/Zn(OH)$_2$/amidon/acid stearic

În acest studiu, a fost realizată o țesătură antibacteriană și hidrofobă din poliester folosind hidroliză și metoda de acoperire prin imersie cu hidroxid de amoniu (NH_4OH), care poate fi fabricat cu compozit oxid de zinc (ZnO)/hidroxid de zinc $Zn(OH)_2$)/amidon/acid stearic (STA) pe suprafața textilă. Identificarea fazelor, morfologia suprafeței și chimia compozitului au fost identificate prin spectroscopie Raman și tehnici SEM/EDX. Proprietățile hidrofobe și antibacteriene durabile au fost investigate prin măsurarea unghiului de contact cu apa și împotriva bacteriei Escherichia coli gram-negative și Staphylococcus aureus gram-pozitive, conform metodei de numărare a coloniilor în conformitate cu metoda de testare antibacteriană AATCC 100. Rezultatul spectrului Raman arată suprafața eșantionului textil din poliester modificat, nu numai ZnO cristalizat în structura hexagonală de wurtzit, ci și $Zn(OH)_2$, amidonul și compozitul STA. Imaginile SEM au confirmat o suprafață netedă a fibrei tratate înainte de spălare datorită utilizării STA ca al doilea agent de acoperire. În ciuda faptului că acest compozit a fost desprins de pe suprafața fibrei după 5 cicluri de spălare, s-a observat că țesătura din poliester finisată are o rezistență bună la apă. În plus, s-a observat și o activitate antibacteriană bună și durabilă împotriva tulpinilor de Staphylococcus aureus după 20 de cicluri de spălare. Diferențele de culoare și indicele de alb al țesăturii din poliester tratată după 20 de cicluri de spălare repetată nu au fost modificate semnificativ.

Cuvinte-cheie: *compozit ZnO/Zn(OH)$_2$/amidon/STA, activitate antibacteriană, efecte hidrofobe, acoperire, țesătură din poliester*

INTRODUCTION

Smart textiles are materials for our daily life and healthcare with more proper self-cleaning, hydrophobic, antibacterial, UV protection, and other properties that are essential requirements [1]. Currently, synthetic polyethylene terephthalate (PET) or polyester fibres have been the most popular textiles owing to their superior performances. There is known to have water-repellent properties, however, textiles manufactured thereof have a complex capillary-porous structure and do not possess waterproof properties. Therefore, it should be subjected to alteration waterproof treatment [2], included it is an unfavourable microorganism [3] for smart textiles. The smart textile modified with ZnO nanomaterial has been focused, for example, the achieving of fabricated UV protection and self-cleaning properties on polyester textiles, wherewith excellent antimicrobial agents of ZnO nanoparticles, promoted reactive oxygen species (ROS) on the surface of these oxides as reported in previous paper [4].

The hexagonal wurtzite phase of ZnO, a general theoretical photocatalyst active under UV light with a maximum wavelength at 376 nm corresponding to band gap energy (E_g) at around 3.37 eV, even in the dark which can generate ROS, i.e., especially H_2O_2 and $^{\cdot}OH$, to destroy *Escherichia coli* or *Staphylococcus aureus* strains as found in previously reports [5–6]. Other advantages are low-cost, non-toxic, and chemical uniform. The process for ZnO preparation is normally initiated by the obtained $Zn(OH)_2$, zinc ion in an alkaline aqueous solution or utilizing the hydroxide ion (OH^-) source, followed by their transformation into ZnO with air annealing [2, 7–10].

The modified textile process can be done by using colloidal nanoparticles of ZnO or solution of zinc ion batch, deposited electrochemistry, dip-pad, and dip-coating, and in situ on textile with precipitation, hydro/solvothermal, ultrasonic, mechanical-chemistry, microwave, and sol-gel techniques. We had prepared successfully the coated $Zn(OH)_2$/ZnO polyester woven textile with pre-alkaline-treatment of hot ammonium hydroxide (NH_4OH) act as scourer and ester hydrolysed agents, hydroxide ion ($OH^–$) source for promoting ZnO deposited surface, controlled ZnO morphology, and environmental friendly [10] than compare to commonly used highly alkaline sodium hydroxide (NaOH) as reported in [11]. In addition, the coated polyester woven textile showed a hydrophobic water contact angle of 138º and 136º before and after 5 washing cycles [10]. Moreover, Ma and coworkers (2016) [12] reported there are a lot of hydroxyl functional groups on the biopolymer structure of starch that can be enhanced and absorbed in a large quantity and also reduce agglomeration of ZnO nanoparticles on textile fibered surfaces, and researchers used STA agent resulting of waterproof character on the textile fibre due to it can reduce the surface energy [13–14].

In this work, the functionalized antibacterial and hydrophobic characteristics of polyester woven textile by using ZnO/$Zn(OH)_2$/starch/STA composite were prepared and compared with the pristine textile. The coated textile was identified phase, surface morphology, and surface chemistry by using Raman spectroscopy and SEM-EDX techniques.

The durable waterproof textile was investigated by water contact angle measuring. The air permeability according to the ASTM D 737:2004. In the study of antibacterial activity, gram-negative *Escherichia coli* and gram-positive *Staphylococcus aureus* bacteria were evaluated using the colony count method (AATCC Test Method 100:2012 standard). To evaluate the appearance and surface colour of the treated polyester textile was tested before and after treatments including 5-10-20 repeated washing according to the ISO 105-J01:1989 standard, and whiteness index (WI) according to the ASTM E313: 2020 standard.

MATERIALS AND METHOD

The 17 warps and 17 wefts in centimetre white plain weave polyester textile was purchased from Sonibrazar shop, Lampang, Thailand. Ammonium hydroxide (NH_4OH) was ordered from Qrec, New Zealand. STA (*n*-octadecanoic acid) and 95%ethanol (95%EtOH) were purchased from World Chemical Group Co., Ltd., and PTT Home-Proservice Ltd., respectively. Starch (glutinous rice) was derived from a Thai commercial shop. Zinc chloride ($ZnCl_2$) was ordered from J.T. Baker. Non-phosphate standard reference detergent (SDCE ECE type A) nonionic soap was ordered from Union TSL Ltd, and distilled water was used.

The fabrication of ZnO/$Zn(OH)_2$/starch/STA composite on polyester textile

The fabricated composite on the polyester textile sample was a modified method from our previous work [10]. Firstly, the white plain weave polyester textiles size of 10×10 cm were washed and cleaned with detergent and distilled water, and continually immersed in 20 $gl^{–1}$ NH_4OH aqueous solution at 90°C for 30 min. Subsequently, dipped for 1 min in the mixed aqueous solution of 6 $gl^{–1}$ $ZnCl_2$, 2 $gl^{–1}$ starch, and 0.05 M NH_4OH, followed by immersing in 50 $gl^{–1}$ STA EtOH solution for 24 hours, and last, dried at 100°C for 1 hour (sample code: PZOS (figure 1, *b*). The controlled textile (sample code: P0 (figure 1, *a*), does not have any chemical solution added, and those processes use a liquor ratio used in textile of 50:1.

The durability of ZnO/$Zn(OH)_2$/Starch/STA composite on polyester textile

The washing test method (ISO 105 C01:2006) was performed to evaluate the washing with soap effect only on the ZnO/$Zn(OH)_2$/starch/STA composite coating fastness of the textile. The pristine and treated polyester textile samples were washed with a liquor ratio used in textile of 50:1 at 40±2°C for 30 min, using 5 $gl^{–1}$ nonionic soap washing liquor. Then, removed the textile sample from the washed cylinder, taken subsequently to half the amount of distilled water, at ambient temperature, of 4 l container, followed softly stirring for 1 min, then rinsed with distilled water for 1 min, squeezed out the excess water by hand after, and continuously pressed the sample onto filter paper, and air dried at ambient temperature. The evaluation of durable composite on the sample fibre surface was done in 5, 10, and 20 washing cycles (Sample codes: PZOS-5WC, PZOS-10WC, and PZOS-20WC (figure 1, *c, d, e*).

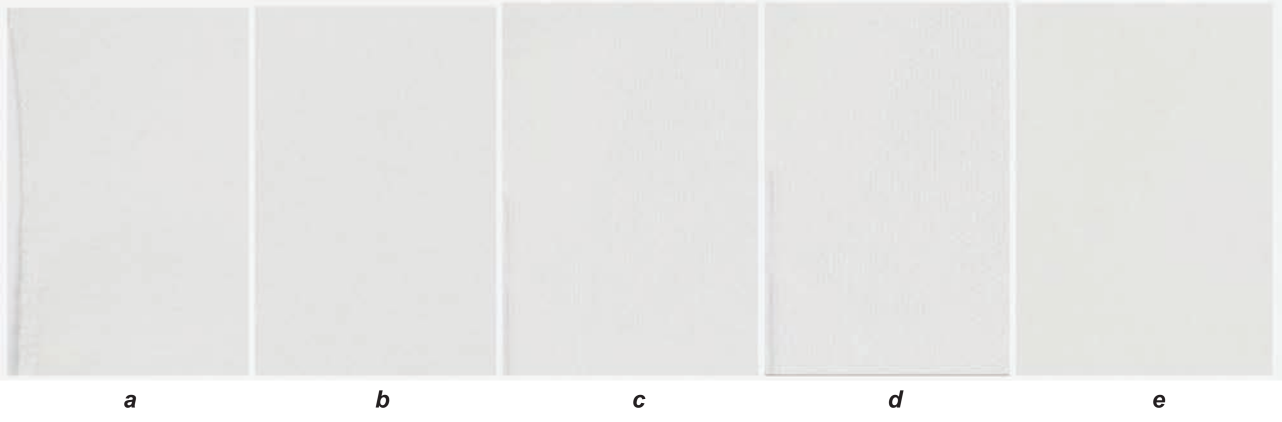


Fig. 1. Textile samples of: *a* – P0; *b* – PZOS; *c* – PZOS-5WC; *d* – PZOS-10WC; *e* – PZOS-20WC

Characterization methods

Raman spectroscopy

The phase identification of untreated (P0) and the treated polyester textile (PZOS) were investigated by a confocal Raman spectrometer (Jobin Yvon horiba LabRAM HR) using 532 nm excitation.

Scanning electron microscopy (SEM)

The surface morphology of the untreated (P0) and the treated polyester textile (PZOS) including 5-10-20 repeated washing were performed on a field emission scanning electron microscope (FE–SEM, JSM 6335 F) integrated with the incorporation of an energy-dispersive X-ray spectrometer (EDX) (Oxford Instruments). The electron microscope operating at 15.0 kV as accelerating voltage, was used to scan the surface morphology and potential elemental analysis on the fibered surface.

The hydrophobic property measurement

The hydrophobic surface of the pristine (P0), the treated polyester textile (PZOS), and 5–20 repeated washing were performed by optical contact angle measuring of water and contour analysis (Dataphysics, OCA40), operating the volume of distilled water dropping of 10 μl for 3 seconds at the humidity of 63% and temperature of 23°C.

The air permeability and antibacterial activity tests

The PZOS and 20-repeated washing were tested in the air permeability according to the ASTM D 737: 2004, using an M021A air permeability tester under the pressure difference between the textile surface of 125 Pa. For the antibacterial activity, the test organisms used a gram-positive organism, *Staphylococcus aureus* (ATCC 6538), and a gram-negative organism, *Escherichia coli* DMST 4212 (ATCC 25922), as per AATCC 100 antibacterial test standard [15]. A colony count method using AATCC Test Method 100:2012 standard (AATCC 100, 2012) evaluated quantitatively antibacterial activity of the textiles coated with $ZnO/Zn(OH)_2$/starch/STA composite (PZOS) before and after 20 washing cycles. The test specimens were prepared by the client and sterilized before testing by using the autoclave at 121°C and 15 psi for 15 min. 4.8±0.1 cm treated sterilized and control samples were inoculated with a suspension of microorganisms. After inoculation, a 100 mL volume of neutralizing solution was added to the bottles containing both the test and control swatches. The bottles were shaken forcefully for 1 min and serial dilutions were made with water subsequent by the standard plate count method in repetitive using nutrient agar. The plates were continually incubated for 24 hours at 37°C and the bacterial colonies were counted using a colony plate counting method. The assessment of antimicrobial activity was evaluated the comparing the percent reduction of bacteria between control and treated samples Percent reduction of bacteria (R) by specimen treatments was calculated using the following equation 1 formula:

$$\%\text{Reduction (R)} = 100(C - A)/C \tag{1}$$

where A and C are the number of bacteria (CFU/sample) recovered from inoculated treated test specimen swatches in the jar after 24 hours and 0 hour contact time, respectively.

Colour fastness and whiteness measurements

To evaluate the appearance and surface colour of the treated polyester textile were tested before and after treatments including 5-10-20 repeated washing, in terms of colourimetric values (CIE Lab) and colour differences (ΔE) according to the ISO 105-J01:1989 standard, and whiteness index (WI) according to the ASTM E313:2020 standard. Measurement conditions were performed for a field of view 10° standard observer under a D65 standard light source for conducted to quantify the ability of the human eye to perceive colours. Before the measurement, the samples were put on the white standard plate ($L^* = 93.38$, $a^* = 2.70$, and $b^* = -4.00$), and the degree of lightness (L^*), redness (a^*) or greenness (a^*), and yellowness (b^*) or blueness (b^*) of the treated polyester textile were measured. The following equations (2) and (3) were used to calculate the overall colour difference (ΔE) and WI.

$$\Delta E = \sqrt{(L^*_{sample} - L^*_{standard})^2 + (a^*_{sample} - a^*_{standard})^2 + (b^*_{sample} - b^*_{standard})^2} \tag{2}$$

$$WI = 100 - \sqrt{(100 - L^*)^2 + (a^*)^2 + (b^*)^2} \quad (3)$$

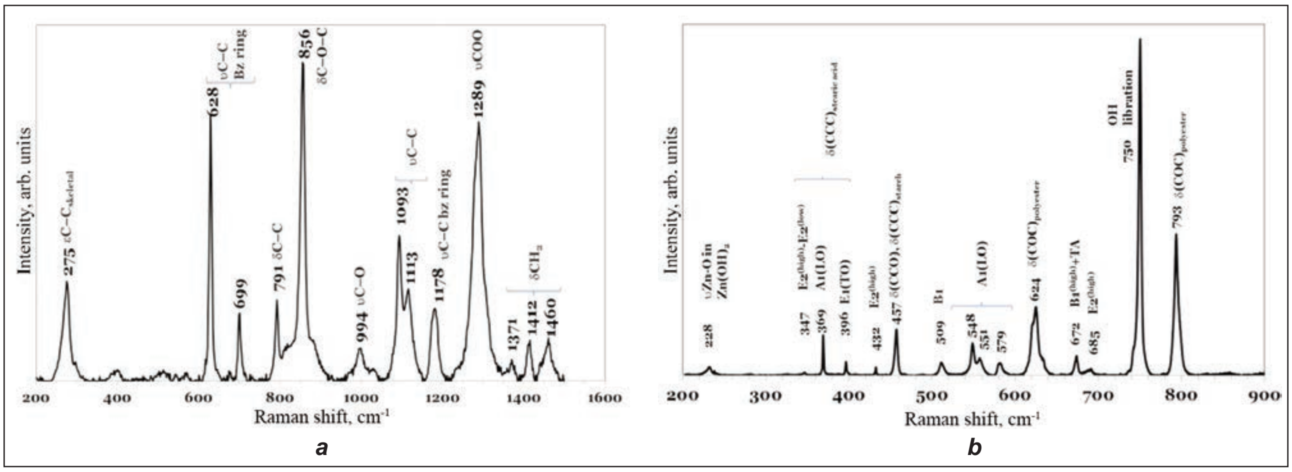
RESULT AND DISCUSSION

Raman spectroscopic results

In figure 2, *a* shows the characteristic bands of the pristine textile (P0) that were observed at 275 cm^{-1} corresponded to deformation of the C–C skeleton, at 658 and 699 cm^{-1} related to stretching of C–C ring, at 791 and 856 cm^{-1} matched to bending of C–C and C–O–C functional groups, at 994, 1093 and 1113 cm^{-1} assigned to stretch of C–O and C–C, at 1178 cm^{-1} matched to stretch of C–C ring, at 1289 cm^{-1} corresponded of COO stretching, and at 1371, 1412, and 1460 cm^{-1} related to bending of CH_2 functional groups [10, 15]. Figure 2, *b* reveals Raman scattering of vibration modes mentioned to $Zn(OH)_2$, ZnO, starch, STA, and polyester fibres in the treated PZOS. The observed bands at 228 cm^{-1} are also ascribed to the symmetric stretching Zn–O vibrational mode in $Zn(OH)_2$ [10, 16–17], whereas a strong band of 750 cm^{-1} is defined to the translational modes and the OH librations of $Zn(OH)_2$ and STA, respectively, as found in previous papers [18–19]. The hexagonal wurtzite structure of ZnO has the C^4_{6v} point group symmetry with each Zn metal ion surrounded by tetrahedral coordinated oxygen atoms and vice versa. This arrangement gives rise to polar symmetry along the hexagonal vertical axis (*c* axis). The optical phonons at the Γ point of the Brillouin zone correspond to the irreducible representation: Γ opt = A1 + + E1 + 2E2 + 2B1 [20]. The nine optical phonons are divided into one polar A1 mode and one doubly degenerate polar E1 mode which are split out into transverse (TO) and longitudinal optical (LO) phonons (Raman and IR active) while two doubly degenerate E2 modes (Raman active only), and two inactive B1 modes. Peaks appeared at 347, 396, 432, and 509 cm^{-1} assigned to $E2^{(high)}$-$E2^{(low)}$, $E2^{(high)}$, and B1, respectively. The others at 548, 551, and 579 cm^{-1} corresponded to A1(LO). Last, at 672, and 685 cm^{-1} matched with $B1^{(high)}$ +TA and $E2^{(high)}$ [7, 10, 16, 18–19]. In addition to the disappeared peaks at 275 and 856 cm^{-1} due to the hot NH_4OH possibly hydrolysed surface of polyester textile (P0) at ester-bonded carbonyl carbon and formed of ammonium terephthalate salt. Moreover, its carboxylate and hydroxyl groups of terephthalate and ethylene glycol were bonded with Zn^{2+} ion after being treated with the mixed solutions of Zn and starch, following coated with the alcoholic STA, and dried at 100°C for 1 h for dehydration formed PZOS as reported in our previous paper [10], others at 624 and 793 cm^{-1} corresponded δ(COC) and ring deformation of polyester as reported from [19]. Raman peak at 457 cm^{-1} is also assigned to δ(CCO), δ(CCC), ring deformation, and skeletal bending of glucose units in starch that is observed in [21]. Additionally, the experimental modes observed at about 339, 369, and 402 cm^{-1} were assigned as chain deformations, δ(CCC), of STA, constituting the most important vibrational modes in this spectral region as the previous report [22].

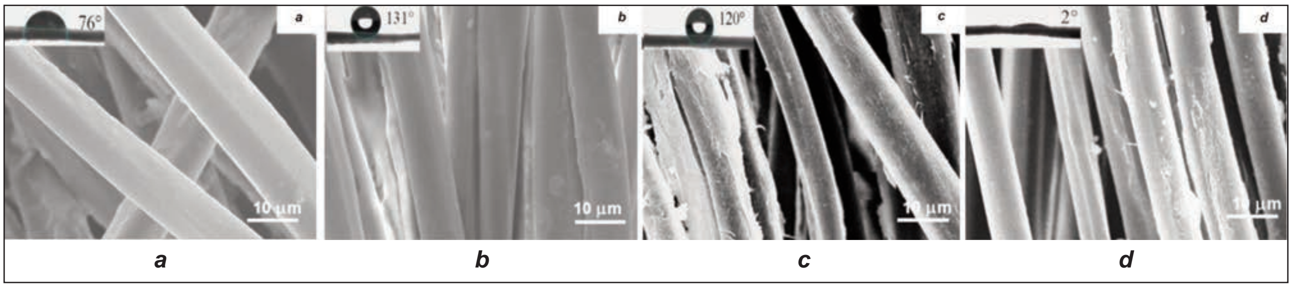
Morphological, elemental, and hydrophobic property studies

Figures 3, *a* and *b* report SEM images of PZOS revealing quite smooth fibered surface ZnO/$Zn(OH)_2$/Starch/STA composite as similar to the P0 due to using immersing time of about 24 hr for STA as final coated agent. In the case of before washing, the EDX spectrum shows the amount of Zn element about 6.38 %w/w as shown in figure 4, *a* and table 1. Whereas the composites were peeled off from the fibered surface after 5 and 20 washing cycles as observed from SEM images in figures 3, *c* and *d*, the EDX spectra show the amount of Zn element decreased about 1.39 and 0.87 %w after 5 and 20 washing cycles, respectively, as shown in figures 4, *b* and *d* and table 1, reported % weight element in only 20 washing cycles. The other peaks corresponded to the metal supporter and material that was conducted for sample preparation coating of SEM/EDX operation. In addition, synthetic polyester woven textile has hydrophilic behaviour with a water contact angle of



a *b*

Fig. 2. Raman spectra of: *a* – P0; *b* – PZOS



a *b* *c* *d*

Fig. 3. SEM images of: *a* – pristine (P0); *b* – PZOS; *c* – PZOS-5WC; *d* – PZOS-20WC included water contact angles of 76°, 131°, 120° and 2°, respectively

76º, figure 3, *a*, due to the textile manufactured thereof having an intricate capillary-porous structure and not possessing hydrophobic properties [2], while PZOS consisting of ZnO/Zn(OH)$_2$/starch/STA composite enhanced to reduce the surface energy on polyester woven textile that can be enhanced the hydrophobic property with a water contact angle of 131º as shown in figure 2, *b*. Figures 3, *c* and *d* show the durability of ZnO/Zn(OH)$_2$/ starch/STA composite decreased with increasing the washing cycles, therefore, the water contact angle decreased to 120º and 2º of 5 and 20 washing cycles.

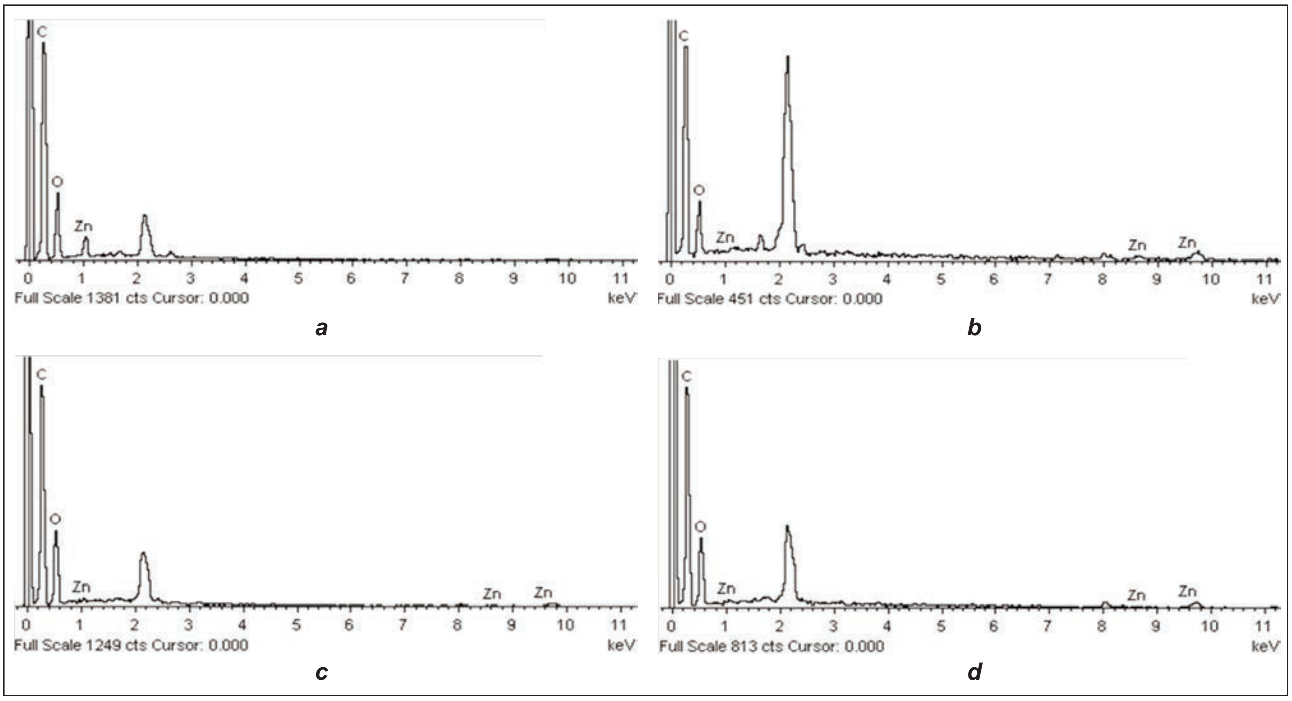
The air permeability and antibacterial activity studies

Table 1 shows the air permeability value of the PZOS-treated textile is high when compared with the 20-washing cycles due to the PZOS-treated textile containing a high amount of ZnO/Zn(OH)$_2$/starch/STA composite coated on the fibered surface. Moreover, good durable antibacterial activity against *Staphylococcus aureus* strains after 20 washing cycles was observed. As suggested the antimicrobial activity of functionalized PZOS-coated textile materials against gram-positive and gram-negative bacteria

Table 1

%WEIGTH ELEMENTS, THE AIR PERMEABILITY AND ANTIBACTERIAL ACTIVITY

Samples	**%Weight elements**			**The air permeability (mm/s)**	**%Reduction (AATCC TM 100: 2012)**	
	C	**O**	**Zn**		***Staphylococcus aureus***	***Escherichia coli***
PZOS	63.97	29.65	6.38	219.00	>99.92	>99.95
PZOS-20WC	60.49	38.64	0.87	87.96	>99.92	0



a *b* *c* *d*

Fig. 4. EDX analyses of: *a* – PZOS; *b* – PZOS-5WC; *c* – PZOS-10WC; *d* – PZOS-20WC

Table 2

COLOUR FASTNESS AND WHITENESS INDEX					
Samples	**Textile colour**			**Colour differences**	**Whiteness index**
	L*	***a****	***b****	**Δ*E***	
P0	93.38	2.70	–4.00	0	91.81
PZOS	91.78	2.25	–3.59	0.94	90.75
PZOS-5WC	93.39	2.47	–3.35	0.57	92.19
PZOS-10WC	93.07	2.62	–3.28	0.63	91.90
PZOS-20WC	93.06	2.75	–3.95	0.16	91.55

because the surface of polyester textile was deposited with approximately in the range of 0.87–6.38 %w of ZnO-based composite that is more the crystal form which was confirmed by Raman spectroscopic result. Therefore, ZnO-based composite even in the dark can generate ROS, i.e., especially H_2O_2 and $^{\cdot}OH$, to destroy *Escherichia coli* or *Staphylococcus aureus* strains as found in previous reports [5, 6].

Colour fastness and whiteness index studies

The colour differences and the whiteness index of the treated polyester textile after repeated washing did not significantly change as reported in table 2.

CONCLUSION

Raman spectroscopy and SEM-EDX techniques revealed clear identifications of phase, surface morphology, and surface chemistry of the finished polyester woven textile with ZnO/$Zn(OH)_2$/starch/STA composite through NH_4OH hydrolysis and dip-coating method. The hydrophobic finished polyester woven textile with a water contact angle of 131°, the optimum durable hydrophobicity of 5 washing cycles. Notably, the water contact angle and the air permeability values decreased with increasing repeated washings. The highly durable antibacterial finished polyester woven textile with >99.92% reduction of a gram-positive organism, *Staphylococcus aureus*, while >99.95% reduction of a gram-negative organism, *Escherichia coli* was observed only on the finished textile before washing. Nevertheless, the colour differences and the whiteness index of the pristine, treated, and 20 repeated washing polyester textiles were not markedly changed.

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Authors:

PHIPHOP NARAKAEW[1], SIWAT THUNGPRASERT[2], SAMROENG NARAKAEW[2], WIPANOOT BAISON[2],
THEERAPORN PROMANAN[3], PAKORN SANTAKIJ[4], SUKEE SUKDEE[3], CHAINET CHANOGKUN[5],
KANJANA RUTTANATEERAWICHIEN[6], APHIRUK CHAISENA[2], PIYAPORN KRACHODNOK[7]

[1]Department of Physics, Lampang Rajabhat University, 52100, Lampang, Thailand

[2]Department of Applied Chemistry and Center for Innovation in Chemistry, Lampang Rajabhat University,
52100, Lampang, Thailand

[3]Department of Chemistry, Lampang Rajabhat University, 52100, Lampang, Thailand

[4]Department of Information Technology, Lampang Rajabhat University, 52100, Lampang, Thailand

[5]Department of Communicative Thai for Foreigners, Lampang Rajabhat University, 52100, Lampang, Thailand

[6]Department of Digital Business Management, Lampang Rajabhat University, 52100, Lampang, 52100, Thailand

[7]School of Telecommunication Engineering, Institute of Engineering, Suranaree University of Technology,
30000, Nakhon Ratchasima, Thailand

Corresponding author:

SAMROENG NARAKAEW
e-mail: krachodnok@lpru.ac.th

Clusters analysis in technical textiles and composite materials sector: a regional case study

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MEHMET KARAHAN
ALİ ARI
NEVİN KARAHAN

ABSTRACT – REZUMAT

Clusters analysis in technical textiles and composite materials sector: a regional case study

This study was carried out as a cluster analysis for the Technical Textile and Composite Materials Cluster in the Bursa region of Türkiye. The study seeks to establish a solid foundation for the initial phase of cluster development in Bursa and for future stages, particularly the formulation of the cluster strategy and execution plan. The study's industrial scope encompasses technological textiles and composite materials due to Bursa's advanced enterprises and robust infrastructure, which enable it to specialise in several areas and emerge as a global industry hub. Cluster analysis examines the components of the Diamond Model to establish a foundation for a strategic outlook on the future. The SWOT part provides a concise overview of the main concerns, followed by the concluding sections introducing the initial vision statement and important strategic areas for future actions.

Keywords: *composite materials, technical textiles, clusters analysis, Bursa*

Analiza clusterelor în sectorul textilelor tehnice și materialelor compozite: un studiu de caz regional

Acest studiu a fost realizat ca o analiză a Clusterului Textilelor Tehnice și al Materialelor Compozite din regiunea Bursa din Turcia. Studiul urmărește să stabilească o bază solidă pentru faza inițială de dezvoltare a clusterului în Bursa și pentru etapele viitoare, în special formularea strategiei clusterului și a planului de execuție. Scopul industrial al studiului include textilele tehnologice și materialele compozite, datorită întreprinderilor avansate și infrastructurii robuste din Bursa, care îi permit să se specializeze în mai multe domenii și să devină un hub industrial global. Analiza clusterelor examinează componentele "modelului diamant", pentru a stabili o bază pentru o perspectivă strategică asupra viitorului. Analiza SWOT oferă o imagine de ansamblu concisă a principalelor preocupări, urmată de secțiunile finale care introduc declarația de viziune inițială și domenii strategice importante pentru acțiunile viitoare.

Cuvinte-cheie: *materiale compozite, textile tehnice, analiza clusterelor, Bursa*

INTRODUCTION

Cluster thinking has significantly improved the economic policy agenda, academic circles, and the corporate world over the past thirty years [1]. Clusters refer to agglomerations of enterprises and organizations operating in the same industry, located in close proximity to one another, and linked by shared characteristics and distinctions [2]. These clusters have the potential to collaborate and generate synergistic effects [3]. A search conducted on Google in February 2015 for 'Cluster Competitiveness' yielded 14900 results. The resulting pages are primarily from renowned institutions such as the World Bank, as well as institutions that promote clustering, such as the US Cluster Mapping Project and the European Foundation of Cluster Excellence. Michael Porter is widely credited for the tremendous popularity of clusters and their correlation with competitiveness. Porter emphasized that the fundamental source of competitive advantage is located inside clusters [4]. The World Economic Forum (WEF), an organization that regularly assesses the economic environment of prominent countries globally, regards the role of clusters as a significant factor in national competitiveness. According to the annual Global Competitiveness Report (GCR) by WEF, the level of cluster development in a country is considered as a factor within the pillar of "business sophistication". The business sophistication and innovation pillars are the most critical components of the WEF's Global Competitiveness Index. The intensity of interest in clusters can also be measured by the connections the notion has with a diverse range of current happenings. Cluster development is seen as a solution to the common issue of the "missing middle" problem that small and medium firms (SMEs) face in developing countries [5]. Clusters have been identified as catalysts for promoting regional innovations and globalization in certain instances. The concept is captivating, garnering the interest of governments as a policy tool and corporations as a strategic choice. The concept of promotion is being widely adopted by governments in the majority of countries. The literature extensively covers studies on cluster development from both advanced and emerging economies. Zeng attributes the remarkable rise of China over the past four decades to industry clusters, providing an illustrative illustration of their influence [6]. China's ranking as the second country in cluster development, following Italy, which was the first to deploy clusters (formerly known as industrial districts), among 144 nations in the World Economic Forum's Global Competitiveness Report (2014–2015), serves as evidence of this fact. The development path of a rising country such as China exemplifies the brilliance of Michael Porter's concept of clusters as the driving force behind the competitiveness of states, regions, and industries. There is only a limited amount of analysis on the competitiveness of clusters [7]. The majority of studies conducted on clusters are predominantly unidirectional [8].

As to the WEF, a nation's competitiveness refers to the collection of institutions, regulations, and factors that affect the country's degree of production. Porter conceptualized clusters as the fundamental basis for increased productivity [9]. Clusters can be defined as a subset that is part of the nation. Clusters can be seen as a condensed representation of a country to assess competitiveness. This is because they effectively incorporate local institutions, policies, and influences, which can subsequently be expanded to the national level. Therefore, it is crucial to quantify the competitiveness of clusters to understand the overall competitiveness of a nation [10].

We conducted regional and global market research and added value analysis on technical textiles [11] and composite materials [12] In our past studies. Our study indicates a rising demand in global marketplaces for high-value-added items like technology textiles. In the past ten years, numerous countries have revamped their production systems to prioritize the manufacturing of these items to enhance their economic competitiveness internationally. Global exports of technical textiles totalled over 118 billion dollars, reflecting a 3.38 percent growth from the previous year. Türkiye's exports in 2021 totalled $2.413 billion, marking a 12.91% reduction from the previous year. The Grubel-Lloyd Index calculation for technical textile product groups in Türkiye indicates bilateral intra-industry trade, with few exceptions. The mean index value for all technical textile items was computed as 0.7968. By 2028, Mobiltech, Indutech, and Packtech subcategories of technical textiles are projected to be the leading sectors in the commercial market.

The need for high-value composite products, such as technological textiles, is rising in today's global markets. In the past ten years, numerous countries have changed their manufacturing processes to focus on these items to enhance their competitiveness in the global economy. Türkiye's composite material exports grew by 19.48% in 2021 compared to the previous year, totalling 2.7 billion lire. The study determines that intra-industry trade in Türkiye's composite material product categories is mainly bilateral according to the Grubel-Lloyd Index calculation, with only a few minor exceptions. The mean index value for composite materials was calculated as 0.6890.

The authors examined the competitive forces in the technical textiles and composite industries [13]. The technical textiles and composite industry have been shown to have a substantial impact on the global economy due to aspects like as production prices, technology, product quality, innovation, and sustainability, as indicated by this study. The technical textiles and composite industries' growth and success rely on their capacity to convert competitive attributes into value-added goods. Value-added goods are differentiated from commodity goods by providing unique features, functionalities, and benefits. This enables enterprises to increase prices and generate greater profits.

In addition, in the first part of this study, the main participants, skills and areas that need to be developed within the Bursa Technical Textile and Composite Materials Cluster ecosystem were determined. It laid the foundation for the next stages of cluster development in Bursa, especially in terms of formulating the cluster strategy and implementation roadmap.

Within the scope of this study, it was prepared as a cluster analysis for the Technical Textile and Composite Materials Cluster in the Bursa Region of Türkiye. The study provides a concrete basis for further steps in the first stage of cluster development in Bursa, especially for the development of the cluster strategy and implementation roadmap. Information is provided on regional factors that have an impact on cluster development.

METHODOLOGY

Cluster analysis is crucial for assessing and positioning the competencies of a cluster about future trends and directions, to provide a competitive framework for both the cluster and its enterprises. Technical textiles and composite materials industries are highly fragmented and have complicated value chains. A thorough grasp of the industry structure, an integrated strategy, and an analysis of industry trends are essential. Before utilizing established tools like value chain analysis and M. Porter's Diamond framework, it is essential to comprehend the primary factors influencing the sector. This document has utilized a customized and well-organized analysis framework to examine the cluster environment and industry based on process, material, application, and technology (figure 1).

The study utilizes three primary analysis tools: i) desk review, ii) value chain analysis, and iii) cluster analysis (figure 2). The results of these analyses have

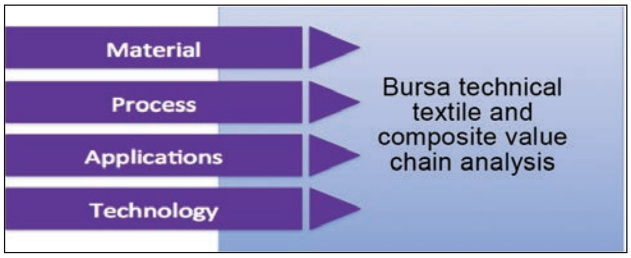


Fig. 1. Value chain analysis context

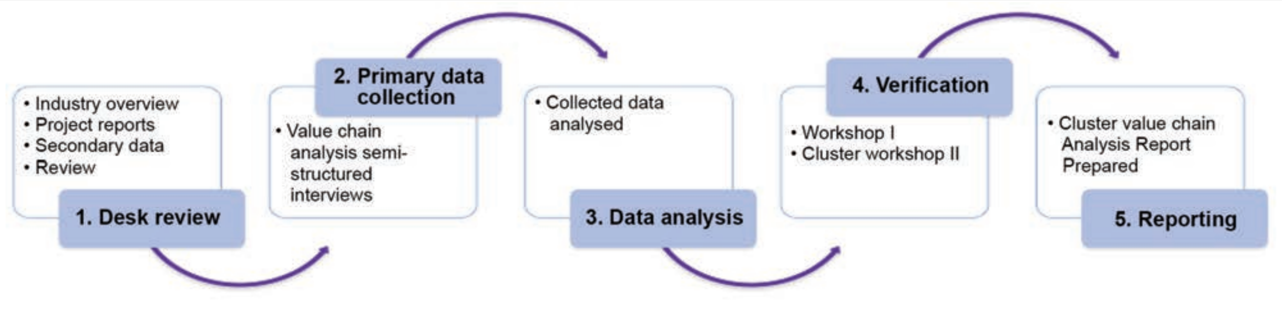


Fig. 2. Workflow

been examined and structured in the procedure given below.

Desk review

This study aims to analyse the industry structure and gain a comprehensive understanding of the industry through defining market categories, market size, and growth. The project evaluated and merged previous analyses and reports into pertinent portions of the study to provide an industry overview and assess the present situation of the sector in Bursa. Desk review, as a form of secondary data gathering, offered valuable insights for designing and developing tools to achieve the study's objectives before moving forward with subsequent steps.

Primary data collection

The main method used for obtaining primary data in this study was Value Chain Analysis. A customized project has been created to align with the industry framework. Primary data was gathered by creating a survey sheet and conducting semi-structured interviews with companies and stakeholders. During the study, 57 companies and significant stakeholders were interviewed.

Data analysis

It involved the examination and manipulation of primary and secondary data using various sector and cluster methods. Value Chain Analysis, Porter's Diamond, and SWOT analysis were employed to analyse the gathered data. A value chain map draft was created.

Data verification

It involved presenting the analysis results and draft value chain, which were then discussed in two workshops. Key competencies and opportunities for development were identified through a value chain map, and the results of the analysis were confirmed.

Reporting

The finalized value chain map was based on collected data, analysis, and input from stakeholders and cluster enterprises, and reporting work was carried out.

Bursa Chamber of Commerce and Industry (BTSO): BTSO aims to meet the common needs of its members, facilitate their professional activities, ensure the development of the sector, ensure the superiority of honesty and trust in the interaction of members with each other and with the public, and maintain professional discipline and harmony (Türkiye).

Bursa Technology Coordination and R&D Centre (BUTEKOM): To lead the work in national and international organizations (fairs, seminars, R&D project markets, etc.) and to convey the information in the organizations to corporate and expert members (Türkiye).

Bursa Technical Textile and Composite Materials Cluster (BUTEXCOMP): Bursa Technical Textile and Composite Materials Cluster is an innovation cluster that brings together companies producing textiles, technical textiles and composite materials, subindustry companies, academic and research institutions and public institutions, reflecting the entire sectoral value chain (Türkiye).

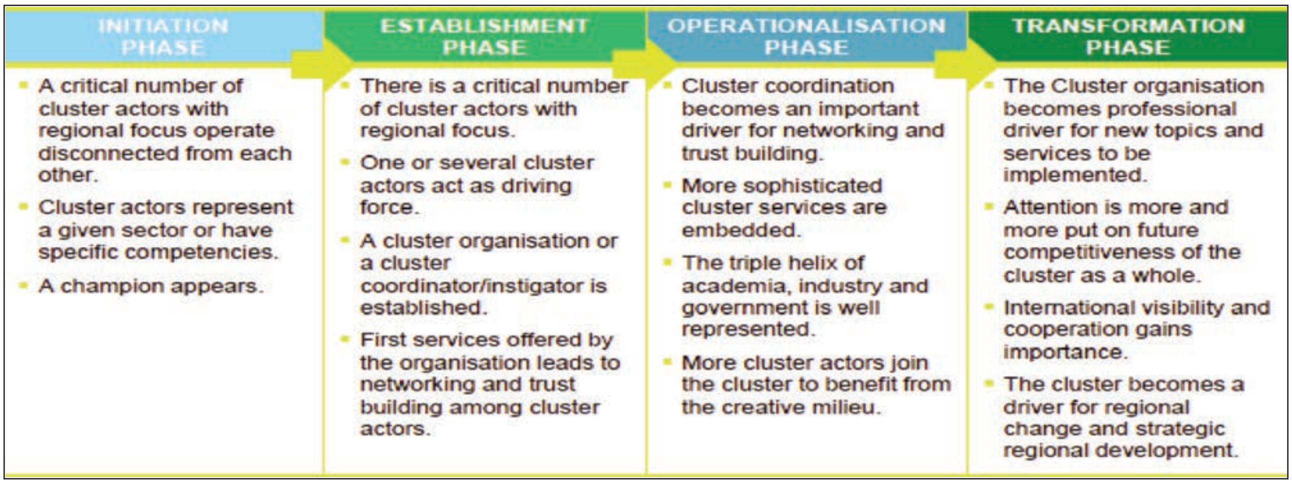
CLUSTER ANALYSIS

Cluster concept and terminology

Clusters can be characterised as geographically limited critical mass of strongly interdependent firms (i.e. sufficient to attract specialized services, resources and suppliers), knowledge-producing agents (universities, research institutions), and bridging institutions and customers, have relationships and are linked to each other in a value adding production chain [14]. Porter also describes a cluster as "a geographically proximate group of interconnected companies and associated institutions in a particular field, linked by commonalities and complementarities". According to Porter, it is clear that clusters are dependent on informal contacts, which are based on trust and reciprocity. Equally, the transfer of ideas and a common labour pool enhances competition and reinforces the competitive advantage of the cluster as a whole.

Another definition has been published by the European Cluster Collaboration Platform, which emphasises cluster scale and specialised expertise of industrial clusters. According to this definition; "Industrial clusters are groups of firms, related economic actors, and institutions that are located near each other and have reached a sufficient scale to develop specialised expertise, services, resources, suppliers, and skills".

There is an important issue that shall be highlighted before moving on to the details of this report. First of



INITIATION PHASE	ESTABLISHMENT PHASE	OPERATIONALISATION PHASE	TRANSFORMATION PHASE
- A critical number of cluster actors with regional focus operate disconnected from each other. - Cluster actors represent a given sector or have specific competencies. - A champion appears.	- There is a critical number of cluster actors with regional focus. - One or several cluster actors act as driving force. - A cluster organisation or a cluster coordinator/instigator is established. - First services offered by the organisation leads to networking and trust building among cluster actors.	- Cluster coordination becomes an important driver for networking and trust building. - More sophisticated cluster services are embedded. - The triple helix of academia, industry and government is well represented. - More cluster actors join the cluster to benefit from the creative milieu.	- The Cluster organisation becomes professional driver for new topics and services to be implemented. - Attention is more and more put on future competitiveness of the cluster as a whole. - International visibility and cooperation gains importance. - The cluster becomes a driver for regional change and strategic regional development.

Fig. 3. Four stages of cluster development [15]

all, a “cluster” is quite different from a complete sector in two ways: (a) it includes support agencies and key supply-chain companies and organisations; and (b) it usually splits up a sector to focus on specific distinctive sub-sectors, especially product or market-based. These differences between a “cluster” and a “sector” have implications for cluster development. The challenge is to develop effective strategies – ones that reflect an understanding of the complexities of cluster dynamics in a changing world.

The cluster analysis study was mainly based on Michael Porter’s Diamond of Competitiveness. Critical to Porter’s analysis of clusters are the dynamic effects created by the interaction of industry and place. Porter attributes the success of local cluster development in the global economy to the following set of factors:

- **Factor conditions:** include access to a pool of skilled workers, availability of physical infrastructure, basic research, and applied technology, sources of capital that are tailored to the needs of particular industries. Factor conditions support the development of the cluster.
- **Context for firm strategy, structure and rivalry inside the cluster:** The benefit of domestic rivalry is the pressure it creates for constant upgrading of the sources of competitive advantage.
- **Demand conditions:** level of sophistication and demand of consumers. Clusters may develop where the presence of the home market stimulates the development of and fosters competitive advantage among suppliers. According to the cluster theory, three broad attributes of home demand have an impact on the competitiveness of clusters: (1) Composition of home demand, (2) The size and pattern of growth of home demand, and (3) The mechanisms by which a nation’s domestic preferences are transmitted to foreign markets.
- **Related and supporting industries:** internationally competitive home-based suppliers create advantages in downstream industries in several ways. First, they deliver the most cost-effective inputs in an efficient, early, rapid, and sometimes preferential way.
- **Government:** government at all levels has an influence on the business environment and the innovative potential of clusters: i) improves the quality of basic inputs that firms draw upon, such as human resources, physical and technological infrastructure and capital; ii) creates rules, regulations and incentives that encourage innovation and upgrading; iii) build upon and reinforce the formation of local clusters.
- **Institutions for collaboration:** institutions for collaboration are formal and informal organisations and networks that: i) facilitate the exchange of information and technology, ii) foster various kinds of collaboration and cooperation that can improve the business environment in a cluster [4].

It is also highly important to bear in mind that clusters are evolving systems. Starting from the analysis stage, the establishment of the cluster, and developing and implementing the cluster road map have to be reality-based and should consider the maturity level of the cluster surrounded with its regional context. Figure 3 shows the main four stages of cluster development and the key indicators of each stage.

Cluster profile

Bursa Technical Textile and Composite Materials Cluster is an innovation cluster located in Bursa. Development of the technical textile and composite cluster is based on the strong presence of the textile, automotive and furniture industries. Textile, technical textile and composite materials manufacturing industries constitute the sectoral scope of the cluster.

Composition of the cluster

As of May 2023, number of companies participated in the cluster and value chain analysis was 57. Distribution of companies by scale is as follows 68% SMEs, 27% Large-scale companies and 5% start-ups (figure 4, *a*). Distribution of companies by sub-sectors is; 66.7% technical textiles, 12.26% textiles, 12.26% composite materials and 8.80% another sector (figure 4, *b*). Other sectors are the companies

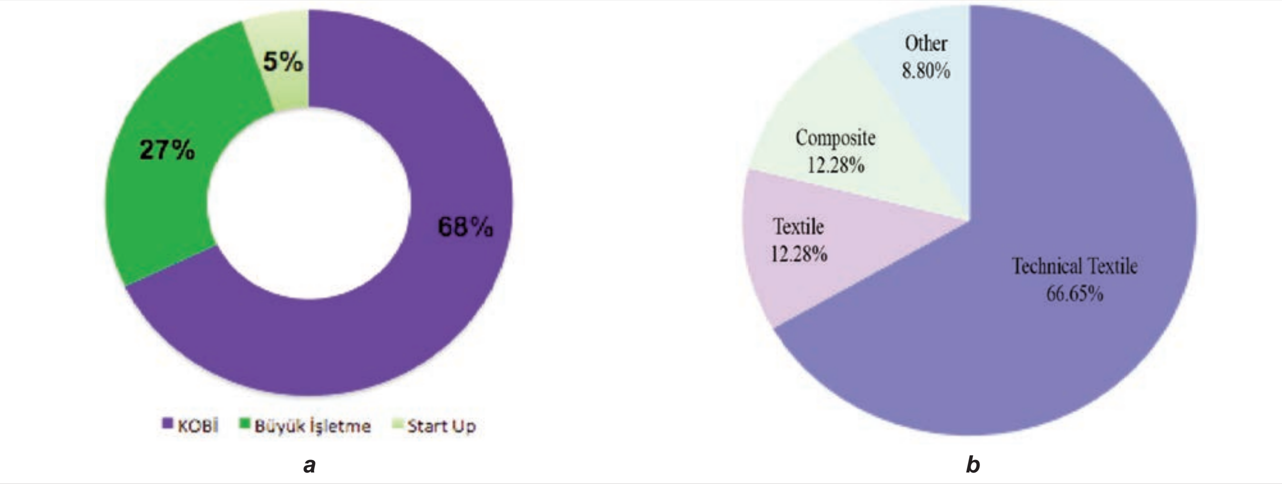


Fig. 4. Graphs of: *a* – Distribution of cluster companies by scale; *b* – Field of operation

in supporting industries, the main field of operations are chemical manufacturers and suppliers, metal and plastic manufacturers etc. As the initial stage of the cluster development below profile can be considered as the company composition of the cluster.

Along with companies, the Technical Textile and Composite Materials Cluster is well represented and supported by other actors of the triple helix. Research institutions, business support organisations, universities, development agencies and other key stakeholders are natural members of the cluster with their active involvement in the activities started by the cluster analysis and other related activities of the project. The cluster has at least 15 natural members from key stakeholders.

Cluster products and specialisation

Bursa is a province highly specialised in manufacturing textiles and apparel, especially in home textiles products; curtains and upholstery and baby and kids wear. Secondly, Bursa is one of the leading provinces for automotive manufacturing. Additionally, the manufacture of furniture products constitutes another sectoral concentration and export. Development of technical textile and composite materials is in parallel with developed industries and specialised product groups can be listed as follows:

- Vehicle seat group, trim and chassis systems,
- Functional (home, hotel, hospital) textile products including curtains made of functional textiles; i.e. acoustic and blackout curtains,
- Apparel, active wear technical textiles,
- Carbon fibre weaved textures, materials comprising reinforcement materials such as carbon fibres, glass fibres,
- Interior and exterior moulded parts for the automotive industry,
- Interior automotive textiles,
- Synthetic yarns.

Diamond analysis

Factor conditions

The strength of factors conditions in a cluster ecosystem has strong implications for cluster competitiveness. Identification of weaknesses in factor condition parameters can constitute a basis for cluster development strategies in which different actors of the cluster can take roles. Factor conditions including the presence of a skilled workforce, innovation and research infrastructure are among the key parameters for improving competitiveness of companies and the cluster.

Bursa Technical Textile and Composite Materials Cluster have a variety of competitive advantages in terms of factors and conditions. Below are the key findings from the Cluster Analysis Field Study about factor conditions of the cluster;

- Bursa is an industrial province with a highly developed industrial infrastructure and strengthened with a skilled workforce. There are 26 OIZs Bursa home to key manufacturing industries of Bursa. (+)
- Bursa's geographical location constitutes a strong advantage for the development of technical textile and composite materials. With the strong transportation infrastructure proximity of Bursa to leading other industrial centres such as İstanbul, Kocaeli and Eskisehir, especially for automotive and aviation industries is one of the most important competitive advantages. Proximity to European markets is also another important competitive advantage. (+)
- Due to the sectoral scope of the cluster including textile, technical textile and composite materials it is not possible to identify an exact number of employments of the entire cluster ecosystem. However, the number of employees in the current composition of the cluster is more than 6360 employees (+)
- Knowledge accumulated in textile manufacturing and automotive is very high, however, findings of the analysis reveal that there is a need for improving skills, knowledge and capacity of the workforce and talents in Bursa in line with the needs of technical textile and composite materials. It is not wrong to conclude that the level of skills and knowledge of the workforce for technical textile and composite manufacturing is low. Need for improving skills of

technicians, engineers and other related staff taking role in design, manufacture and marketing of technical textiles and composite materials. (–)

- Apart from textile engineering, and chemistry faculties, the presence of polymer engineering and materials science are highly crucial for innovation and research studies to be undertaken for developing new products for technical textiles and composite materials. In this sense presence of Bursa Technical University and Uludağ University with the aforementioned faculties is highly important. However, there is a need for improving collaboration between universities and cluster companies. (+, –)
- The Bursa Technical Textile and Composite Materials Cluster ecosystem is highly competitive in terms of the presence of research institutions including BUTECOM, BUTAL and TSE. However, there is a significant need for test, analysis and certification services for companies, to leverage dependency on foreign providers. There is a need for centres to promote themselves better and introduce their services to the industry (+, –)
- The number of research studies on technical textile and composite materials in collaboration with regions' research institutions has to be increased. Several research projects such as Horizon Europe have to be increased. (–)
- The strong infrastructure of BUTECOM constitutes an important competitive advantage for running collaborative research studies; there is a need for an increasing number of studies and development of collaborative work within the cluster to activate the potential of the Centre for the transformation of the textile industry to technical textiles and composite materials. (–)
- Bursa is one of the provinces in Türkiye with an improved cluster development culture. Both institutions and companies are highly familiar with the need for clusters to increase competitiveness. (+)
- A high level of entrepreneurial culture, presence and support of Techno Parks in Bursa is one of the key competitive factors in Bursa. Taking this factor as an advantage need to promote start-ups to be established in the technical textiles and composite materials industry. (+)
- There is a need for a qualified workforce at different levels and operations for manufacturing technical textile and composite products. (–)

For the transformation of the Bursa textile and manufacturing industry to technical textile and composite materials, the status of factor conditions constitutes a competitive environment for the development of the cluster. However, there are still essential steps to be taken, especially improving specialization in the industry. There is a need to improve knowledge of technical textile and composite materials among companies and the workforce. There is a need for improving and upskilling both the current workforce and students in line with the increasing needs of companies for entering and manufacturing technical textile and composite materials.

In terms of developing research and innovation aspect factor condition analysis reveals that there is a need for improving collaboration projects between universities and cluster companies. Especially when it is the case for improving collaborative and joint projects in basic and applied research presence and applications for Horizon Projects gain utmost importance. To increase both the number of projects and improve specific research capacity for technical textile and composite material areas there is a need for taking steps to develop Horizon Europe Projects.

Firm strategy, structure and rivalry

As M. Porter stated in Competitive Advantage of Nations, "The role of domestic rivalry illustrates how the diamond operates as a self-reinforcing system. Vigorous domestic rivalry stimulates the development of unique pools of specialized factors, particularly if the rivals are all located in one city or region… Another benefit of domestic rivalry is the pressure it creates for constant upgrading of the sources of competitive advantage. The presence of domestic competitors automatically cancels the types of advantage that come from simply being in a particular nation – factor costs, access to or preference in the home market, or costs to foreign competitors who import into the market. Companies are forced to move beyond them, and as a result, gain more sustainable advantages. Moreover, competing domestic rivals will keep each other honest in obtaining government support".

Well-understood parameters of the diamond and how these parameters work in a given cluster provide a unique opportunity to set well-established bases for developing cluster strategies (figure 5). It is therefore highly important to review the findings of the cluster analysis for the Bursa Technical Textile and

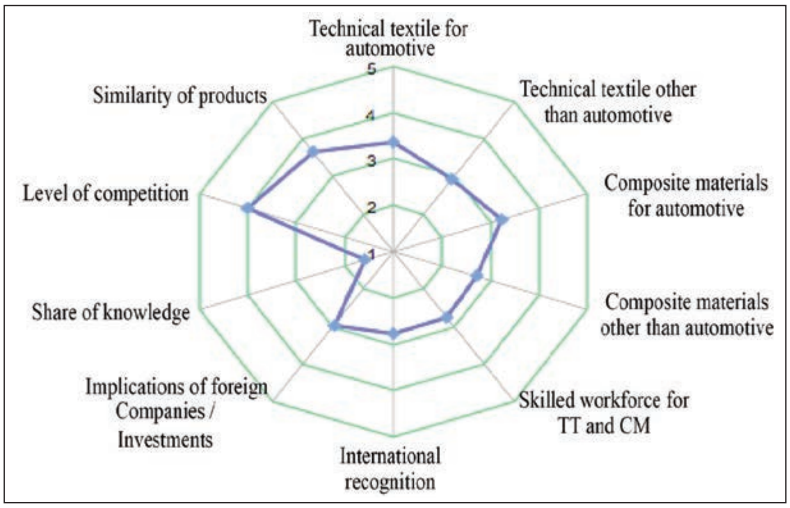


Fig. 5. Selected parameters in technical textile and composite materials competitiveness

Composite Materials Cluster. Within the scope of the cluster value chain analysis set of questions was raised to evaluate selected parameters providing insights into firm rivalry.

Companies were asked to evaluate given parameters from 1 to 5 according to the presence of each factor in Bursa. The level of similarity in cluster companies has been evaluated as 3.65, which puts relatively limited pressure on competition, by product type. The level of competition between companies was evaluated as 4.00, which can push companies to change to more innovative solutions, especially in the manufacturing of technical textiles and composite materials. Regarding the current level of technical textile and composite materials for automotive and areas other than automotive, it is seen that the current status has been evaluated under 4 points. It would not be wrong to comment that at the current stage of manufacturing technical textiles and composite materials level of competitiveness of Bursa has to be improved. Production of technical textiles and composite materials has to be increased for different application areas including automotive. Other parameters worth underlining are: i) low level of international recognition of Bursa in technical textile and composite materials production, elaborated as 2.77; ii) low level of skilled workforce, elaborated as 2.76; iii) low level of share of knowledge by 1.58. Taking into consideration the above chart, there is a need for improving the skills of the workforce, need for improving international recognition and increasing the level of knowledge exchange in the cluster ecosystem. Below are the key findings about the nature of competition in the cluster ecosystem.

- Collaboration among cluster companies towards developing new projects or a product in a new innovative area is low, however, it is seen that willingness for collaboration is high, especially for developing innovation capacity in new areas of technical textile and composite materials as well as developing new export markets. (–, +)
- Presence of network relations along with the industry value chain has been identified. Companies are working together as Tier 1 and Tier 2 suppliers of automotive OEMs. The presence of such networks among cluster ecosystems is considered one of the key drivers for competition and innovation in close collaboration with the end market side. (+)
- In line with the current maturity level, products in technical textile and composite materials are in the transition and development stage. Companies manufacturing technical textile products and/or composite materials are – mainly – also manufacturers of textile products, plastic and metal products. When it comes to competition among companies for sales of similar products, the level of competition based on product differentiation and innovation is medium. (–)
- Level of awareness and readiness among companies towards innovation for transformation to technical textile and composite materials is high. (+)
- To facilitate innovation-driven competition and collaboration among companies there is a need for increasing “critical mass” specific to technical textile and especially composite material manufacturing companies. (–)
- The level of specific and value-added technology and manufacturing infrastructure for producing specialised technical textile products and composite materials needs to be increased. (–)
- Low level of profitability in the current business model especially shaped by the global supply chain of the textile industry. Need for entering new market segments and willingness to adapt to innovation-based new business models. (–)
- Capabilities of companies have to be improved in manufacturing competence from weaving to technical textile manufacturing such as warp knitting, and improved processes such as laminating and coating (–)
- When it comes to competing internationally, one of the most important aims is as a province/cluster to be known with a specialised area at regional, national and global levels. Analysis reveals that Bursa is not known with competencies for manufacturing technical textile and composite materials globally yet. There is a need for increasing parallel manufacturing competencies and visibility of the cluster through different channels including globally known cluster and sectoral initiatives and platforms. (–)
- Need for development and investment in sample manufacturing lines, and operations within companies as well as in common-use facilities. (–)
- Findings of analysis and workshop reveal that companies need to increase their competencies in materials, need for technical training on materials and possible production areas for companies in consideration with current and new materials companies can use for productions. (–)
- There are seven companies in Bursa, a member of the Composite Industrialists Association. (+)

Key findings of the “firm rivalry” parameter, which are considered to be the basis for cluster strategy can be concluded as “need for technology adaptation and development”, “need for innovation-based business models”, “ need for increasing innovation-based completion among companies” and “need for increasing critical mass of companies specialised in technical textile and composite materials”.

Demand conditions

Demand conditions have been analysed both at industry-level implications and home demand level. Presence of level of sophistication and demand of consumers is highly determinant in the development of new and innovative products in the technical textile and composite material industry. Products in most cases can carry interdisciplinary functions, which may be used in different end markets but with similar purposes. Key findings about demand conditions from desk review and cluster analysis are presented as follows:

- There are manufacturing plants of automotive OEMs such as Tofaş, and Oyak Renault. Their work with regional companies as Tier 1, Tier 2. (+)
- The number of companies as suppliers and manufacturers to automotive OEMs and the level of joint research studies has to be increased. The need for more collaborative work and development especially SMEs to integrate in the supply chain has to be increased. (–)
- Both technical textile and composite materials buyers/OEMs have to be members of the cluster and take a role in cluster development. (–)
- Bursa is one of the exporting provinces of Türkiye. Likewise, companies in the cluster are exporting their products to a wide range of countries. Experience in export is a competitive advantage for the cluster for entering markets in technical textile and composite materials-related segments. Cluster analysis also revealed that Germany is the leading export market for companies. Germany is also among the primary target export markets for technical textile and composite material products. (+)
- Bursa is home to end markets and other related clusters constituting home demand for cluster companies. These end markets are the furniture industry and the need for upholstery textiles, automotive and the need for various functional interior and exterior textile and composite materials, apparel industry and the need for functional textiles.

One of the biggest competencies of the Bursa Technical Textile and Composite Materials Cluster is the presence of home demand in the region. OEMs such as Tofaş, and Oyak Renault work with companies as regional suppliers of Tier 1, Tier 2. Their demand for sophisticated and innovative products and collaborative work with regional companies leads to faster development of specialization.

The presence of supporting industries

Related and supporting industries under this parameter have been reviewed along with the value chain of the cluster and the industry. Supporting industries in the analysis have been identified as the actors providing input materials and services mainly for core companies manufacturing yarns, textiles and composite materials. In this sense main actors identified, as supplying industries are; chemical and other finishing substances providers, resin and other service providers etc.

- Input materials manufacture of high tenacity/high-performance technical textile and composite materials play key importance in many ways, including cost, quality and diversity of the product. As stated, in initial analysis studies of the project; “Cluster companies producing technical textiles get raw materials from European countries such as Spain, Italy, and France, particularly Germany. Companies with technical textile output lower or more than 50% do not significantly alter the raw material purchasing profile. China stands out within this category as the country where most of the raw resources are acquired”. There is a need for studies to eliminate the risks of dependency on supplying certain raw materials from abroad. (–)
- Reinforcement materials such as acrylic, carbon fibre and glass fibres are among the key materials providing added value to products. Fibres reinforced with aforementioned reinforcement materials purchased from out of Bursa, either from İstanbul or imported. The purchase of acrylic fibres to manufacture high-tenacity yarns can be limited due to the monopoly structure of the main suppliers. For glass fibres, companies can purchase from Şişecam or one of the supplier companies in Bursa. Composite fibres can be also purchased from different suppliers in Türkiye. Supplying industry in technical textile and composite materials may be challenging from time to time both at the availability of the input material at the required volume and adequate price. Suppliers of reinforcement materials have the bargaining power over manufacturing companies. (–)
- Another group of supplying and related industry actors is chemicals and auxiliary chemical providers. The cluster has actors in Bursa providing high-quality chemical substances and finishing materials. (+)
- Resin is one of the key input materials for composite manufacturing. There is a need for increasing resin manufacturing capacity in Bursa. (–)
- Plastic and metal processing and moulding technologies, and moulding suppliers are important providers for manufacturing companies. There is a need for supporting key technologies for a better competence level. (+, –)
- Companies providing finishing services such as dying, and lamination have to be improved with the information, skills and manufacturing capabilities. (–)
- Support needed for access to textile machinery for technical textiles, and composite materials. This support can be in the form of financial support and advisory services for adaption and maintenance of current technology and processes (–)

Government and business support environment

Under this parameter of the Diamond, apart from the expected role of government, the presence and implications of the business support environment have been reviewed. Below are the key findings about government parameters based on cluster analysis and findings from Cluster workshops undertaken.

- Cluster development is a well-accepted approach in Bursa and BTSO is a leading business support organisation for the establishment of clusters and implementation of cluster development supports such as UR-GE Projects. (+)
- Public Institutions are supporting the development of clusters in Bursa. (+)
- Presence of Smart Specialisation Strategy prepared by BEBKA. (+)
- Strong OIZ infrastructure is one of the key assets for the competitiveness of clusters in Bursa. (+)
- Strong presence and support of UIB for export development of companies. (+)

- There are incentives such as TUBITAK, KOSGEB, and Ministry of Trade that companies can benefit from, however, there is a need to apply for incentives and funds specifically designed to support the transformation of companies from textile to technical textiles. (+, –)
- Test, analyse and consultancy services provided by stakeholders including Bursa Technical University, however cluster and value chain analysis reveal that there is a need for increasing test services for meeting the needs of companies manufacturing technical textiles and composite materials. (+, –)
- Export promotion and export development supports needed for improving export capacity in technical textile and composite materials products, primary markets have been indicated as EU markets. (–)
- Need for supporting companies in sample production, prototypes and testing for preparing companies for international markets. (–)
- Exchange of know-how has to be promoted and enriched within the cluster with the help of business support organisations and especially by the cluster management body.
- In test, analysis and certification, the cluster environment has to be improved, need for tests, analysis and internationally accepted certifications in Bursa. (–)
- Need for promotion and branding of the cluster and cluster companies. (–)

SWOT

Strengths

- Cluster is based on a critical mass of textile manufacturers and historical background in manufacturing textiles and automotive in Bursa
- Presence of know-how and critical mass of automotive industry and supporting industries and close linkages with technical textile and composite materials
- Presence of competence and knowhow on functional fabrics
- High company awareness in clustering in Bursa, willingness of companies to participate in cluster studies
- High level of complementarity and presence of actors along with technical textile and composite materials value chain in Bursa
- Support of BTSO and presence of BUTECOM
- Strong support and ownership of stakeholders, public institutions and universities
- Developed industrial infrastructure and presence of well-developed OIZs
- Proximity to other industrial regions and key markets
- Presence of skilled workforce due to industrial concentration in Bursa
- Presence of leadership of BTSO and BUTECOM
- Presence of advanced supporting industries
- Strong entrepreneurship environment

Weaknesses

- Manufacture of technical/high-tenacity yarns has to be increased, and capacity and competencies have to be increased
- Need for increasing capacity of manufacturing composite materials, supporting companies in their product and product manufacturing processes, increasing the number of companies manufacturing composite materials
- Lack of technical knowledge on materials, processes for manufacturing technical textile products and composite materials in line with trends and needs of end markets
- Low level of collaboration and projects between OEMs and SMEs in Bursa, need for increasing number of joint projects and involvement OEMs and large companies in cluster activities
- Companies in cluster and value chain ecosystems do not know each other's capabilities, products and where they can collaborate, there is a need for cluster internal networking activities
- Lack of knowledge and awareness in traditional companies about their possibilities for manufacturing technical textile products,
- Need for improving specialisation in lamination applications and improving lamination infrastructure of companies
- Need for improving factor conditions, especially upskilling the current workforce and improving the employment environment in line with industry needs,
- There is a need to improve resin manufacturing
- Relatively low number of companies manufacturing composite materials, products and carbon weaving companies in Bursa

Opportunities

- Continuous growth of industry and increasing demand for technical textile and composite materials
- Presence of BUTECOM and services for companies to manufacture more innovative products, and infrastructure for prototyping, sample manufacturing
- Willingness of companies for cluster development
- Strong supporting industries, and complementarity of the industry value chain
- Presence of OEMs, Tier 1 and Tier 2 companies in Bursa for manufacturing products for the Mobiltech industry
- Supporting and promoting the transformation of traditional textile manufacturers to technical textiles,
- Variety of opportunities in different application areas such as Mobiltech, Protech, Builtech

Threats

- High demand for reinforcement materials such as carbon and glass fibres, acrylic fibres; on the contrary increasing prices, limited access to acrylic fibres and in some cases carbon and glass fibres

- Possibility of late uptake of green and digital transition, sustainability is one of the key determinants of the industry
- Lack of knowledge and awareness in traditional companies about their possibilities for manufacturing technical textile products,
- Need for an increasing number of companies operating in the composite materials segment
- Possibility of low interest of large-scale companies and OEMs to collaborate with cluster companies
- Presence of innovative competitors in the EU and the globe, ongoing investments in new products and projects of competitors
- A relatively long period is required for a product idea to become commercialised, which needs time and investment.

ADDITIONAL FINDINGS AND DISCUSSION

Bursa Technical Textile and Composite Materials Cluster Strategic Approach

"Strengthening open innovation for new product development and product diversification towards high-performance and sustainable products".

With the comprehensive analyses carried out within the scope of clustering studies, the basic issues for the success of the cluster in the medium and long term have been identified. The focus of the cluster is innovation. Bursa Technical Textile and Composite Materials Cluster is an innovation cluster.

Although the products within the cluster have a wide range, it is beneficial to optimize the cluster resources by clarifying the main areas of expertise. The sectoral transformation vision put forward by the BUTEXCOMP Project and BUTECOM should continue in the future with the cluster development and implementation stages. Sectoral transformation of the cluster based on the principles of "innovation" "productivity" and "growth through internationalization" are among the main strategic priorities.

In the technical textiles and composite materials sector, especially in the field of high-performance automotive materials and textiles, Bursa should be positioned as one of the first production and solution centres that come to mind in Türkiye and the world. With its production infrastructure and capabilities, Bursa will be among the centres that have a say in areas such as home and office technical textiles and, the strengthening of buildings with innovative materials and protective textiles.

It is aimed for the Bursa Technical Textiles and Composite Materials Cluster to strengthen its position in the world market as the address of high-performance and sustainable materials in the technical textile and Composite materials sector. From this perspective, the cluster vision proposal in the cluster strategy document is as follows: "BUTEXCOMP Cluster aims to be one of the best-known clusters in the EU with its technical textile and composite products and solutions for transportation, home and clothing areas, and other areas where sustainable and high-performance materials are used" stated.

It is possible to achieve the proposed vision only with a strong strategy and road map. As briefly mentioned above, the main strategies are the development of open innovation in the cluster ecosystem, increasing specialization and efficiency to accelerate the sectoral transformation and internationalization of the cluster for technology and market development. These main strategies are supported by strategies of strengthening the skill and knowledge infrastructure, strengthening the network and cooperation structure, and strengthening the national and international recognition of the cluster. Another fundamental basis of the cluster strategy is sustainability and digitalization; These will be included in all strategic pillars and actions of the cluster.

The cluster governance structure has a critical role in achieving cluster goals and success. In this regard, it is important that the cluster management and coordination team, which will continue its operations within the cluster governance structure, begins its activities within the scope of the Cluster Strategy and Road Map.

Cluster foundation and supporting strategies

Strategic priority areas

Both in the first months of the project and during the cluster analysis studies, sectoral data were scanned, interviews were held with companies operating in the cluster ecosystem, and sectoral trends were examined during the cluster development roadmap process. Through analysis studies, priorities – improvement areas – that form the basis of the basic and supporting activities in the cluster road map have been determined. These areas are the following:

- Developing open innovation, applied research and innovation-oriented collaborations in the cluster ecosystem, especially new products and product diversification in technical textiles and composite materials.
- Continuing the sectoral transformation approach by strengthening the production technologies, capacities and processes of cluster companies and supporting industries.
- Strengthening the cluster's testing, analysis and certification competencies and infrastructure, taking into account sectoral needs, in the light of the sustainable and digital transformation approach,
- Getting a higher share of the export market, and for this purpose, internationalization through technology and commercial collaborations in the global environment.
- Increasing network development and strengthening ties between cluster companies to act together in line with the cluster vision and common opportunities.
- The need to increase Bursa's national and international recognition as a cluster in technical textile and composite material products and solutions.
- Developing knowledge, training and skills in the cluster ecosystem to meet the needs of the industry, the use and application of technical textiles and composite materials, especially in automotive, transportation, home and clothing technical textiles, construction and other fields.

- The need to operationalize and institutionally develop the cluster coordination unit to ensure the smooth implementation of the cluster action plan towards the achievement and realization of the cluster vision.

Cluster master strategies

Innovation strategy

Cluster innovation strategy, the development of an open innovation culture in the cluster ecosystem (The term open innovation refers to the development of an organization's innovation (products, services, business models, processes, etc.) but also multiple external sources (customer feedback, published patents, competitors) to stimulate innovation, external institutions, public, etc.). Although the companies in the cluster have R&D and innovation studies and collaborations with universities, it has been determined that innovation-oriented studies are relatively within the company and have a closed structure. The cluster aims to support collaborative innovation among cluster actors in light of the needs and trends of the priority target sectors in the field of technical textiles and composite materials. The cluster with its innovation strategy aims to carry out studies throughout the technology readiness levels and to support collaborations starting from the product idea to the commercialization stage. The cluster innovation strategy is aimed to strengthen the structure of the cluster that produces intellectual property, patents and licenses.

Innovation in the Bursa Technical Textile and Composite Materials cluster can be interpreted as a "paradigm shift from closed innovation to open innovation" that can be achieved through collaboration. In other words, the cluster's strategy can be summarized as "maximizing research and innovation efficiency for new ideas and products through collaboration".

The cluster innovation strategy priority areas are:

- Strengthening the research and innovation environment in the cluster ecosystem;
- Supporting the innovation capabilities and work of cluster companies;
- To support entrepreneurship and the opening of new businesses in the cluster ecosystem.

R&D and Innovation areas that come to the fore within the scope of clustering studies:

- To develop knowledge on thermoplastic composites, especially in the automotive industry, and to carry out product development, new product and R&D studies;
- Conducting R&D and innovation studies in the fields of advanced materials, semiconductors, biomaterials, smart materials, and nano-engineering materials;
- Carrying out studies in the fields of carbon and glass-reinforced plastic composites and technical textile materials;
- Bio-based composites with fireproof properties;
- Natural fibre-reinforced technical fabrics, carbon and aramid fabrics;
- Conductive threads, mixtures and coatings, especially those made of metal, copper, etc.;
- Recycling waste materials and using them in the production of composite materials and technical textiles;
- Developing lightweight products (i.e. seating systems) with lightweight materials; thermoplastics;
- Carrying out studies in the field of recycling of composite materials among the forward-looking areas;
- Prepreg, perform 3D, 2D, autoclave, tape fabric, thermosets, epoxy, engineering plastics composite materials;
- Fabrics that provide high strength and heat balance;
- Electromagnetic, encapsulation, lamination, plasma, metal plating, etc. fields;
- Research studies on materials, products and application methods for strengthening buildings and the use of technical textiles and composite materials in building technology.

Transformation strategy in production

"Continuous industrial transformation through the adaptation, development and adoption of sustainable production solutions".

The second pillar of the key strategies of the cluster strategy is productivity. The strategic goal is to ensure the continuation of the sectoral transformation approach initiated with the BUTEXCOMP Project. The basic idea behind this strategic area is to increase the production capabilities and productivity of companies producing technical textiles and composite materials to meet the growing demand in the market in terms of technology and quality. Productivity strategy consists of 3 subcomponents. These sub-components;

- Adaptation of new production processes and technologies;
- Resource efficiency, digitalization and sustainability;
- Development of cluster capacity in industrial testing, analysis and certification areas.

Internationalization strategy

"Maximizing the effectiveness of commercialization"

The internationalization strategy of the cluster aims to ensure that cluster companies produce value in line with the internationalization objectives of the cluster and to internationalize the cluster as a whole. The internationalization strategy aims to increase the export market and technology partnerships of clusters and cluster companies, thus supporting the integration of global value chains and information and technology exchange.

The internationalization strategy aims to enter new export markets and/or integrate into global supply chains and establish connections with actors in target countries. Within the scope of the internationalization strategy; Business relations will be established with other clusters, actions will be taken to create job opportunities for cluster members, and cluster members will be supported in their international goals, including export development and technology collaborations, information about market opportunities and cooperation opportunities will be collected and shared with cluster companies, and collaborations will be developed between clusters and companies in the global environment. . There are two sub-areas of internationalization strategy.

- Improving the export capability of the cluster and increasing its export market share,
- Developing technology-focused global collaborations between clusters, research centres and companies.

Cluster support strategies

Knowledge and skills development strategy

Developing skills and knowledge in line with the cluster's research, innovation, specialization, technology, production and market needs are among the supporting strategies of the cluster. The strategy is directly related to the parameters of factor conditions and aims to contribute to the improvement of the level of cluster competition in the form of collaborative actions with universities, vocational schools and cluster companies. This strategy also aims to increase the level of industrial knowledge, facilitate the transfer of technical knowledge and contribute to the formation of relevant regional policies. As a two-way strategic area: i) increasing the level of knowledge in a cluster environment; ii) contributing to the development of skills related to studies on the production of future products of technical textiles and composite materials with a focus on primary target markets. In this context:

- Supporting cluster actors with collaborative projects, contributing to increasing the knowledge of universities and academicians in the cluster ecosystem, and enabling the number of articles and publications to be increased.
- Facilitating national and international partnerships and collaborations between research institutions and universities for sectoral transformation.
- Developing the necessary skills for design, development, production and marketing for industry, especially at the level of technicians and engineers.
- Develop and provide information about the industry, trends, markets, technology and processes to cluster members.

Network development strategy

Network development is the second supporting strategy of the cluster, which aims to increase relationships between cluster firms and establish connections with relevant actors in the internal and external environment of the cluster to achieve the cluster's goals and vision. Network development provides cluster actors, especially cluster companies, the opportunity to collaborate and work with companies or the cluster to develop competencies, technologies and competitive collaborations aimed at a common market. The network development strategy is linked to the core strategies of the cluster; it includes establishing connections at regional, national and international levels:

- Intra-Cluster Network Development*:* it is aimed to strengthen ties between cluster members, facilitate the exchange of experience and technical knowledge transfer, and increase the number of specialized companies within the cluster. The strategy aims to strengthen the cluster profile by bringing new members to the cluster in line with the strategic objectives of the cluster especially in the areas of innovation, production and internationalization.
- Cluster network development activities at the regional and national level will include establishing relationships with relevant clusters at the regional and national level. First of all, relationships will be established by initiating informational meetings through visits to clusters and relevant business support organizations. The network development strategy also aims to establish connections between cluster companies and OEMs located in Bursa and other regions of Türkiye.
- Cluster network development activities at the international level will be linked to the internationalization strategy of the cluster, including the development of relationships with clusters, companies possible actors and platforms relevant supply chains, research institutions and international organizations.

Cluster promotion and branding

Cluster promotion and branding is one of the most important support strategies of the cluster that can help both the cluster and its members to be recognized at national and international levels and to position themselves as a technical textile and composite material centre in the EU and in the world for the determined priorities. Cluster promotion and branding strategy aims to contribute to the strategic positioning of the cluster through branding of the cluster in line with a cluster communication strategy.

CONCLUSIONS

Analysis shows that the technical textile and composite materials business in Bursa is transitioning to a more specialized level by providing value-added products and solutions through a cluster development method. Technical textiles are distinguished by the solutions and services they provide, while composite materials are characterized by their strength and performance, typically achieved via the use of reinforced materials and specialized methods. It is possible and highly beneficial to create an early vision and mission statement for Bursa technical textile and composite materials based on their competitive advantages, key competencies, and analysis-based knowledge of areas to be developed. This statement can be further verified with cluster members. Clusters offer a variety of products and services within the technical textiles and composite materials sectors. It is advisable to concentrate on certain segments and enhance specialization. Bursa can enhance its manufacturing capacity, innovation, talent development, and know-how in the Mobiletech and home tech areas. By enhancing its competitive value chain, supporting industries can offer customized services to companies, aiding small and medium-sized enterprises in joining global value and supply chains.

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Authors:

MEHMET KARAHAN[1,2], ALİ ARI[3], NEVİN KARAHAN[1]

[1]Vocational School of Technical Sciences, Bursa Uludag University, 16059, Bursa, Türkiye
e-mail: mkarahan@uludag.edu.tr

[2]Butekom Inc., Demirtas Dumlupinar OSB District,
2nd Cigdem Street No:1/4, 16245, Osmangazi, Bursa, Türkiye

[3]Department of Weapon Industry Technician, Vocational School of Higher Education, Ostim Technical University,
06374, Ankara, Türkiye

Corresponding author:

ALİ ARI
e-mail: ali.ari@ostimteknik.edu.tr

Exploring the determinants of lean manufacturing adoption by textile enterprises in India: An investigation based on the latest World Bank Survey Data

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MOHAMMAD ASIF
FIROZ ALAM
MOHD SHUAIB SIDDIQUI
UMME HANI

ABSTRACT – REZUMAT

Exploring the determinants of lean manufacturing adoption by textile enterprises in India: An investigation based on the latest World Bank Survey Data

The study aims to identify the factors affecting the adoption of lean manufacturing by textile enterprises in India using the latest World Bank's Enterprises Survey (WBES) 2022 data of India. Three sets of variables namely enterprise characteristics, access to resources, which includes access to electricity, access to land and credit-line while in the last group, certification and competitive development are taken as explanatory variables of lean manufacturing adoption. The chi-square test is employed to investigate the significant association between firm profile and lean manufacturing adoption. Further, a logistic regression model has been applied to determine factors influencing lean manufacturing adoption. The estimates of logistic regression reveal that among firms' characteristics only legal status, access to resources, credit from financial institutions and access to electricity and from the third set of explanatory variables, certification and upgraded machinery and equipment are identified as significant factors in the adoption of lean manufacturing by textile enterprises. The value of the study lies in analysing factors affecting the adoption of lean manufacturing in textile enterprises which is not explored in the case of developing countries like India using comprehensive World Enterprises Survey data.

Keywords: *India, lean manufacturing, textile enterprises, world enterprises survey, waste minimization*

Explorarea factorilor determinanți ai adoptării producției de tip Lean de către întreprinderile textile din India: o analiză bazată pe cele mai recente date din Sondajul Băncii Mondiale în rândul întreprinderilor

Studiul își propune să identifice factorii care afectează adoptarea producției de tip Lean de către întreprinderile textile din India, utilizând cele mai recente date ale Sondajul Băncii Mondiale în rândul întreprinderilor (WBES) din 2022. Trei seturi de variabile, și anume caracteristicile întreprinderilor, accesul la resurse, care include accesul la energie electrică, accesul la teren și linia de credit, în timp ce în ultimul grup, certificarea și dezvoltarea competitivă sunt considerate variabile explicative ale adoptării producției de tip Lean. Testul chi-pătrat este folosit pentru a investiga asocierea semnificativă dintre profilul firmei și adoptarea producției de tip Lean. Mai mult, a fost aplicat un model de regresie logistică pentru a determina factorii care influențează adoptarea producției de tip Lean. Estimările regresiei logistice relevă faptul că printre caracteristicile firmelor, doar statutul juridic, de la accesul la resurse, creditul de la instituția financiară și accesul la energie electrică și, din al treilea set de variabile explicative, certificarea, mașinile și echipamentele modernizate sunt identificate ca factori semnificativi în adoptarea producției de tip Lean de către întreprinderile textile. Valoarea studiului constă în analiza factorilor care afectează adoptarea producției de tip Lean în întreprinderile textile, care nu este explorată în cazul unei țări în curs de dezvoltare precum India, folosind date cuprinzătoare ale Sondajul Băncii Mondiale în rândul întreprinderilor.

Cuvinte-cheie: *India, producție de tip Lean, întreprinderi textile, sondaj mondial în rândul întreprinderilor, reducerea deșeurilor*

INTRODUCTION

Lean manufacturing is one of the techniques that manufacturing organisations are required to use in today's highly competitive and dynamic business environment to improve and preserve their competitiveness on one hand and reduce waste on another hand [1–3]. In recent years, the notion of lean manufacturing (LM) has emerged as a highly significant field of research in operations management. Lean manufacturing (LM) is a multifaceted strategy that comprises a wide range of management techniques to reduce waste and enhance operational performance [4, 5]. The main purpose of lean manufacturing is to eradicate any form of waste within the manufacturing process. Lean manufacturing arose from lean thinking, which offers a solution to waste. Lean thinking enables the identification of value, the sequencing of value-creating operations, and the execution of these activities with less human effort, less apparatus, and less time and space [6]. The successful operation of lean manufacturing in industrial systems effectively reduces inefficiencies, enhances output and financial gains, improves product standards, reduces cycle time, and minimises work in progress, inventory and raw material usage and expenses [7]. Lean manufacturing promotes continual improvement in a dynamic and competitive setting, helping many companies achieve high financial performance [8]. Companies use lean methodology to avoid waste in the manufacturing process, which provides a cost advantage and makes the company more productive [9]. Lean manufacturing (LM) uses a various approach to minimise wastage and unproductive activities in the production process to maximise customer satisfaction.

The textile sector is a significant contributor to the generation of effluent wastewater owing to its extensive utilisation of water in various wet processing procedures [10, 11]. The wastewater that is discharged contains various chemical components such as acids, alkalis, dyes, hydrogen peroxide, starch, surfactants, dispersing agents, and metallic soaps [12]. The textile industry is believed to have the highest water usage among all industries worldwide, resulting in significant environmental consequences. The textile sector engages in the preparation of fibres, the conversion of fibres into yarn, and the subsequent modification of yarn into fabric. The resulting fabrics then undergo multiple phases of wet processing [11]. Even though the idea of lean production has worked well in industries with a constant process, it has not been used as much in industries with discrete processes. In the process industry, and especially in the textile industry, there is a lot of high-volume, low-product-variety automatic machinery that is not very versatile. Lean production strategies are hard to implement in the textile industry because it perceived as complicated. However, it has been taken as a task to implement lean strategies in the textile market. Various crucial determinants that ascertain the efficacy of incorporating the notion of lean manufacturing in small and medium-sized enterprises (SMEs) have been recognised. The successful implementation of lean manufacturing is contingent upon several key factors, including but not limited to leadership, management, finance, organisational culture, and skills and expertise [13].

The textile industry supports a significant number of jobs in emerging nations like India and provides around 14% to industrial output and 4% to overall GDP. However, since industrial facilities have grown in number, the likelihood of environmental problems has also grown. It has been noted that the Indian process industries are not fully embracing lean manufacturing. According to the findings of Panwar, sectors that have adopted lean have found it particularly effective in cutting down on waste and boosting product quality [14]. Dora et al. [15] argued that Indian companies are not doing a very good job of putting lean to use and knowing it.

Several studies have discussed environmentally friendly practices and the latest technology used in the textile industry [16–18]. There are two major gaps in the literature on lean manufacturing, first, studies do not capture the managerial perspective in the textile industry to influence the adoption of lean manufacturing. Second, there is very limited literature in the context of developing countries about lean manufacturing in the textile industry, however textile sector is sharply expanding in developing countries and requires lean manufacturing to reduce the waste in the production process [19]. Considering the gap in the literature, there is a need to study lean manufacturing adoption in the context of a developing country like India. Therefore, it is imperative to know the factors affecting the adoption of lean manufacturing in the textile industry because there are no such empirical studies which identify these factors. Some studies have identified the barriers and enablers of lean manufacturing but the majority of the studies are expert opinion based while few are case studies [20, 21], a firm-level primary data-based study on textile enterprises is still lacking. Understanding the factors influencing the adoption of lean manufacturing by textile enterprises is important to designing enterprise-level actions, and smooth and efficient production processes in the textile sector. The broad objective of the present study is to identify the factors which influence the adoption of lean manufacturing practices by textile enterprises in India. This study evaluates the relationship between textile firm characteristics and the adoption of lean manufacturing. Further, this research paper explores the factors affecting the adoption of lean manufacturing practices among textile enterprises by using a logistic regression model.

This study contributes both practically and theoretically to the existing literature on lean manufacturing in India's textile industry. The textile sector has serious concerns about waste reduction for sustainable production processes, therefore the present research contributes to filling the gap by analysing the factors affecting the adoption of lean manufacturing. Further, various firm-level factors may influence the adoption of lean manufacturing, this study provides an in-depth understanding of these factors. Knowledge of the determinants of lean manufacturing adoption provides opportunities for future research expansion on the topic. Moreover, the study contributes by establishing a relationship between the characteristics of textile firms that have adopted lean manufacturing and those that have not. This research paper concludes by analysing the factors that influence the adoption of lean manufacturing by textile enterprises, which is crucial for waste reduction in the textile industry. Therefore, identifying the main factors influencing the adoption of lean manufacturing can aid in the development of a more effective waste reduction strategy for textile companies.

The remaining parts of this paper are organized as follows. The next section deals with a review of previous work in the related areas. 3rd section presents the research methodology which includes data source and sample size, survey instrument and variables selection and estimation strategy. Results and discussion of the study are given in the 4th section. Lastly, the conclusion, managerial Implications and limitations of the research are highlighted in the 5th section.

REVIEW OF LITERATURE

A substantial body of literature about sustainability concerns within the textile industry exists. This includes works that address issues related to water, and waste management and the works that address energy management [22–25]. There are two ways to discuss lean production: philosophically, in terms of guiding principles and overall goals, or practically, in terms of management practices followed related to tools and methods [26, 27]. Bhasin [28] expresses that though lean manufacturing has been popular since 1990, but still, it is still unclear about the major factors in adopting lean or making it more widespread among companies. In their research work, Jadhav et al. [29] presented twenty-four obstacles in the implementation of lean operations, the leadership and participation of upper management, the attitude of employees, access to resources, and the organization culture played a significant role in the successful implementation of lean.

Lean has been very successful and is known all over the world, but many companies have failed when they tried to use lean. Almutairi et al. [30] list the factors that make it difficult to implement Lean. These factors encompass the necessity for financial investments, limited expertise, insufficient dedication, lack of confidence, previous managerial failures, inadequate comprehension, reluctance to change, and inertia among personnel. Lack of understanding about lean (its theory, principles, and tools), poor leadership, and a lack of top management support, commitment, and involvement are the major barriers to implementing lean operations [4, 31].

According to Prasad et al. [20], a comprehensive examination of operation, set-up, and changeover time (CO) is crucial for successful lean implementation in the textile industry. Additionally, the use of colour coding for volume-mix recognition, the application of kaizen, and the implementation of consistency circles to motivate workers are also important factors. In their study, Singh et al. [32] found that effectively implementing lean methodology in firms requires a focused approach to tackling management and market-related issues. Numerous developing nations' industries employ outdated and antiquated manufacturing methods and do not focus on new-age methods of production [33].

In the study conducted by Scherrer-Rathje et al. [34] lean success can be defined as the achievement of key components of a lean strategy, such as management commitment, utilisation of autonomy, transparency of information, and cultural alignment, together with the successful implementation of many techniques to support lean operational and tactical features. Chiarini [35] discussed the integration of lean orientation and ISO 9001 and found that, in general, the implementation of lean affects ISO 9001 documentation, which includes quality manual, procedure and work instructions. Further, he suggested that the principles, tools and techniques used in the implementation of lean procedures are considerably the same as those used by ISO-certified companies. Chauhan et al. [36] indicate that labour and machine flexibility contribute positively and substantially to lean philosophy-based production methods.

Motherwell et al. [37] point out that except for 5S strategies, managers either hesitate to use lean manufacturing or have limited knowledge of lean implementation.

According to the literature, lean operations in the textile industry are a major concern in India as well as around the globe. The adoption of lean manufacturing is facilitated by several factors, including firm profile, access to resources, new technology and certifications, and employee and machine upgrades. The adoption of lean manufacturing in the textile industry has substantial implications for maximising productivity and minimising waste within a manufacturing operation. Given the significance of waste minimization for sustainable production in achieving the SDGs, it is crucial to have a thorough comprehension of the factors that influence the adoption of lean manufacturing in general and the textile industry in particular. This study addresses two primary research questions: (1) whether there is an association between the adoption of lean manufacturing and the profile of textile firms and (2) which factors influence the adoption of lean manufacturing by textile enterprises.

RESEARCH METHODOLOGY

Data source and sample size

This paper uses the recent World Bank Enterprise Survey (WBES). Data was collected by the World Bank using stratified random sampling. The population of establishments is divided into non-overlapping strata, from which straightforward random sampling is then used to select respondents. NielsenIQ (India) Private Limited was in charge of the India 2022 WBES fieldwork. The selection of the implementing agency was conducted by the Enterprise Surveys Manual and Guide's standard procurement procedures. The fieldwork team employs Computer-Assisted Personal Interview (CAPI), an in-person technique in which the interviewer uses a tablet to transcribe responses given during the interview. A total of 9376 enterprises from 24 different states and union territories and 17 major sectors of India were included in the survey. Among the total surveyed firms, 596 are textile firms and from these 596 textile firms, 318 (53.3%) of the firms have given responses on the concern variables "Does establishment use formal lean manufacturing or operations?". Therefore, finally, 318 textile firms are taken for study.

Survey instrument and variables selection

A structured questionnaire has been used to survey the enterprises. Data has been collected on a wide range of questions related to business situations under fourteen subheads. In the present study, a set of related variables are extracted from the World Enterprises Survey of the World Bank (WBES), 2022. The data has been collected on different scales such as binary, Likert, and rating scales. The dependent variable of the study "Does establishment use formal lean manufacturing or operations?" is recorded on a binary scale, where 1 is used for adoption, while 0 depicts non-adoption. Further, the set of explanatory variables is divided into three groups (i) enterprise characteristics which include firms' age (Age), firm size (Size), legal status (Legal) and export-based enterprises (Expo), (ii) access to resources, under this group access to electricity (Elect), access to land (Land) and credit-line (Credit) has been taken while in last group namely certification and competitive development have four variables international quality certification (IQC), technology license from a foreign company (TLFC), upgraded machines and equipment's (UME) and formal training (Training). Suitable transformation in scale has done to include in the analysis.

Estimation strategy

In this research paper, the chi-square test is employed to investigate the significant association between firm profile and adoption of lean manufacturing. Using the following formula, the value of chi-square statistics was determined.

$$\chi^2 = \Sigma(O - E)^2 / E \qquad (1)$$

In equation 1, the expected and observed values are denoted by *E* and *O* respectively.

Further, an empirical model was developed to identify factors affecting the adoption of lean manufacturing in textile enterprises in India. The variable "Does establishment use formal lean manufacturing or operations" has been taken as the dependent variable while the three groups of variables namely enterprise characteristics, access to resources, and certifications and competitive development are taken as explanatory variables. Logistic regression is used when the dependent variable has only two possible outcomes (1,0), and the independent variables might be categorical, continuous, or a combination of both. In the present study, our dependent variable is adoption of lean manufacturing is measured on a dichotomous scale. It has been converted into a binary scale where 1 depicts the adopters and 0 is given to non-adopters of lean manufacturing by textile enterprises. Therefore, logistic regression is the most appropriate method for investigating the factors influencing the adoption of lean manufacturing. The logistic regression model can be expressed in the following generic form:

$$y_i^* = \alpha + \sum_{i=1}^{n} \beta_i X_i + \varepsilon_i \qquad (2)$$

The unobserved response to lean manufacturing is y_i^*, X_i is the matrix of independent variables comprising enterprise characteristics, access to resources, certification and competitive development, and β_i is the vector of regression coefficients. The symbols α and ε_i represent the intercept and error terms respectively.

Based on the aforementioned variables, the following empirical model was specified and estimated to forecast the likelihood of the following factors influencing the adoption of lean manufacturing by textile companies in India:

$$LMO = \beta0 + \beta1 Age + \beta2\, Size + \beta3\, Legal +$$
$$+ \beta4\, Expo + \beta5\, Elect + \beta6\, Land + \beta7\, Credit +$$
$$+ \beta8\, IQC + \beta9\, TLFC + \beta10\, UME + \beta11\, Training + \varepsilon$$

The following is the specification of the logit model, which is derived from the cumulative logistics probability function:

$$Pi = \frac{1}{1 + e^{-(\alpha + \Sigma_{i=1}^{n} \beta_i X_i)}} \qquad (3)$$

RESULTS AND DISCUSSION

The profile of the textile firm differs between those who have adopted lean manufacturing and those who have not. Table 1 depicts the association between the adoption of lean manufacturing methods and the characteristics of textile companies. Of the total textile firms, 18 percent reported that they have adopted lean manufacturing. Results show a significant association between firms' age and adoption of lean manufacturing at a 10 percent level of significant ($\chi^2 = 7.174$, $P < 0.09$). The frequency distribution of firms' age categories across adopters and non-adopters shows that firms' age is significantly associated with the adoption of lean manufacturing. The percentage of adopters is higher in firms' age above 30-year-old textile firms. The chi-square test shows that significant association between the adoption of lean manufacturing and a line of credit from a financial institution ($\chi^2 = 23.500$, $P < 0.01$). 31.6 percent of credit users have adopted lean manufacturing as opposed to 68.4 percent are adopters do not have a credit line, but in the non-adopters category, only 8.2 percent have credit from a formal institution. It implies that credit user relatively more adopts lean manufacturing in the textile industry. Similarly, for the case of international quality certification, a statistically significant association is observed between lean manufacturing and ownership of internationally recognised quality certification ($\chi^2 = 15.874$, $P < 0.01$). 63.8 percent of the lean manufacturing enterprises reported that they have internationally recognised quality certification as opposed to 36.2 percent of adopter firms that do not have an internationally recognised quality certification. It shows that the majority of the adopters have international quality certifications. Firms' distribution across the adopters and non-adopters of lean manufacturing concerning technology licensed from a foreign-owned company reveals that 37.9 percent of adopters of lean manufacturing have technology licensed from a foreign-owned company. χ^2 test Chi-square reveals that technology licensed from a foreign-owned company is statistically significantly associated with the adoption of lean manufacturing methods in textile enterprises. The association between upgraded machinery and equipment and adoption of lean manufacturing operations is significant ($\chi^2 = 16.179$, $P < 0.01$), implying that firms with upgraded machinery are more adopters of lean manufacturing and operations. The frequency distribution of firms shows that 82.8 percent of the firms adopt lean if they have upgraded machinery and equipment as opposed to 17.2 if do not have upgraded machinery and equipment. As evident from the chi-square test adoption of lean manufacturing is significantly associated with export operation by the firms ($\chi^2 = 7.13$, $P < 0.01$).

Factors affecting the adoption of lean manufacturing in the textile industry

The estimates of factors affecting the adoption of lean manufacturing among textile firms in India are presented in table 2. The regression coefficient and odd-ratio have been calculated for three sets of explanatory variables namely enterprise characteristics, access to resources and certification and competitive development to predict the adoption of lean manufacturing. Estimates of the omnibus test of model coefficient ($\chi^2 = 75.584$, $P < 0.01$) reveal that all variables in the model are jointly significant, implying that variables taken in the model have significant power to explain the adoption of lean manufacturing. The value of Log-likelihood is negative and adequately high showing good model strength. Among four enterprise characteristics namely firm age, firm size, legal status and export, only one variable legal status is significantly affecting the adoption of lean

Table 1

PROFILE OF TEXTILE FIRMS ACROSS THE ADOPTION OF LEAN MANUFACTURING

Firms profile	Yes (%)	No (%)	χ^2	df	Sig
Firms age category					
<10 years	5.2	9.2	7.174***	3	0.067
10–20 years	17.2	26.9			
20–30 years	29.3	33.1			
Above 30 years	48.3	30.8			
Firms size					
Medium	36.2	44.8	1.422	1	0.233
Large	63.8	55.2			
The legal form of the enterprises					
Shareholding company	10.3	12.3	0.529	2	0.768
Sole proprietorship	62.1	56.9			
Partnership and limited partnership	27.6	30.8			
The establishment has access to credit					
Yes	68.4	91.8	23.500*	1	0.000
No	31.6	8.2			
Does the establishment have an internationally recognised quality certification?					
Yes	63.8	35.4	15.874*	1	0.000
No	36.2	64.6			
Do firm use technology licensed from a foreign-owned company?					
Yes	37.9	4.7	53.622*	1	0.000
No	62.1	95.3			
Firms upgrade machinery and equipment					
Yes	82.8	54.1	16.179*	1	0.000
No	17.2	45.9			
Export firms					
Yes	39.7	22.7	7.13*	1	0.008
No	60.3	77.3			

Note: *Significant 1 percent, **Significant 5 percent, ***Significant 10 percent.

manufacturing by textile enterprises. The estimated regression coefficient of legal status is positive and significant (β = 1.013, P < 0.05), implying that textile firms having sole proprietorship as legal status are more likely to adopt lean manufacturing as compared to another type of legal ownership. It may be because generally, sole proprietorship firms are small and looking for greater growth and development aspirations. Sole proprietorship ownership type has significant indirect effects on innovation It can be concluded regarding firm profile that it is not very important in the adoption of lean manufacturing in textile enterprises. The findings of the study are in line with the outcome of the previous studies [3, 15, 27].

Further, access to resources improves the ease of doing textile business in India [38]. The logistics regression estimates show that out of a total of 3 variables under access to resources, two variables access to electricity and credit from institutional sources significantly affect the adoption of lean manufacturing in India. The regression coefficient is positive and significant for access to electricity (β = 1.157, P < 0.05), which implies that textile firms that have access to electricity are more likely to adopt lean manufacturing. The odd ratio indicates that firms with access to electricity are 3.181 times more likely to adopt lean manufacturing as compared to the textile which perceived access to electricity as an obstacle for them. Similarly, the analysis for credit lines suggests that it has positively significant effects on the adoption of lean manufacturing (β = 1.288, P < 0.01). The odd value of the credit line is 3.626, which shows that the textile enterprises that have taken credit have 3.626 times more chance to adopt lean manufacturing operations. Previous researchers support the findings that access to resources is essential to adopt new systems like lean manufacturing [13, 39, 40].

Finally, the impact of certification and competitive development on the adoption of lean manufacturing has been analysed. Out of four variables international quality certification, technology licensed from a foreign company, upgraded machines and equipment and formal training, three variables have significant implications on the adoption of lean manufacturing. The international quality certifications have positive and significant effects on the adoption of lean manufacturing (β = 0.814, P < 0.05), the odd value is 2.257, which implies that the textile enterprises with

Table 2

DETERMINANTS OF LEAN MANUFACTURING IN TEXTILE FIRMS

Determinants	Adoption of lean manufacturing (Yes=1, No=0)				
	B	**S.E.**	**Wald**	**Sig.**	**Exp(B)**
Enterprises Characteristic					
Firms Age (Year In Number)	0.002	0.011	0.037	0.848	1.002
Firm Size (Large=1, Otherwise=0)	0.192	0.368	0.273	0.602	1.212
Legal Status (Sole Prop.=1, Otherwise=0)	1.013**	0.405	6.277	0.012	2.755
Export (Yes=1, No=0)	0.223	0.412	0.292	0.589	1.25
Access to Resources					
Access to Electricity (Yes=1, No=0)	1.157**	0.461	6.298	0.012	3.181
Access to Land (Yes=1, No=0)	–0.13	0.46	0.079	0.778	0.878
Credit-line (Yes=1, No=0)	1.288*	0.48	7.193	0.007	3.626
Certification and competitive development					
International Qty. Certification (Yes=1, No=0)	0.814**	0.39	4.359	0.037	2.257
Tech. Licensed from A Foreign Company (Yes=1, No=0)	1.518*	0.46	10.873	0.001	4.561
Upgraded machines and equipment (Yes=1, No=0)	0.98*	0.422	5.381	0.020	2.664
Formal training (Yes=1, No=0)	0.51	0.457	1.247	0.264	1.666
Constant	-4.564*	0.738	38.299	0.000	0.010
Chi-square	75.584*				
df	11				
Sig.	0.000				
-2 Log likelihood	218.238				
Cox & Snell R Square	0.219				
Nagelkerke R Square	0.355				
Correction prediction (%)	87.2				

Source: Author’s calculation based on WBES (2022),*Significant 1 percent, **Significant 5 percent.

international quality certification are 2.257 times more likely to adopt lean manufacturing as compared to the firm which do not have international quality certification. The estimated coefficient and odd value for technology licensed from a foreign company is positive and significant ($\beta = 1.518$, $P < 0.01$) revealing that firms with technology licences are 4.561 more likely to adopt lean manufacturing. The use of upgraded machinery and equipment has significantly positive implications on the adoption of lean manufacturing ($\beta = 0.98$, $P < 0.05$), which implies that upgraded machinery and equipment are instrumental in lean manufacturing adoption in textile enterprises.

Access to resources has significant implications for the adoption of lean manufacturing by textile firms in India. To develop sustainably, access to resources by business enterprises such as land, capital, finance, electricity and other fundamental infrastructure is essential. Limited expertise and resources are challenges in implementing the lean manufacturing method. Although lean manufacturing has achieved significant success and worldwide recognition, some firms have experienced failure in implementing lean methodologies. Multiple factors purportedly contribute to the lack of success. Lack of access to financial resources is one of them, which includes funds for investment in training. As the results suggest that quality and technology-certified textile firms are more adopters of lean manufacturing, it may be because facilities that are certified firms generate significantly less waste. Quality certification or the receipt of quality awards has significant implications for adopting the updated management techniques [41].

The ISO 9001-certified factories generate much less waste. Having certifications such as ISO 9001 and ISO 14001 has a favourable impact on an organization's management effectiveness, financial performance, environmental performance, and competitiveness, which may help in the adoption of lean manufacturing.

CONCLUSION AND MANAGERIAL IMPLICATIONS

Lean manufacturing is the solution to waste in general and textile industry in particular. Waste is one of the most severe problems of the modern era in the industrial sector. Lean manufacturing is a structured method that seeks to eliminate non-value-added activities or waste. This methodology is designed to maximise productivity while minimising waste in manufacturing settings. It focuses on the optimisation of processes, the elimination of waste and inventory, the production of high-quality products, the creation of a more cost-effective and efficient production system, and the reduction of human effort. This present study analyses the factors affecting the adoption of lean manufacturing in the textile industry based on the latest World Bank Enterprises Survey (WBES)-2022 data, the textile enterprises data is extracted from large survey data. Analysis shows that significant association between firms profile and the adoption of lean manufacturing. Test of association indicated that older firms, involved in export and took institutional credit, having international quality certification and technology licence from a foreign-owned company with upgraded machinery and equipment are significantly associated with lean manufacturing adoption in India. Further, the estimates of logistic regression show that among firms' characteristics, only legal status significantly affects the adoption of lean manufacturing, sole proprietorship firms are more likely to adopt lean manufacturing. Moreover, access to resources, credit from financial institutions and access to electricity is positively significant. Moreover, certification and upgraded machinery and equipment are identified as significant factors in the adoption of lean manufacturing.

The present paper offers various implications. It is evident that very limited numbers of firms adopt lean manufacturing however waste minimization is a severe concern among policymakers. There is a need to promote lean manufacturing among textile enterprises. Though the Indian government introduced a lean manufacturing competitive scheme (LMCS), it should be promoted among textile enterprises to be aware of them. Secondly, based on the association between a firm's profile and lean manufacturing, policymakers should encourage young firms to adopt lean manufacturing, it should be linked with the registration process, and the textile enterprises that follow lean manufacturing should be registered only. Thirdly, credit norms should be easy for textile enterprises as it is shown that they significantly affect the adoption of lean manufacturing. Being a significant enabler of lean manufacturing, the textile enterprises should provide the resources at a subsidized rate. Finally, the upgraded machinery seems to have significant implications for the adoption of lean manufacturing, the textile enterprises should be exhilarated to upgrade their machinery and equipment in their inspections of compliance because both quality certification and upgraded machinery and equipment have affected the adoption of lean manufacturing in textile enterprises.

The study is based on the comprehensive survey of the World Bank, the variable related to lean manufacturing is very limited and the measurement scale is binary for the majority of the variables. Which restricted to adoption of advanced econometric methodology and extended the conceptual research model. Future researchers may collect the data on a wide range of questions related to lean manufacturing only on an appropriate scale which may provide the flexibility to adopt the latest data analysis techniques.

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Authors:

MOHAMMAD ASIF[1], FIROZ ALAM[1], MOHD SHUAIB SIDDIQUI[2], UMME HANI[1]

[1]College of Administrative and Financial Science, Saudi Electronic University,
Riyadh 11673, Saudia Arabia

[2]Department of Management, University of Tabuk, Tabuk, Saudi Arabia

Corresponding author:

MOHAMMAD ASIF
e-mail: masif@seu.edu.sa

Determination of the effects of knitted fabric sewing parameters on seam damage under multiaxial loading

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EMINE ERYAZICI ÖZGE URAL

ABSTRACT – REZUMAT

Determination of the effects of knitted fabric sewing parameters on seam damage under multiaxial loading

The body's movement during use exposes garments to tension and stress in different directions. To set the sewing parameters for clothing made of knitted fabrics, especially those commonly used for daily wear and sports, the damage caused by the seams to the fabric under multiaxial loading should be examined when determining sewing performance. This study examined the impact of sewing parameters on damage to knitted fabrics under multiaxial loading to identify the factors affecting sewing quality and performance. For this purpose, to perform the sewing damage tests, the single jersey, Pique, and interlock fabrics in three colours (white, red, and black) were cut into 30×30 cm-sized swatches. Samples were sewn parallel to the loop bar (lengthwise) and the fabric's loop line (widthwise) using two different stitch lengths, four needle sizes and four stitch types. A total of 576 samples were subjected to stress and strain on a seam damage testing apparatus as per DIN standard 53 882. Following the tests, the samples were examined under a microscope, and images were taken. The resulting data was analysed using the SPSS 26.0 statistical program. The Pearson Chi-squared and Fisher Exact Test were used to compare qualitative data. According to the test results determined that more significant seam damage occurred along the lengthwise samples of the fabric than the widthwise for all three fabric types. The study found that as damage increased with needle size, stitch type affected sewing damage, with the lockstitch causing minor damage, and fabric colour and stitch length had no impact on sewing damage.

Keywords: *knit fabrics, multiaxial loading seam damage, sewing parameters, textile*

Determinarea influenței parametrilor de coasere ai tricoturilor asupra deteriorării îmbinării prin coasere sub încărcare multiaxială

Articolele de îmbrăcăminte sunt expuse la tensiuni și stres în direcții diferite de mișcare a corpului în timpul utilizării. Pentru a seta parametrii de coasere pentru îmbrăcămintea realizată din tricoturi, în special cele utilizate în mod obișnuit pentru purtarea zilnică și sport, defectele cauzate de cusături sub încărcare multiaxială trebuie examinate atunci când se determină performanța de coasere. Acest studiu a examinat impactul parametrilor de coasere asupra deteriorării tricoturilor sub încărcare multiaxială, pentru a identifica factorii care afectează calitatea și performanța cusăturii. În acest scop, pentru a efectua testele de deteriorare a cusăturii, tricotul glat, tricotul Pique și tricotul interlock în trei culori (alb, roșu și negru) au fost tăiate în mostre de dimensiunea 30×30 cm. Probele au fost îmbinate prin coasere paralel cu șirurile de ochiuri (în lungime) și paralel cu rândurile de ochiuri (în lățime), folosind doi pași diferiți ai cusăturii, patru dimensiuni de finețe a acului și patru tipuri de cusături. Un total de 576 de probe au fost supuse la stres și efort pe un aparat de testare a deteriorării cusăturilor, conform standardului DIN 53 882. În urma testelor, probele au fost examinate la microscop și au fost captate imagini. Datele rezultate au fost analizate folosind programul statistic SPSS 26.0. Pentru a compara datele calitative au fost utilizate testul chi-pătrat Pearson și testul Fisher Exact. Rezultatele testelor au determinat că a avut loc o deteriorare mai semnificativă a cusăturilor mostrelor de tricot pe lungime decât pe lățime, pentru toate cele trei tipuri de tricoturi. Studiul a constatat că, pe măsură ce defectele au crescut odată cu finețea acului, tipul de cusătură a afectat deteriorarea cusăturii, cusătura cauzând defecte minore, iar culoarea tricotului și pasul cusăturii nu au avut niciun impact asupra deteriorării cusăturii.

Cuvinte-cheie*: tricoturi, deteriorări ale cusăturilor sub încărcare multiaxială, parametrii de coasere, material textil*

INTRODUCTION

As knitted fabrics fulfil consumer expectations thanks to the diversity in fabric, design, and production methods, along with the contributions of technological developments, their use is widespread in the fashion industry, from casual daily wear and activewear to stylish and classic clothing. Garments from knitted fabrics, trendy in athletic apparel and daily wear, are exposed to loads, pressure, and tension in different directions during use. Knitted clothing must incorporate features that meet the expected performance characteristics for the body's movement, the type of clothing, and the environment. Therefore, to ensure the longevity and garments composed of knitted fabrics, fabric strength and sewing performance must be considered.

The primary performance features that constitute the criteria for the sewing performance of ready-made garments are strength, flexibility, durability, and safety. Sewing performance criteria are decisive for determining seam designs and seam-processing variables before the start of production [1]. The sewing process and performance are influenced by numerous variables, including the type of sewing machine, machine settings and speed, the nature of the sewing operation, working method and ability of the garment worker, and selection of sewing parameters such as sewing thread and tension, needle size, and stitch length. Seam appearance (straightness, proper stitches) and seam tension performance (strength and flexibility) are the result of a combination of all these factors [2–5].

Sewing quality, a fundamental component of apparel production significantly affecting the overall quality of a garment, is analysed according to the functional and aesthetic performance criteria required by the garment until its final stage of use. Functional performance and seam quality (i.e., the strength and effectiveness of the seam) are evaluated based on seam strength, performance, elongation, bending, hardness, abrasion resistance, seam shear strength, shrinkage, tightness, thickness, resistance to washing and dry cleaning, and the damage sustained by the seam under various mechanical stress conditions [6–10].

During the sewing process, the fabric structure resistance and restriction to the sewing needles' entry cause sewing damage/defects.

These problems result from the fabric structure and an incorrect selection of sewing parameters such as needle type, needle size, sewing machine settings, thread, etc. [1, 11–14]. The most common types of damage caused by stitching include needle breaks, skipped stitches, seam slippage, thread breaks, seam cracking, and seam rips [11, 15].

Sewing damage, characterized by fragmented or broken fibres, filaments, or threads during the process of stitch formation on the fabric, can occur either immediately following sewing, during or after consumer use due to pressure, strain, and/or tension or as a result of washing [1].

Knitted fabrics are structurally more susceptible to damage during sewing because they contain gaps between the yarns at loop transitions and possess high elasticity [11, 16]. Therefore, stitch optimization is especially critical for knitted fabrics due to their structure and extensive usage.

The seams formed in knitted fabrics are superior at simulating garment performance, as these fabrics are more flexible and have greater exposure to tensile force. The seam strength expected from knitted fabrics may vary depending on the end use of the garment in question. For example, the seam strength of a t-shirt may be lower, while that of athletic apparel may be higher. Strong seams are a significant factor in overall garment quality. Performance, durability, usability, aesthetics, and suitability represent the most critical properties expected of a garment [2].

To increase seam strength, the type and quality of thread selected must be suitable, correct sewing techniques must be employed, and needle and machine settings should be appropriate for the density of the fabric to be sewn. In addition, attention should be paid to parameters such as optimal stitch length/density for seam quality and durability.

With an increase in stitch density, stitch strength has been observed to increase up to a certain density limit, after which mechanical damage occurs to the fabric due to the movement of the sewing needle [17, 9]. Knitted fabrics are more likely to be damaged during sewing due to the passing of loops in the fabric and their greater elasticity.

The literature on knitted fabrics is limited, and research on multiaxial loading has yet to be published. Some relevant studies have analysed the effect of fabric structures and the sewing performance properties of weft-knitted cotton garments [2]. The seam strength and breaking elongation of 100% polyester knitted fabrics have been measured along both the width and length of the fabric [18]. The sewing parameters of cotton-knitted fabrics were assessed by examining their efficiency and strength [19]. Another study investigated the effect of sewing techniques on seam strength and length using 100% polyester double-layer knitted fabrics [20]. The durability and breaking elongation values of various knitted and woven fabrics have been measured by testing their seam strength [9–15].

Several studies have explored the topic of the sewing properties and seam performance of various woven fabrics [6, 20, 21]. Research has also been conducted on how sewing parameters affect sewing quality and efficiency for different woven fabrics [22, 23]. The effects of sewing thread and stitch types on sewing strength and efficiency in woven cotton garments have also been investigated [17].

The present study examined the effects of seam parameters on seam damage incurred by knitted fabrics under multiaxial loading. Thereby determining the factors affecting seam quality and performance.

MATERIALS AND METHODS

Material

The fabric properties of the 100% cotton knitted fabrics (single jersey, Pique, and interlock; all obtained from the firm of Ares Örme, Turkey) analysed in the study are presented in table 1. Before starting the sewing process, all fabric samples were stored at standard room temperature (20±2°C) and relative humidity (65±4%) for 24 hours.

Since the fabrics being tested possessed different structural characteristics (e.g., loop properties, thickness, weight), sewing threads and needle sizes were selected by the fabric structures. The machine needles used in the study were obtained from Groz-Beckert, while the sewing threads were procured from Coats. JUKI brand machines were used for all stitch types on all fabric samples. The stitches tested included a 301 lockstitch, 401 chainstitch, 504 three-thread overlock, and 514 four-thread overlock. Characteristics of the needles used are shown in table 2, sewing thread properties are listed in table 3, and information on the sewing machines is given in table 4.

Table 1

KNIT FABRIC CHARACTERISTICS

Knit face structure	Colour	Fiber content	Knit density		Weight (g/m^2)	Yarn count (Ne)
			Wales (no./cm)	Courses (rows/cm)		
Single jersey	White	100% Cotton	15	20	150	30/1
	Red	100% Cotton	15	21	150	30/1
	Black	100% Cotton	15	20	150	30/1
Pique	White	100% Cotton	12	18	200	30/1
	Red	100% Cotton	11	18	200	30/1
	Black	100% Cotton	12	18	200	30/1
Interlock	White	100% Cotton	14	16	250	30/1
	Red	100% Cotton	14	16	250	30/1
	Black	100% Cotton	14	16	250	30/1

Table 2

MACHINE NEEDLE CHARACTERISTICS

Groz-Beckert machine needle properties

Size	Point type
Nm 60	FFG/SES
Nm 65	FFG/SES
Nm 70	FFG/SES
Nm 75	FFG/SES
Nm 80	FFG/SES
Nm 90	FFG/SES

Table 3

SEWING THREAD CHARACTERISTICS

Coats sewing thread properties

Number	Tex	Length	Average strength (cN)	% Stretch min – max
150	24	5,000 m	980	17 – 22
120	21	5,000 m	1,190	17 – 22

Table 4

MACHINE TYPE AND CHARACTERISTICS

Brand	Machine type	Revolutions (RPM)
JUKI	Lockstitch	1000 – 4500
JUKI	3-4 Thread Overlock	2860 – 3450
JUKI	Chainstitch	2860 – 3450

Method

Sample preparation

To perform the sewing damage tests, the single jersey, Pique, and interlock fabrics were cut into 30×30 cm-sized swatches. Two groups of samples were prepared to determine seam damage lengthwise and widthwise for each fabric. The first group samples were sewn parallel to the loop bar for each stitch type to examine lengthwise damage. The second group of samples was sewn parallel to the loop line for each stitch type. In the continuation of the study, sample groups were expressed as lengthwise and widthwise in damage evaluations. Information about the samples is given in table 5.

Sewability tests were conducted based on the DIN 53 882 standard. Testing of textiles; determination of the sewing behaviour of knitted fabrics [24]. After straight test seams were sewn, the fabric swatches, while being held between two clamps, were subjected to a 200 N load as well as 30 cross movements to simulate garment wear and tear (figure 1). Following this testing process, the fabric seams were inspected for sewing damage.

The microscope used was a Leica MZ7.5 Stereo Zoom Microscope 6.3× – 50×, as depicted in figure 2. Images of seam damage were obtained at 1.0 magnification.

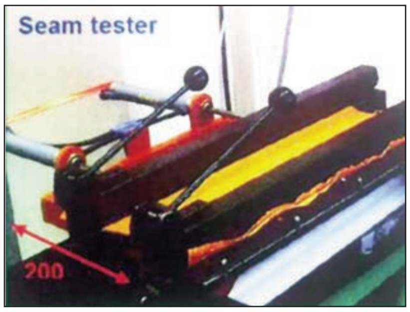

Fig. 1. Seam damage test apparatus

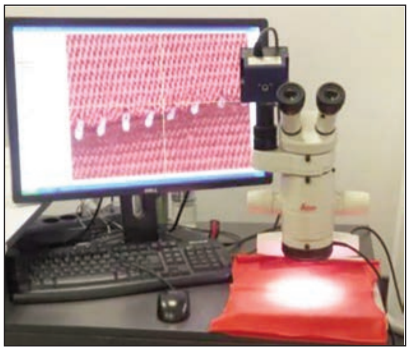

Fig. 2. Leica MZ7.5 Stereo Zoom Microscope

Table 5

STITCHING PARAMETERS FOR FABRIC SAMPLES							
Fabric type	**Colour**	**Width-wise samples (pcs.)***	**Length-wise samples (pcs.)****	**Needle sizes**	**Thread number**	**Stitch classes**	**Stitch length (per cm)**
Single Jersey	White	32	32	60-65-70-75	150	301-401-504-514	3–5
	Red	32	32	60-65-70-75	150	301-401-504-514	3–5
	Black	32	32	60-65-70-75	150	301-401-504-514	3–5
	Total	192 pieces					
Pique	White	32	32	65-70-75-80	120	301-401-504-514	3–5
	Red	32	32	65-70-75-80	120	301-401-504-514	3–5
	Black	32	32	65-70-75-80	120	301-401-504-514	3–5
	Total	192 pieces					
Interlock	White	32	32	70-75-80-90	120	301-401-504-514	3–5
	Red	32	32	70-75-80-90	120	301-401-504-514	3–5
	Black	32	32	70-75-80-90	120	301-401-504-514	3–5
	Total	192 pieces					
Grand Total		576 pieces					

Note: * Width-wise samples pcs.: Number of samples sewn into parallel to loop line; ** Length-wise samples pcs.: Number of samples sewn into parallel to loop bar.

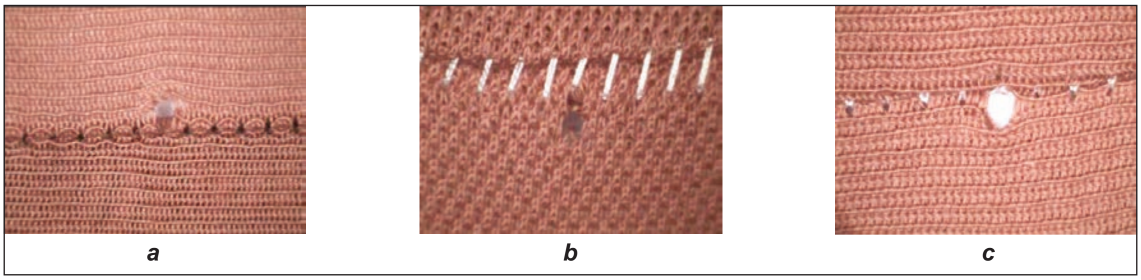

Fig. 3. Single jersey, Pique, and interlock fabric test swatches showing damage from the seam tester: *a* – Single Jersey; *b* – Pique; *c* – Interlock

FINDINGS

Statistical Evaluation of the Data The SPSS 26.0 statistical package program was used to analyse the findings obtained in the study. Descriptive characteristics of the fabric samples in the study were examined. Afterwards, the Pearson Chi-Square and Fisher Exact tests were employed to compare the qualitative data. The results were evaluated at 95% and 99% confidence intervals, with corresponding significance levels of $p<0.05$ and $p<0.01$, respectively.

The sewing damage incurred along the widthwise and lengthwise samples of the fabrics is examined in table 6 and figure 4. More damage in lengthwise samples than in widthwise samples was observed for all three fabric types. Since these knitted fabrics possess more significant stretch along the length, the damage was more visible there than along the width. To produce a quality garment, stitching and sewing parameters must be selected correctly [2–14].

The seam damage seen along the widthwise and lengthwise samples of single jersey fabric is shown in table 7 and figures 5 and 6. There was a relationship between seam damage (both widthwise and lengthwise) and needle size and stitch type ($p<0.01$ for all). Upon closer examination of the effect of needle size, damage was found to be high in samples produced using Nm 75 needles but low in those sewn with Nm 60 needles. While there were high rates of damage associated with 4-thread and 3-thread overlock and chainstitching, no specific damage was detected with lockstitching.

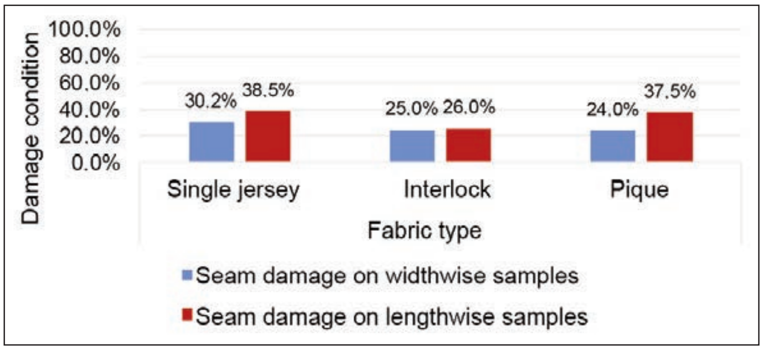

Fig. 4. Seam damage lengthwise and widthwise for each fabric

Table 6

SEAM DAMAGE ON LENGTHWISE AND WIDTHWISE SAMPLES

Fabric		**Indicator**	**Seam damage on widthwise samples**		**Total**	**Chi-squared**	***p***
			Absent	**Present**			
Fabric type	Single Jersey	F	67	29	96	1.108[a]	0.575
		%	69.80%	30.20%	100.00%		
	Interlock	F	72	24	96		
		%	75.00%	25.00%	100.00%		
	Pique	F	73	23	96		
		%	76.00%	24.00%	100.00%		
Fabric		**Indicator**	**Seam damage on lengthwise samples**		**Total**	**Chi-squared**	***p***
			Absent	**Present**			
Fabric type	Single Jersey	F	59	37	96	4.114[a]	0.128
		%	61.50%	38.50%	100.00%		
	Interlock	F	71	25	96		
		%	74.00%	26.00%	100.00%		
	Pique	F	60	36	96		
		%	62.50%	37.50%	100.00%		

Note: [a] Pearson Chi-squared Test.

Table 7

SEAM DAMAGE ON LENGTHWISE AND WIDTHWISE SAMPLES IN SINGLE JERSEY FABRIC

Single jersey		**Seam damage on widthwise samples**			**Total**	**Chi-squared**	***p***
		Indicator	**Absent**	**Present**			
Needle size	Nm 60	F	23	1	24	23.167[b]	0.000**
		%	95.80%	4.20%	100.00%		
	Nm 65	F	18	6	24		
		%	75.00%	25.00%	100.00%		
	Nm 70	F	18	6	24		
		%	75.00%	25.00%	100.00%		
	Nm 75	F	8	16	24		
		%	33.30%	66.70%	100.00%		
Stitch type	3-Thread Overlock	F	14	10	24	17.656[b]	0.000**
		%	58.30%	41.70%	100.00%		
	4-Thread Overlock	F	15	9	24		
		%	62.50%	37.50%	100.00%		
	Lockstitch	F	24	0	24		
		%	100.00%	0.00%	100.00%		
	Chainstitch	F	14	10	24		
		%	58.30%	41.70%	100.00%		
Single jersey		**Seam damage on lengthwise samples**			**Total**	**Chi-squared**	***p***
		Indicator	**Absent**	**Present**			
Needle size	Nm 60	F	23	1	24	27.718[b]	0.000*
		%	95.80%	4.20%	100.00%		
	Nm 65	F	14	10	24		
		%	58.30%	41.70%	100.00%		
	Nm 70	F	16	8	24		
		%	66.70%	33.30%	100.00%		
	Nm 75	F	6	18	24		
		%	25.00%	75.00%	100.00%		
Stitch type	3-Thread Overlock	F	9	15	24	31.846[b]	0.000*
		%	37.50%	62.50%	100.00%		
	4-Thread Overlock	F	9	15	24		
		%	37.50%	62.50%	100.00%		
	Lockstitch	F	24	0	24		
		%	100.00%	0.00%	100.00%		
	Chainstitch	F	17	7	24		
		%	70.80%	29.20%	100.00%		

Note: **$p<0.01$; *$p<0.05$; [a] Pearson Chi-squared Test; [b] Fisher Exact Test.

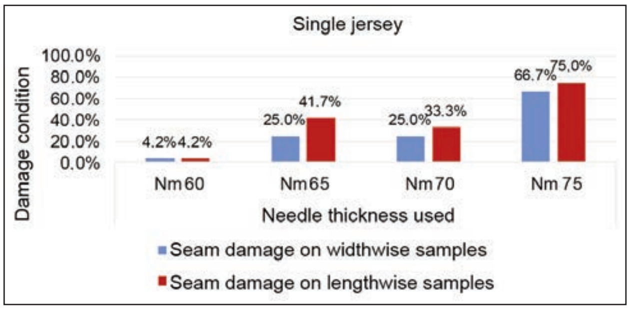

Fig. 5. Comparison of seam damage lengthwise and widthwise in single jersey concerning needle size

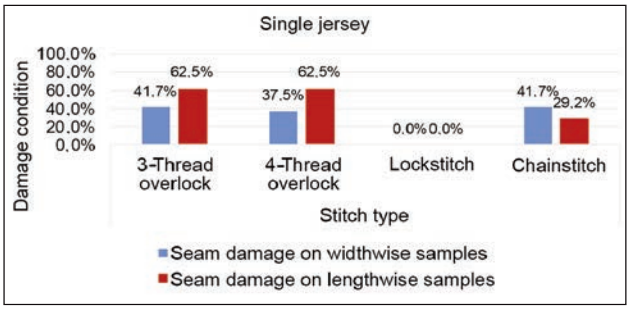

Fig. 6. Comparison of seam damage lengthwise and widthwise in single jersey concerning stitch type

No statistically significant relationship was observed between the sewing damage (both widthwise and lengthwise) and fabric colour or stitch length (p>0.05 for all).

Seam damage along the widthwise and lengthwise samples of the Pique fabric is presented in table 8. and figures 7 and 8. No statistically significant relationships were observed between damage along the widthwise samples, fabric colour, needle size, or stitch length (p>0.05 for all).

Regarding seam damage along the lengthwise samples of the fabric, a statistically significant relationship was detected between seam damage along the lengthwise and needle size (p<0.01). In particular, a

Table 8

SEAM DAMAGE ON LENGTHWISE AND WIDTHWISE SAMPLES IN PIQUE FABRIC

Pique		**Seam damage on widthwise samples**			**Total**	**Chi-squared**	***p***
		Indicator	**Absent**	**Present**			
Needle size	Nm 65	F	22	2	24	6.223^b	0.091
		%	91.70%	8.30%	100.00%		
	Nm 70	F	19	5	24		
		%	79.20%	20.80%	100.00%		
	Nm 75	F	17	7	24		
		%	70.80%	29.20%	100.00%		
	Nm 80	F	15	9	24		
		%	62.50%	37.50%	100.00%		
Stitch type	3-Thread Overlock	F	14	10	24	17.656^b	0.000**
		%	58.30%	41.70%	100.00%		
	4-Thread Overlock	F	15	9	24		
		%	62.50%	37.50%	100.00%		
	Lockstitch	F	24	0	24		
		%	100.00%	0.00%	100.00%		
	Chainstitch	F	14	10	24		
		%	58.30%	41.70%	100.00%		
Pique		**Seam damage on lengthwise samples**			**Total**	**Chi-squared**	***p***
		Indicator	**Absent**	**Present**			
Needle size	Nm 65	F	20	4	24	29.730^b	0.000**
		%	83.30%	16.70%	100.00%		
	Nm 70	F	22	2	24		
		%	91.70%	8.30%	100.00%		
	Nm 75	F	12	12	24		
		%	50.00%	50.00%	100.00%		
	Nm 80	F	6	18	24		
		%	25.00%	75.00%	100.00%		
Stitch type	3-Thread Overlock	F	14	10	24	18.339^b	0.000**
		%	58.30%	41.70%	100.00%		
	4-Thread Overlock	F	11	13	24		
		%	45.80%	54.20%	100.00%		
	Lockstitch	F	23	1	24		
		%	95.80%	4.20%	100.00%		
	Chainstitch	F	12	12	24		
		%	50.00%	50.00%	100.00%		

Note: $^{**}p<0.01$; $^{*}p<0.05$; ^{a} Pearson Chi-squared Test; ^{b} Fisher Exact Test.

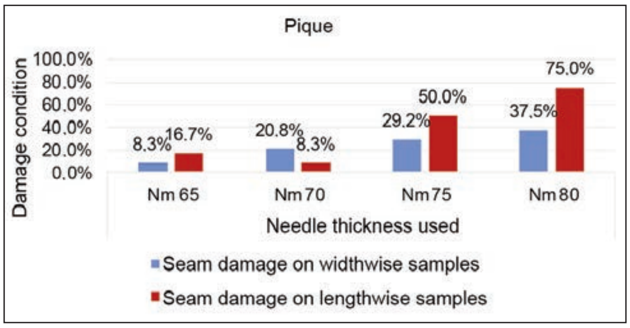

Fig. 7. Comparison of seam damage lengthwise and widthwise in pique concerning needle size

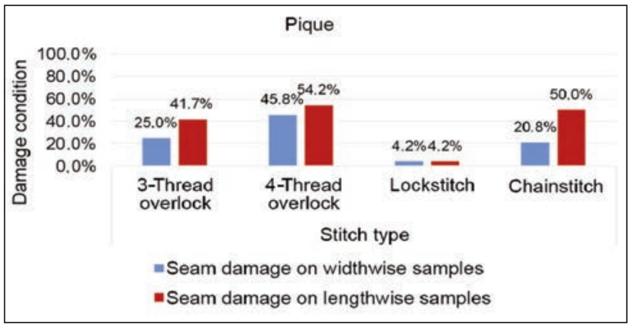

Fig. 8. Comparison of seam damage lengthwise and widthwise in pique concerning stitch type

high degree of damage was detected in the samples sewn using Nm 80 and Nm 75 needles. In contrast, examining samples produced with Nm 65 and Nm 70 needles exhibited low levels of damage.

There was a statistically significant correlation between seam damage widthwise-lengthwise samples and the type of stitching used ($p<0.01$). While noticeable damage occurred in the samples sewn using 4-thread and 3-thread overlock and chainstitching, with lockstitching, damage rates were low.

The seam damage observed in the interlock fabric samples is shown in table 9 and figures 9 and 10.

Table 9

SEAM DAMAGE ON LENGTHWISE AND WIDTHWISE SAMPLES IN PIQUE FABRIC

Interlock		Seam damage on widthwise samples			Total	Chi-squared	*p*
		Indicator	**Absent**	**Present**			
Needle size	Nm 70	F	24	0	24	94.593 [b]	0.000**
		%	100.00%	0.00%	100.00%		
	Nm 75	F	24	0	24		
		%	100.00%	0.00%	100.00%		
	Nm 80	F	24	0	24		
		%	%	0.00%	100.00%		
	Nm 90	F	0	24	24		
		%	0.00%	100.00%	100.00%		
Stitch type	3-Thread Overlock	F	18	6	24	0.113[b]	1.000
		%	75.00%	25.00%	100.00%		
	4-Thread Overlock	F	18	6	24		
		%	75.00%	25.00%	100.00%		
	Lockstitch	F	18	6	24		
		%	75.00%	25.00%	100.00%		
	Chainstitch	F	18	6	24		
		%	75.00%	25.00%	100.00%		
Interlock		**Seam damage on lengthwise samples**			**Total**	**Chi-squared**	***p***
		Indicator	**Absent**	**Present**			
Needle size	Nm 70	F	24	0	24	90.272[b]	0.000**
		%	100.00%	0.00%	100.00%		
	Nm 75	F	24	0	24		
		%	100.00%	0.00%	100.00%		
	Nm 80	F	23	1	24		
		%	95.80%	4.20%	100.00%		
	Nm 90	F	0	24	24		
		%	0.00%	100.00%	100.00%		
Stitch type	3-Thread Overlock	F	18	6	24	0.259[b]	1.000
		%	75.00%	25.00%	100.00%		
	4-Thread Overlock	F	17	7	24		
		%	70.80%	29.20%	100.00%		
	Lockstitch	F	18	6	24		
		%	75.00%	25.00%	100.00%		
	Chainstitch	F	18	6	24		
		%	75.00%	25.00%	100.00%		

Note: ***p*<0.01; **p*<0.05; [a] Pearson Chi-squared Test; [b] Fisher Exact Test.

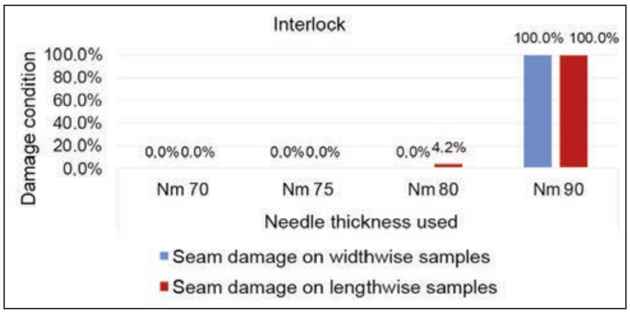

Fig. 9. Comparison of seam damage lengthwise and widthwise in interlock concerning needle size

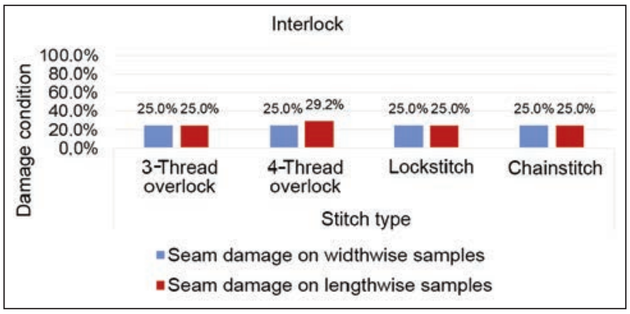

Fig. 10. Comparison of seam damage lengthwise and widthwise in interlock concerning stitch type

There were statistically significant differences between seam damage along the widthwise and lengthwise fabric samples and needle size ($p<0.01$ for all). A closer examination of the role of needle size revealed high damage in samples produced with Nm 90 needles. In contrast, no damage was detected in samples created using other needle sizes.

No statistically significant relationship was observed between widthwise and lengthwise damage and fabric colour, stitch length, or stitch type ($p>0.05$ for all).

CONCLUSION

This research examined the effects of stitch parameters on stitch damage of knitted fabrics under multiaxial loading, and the factors affecting stitch quality and performance were determined. The tests performed on knitted fabrics sewn in the loop bar direction and loop line determined that the damage was more in the lengthwise direction than in the widthwise direction.

To determine the effects of needle size and stitch type on seam damage, tests were performed on a single jersey, Pique, and interlock knitted fabrics in white, red, and black (all colours for each fabric type were produced in the same weights). According to our results, needle size affected seam damage on knitted fabrics, with the latter increasing with larger needle sizes. This finding highlights the importance of selecting needle size based on fabric thickness. Needle sizes in the range of Nm60-Nm65-Nm70 for single jersey, Nm65-Nm70 for Pique, and Nm70-Nm75-Nm80 for interlock were determined to be optimal for minimizing seam damage. The stitch types tested included lockstitching, chainstitching, and 3-thread and 4-thread overlock. The test results revealed that more damage was detected in samples of all three fabric types produced using both 3-thread and 4-thread overlock and chainstitching than the lockstitched samples.

The appearance and performance of seams depend on the sewing and stitch type, stitch density, sewing machine settings, and quality of sewing thread [2].

The importance of material and stitch type has emerged to ensure the stitch quality on knitted fabrics before production, to increase the quality of the product and to avoid any problems in consumer use.

The selection of supplies and stitch types most suitable for the product, fabric, and design features should be prioritized. The overall performance of the garment substantially depends on the quality of the sewing [8].

The sewability of knitted fabrics is a comprehensive and challenging field. The selection of appropriate supplies, yarn, fabric type, sewing thread, and machine parameters is critical for the production of high-quality garments with minimal defects [11]. Therefore, to evaluate the necessary improvements regarding machine design, fabric parameters, and sewing thread, it is necessary to examine the parameters associated with and affecting fibre, yarn, fabric structure, thread, and sewing machine.

Although relevant studies are to be found in the literature, especially concerning woven fabrics, in the garment industry, testing devices used for seam strength and sewability are common, mainly for woven fabrics. However, because of knitted fabrics' flexible structure and superior sewing simulation, sewing damage tests are rarely performed in the apparel sector.

The findings obtained in this study, explicitly conducted on knitted fabrics, will constitute a meaningful contribution to the literature and a valuable reference for manufacturers in material selection for optimal sewing quality.

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Authors:

EMINE ERYAZICI, ÖZGE URAL

Marmara University, Technology Faculty, Textile Engineering,
Aydınevler Mah. İdealtepe Yolu No:15 34854 Maltepe. 34854, Istanbul, Türkiye
e-mail: ozge.ural@marmara.edu.tr

Corresponding author:

EMINE ERYAZICI
e-mail: e.eryazici@gmail.com

Analysis and classification of footwear line drawings: research on fashion attributes using computer vision algorithms

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LI JINGJING
ZHAO YEBAO
KEYU HOU
ZHOU JIN

ABSTRACT – REZUMAT

Analysis and classification of footwear line drawings: research on fashion attributes using computer vision algorithms

With the rapid evolution of fashion trends and consumer preferences, the imperative for agility in footwear design has become increasingly pronounced. Central to the design process was the criticality of shoe line drawings, the burgeoning advancements in computer vision and deep learning technologies have engendered a wealth of research in fashion element recognition. Regrettably, the application of such advancements to footwear remains relatively underexplored. This study introduces a novel computer vision system tailored to discern and categorise footwear line drawings. The methodology entails the preliminary training of Mask R-CNN for shoe body extraction from footwear imagery, followed by applying the PIDINet edge detection algorithm for line drawing delineation, culminating in utilising a classification model for line drawing. Encouragingly, our findings evince the system's adeptness in successful line drawing extraction and classification, particularly demonstrating heightened accuracy in differentiating distinct styles such as nude shoes, boots, and slippers characterized by salient outline features. This pioneering endeavour not only addresses a gap in footwear element recognition research but also circumvents the need for an extensive footwear database for algorithmic training. The anticipated automation of algorithmic footwear line drawing recognition holds promise for enhancing operational efficiency and innovation, fostering sustainable advancements in fashion research.

Keywords: *footwear, computer vision, line drawing, fashion attribute, classification*

Analiza și clasificarea schițelor liniilor de încălțăminte: studiu asupra atributelor modei folosind algoritmi de viziune computerizată

Odată cu evoluția rapidă a tendințelor modei și a preferințelor consumatorilor, imperativul pentru agilitate în designul încălțămintei a devenit din ce în ce mai pronunțat. Pentru procesul de proiectare, necesitatea schițelor liniilor de încălțăminte a fost esențială, iar progresele în domeniul viziunii computerizate și tehnologiile de învățare profundă au generat o serie de cercetări în recunoașterea elementelor de modă. Din păcate, aplicarea unor astfel de progrese în domeniul încălțămintei rămâne un element relativ subexplorat. Ca răspuns, acest studiu introduce un nou sistem de viziune computerizată, adaptat pentru discernământul și clasificarea schițelor liniilor de încălțăminte. Metodologia presupune instruirea preliminară a modelului Mask R-CNN pentru extragerea formei pantofului din imaginile încălțămintei, urmată de aplicarea algoritmului de detectare a marginilor PIDINet pentru delimitarea schițelor de linii, culminând cu utilizarea unui model de clasificare pentru schița liniilor. În mod încurajator, rezultatele cercetării evidențiază eficiența sistemului în extracția și clasificarea cu succes a schițelor liniilor de încălțăminte, demonstrând în special o acuratețe sporită în diferențierea stilurilor distincte, cum ar fi pantofii decupați, cizmele și papucii, definiți prin caracteristici de contur proeminente. Acest efort de pionierat nu numai că abordează o lacună în cercetarea recunoașterii elementelor de încălțăminte, dar elimină și nevoia unei baze de date extinse pentru încălțăminte pentru instruirea algoritmică. Automatizarea anticipată a recunoașterii algoritmice a schițelor liniilor de încălțăminte este promițătoare pentru îmbunătățirea eficienței operaționale și a inovației, ducând la progrese durabile în cercetarea modei.

Cuvinte-cheie*: încălțăminte, viziune computerizată, schița liniei, atribut de modă, clasificare*

INTRODUCTION

The current fashion cycle has suddenly become shorter [1], leading to intense competition. Designers need to quickly keep up with trends and create shoes that meet the diverse needs and preferences of consumers. Traditional fashion design work heavily relies on designers [2], as well as hand-line drawings were often the starting point and key to many creative and fashion workflows [3, 4]. For footwear designers, line drawing of shoes was crucial in determining their shape, size, and details [5]. The quality of line drawing directly impacts the shoe's appearance and comfort. Traditional shoe design requires a lot of manual drawing and sample making, which is time-consuming and labour-intensive. In addition, new designers often struggle to create line drawing styles that are accepted by the general public due to lack of experience. Hand-line drawings are subjective and vary from individual to individual, leading to differences in product understanding. Furthermore, shoe design also needs to consider ergonomics, materials, and processes, making the design process more complex and difficult. Currently, well-known fashion trend websites such as WGSN (the world's leading consumer trend forecaster: https://www.wgsn.com), POP (a fashion Trend Network: https://www.pop-fashion.com), and Diexun (global fashion consulting provider: https://www.diexun.com) provide line drawing design materials for footwear and apparel, allowing designers to quickly grasp design trends. However, most of these were manually drawn, resulting in low output efficiency, small quantity, and untimely updates. For different footwear designers, more efficient exploration of line drawing design trends can better grasp market demand, cater to consumer preferences, and introduce more competitive products.

Computer vision technologies have become indispensable tools for understanding and analysing large-scale cross-media fashion data semantics and studying the mechanisms of fashion trends. There is a growing interest in using computer systems to analyse collected images, automatically detect and identify objects, and extract valuable information in the fashion industry. Research on fashion style recognition has been extensive, with studies such as that of Al-Halah et al. [6] utilising supervised deep convolutional models and non-negative matrix factorization to discover the "vocabulary" of latent styles, and then train a predictive model to represent the trend of latent styles over a period, providing an overall view of the fashion visual style lifecycle. Ferreira et al. [7] proposed a unified model with structured output to classify categories, subcategories, and attributes of high-end fashion website images using an end-to-end architecture, thoroughly identifying visual information in fashion images to analyse potential key elements for trend forecasting. Bossard et al. [8] applied random forests to classify garment types and used multiple Support Vector Machines (SVMs) to train 78 attributes to identify garment styles. Shi et al. [9] modified the Faster Region-based Convolutional Neural Network (Faster R-CNN) and Mask Region-based Convolutional Neural Network (Mask R-CNN) for identifying attributes in images and videos to recognize texture, style, and design details. Zhao et al. [10] applied Mask R-CNN for garment segmentation and classification, analysing colour, style, and other attributes as well as fashion trends in garment combinations. While research on the application of computer vision in fashion design was extensive, existing studies and applications related to footwear were limited. Additionally, there was a lack of research on the classification and detection of popular elements related to shoes in fashion element recognition studies.

The aforementioned deep learning algorithms have demonstrated better performance than traditional methods. These algorithms can overcome the drawbacks of manual image interpretation, such as fatigue, low efficiency, and high subjectivity, and offer broad application prospects [11]. Mask R-CNN [12], as one of the most widely used instance segmentation networks in recent years, was capable of simultaneously performing object detection, classification, and semantic segmentation tasks. It excels in instance segmentation by first classifying objects through the detection of candidate regions and then achieving pixel-level instance segmentation (classification before segmentation). Edge detection, an important branch of image segmentation, was commonly used to evaluate object shapes by identifying positions where intensity levels change sharply [13]. The Pixel Difference Network (PidiNet) proposed by Su et al. [14] integrates traditional Canny and SE edge detection results as candidate points, for a convolutional network and extends the Local Binary Pattern to derive the Pixel Difference Convolutionvas the main convolutional kernel for building a lightweight network. Due to its integration of traditional edge detection operators into modern CNN, PidiNet possesses advantages such as a smaller memory footprint, high accuracy without pre-training, and faster inference speed [14].

This study aimed to analyse and classify shoe line drawings to improve shoe design efficiency and innovation capability through computer vision algorithms. The technical approach involved using the Mask R-CNN instance segmentation algorithm to extract shoes from complex backgrounds, utilising PidiNet edge detection for rapid extraction of line drawings, and then analysing footwear classification to output line templates. This would provide designers with a large number of professional footwear line drawing templates made to the correct proportions, enabling them to explore diverse design inspirations and possibilities more quickly.

METHODOLOGY

This study proposed a computer vision-based analysis system to analyse and classify footwear line drawings. First, the original images were input into Mask-RCNN to extract the shoes from the background. Then, the PidiNet edge detection was used to recognize the contours of the extracted shoes and generate the lines. Finally, the line drawings were identified and classified based on a classification model. The classification model was empirically studied using footwear images collected from WGSN.

Image segmentation and line extraction

Training and inference on the Microsoft Common Objects in Context Dataset (COCO dataset) using different backbone networks in Mask RCNN. 4744 shoe images were collected for testing the accuracy. After training, Mask RCNN was used to identify and segment the shoes from the background of the complete images. Subsequently, PidiNet was employed to extract the outlines of the shoes. PidiNet has an efficient backbone network consisting of four stages, with each stage using a pooling layer for downsampling. The first stage comprises an initial convolutional layer and three residual modules, while the second,

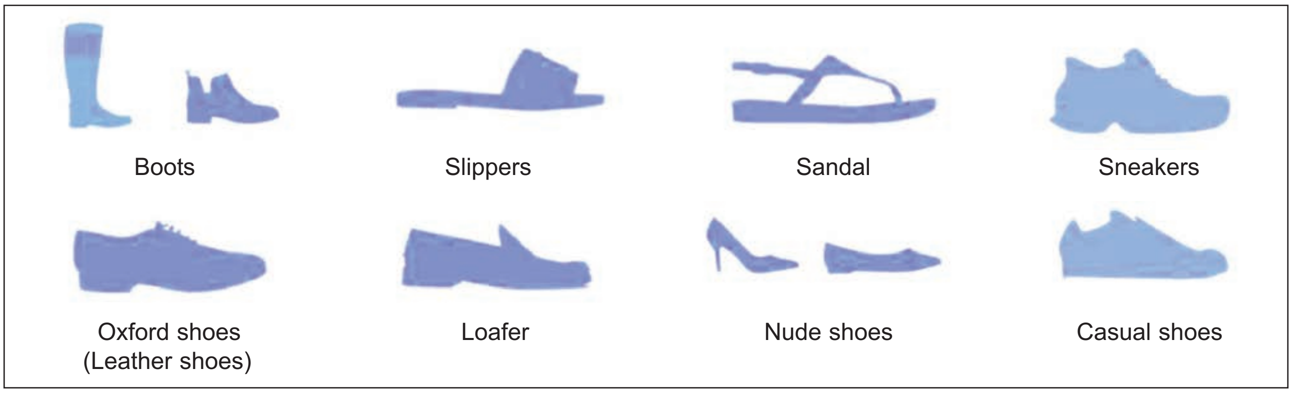


Fig. 1. Classification of shoes and description of shape features

third, and fourth stages each contain four residual modules. Each residual module includes Pixel Difference Convolution (PDC) depth convolutional layers, Rectified Linear Unit (ReLU) layers, and point convolutional layers. To ensure comprehensive learning of edge features, an edge feature map was generated from each stage and used to calculate the loss function with the Ground Truth, enabling deep supervised learning.

Establishment of footwear line drawing classification model

We chose to label the shoe images from the full side view to avoid recognition errors caused by angles. The classification of shoes was mainly based on their external contour characteristics, as shown in the following figure. For example, compared to slippers, boots have distinct features such as a boot shaft and a high top, whereas slippers lack back support.

As shown in figure 2, the modelling steps for marking the shoe line drawing were as follows:

a. Identified the toe cap point (T), heel midpoint (H), quarter bump (B) for the back of the shoe, quarter vertex (Q), and vamp front vertex (V).
b. Connected the five marked points in sequence to form a pentagon. Compared the heights of points B and V. If point B was lower than point V, connected points Q and H to form the quadrilateral 'THQV'. If point B was higher than point V, connected points Q and T to form the quadrilateral 'THBQ'.
c. The acute angle formed by the line HT and line l, passing through point H, was denoted as angle α.
d. Draw a perpendicular line from point B to line l, intersecting at point A. The acute angle formed by the extension of line BQ and line AB was denoted as angle β.
e. Draw a perpendicular line from point Q to line l, intersecting at point P.
f. Connected TQ and HV in quadrilateral THQV to form m_1 and n_1. Connect TB and HQ in quadrilateral THBQ to form m_2 and n_2.
g. The angle formed by the intersection of m_1 and n_1 was denoted as γ_1, and the acute angle formed by the intersection of m_2 and n_2 was denoted as γ.

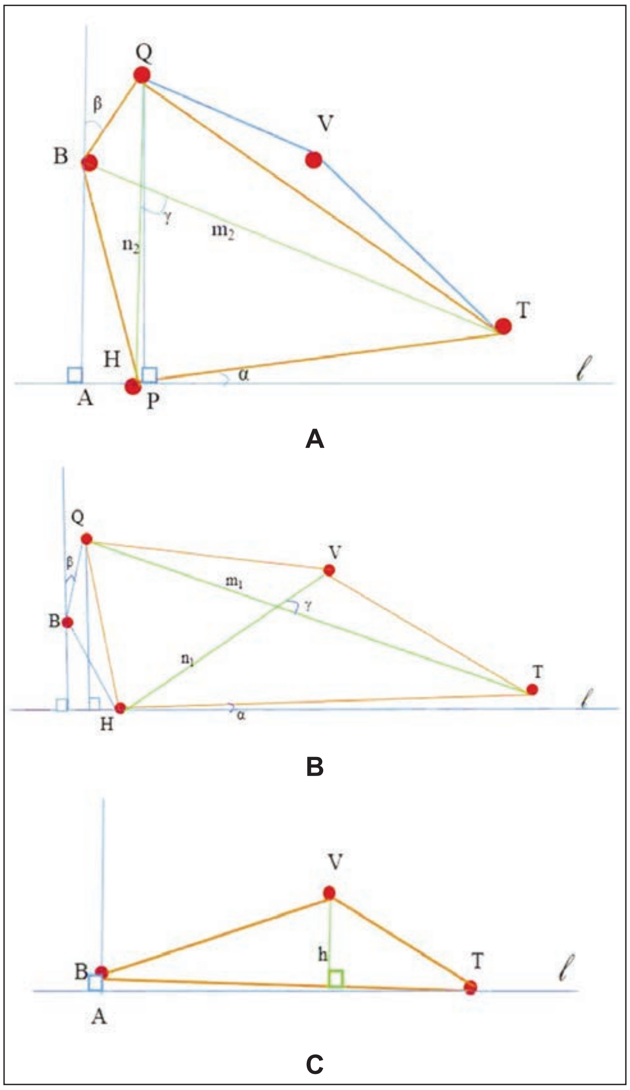


Fig. 2. Footwear line drawing classification model.
A: Modelling when point B was higher than point V;
B: Modelling when point B was lower than point V;
C: Triangle shoe modelling

For shoes without heels, such as flat shoes and loafers, point B was directly marked at the rear end of the sole, and point H could be disregarded. For shoes without a quarter or with open toes, such as sandals and flip-flops, point Q could be disregarded, and point T was marked at the front end of the sole. Therefore, besides forming a pentagon, some shoes could only be marked as a quadrilateral or a triangle. The modelling method for forming a quadrilateral was the same as described above.

The modelling method for shoes that could only form a triangle was as follows:

a. Identified the front end of the sole (T), the high point of the vamp (V), and the rear end of the sole (B).
b. Connected the three points in sequence to form a triangle.
c. Draw a horizontal line passing through point T, and draw a perpendicular line from point B intersecting with the horizontal line at point A.
d. Draw a perpendicular line from point V to line segment BT, and denote this line as h.

Application of the classification model

The quadrilateral or triangle formed by connecting points represents the area occupied by the shoe in the image. In the case of a fixed shoe length, the area of the shoe could be calculated through the formula which could be used for style classification later. At present, the area sizes are correlated with the corresponding shoe styles to establish a ranking.

(1) Area (S) Formula for Quadrilateral Shoe Styles

① Situation where point B was lower than point V (Part A of figure 3).

$$S = \frac{1}{2} m_1 n_1 \cdot \sin\gamma \qquad (1)$$

② Situation where point B was higher than point V (Part B of figure 3).

$$S = \frac{1}{2} m_2 n_2 \cdot \sin\gamma \qquad (2)$$

(2) Area Formula for Triangle Shoe Styles (Part C of figure 3).

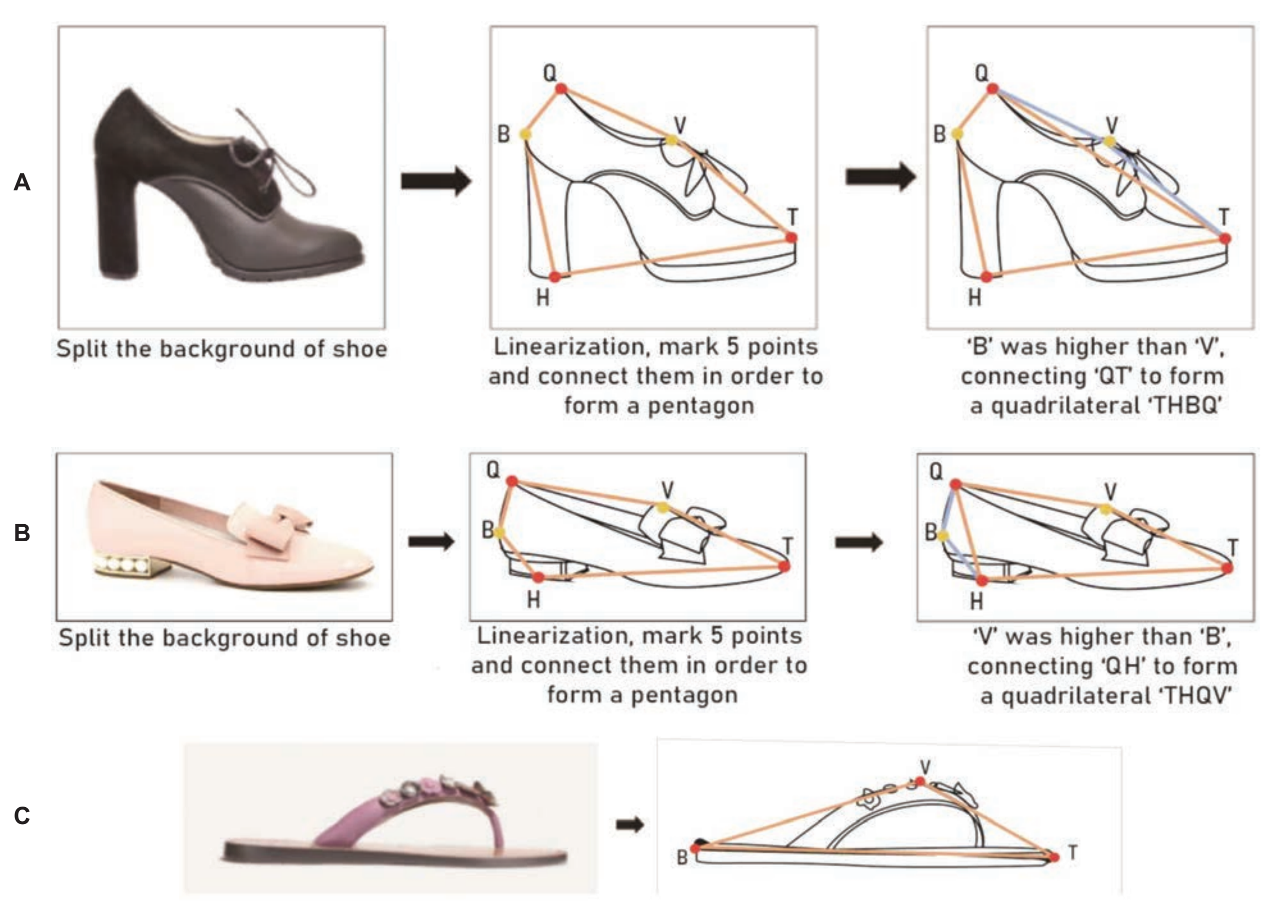
$$S = \frac{1}{2} AB \cdot h \qquad (3)$$

(3) In general, the area size corresponds to the ranking of the shoe categories.

$$S_{Slippers} < S_{Sandal} < S_{Nude} < S_{Loafer} <$$
$$< S_{Oxford} < S_{Sneakers} \approx S_{Casual} < S_{BOOT}$$

The size of angle α depended on the distance of point T from the horizontal plane, representing the thickness of the waterproof platform or the forefoot part of the sole. A larger angle α indicated a greater distance of point T from the horizontal plane, therefore, a thicker waterproof platform or forefoot part of the sole. Conversely, a smaller angle α indicated a smaller distance of point T from the horizontal plane, hence, a thinner waterproof platform or forefoot part of the sole.

The size of angle β was related to the height of the heel. A higher heel results in a larger angle β, while a lower heel results in a smaller angle β.



Split the background of shoe

Linearization, mark 5 points and connect them in order to form a pentagon

'B' was higher than 'V', connecting 'QT' to form a quadrilateral 'THBQ'

Split the background of shoe

Linearization, mark 5 points and connect them in order to form a pentagon

'V' was higher than 'B', connecting 'QH' to form a quadrilateral 'THQV'

Fig. 3. Shoe modelling case. *A:* Modelling when point B was higher than point V; *B:* Modelling when point B was lower than point V; *C:* Triangle shoe modelling

The position and direction of line BH were directly related to the degree of heel inclination and the position relationship.

Point B was approximately located at one-third of the height of the shoe's heel. Line segment PQ represents the distance from the high point of the heel to the horizontal plane. Therefore, the height of the heel could be calculated using the lengths of line segment BA and line segment PQ. By deriving a simplified formula, the height of the heel (h_{HEEL}) could be calculated.

$$h_{HEEL} = \frac{3}{2}AB - \frac{1}{2}PQ \tag{4}$$

Finally, the feasibility of the shoe line drawing classification method was verified by shoe images of fashion trends from autumn/winter 2023 to spring/summer 2024 from the WGSN website.

EXPERIMENTS AND RESULTS

Shoe recognition and extraction

This study trained on the COCO dataset using Mask-RCNN with different Residual Network Backbone. Combining the efficiency and performance comparisons of various backbone networks, ResNet-101-FPN achieved the best balance between performance and consumption and was ultimately adopted. Figure 4 shows segmentation examples using Mask R-CNN and ResNet-101-FPN backbone. It could be seen that Mask-RCNN could effectively segment the shoe body from the background.

Shoe body line drawing extraction

Based on the Python Torch framework, using the Adaptive Moment Estimation Optimizer, PidiNet was trained on the Berkeley Segmentation Dataset and Benchmark 500 (BSDS500) dataset. PidiNet's performance on the BSDS500 dataset was significantly better than some edge detection networks that have emerged in recent years. The following figure 5 shows the recognition effect of the Pixel Difference Network (PidiNet), Dense Extreme Inception Network for Edge Detection (DexiNed), Richer Convolutional Features (RCF), and Canny edge detection networks on typical sneakers, board shoes, and boots. The DexiNed focused too much on detailed edges and identified subtle edges such as fluff and mesh, which was not conducive to establishing a database of the line drawings of the shoe. RCF focused too much on the line drawings and ignored some details of the shoe body, which were likely to be special designs that attracted consumers. Compared to other networks, thanks to the simplified network architecture, PidiNet could effectively extract the line drawings of the shoe, it could also eliminate unimportant edge information caused by small mesh and fluff materials.

Fig. 4. The result of instance segmentation by removing shoes from the background of the image

Case study of model recognition

This article collects the shoe images released by brands from autumn and winter 2023 to spring and summer 2024 on WGSN as the analysis object. 476 valid images were crawled as the analysis dataset, including Berluti (https://www.berluti.cn),

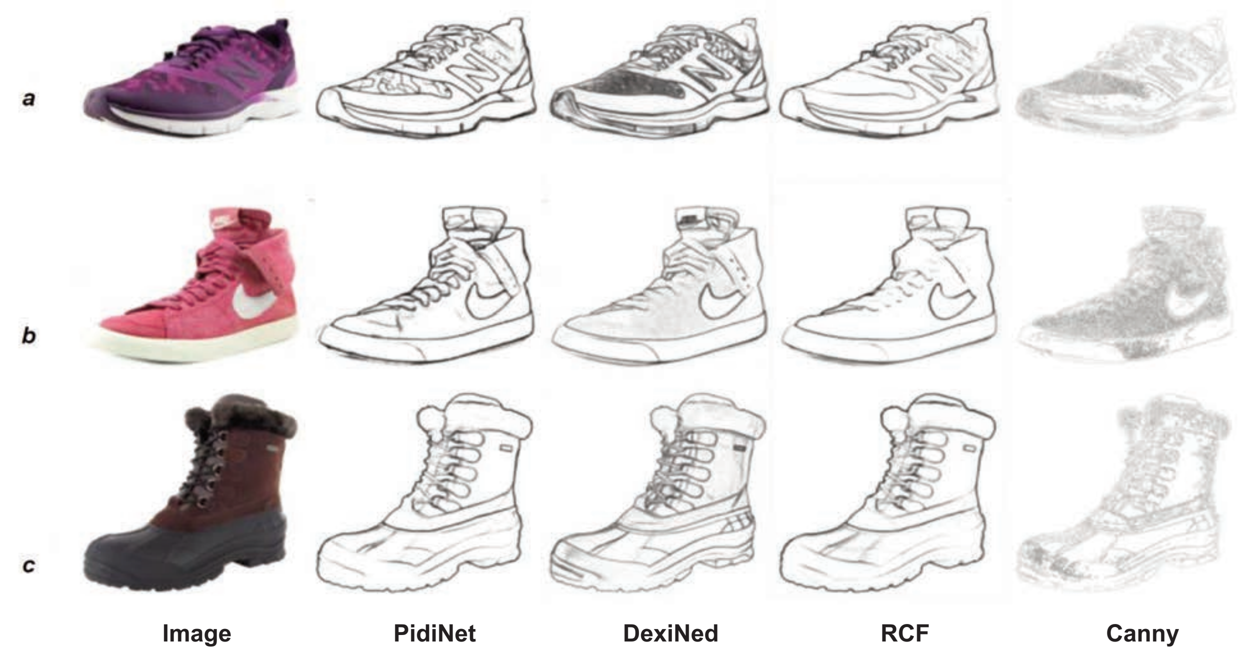


Fig. 5. Shoe Line drawing extraction results

Table 1

THE CLASSIFICATION PERFORMANCE OF SHOE BODY LINE DRAWING

Category	Classification accuracy	Category	Classification accuracy	Category	Classification accuracy
Boots	0.97	Sneakers	0.92	Nude shoes	0.97
Slippers	0.93	Oxford	0.80	Casual	0.84
Sandal	0.92	Loafer	0.83	-	-

Homers (https://www.homers-shoes.com/), Maliparmi (https://www.maliparmi.com/), Urbanima (https://urbanima.com/) and other fashion brands. The performance of image classification was compared and calculated by manual and algorithmic.

It can be seen from table 1 that the classification detection performance of boots, nude shoes, and slippers was relatively good. This may be due to the large differences in the appearance and outline of these shoes, which were easy to distinguish.

Relatively speaking, the recognition performance of loafers and Oxford shoes was the worst, mainly due to these shoes having similar contour characteristics, making it difficult for even ordinary laypersons to distinguish them. Material also affected the classification result, for example, a pair of loafers or leather shoes had a similar outline to a nude shoe, but the algorithm still recognized the shoe as a nude shoe based on the outline characteristics. Of course, the small size of training images in our dataset also restricted the performance of the classification network to some extent.

DISCUSSION

The results strongly verify that computer vision could achieve shoe line drawing extraction and classification. The instance segmentation training based on Mask-RCNN could effectively segment the shoe body. On this basis, we compared the performance and efficiency of various edge detection algorithms for line drawing style recognition, using the PidiNet edge detection network to detect different shoe line templates, and finally using the self-established classification model for classification. The classification results also had significant differences, which may be due to the size of the differences between styles, the influence of some unconventional and exaggerated design line drawings on the results, and the relatively small number of training sets that also restricted the performance of the classification network. Compared with traditional manual hand-drawn lines, this method conveniently improved the efficiency of shoe line drawing extraction and style classification.

This study designed a classification model for shoe line drawing styles. However, in the research on recognition methods based on digital image processing, various techniques mainly recommend and implement deep recognition and extraction classification for clothing fashion elements such as colour and material. Yang et al. [15] developed an effective colour segmentation method and proposed a complete real-time clothing category labelling system. Hidayati et al. [16] determined a set of style elements based on fashion design theory and proposed a new method for automatically classifying clothing genres based on visually distinguishable style elements. Di et al. [17] used Local Binary Patterns (LBP), Scale-Invariant Feature Transform (SIFT), and Histogram of Oriented Gradients (HOG) features and used a Support Vector Machine Classifier (SVM) classifier to classify clothing into 12 categories. Chen et al. [18] used the same features and based on a sparse coding method to classify clothing into 10 fashion style categories. In this study, we innovatively designed a classification method for shoe line drawings, which complements the gap in the field of computer vision fashion research in the classification of shoe style elements.

Secondly, this study successfully extracted the line drawings of shoes with good effect using the edge detection PidiNet algorithm. In the current field of popular element recognition for line drawings, the main methods for feature extraction and classification of clothing line drawings were extreme learning machine classification based on wavelet Fourier descriptor and Euclidean distance classification based on fused features. Manikandan et al. [19] used digital image processing techniques such as image binary conversion, noise point removal, stripe edge smoothing, and stripe width measurement to obtain the image contour of clothes and measure the elongation of fabrics. Takahashi et al. [20] proposed an image processing system that extracts the outline of clothing in images using edge information for automatic inspection of T-shirts and other flat clothing, making the clothing detection process more effective. Wu et al. [21] proposed a classification method based on Fourier contour descriptor using SVM, which obtained the edge of images at various resolutions using an edge detection algorithm. The experiment results of various clothing styles show that the Fourier descriptor had a high recognition rate for each piece of clothing. However, at present, there is no effective method to extract the features of clothing and classify them. Moreover, in many applications, the extracted 2D data line extraction could be very challenging. Donati et al. [3] proposed an automatic vectorization system for fashion hand-drawn sketches based on the Pearson correlation coefficient and multiple Gaussian kernels to enhance and extract the curve structure in sketches. It used a dataset of hand-drawn sketches drawn by professional designers using different pens, different styles, and different backgrounds to train the extracted lines for more reliable vectorization. However, these studies on line drawings also focus more on clothing, and fewer relevant studies could be directly and effectively applied to the field of shoe design.

At the same time, the algorithm classification method in this study overcame one of the main challenges in learning the attributes of shoes, which was the lack of a training database. Nowadays, in the fashion field, most classification methods train algorithms through large-scale clothing databases, for the complex problem of feature extraction in image recognition and have people label the image attributes in the database, allowing deep learning algorithms such as convolutional neural networks to train and self-learn recognition and classification [15, 22, 23]. Elleuch et al. [24] verified on the popular ImageNet clothing dataset. They identify the clothing types based on deep learning and transfer learning in a given dataset from images [25]. ImageNet was the most commonly used dataset in this research field, as it was considered to be one of the largest datasets for image object recognition, with 1.2 million 256×256 RGB images [26]. Chen et al. [27] verified the optimization of convolutional neural network deep learning algorithm in clothing style classification and retrieval tasks in 3 large-scale clothing public databases. Yamaguchi et al. [28] created a dataset containing 158,235 images. Yan et al. [2] established a large-scale dataset consisting of 115,584 pairs of fashion item images for model performance evaluation. Lin et al. [29] applied transfer learning to a clothing retrieval system based on a hierarchical deep search framework on a dataset consisting of 161,234 images from Yahoo Shopping. In these studies, labelling clothing attributes in images required a lot of time, and extensive domain expertise. At the same time, these studies mainly focus on establishing a database for clothing. In contrast, this study did not rely on a large number of shoe images for training, achieving more efficient, fast, and low-cost automatic shoe fashion elements classification.

Overall, by automatically extracting effective and reasonable line drawings from shoe images through image segmentation and edge detection techniques, the efficiency of transforming design line drawings into vector design drawings could be further improved, while providing more design inspiration and possibilities. At the same time, this complements the gap in the specific research on shoe fashion elements in the AI fashion industry. In the future, it could even assist in automatically generating the line design of new shoes, adding direct modification editing and 3D effect transformation functions [30].

CONCLUSION

Our study developed a footwear line drawing analysis and classification system based on computer vision technology. Initially, the study focused on the targeted classification of footwear line characteristics, and the algorithms were trained accordingly. Subsequently, an innovative approach for classifying footwear line drawings was developed, Finally, a high-precision extraction and classification of the lines drawing styles of footwear products from the 2023–2024 WGSN trend website was performed. The results demonstrated a good accuracy in footwear line drawing extraction and classification. The automation of footwear line drawing recognition and extraction was expected to enhance the efficiency and innovation capabilities of the fashion industry, thereby promoting sustainable development in the field of fashion research. This technological advancement not only accelerates product innovation and market entry but also reduces the environmental burden, ensuring the long-term healthy development of the fashion industry in line with social and environmental responsibilities. Furthermore, it provided robust support for the large-scale establishment of foundational datasets for popular footwear trends.

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Authors:

LI JINGJING[1], ZHAO YEBAO[2], KEYU HOU[3], ZHOU JIN[1]

[1]Sichuan University, College of Biomass Science and Engineering, National Engineering Laboratory for Clean
Technology of Leather Manufacture, Section of Chengdu No. 24 Southern Yihuan, 610065, Chengdu, China

[2]Zhejiang Huafeng new material Co., LTD. Wenzhou Zhejiang Province, 325200, China
e-mail: zhao.yebao@huafeng.com

[3]Zhejiang Huilima Industrial Internet Co., Ltd, Wangjiawei Road, Dongou Industrial Zone, Oubei Street, Yongjia County,
Wenzhou City, Zhejiang Province (within Zhejiang Red Dragonfly Shoes Co., Ltd.), China
e-mail: 625368881@qq.com

Corresponding author:

ZHOU JIN
e-mail: zj_scu@scu.edu.cn

Impact of taker-in speed on the characteristics of ring-spun yarn

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ABILDA YESHZHANOV
RAMAZAN ERDEM
GULZHAN MURZABAYEVA
SANJAR TOJIMIRZAEV
AKBOTA BATYRKULOVA
RASHID KALDYBAEV
ASSEL ZHAMBYLBAY

ABSTRACT – REZUMAT

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In this study, experiments were carried out to determine to what extent the card sliver and final yarn quality were altered by a gradual increment in the speed of the taker-in roller on the carding machine. The speeds of the taker-in roller have been determined as 1200 rpm, 1400 rpm and 1600 rpm, respectively. The operating parameters of the carding machine and other equipment in the yarn production line were kept constant. Fibre breakage, neps removal efficiency, and defect index of samples have been measured by the AFIS PRO2 laboratory instrument. The characteristics of ring spun yarn (17.35 tex) were tested on a Uster Tester-5 (UT-5) laboratory device. Research results revealed that the enhancement of taker-in speed led to increased fibre breakage due to the greater impact force on the cotton fibre. This elevates the number of short fibres in the material and also negatively affects the final yarn properties including unevenness (U%), imperfection index (IPI), ultimate yarn strength (cN/tex), and hairiness index (H-value).

Keywords: *ring spinning, carding, taker-in speed, sliver, yarn properties*

Impactul vitezei cilindrului rupător asupra caracteristicilor firelor filate cu inele

În acest studiu, au fost efectuate experimente pentru a determina în ce măsură banda de cardă și calitatea finală a firului au fost modificate prin creșterea treptată a vitezei cilindrului rupător pe mașina de cardat. Vitezele cilindrului rupător au fost determinate ca fiind 1200 rpm, 1400 rpm și, respectiv, 1600 rpm. Parametrii de funcționare ai mașinii de cardat și ai altor echipamente din linia de producție a firelor au fost menținute constante. Ruperea fibrelor, eficiența de îndepărtare a nopeului și indicele de defect al probelor au fost măsurate cu instrumentul de laborator AFIS PRO2. Caracteristicile firului filat cu inele (17,35 tex) au fost testate pe dispozitivul de laborator Uster Tester-5 (UT-5). Rezultatele cercetării au arătat că creșterea vitezei cilindrului rupător a dus la un grad mai mare de rupere a fibrei din cauza forței mai mari de impact asupra fibrei de bumbac. Astfel, crește numărul de fibre scurte din material și, de asemenea, afectează negativ proprietățile finale ale firului, inclusiv neuniformitatea (U%), indicele de imperfecțiune (IPI), rezistența finală a firului (cN/tex) și indicele de pilozitate (valoarea H).

Cuvinte-cheie*: filare cu inele, cardare, viteza cilindrului rupător, bandă de fibre, proprietăți ale firului*

INTRODUCTION

One of the most important factors affecting the quality of final textile products is the efficiency of the utilized yarn production technology [1]. Today, machinery manufacturers and spinning mills face the challenge of producing high-quality yarns at high carding speeds and low waste levels [2–4]. Many studies in the literature state that the carding process is generally based on tasks such as separating the fibres from each other, cleaning them from foreign substances, separating defective fibres from the system, making the fibres partially parallel to each other, thinning the fibre layer up to 100 times, diminishing short term variation in sliver thickness and formation of carding sliver of the required quality and placing it in a basin [5–8].

During manufacturing, there is a close relation between increasing production rate and decreased quality level; as the production rate increases, the carding process gets more severe, and the risk of unfavourable impacts on quality propels [9–11]. Since 1770, the carding machine's operational principle and concept have remained unchanged. Statistical data revealed that, with the advancement of technology, carding productivity has increased from around 5 kg/h to about 100 kg/h since 1965 [12].

Numerous characteristics (tenacity, elongation, unevenness etc.) of the yarn manufactured in a spinning mill are determined by the fibre properties as well as the setting parameters of the machines in the spinning line where the carding process is one of the most crucial ones. To enhance production efficiency, it is necessary to maintain the carding quality and improve the carding process in the drum receiving area (taker-in zone) as well as between the main drum and the carding flats (figure 1). Furthermore, it is essential to ensure that the carded fibres pass completely from the main drum to the separation drum [13].

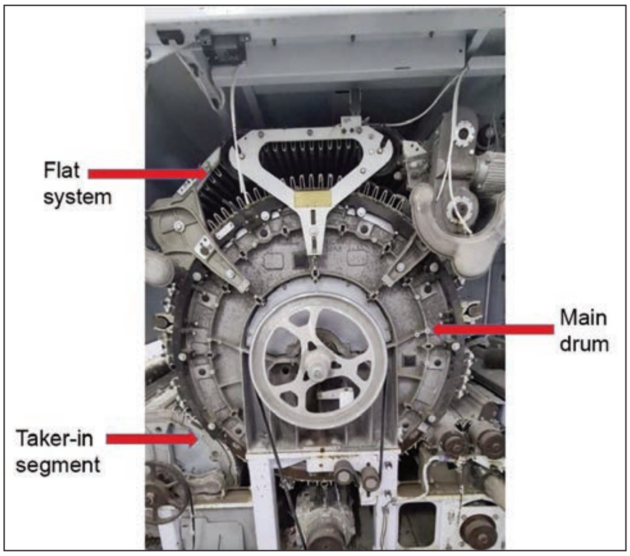

Fig. 1. Main parts of the carding machine

The taker-in zone is crucial during the separation of the bundles into individual fibres and removing the foreign substances and defects from fibrous material. The taker-in zone includes a feed plate, feed roller, taker-in and mote knives. Under a specific load, fibre matt is held between the grooved feed roller and the smooth-curved surface of the feed plate and fed to the taker in segments by the feed roller rotations [14]. In this machine segment, approximately, 70–80% of the fibres are split into individual fibres, and foreign substances and defects are eliminated almost in the same percentage [15]. The following variables have major consequences on the processing of the fibre tuft in the taker-in zone; feed roller speed, setting between the feed plate and the taker-in, feed fibre matt uniformity and its characteristics, taker-in speed, adjustment between taker-in and mote knife, and taker-in wire specifications [16].

The speed of the taker-in drum in the carding machine influences the amount of debris leaving the system; nevertheless, excessive speed may also cause fibre damage. The rotation frequency of the main drum is very effective in opening the fibres individually. The speed of the knives is responsible for the removal of short fibres but does not affect the homogeneity of the product [17].

Several studies were conducted to determine the best configuration parameter for a carding machine to generate a high-quality card sliver. For instance, Ghosh and Bhaduri discovered that the card web is primarily governed by cylinder and doffer speeds, as well as the linear density of the delivered sliver [18]. Zhang and Sun explored the effects of carding machine rear stationary flat gauge and taker-in speed selection [19]. Simpson et al. examined the influence of carding rate and cylinder speed on fibre hooks and spinning efficiency and discovered that enhancing the carding rate elevated minority hooks while declining majority hooks [20].

Despite extensive investigation efforts on various process parameters of carding machine, there is a shortage of specific research on the influence of taker-in speed on the quality of card sliver and the properties of ring spun yarn. In current research, as a novel approach, the impact of three different taker-in speeds (1200 rpm, 1400 rpm and 1600 rpm) on the fibre breakage, cleaning efficiency, carding and drawing sliver unevenness, and the ring spun yarn's strength, unevenness and hairiness have been examined.

MATERIALS AND METHODS

Fibre samples were selected from flowing materials by random sampling method at the Azala Cotton LPP Spinning Mill (Shymkent, Republic of Kazakhstan). Cotton samples were tested on laboratory equipment with AFIS and HVI systems [21]. The properties of the studied cotton fibre samples are depicted in table 1.

Table 1

DETAILED PHYSICAL AND MECHANICAL PROPERTIES OF FACTORY-SORTED COTTON FIBRE

Parameters	Values
2.5% Spun length (mm)	28.5–29
Uniformity ratio (%)	49
Strength (cN/dtex)	2.85–3
Elongation (%)	8
Micronaire, MI	4.4–4.8
Short fibre index (%)	6–10
Reflectance, Rd	74.8
Yellowishness, +b	9.4

In table 1, the micronaire value has been presented as MI by the calculation of equation 1 [22].

$$\text{dtex} = \text{MI} \times 0.394 \quad (1)$$

The following equations have also been used to analyse the measurement results of the current study. For instance, the uneven distribution of fibres along the length of the yarn is the cause of the unevenness (U%), which is the mass deviation of a unit length of material (equation 2) [23].

$$\text{Unevenness (U\%)} = \text{(mean deviation)/mean} \times 100 \quad (2)$$

The imperfection index of yarns (IPI) has been determined according to equation 3 [23].

$$\text{IPI} = \text{Thick places (+50\%), thin places (–50\%), and neps (+200\%)} \quad (3)$$

The following samples were obtained using the random sampling method: at running speeds of 1200 rpm, 1400 rpm and 1600 rpm for the taker-in, the samples were taken from the feed hopper. All the other process parameters remained the same during the production. Selected samples were tested on the AFIS PRO2 laboratory instrument where fibre breakage, neps removal efficiency, and defect index of samples, fed into and exited from the device, have

Table 1

PROCESS PARAMETERS FOR 17.35 TEX COUNT RING YARN PRODUCTION

Process type	1	2	3
Carding	RIETER C60		
Drawing hank (tex)	~ 70	~ 70	~ 70
Taker-in speed (rpm)	1200	1400	1600
Maim drum speed (rpm)	520	520	520
Flats speed (mm/min)	330	330	330
Doffing drum speed (m/min)	152	152	152
Wadding density (g/m)	500-600	500-600	500-600
Productivity (kg/h)	120	120	120
1st drawing transition	RIETER SB-40		
Drawing hank (tex)	~ 70	~ 70	~ 70
Break draft	1.2	1.2	1.2
Total draft	4.56	4.56	4.56
Outlet velocity (m/min)	300	300	300
Doubling	8×8	8×8	8×8
Rolls between settings	A-39, B-37	A-39, B-37	A-39, B-37
2nd drawing transition	RIETER RSB-D 40		
Drawing hank (tex)	~ 70	~ 70	~ 70
Break draft	1.2	1.2	1.2
Total draft	6	6	6
Outlet velocity (m/min)	600	600	600
Doubling	6×6	6×6	6×6
Rolls between settings	A-42, B-37	A-42, B-37	A-42, B-37
Roving	RIETER F-35		
Roving No. (tex)	~ 484	~ 484	~ 484
Flyer speed, rpm	1250	1250	1250
Twist (Turn/meter)	43	43	43
Condenser	Black	Black	Black
Total draft	7	7	7
Break draft	1.2	1.2	1.2
Condenser (mm)	12	12	12
Spinning	RIETER G-35		
Total draft	35.7	35.7	35.7
Break draft	1.1	1.1	1.1
Condenser	White	White	White
Rolls between settings	49	49	49
Spinning chamber speed (rpm)	17400	17400	17400
Twist/meter	771	771	771

been measured. The cleaning efficiency of the carding process was tested using an analyser (MESDAN). The studied material went through a spinning process with constant technical parameters indicated in table 2 and the produced yarn from a ring spinning machine (G-35, RIETER) was tested on a laboratory device Uster Tester-5 (UT-5) in terms of defects (IPI), unevenness (%), hairiness and strength of single yarn. For each test, a total of 30 samples (10 samples from each taker-in speed) were analysed and average results were calculated. Also, ring-spun yarns were examined under a light microscope (Mikromet) at 10× magnification.

RESULTS AND DISCUSSION

Figure 2 illustrates an increase in fibre breakage as the taker-in speed is raised from 1200 to 1600 rpm. The amount of short fibre at the taker-in speeds of 1200 rpm, 1400 rpm and 1600 rpm was determined as 5.6%, 6%, and 6.8% on average, respectively. It may be noted here that as the carding machine's taker-in speed increases, the cotton fibres are exposed to harsher impacts and fibre breakage occurs. This has elevated the number of short fibres in the material. Besides, the overall fibre length of the material has declined. The increase in the number of short fibres directly affects the final yarn properties negatively.

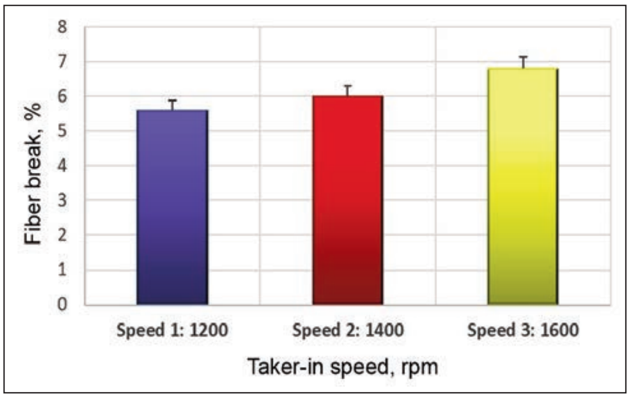

Fig. 2. Effect of taker-in speed modes on fibre breakage

The correlation between taker-in speed and cleaning efficiency is demonstrated in figure 3. Average cleaning efficiency values have been measured as 85.5%, 88.5%, and 94.5% for taker-in speeds of 1200 rpm, 1400 rpm, and 1600 rpm, subsequently.

Experimental observations have proved that the cleaning efficiency improves as the main drum speed accelerates. Moreover, enhancing the taker-in speed

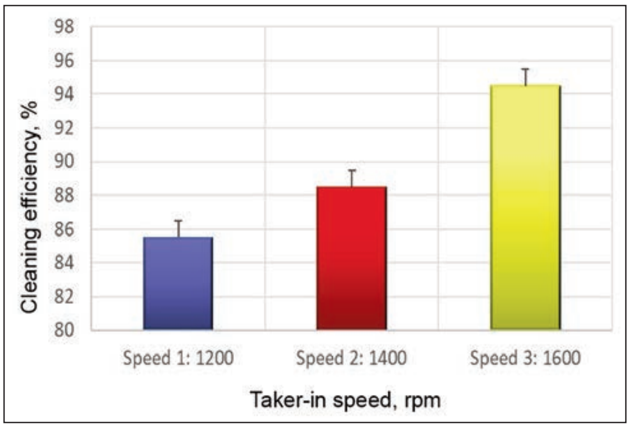

Fig. 3. Effect of taker-in speeds on cleaning efficiency when carding

increases the number of strokes during carding and improves the card's cleaning efficiency. On the other hand, neps removal efficiency increases up to a certain degree as the drum speed goes up, however, further increase in speed reduces the effectiveness of neps removal.

Figure 4 presents the effect of taker-in speed on the unevenness (U%) of the card sliver. According to the graph, unevenness firstly lessens as the taker-in speed increases from 1200 rpm to 1400 rpm, and then it exhibits an enhancing trend at 1600 rpm. Unevenness has been measured as an average of 3.75%, 3.35%, and 4.15% for the taker-in speeds of 1200 rpm, 1400 rpm, and 1600 rpm, respectively. Propelling the taker-in speed induces fibre breaks to occur and, as a result, the percentage of short fibre yield increases. At the optimum speed of entry, short fibres are removed from the flat slivers, thus improving the unevenness in the carding sliver.

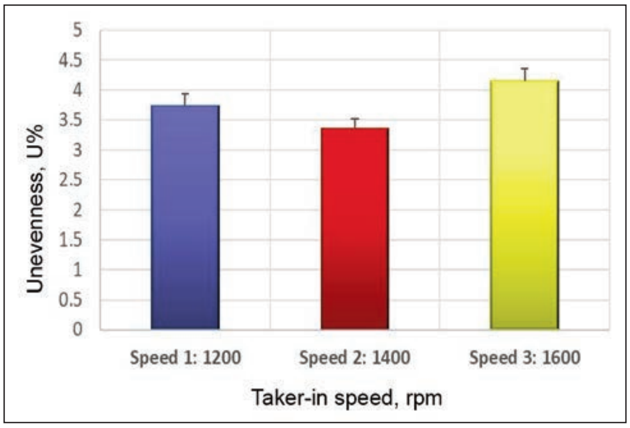

Fig. 4. Effect of taker-in on carding sliver unevenness (U%)

Figure 5 depicts the relation between the taker-in speed and the first draw frame (RIETER SB-40) transition's unevenness. It has been found that the unevenness of the first draw frame pass declines with the increment of taker-in speed. The highest value of the draw frame sliver unevenness (U%-3.39) was measured when the taker-in speed was set to 1200 rpm. Also, unevenness of draw frame sliver values was averagely determined at the taker-in speeds of 1400 rpm and 1600 rpm as an average of U%-3.29 and 3.23%, respectively. For further minimizing the carding sliver unevenness level, the drawing frame process plays a crucial role. The main task of the draw frame is to reduce the unevenness by drawing and doubling the sliver [24]. The draw frame's unevenness is lowered due to the doubling of 8 carding slivers.

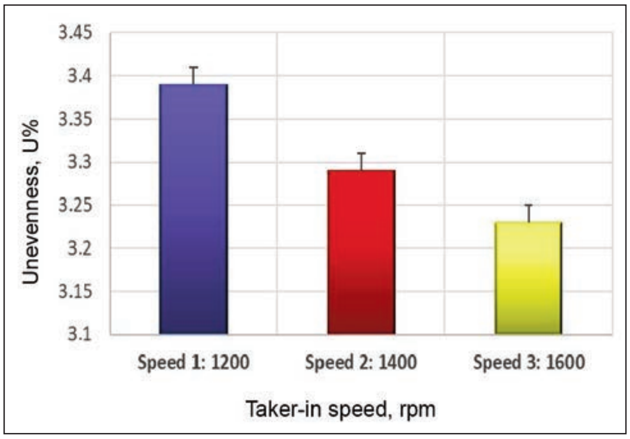

Fig. 5. Effect of taker-in speed on the first transition of the drawing sliver unevenness

At the second transition of the drawing (RIETER RSB-D 40) sliver, the unevenness lessens as the taker-in speed gets higher (figure 6). As represented in the graph, unevenness values have been determined as the average of 2.5%, 2.52%, and 2.21% at the taker-in speeds of 1200 rpm, 1400 rpm, and 1600 rpm, respectively. The primary aim of the second transition of the drawing sliver is to reduce the unevenness by doubling and auto-adjusting [25]. The results proved that a noticeable reduction occurred in unevenness on the second transition of the drawing sliver.

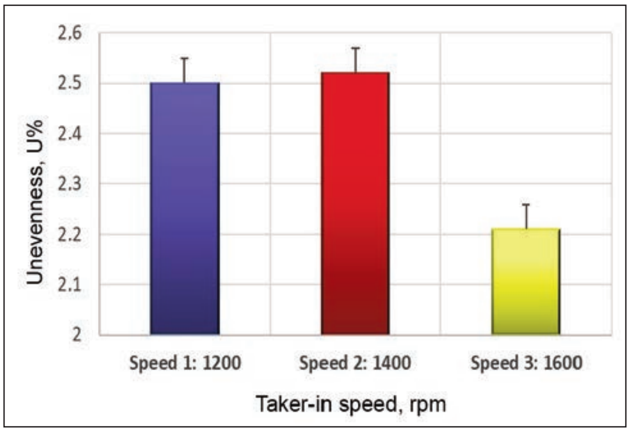

Fig. 6. Effect of taker-in speed on the second transition of the drawing sliver

Figure 7 illustrates the effect of the taker-in speed on the unevenness of the yarn produced by ring spinning. Ten ring bobbins were tested for each taker-in speed to determine yarn unevenness, and the average was determined. Yarn unevenness values were averagely found to be 11.7% for 1200 rpm, 11.4% for 1400 rpm and 10.9% for 1600 rpm, respectively (figure 7). As can be seen from the graph, the most positive result was obtained when the taker-in speed was 1600 rpm. This result could be explained by the fact that at the high speed of the taker-in drum in the carding machine, the amount of fibre per unit area is sufficient and an optimum amount of fibre can be transferred for subsequent processes. As it is known, yarn irregularity reflects negatively on the performance and strength of the yarn, which causes the quality of the yarn to decrease [26].

Figure 8 exhibits the impact of taker-in speed on IPI values. The imperfection index of yarns, or IPI for short, describes the thick places, thin places, and neps in a 1000 m length of yarn [23]. According to the

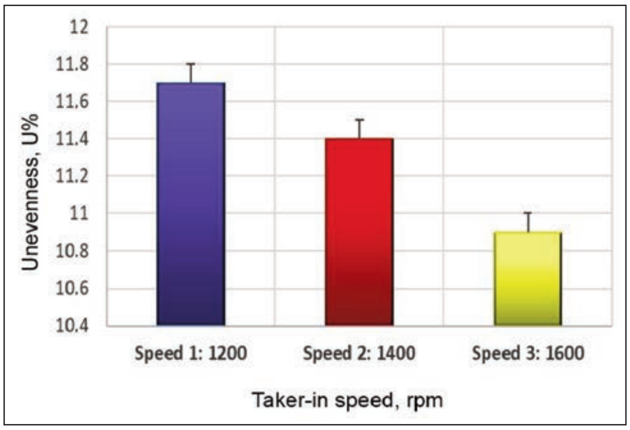

Fig. 7. Effect of taker-in speed on yarn unevenness (U%)

graph, IPI values of the ring spun yarn have been averagely calculated as 190 for 1200 rpm, 250 for 1400 rpm, and 360 for 1600 rpm. It can be concluded that the defect IPI index increases as the taker-in speed goes up. Short fibres directly affect the IPI because more fibres are damaged with increasing taker-in speed.

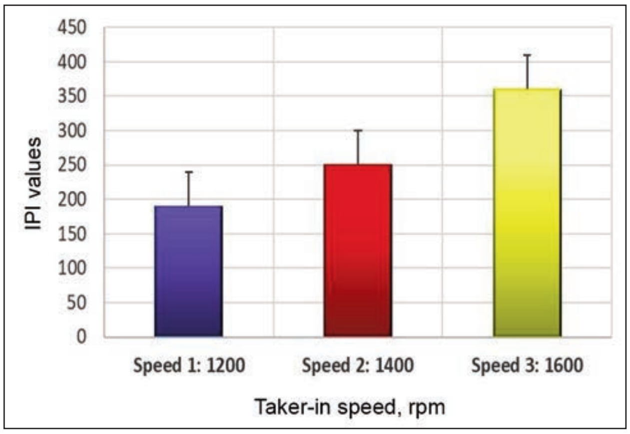

Fig. 8. Effect of taker-in speed on yarn defects (IPI)

Figure 9 represents the influence of taker-in speed on the ultimate yarn strength. It is calculated by utilizing the data gathered from tests of single-yarn strength. The breaking force and associated elongation of 100% carded cotton were ascertained by these strength tests. There is a strong correlation between ultimate yarn strength (cN/tex) and breaking elongation ratio (%) [27]. According to the graph, ultimate yarn strength values have been averagely determined as 15.49 cN/tex for 1200 rpm, 15.1 cN/tex for 1400 rpm, and 14.8 cN/tex for 1600 rpm, respectively. Results revealed that the ultimate yarn strength of ring-spun yarn decreases as the taker-in speed increases. Because of fibre breakage at greater speeds, the number of short fibres in the sliver surges. An enhanced number of short fibres reduces the yarn's relative strength.

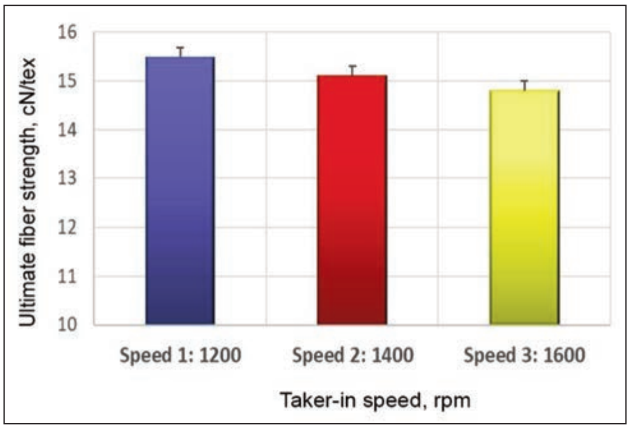

Fig. 9. Effect of taker-in speed on ultimate yarn strength (cN/tex)

The effect of taker-in speed on yarn hairiness is demonstrated in figure 10. The total length of protruding fibre/cm length of yarn is the definition of the hairiness index (H-value). Throughout seven length zones, the number of protruding fibres is counted within a 1–10 mm range. The individual count of protruding fibres in each length zone is normalized to 100 m yarn length [28]. According to the graph, the hairiness properties of the obtained yarns were averagely determined as 5.4 at 1200 rpm, 5.9 at 1400 rpm, and 6.2 at 1600 rpm, respectively. From the graph, it can be determined that as the speed of the receiving drum of the carding machine increases, the hairiness of the ring yarn also increases. This is most probably due to fibre damage at elevated speeds and the formation of short fibres in the system. The rising quantity of short fibres in a yarn causes the growth of protruding fibres, which contributes to the increased hairiness of the yarn.

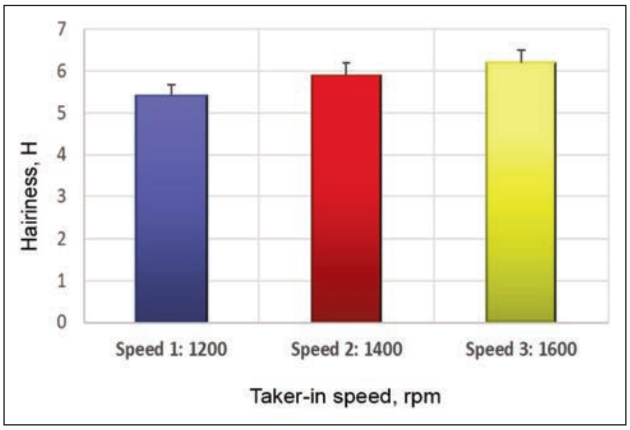

Fig. 10. Effect of taker-in speed on hairiness

Microscopic analyses were also conducted to further investigate the surface characteristics of the ring-spun yarns (17.35 tex) that were produced by utilizing three taker-in speeds of 1200 rpm, 1400 rpm, and 1600 rpm (figure 11). Pictures exhibit that as the taker-in speed increments, unevenness and hairiness properties of the yarns also increase.

CONCLUSION

In the current study, to obtain 17.35 tex count cotton yarn in the ring yarn production line, the speeds of the taker-in segment of the carding machine were set

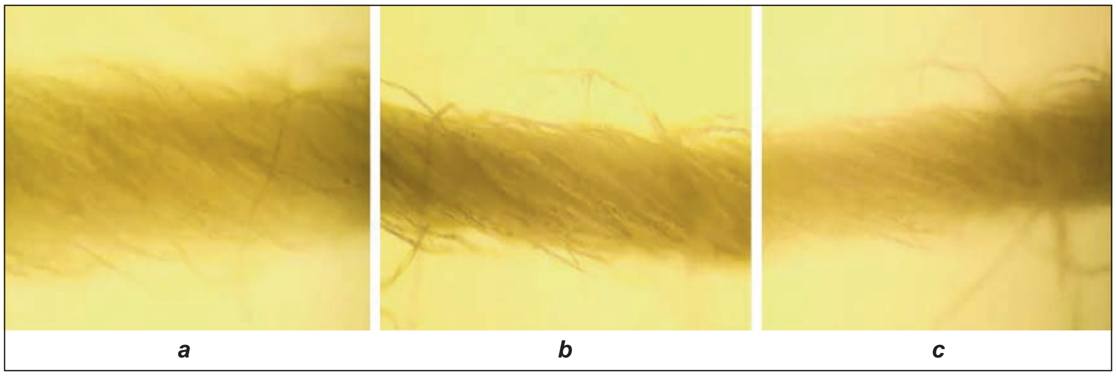

Fig. 11. Microscopic pictures (10x) of ring spun yarn (17.35 tex) produced in different taker-in speeds: *a* – 1200 rpm; *b* – 1400 rpm; *c* – 1600 rpm

as 1200 rpm, 1400 rpm and 1600 rpm and the effect of these speeds on the sliver and yarn characteristics was observed. In addition, the changes in intermediate processes along the yarn manufacturing were analysed. With the increase in taker-in speed, the cleaning efficiency in the carding machine increased. Moreover, with the increment of taker-in speed, the unevenness of the card sliver fluctuated. It has been discovered that the unevenness of the initial draw frame passes declines with the enhancement of taker-in speed. As the taker-in speed increases at the second transition of the drawing, the unevenness decreases. On the other hand, specific properties of ring-spun yarn including unevenness, IPI, ultimate yarn strength (cN/tex) and hairiness exhibited a downward tendency, when the taker-in speed went up. Current research proved that the speed of the taker in the segment of a carding machine is highly influential on the properties of the sliver and yarn qualities so it should be taken into consideration during the experiments regarding the increase of productivity.

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Authors:

ABILDA YESHZHANOV[1], RAMAZAN ERDEM[2], GULZHAN MURZABAYEVA[1], SANJAR TOJIMIRZAEV[3],
AKBOTA BATYRKULOVA[1], RASHID KALDYBAEV[1], ASSEL ZHAMBYLBAY[1]

[1]Textile and Food Engineering, M. Auezov South Kazakhstan State University, Shymkent, Kazakhstan

[2]Textile Technology, Serik GSS Vocational School, Akdeniz University, Antalya, Türkiye

[3]Urgench State University, Uzbekistan

Corresponding author:

RAMAZAN ERDEM
e-mail: ramazanerdem@akdeniz.edu.tr

Second-hand clothing classification algorithm based on feature fusion and attention

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TING CHENG
YUN ZHANG
WEIBO LI
JUNJIE ZHANG

ABSTRACT – REZUMAT

Second-hand clothing classification algorithm based on feature fusion and attention

This study suggests a second-hand clothing categorization method based on enhanced residual networks to enhance the effect of second-hand clothing retrieval and encourage clothing transactions on second-hand platforms. This study first gathers image data on used garments. Web crawlers are utilized to gather internet photos of second-hand clothes to train the network model, while camera equipment is used to take pictures of second-hand clothing. The resulting images are then used to assess the network model's categorization accuracy. The next step is to construct a classification model based on ResNet50, add an attention mechanism, and carry out feature extraction in stages. Finally, the developed classification model's performance is assessed and contrasted with other approaches. The experimental findings demonstrate that this strategy outperforms previous methods in terms of classification accuracy on the self-built dataset and DeepFashion dataset, reaching 79.69% and 82.22%, respectively. Additionally, the sorting and recycling of used clothing is greatly assisted by this method.

Keywords: *clothing image classification*, *second-hand clothing*, *residual network*, *attention mechanism*, *feature extraction*

Algoritm de clasificare a îmbrăcămintei second-hand, bazat pe fuziune de caracteristici și mecanism de atenție

Acest studiu sugerează o metodă de clasificare a îmbrăcămintei second-hand, bazată pe rețele reziduale îmbunătățite, pentru a spori efectul recuperării îmbrăcămintei second-hand și pentru a încuraja tranzacțiile de îmbrăcăminte pe platformele second-hand. Acest studiu adună mai întâi date imagistice despre articolele de îmbrăcăminte uzate. Programele de tip „web crawler“ sunt utilizate pentru a colecta fotografii de pe internet ale îmbrăcămintei second-hand pentru a antrena modelul de rețea, în timp ce echipamentele cu camera web sunt folosite pentru a fotografia îmbrăcămintea second-hand. Imaginile rezultate sunt apoi utilizate pentru a evalua acuratețea de clasificare a modelului de rețea. Următorul pas este construirea unui model de clasificare bazat pe ResNet50, adăugarea unui mecanism de atenție și efectuarea extragerii caracteristicilor în etape. În cele din urmă, performanța modelului de clasificare dezvoltat este evaluată și comparată cu alte abordări. Descoperirile experimentale demonstrează că această strategie depășește metodele anterioare în ceea ce privește acuratețea clasificării pe setul de date autoconstruit și setul de date DeepFashion, atingând valori de 79,69% și, respectiv, 82,22%. În plus, sortarea și reciclarea îmbrăcămintei uzate este îmbunătățită semnificativ prin această metodă.

Cuvinte-cheie: *clasificarea imaginii îmbrăcămintei, îmbrăcăminte second-hand, rețea reziduală, mecanism de atenție, extragerea caracteristicilor*

INTRODUCTION

Although using second-hand clothes reduces carbon emissions significantly, this practice is not widely used worldwide due to the influence of important technology and consumer behaviours. Only 10% to 20% of waste textiles in Europe are sold on the used market to be recycled. The foundation for recycling used garments is an effective sorting method [1]. The two primary methods currently used for sorting textiles are manual sorting and automated sorting. To detect and categorize waste clothing components, automatic sorting mostly uses Near Infrared Spectrometry (NIRS) and Raman Spectrometry (RS) [2]. Since manual sorting typically relies on experienced people to conduct the corresponding sorting procedures on the production line, it is vulnerable to visual fatigue and is more easily influenced by subjective factors. As a result, there are many missed and incorrect detections. Contrarily, even though NIRS and RS identification techniques offer great accuracy for waste textiles, their use in industrial settings is constrained by their high working environment requirements. The most effective option to implement the classification of used clothing is the recognition system based on machine vision since it can more adequately compensate for their limitations [3]. The machine vision recognition system can also be used in the commercial sector in addition to the industrial sector. For instance, improved clothes categorization on the second-hand clothing trading platform makes it easier for buyers to locate listed second-hand clothing through suggested information, encouraging both buyers and sellers to complete deals faster.

Classification methods based on machine vision can be divided into two categories: clothing classification methods based on traditional image content and clothing classification methods based on deep learning. Clothing classification methods based on traditional image content mainly use image processing technology to extract image features to describe clothing. Commonly used image features include Local binary pattern (LBP) [4], Scale-invariant feature transform (SIFT) [5], Histogram of oriented gradient (HOG) [6], etc. Classification is performed by inputting the extracted features or combination of features into classifiers such as Support Vector Machine (SVM) [7] and Random Forest (RM) [8]. Such methods are limited by their reliance on the manual design of features and feature combinations, which are highly subjective and task-specific. At the same time, these models can only extract shallow features, and the models are prone to overfitting and inefficiency due to the large amount of data, which ultimately affects the classification accuracy. However, the clothing classification method based on deep learning is not limited by the above conditions. Among them, Convolutional Neural Network (CNN), as a deep learning technology for analysing visual images, can directly convolve image pixels and extract image features from image pixels. In addition, the weight-sharing property and pooling layer of the CNN greatly reduce the parameters that the network needs to train, simplify the network model, and improve the efficiency of training [9, 10]. Yu et al. [11] used VGG16 as the feature extraction network and then added a convolutional block attention module in the second convolutional block to enhance attention to the target area. Therefore, feature extraction is very suitable as a visual recognition technology applied to the field of second-hand clothing classification.

Images of used clothing have the following issues in comparison to brand-new clothing: first, there are frequently issues with cluttered shooting situations, complicated shooting backgrounds, and inadequate lighting when it comes to second-hand clothes photographs. Second, there are unknown elements in used clothing such as deformation, folds, and occlusion. The current second-hand clothing image classification impact is frequently unsatisfactory due to these ambiguous elements, and it is unable to adequately address the needs of second-hand clothing classification in the industrial and commercial domains [12]. This research suggests a second-hand clothing classification method based on an enhanced residual network to more accurately categorize used apparel. In figure 1, the experimental procedure is depicted.

The paper is structured as follows: we described the procedures used to get the data, as well as the training and test sets in 2nd section. In 3rd section, the classification models are designed and implemented, and the model is trained with the created training set.

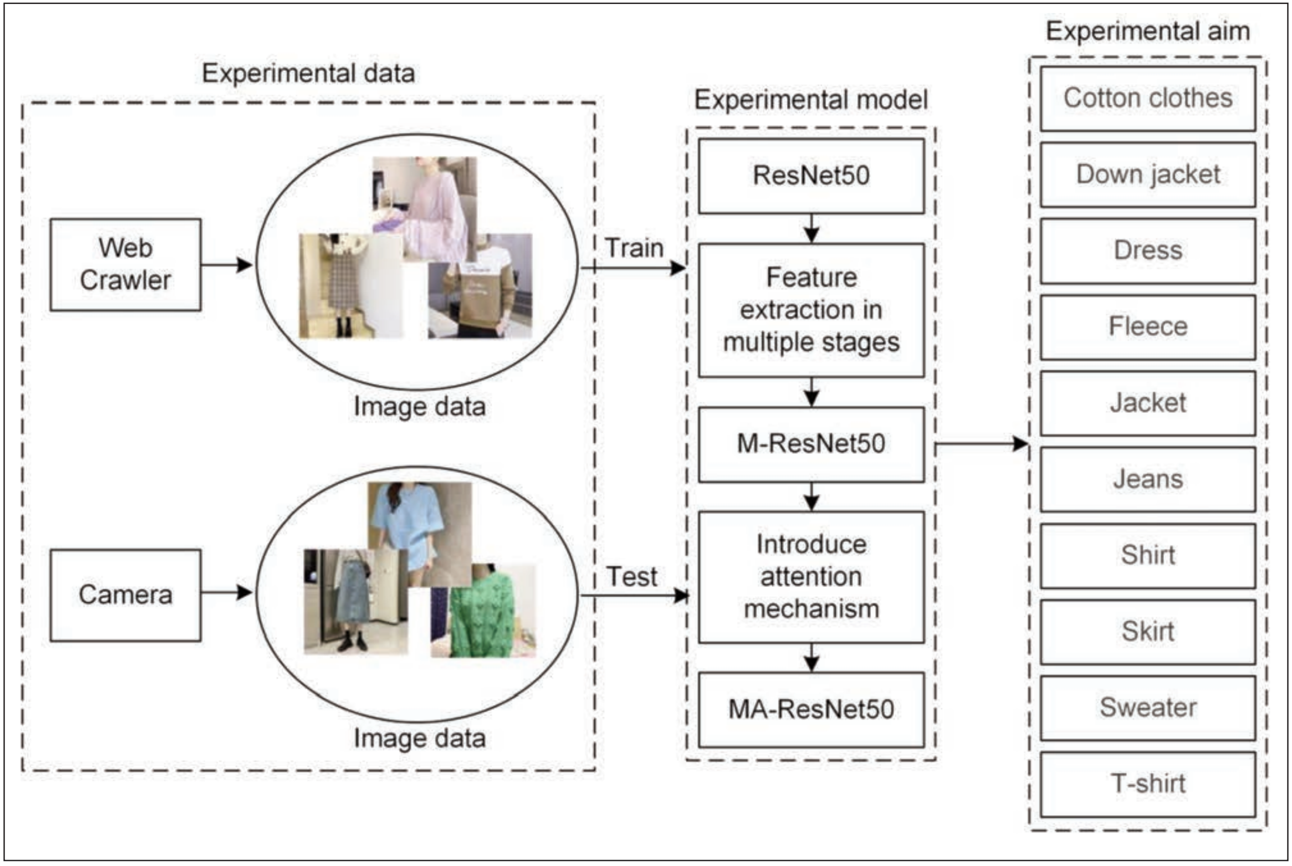


Fig. 1. Experimental process of second-hand clothing classification

In the 4th section, we utilized the trained classification model to identify the second-hand clothing image and compared the accuracy of different models on the second-hand clothing dataset. The advantages and characteristics of this categorization model are summarized in the concluding section.

DATA COLLECTION AND PROCESSING

Users who trade used clothing are likely to need to take pictures of the used clothing as part of the transaction, and they are also likely to utilize online images of the same models as inspiration for their product descriptions. Therefore, when it comes to data collecting, we employ two different methods: the first is to shoot used clothes using photography equipment, and the second is to utilize web crawlers to gather the already-existing photographs of used clothing on online purchasing platforms. We utilized the images captured by the camera equipment as the garment image dataset for the training set and test set because the clothes that are taken with the camera equipment are frequently the ones that require more sorting.

Due to the complicated context in which the garment is positioned, there are several surroundings present as well as a significant amount of noise, distortion, occlusion, and light fluctuations in the image (figure 2). Therefore, it is necessary to manually screen and classify the raw picture data first. The guidelines for screening and categorizing clothes are as follows: if the clothing category is not clearly defined, group conversation is used to decide on the category, and if the group discussion cannot come to a clear decision, the image data is discarded to prevent the problem of misclassification. All manual classification results are further verified thereafter to make sure they are accurate.

Following the collection of all the data, a 500×500 size pixel image of the garment is created by uniformly storing the various pixel sizes of the garment images. The data was then sorted into datasets, with the images being divided into a training set and a training set. The final dataset of second-hand clothing images is shown in table 1.

Table 1

SECOND-HAND CLOTHING DATASET

Class	Train	Test	Sum
Cotton clothes	1412	525	1937
Down jacket	1305	475	1780
Dress	1482	637	2119
Fleece	1487	642	2129
Jacket	1492	666	2158
Jeans	1117	493	1610
Shirt	1472	584	2056
Skirt	821	238	1059
Sweater	1502	619	2121
T-shirt	1276	596	1872
Total	13366	5475	18841

MODEL DESIGN AND IMPLEMENTATION

Overall model architecture

In general, it is believed that the lower-level features of an image can be recovered using CNN's first few layers, while the higher-level characteristics can be extracted using the network's deeper layers. Different features have distinct traits from one another; that is, lower-layer features have a higher resolution and more position and specific details are contained, but since they have undergone less convolution, they are less semantic and noisier. Despite having relatively low resolution and a reduced ability to perceive detail, upper-layer characteristics carry more robust semantic information [13]. It is clear that the properties of CNN retrieved at different levels complement one another.

MA-ResNet50 is built based on ResNet50 [14]. The feature extractor of ResNet50 has five stages, and the spatial size of the feature map is halved after each stage. Considering that deep layers have more semantic information, this paper plugs the attention module at the end of stage 3, stage 4 and stage 5. Figure 3 shows the architecture diagram of MA-ResNet50. The application of the attention mechanism can effectively capture extensive context

Fig. 2. Sample graph of second-hand clothing

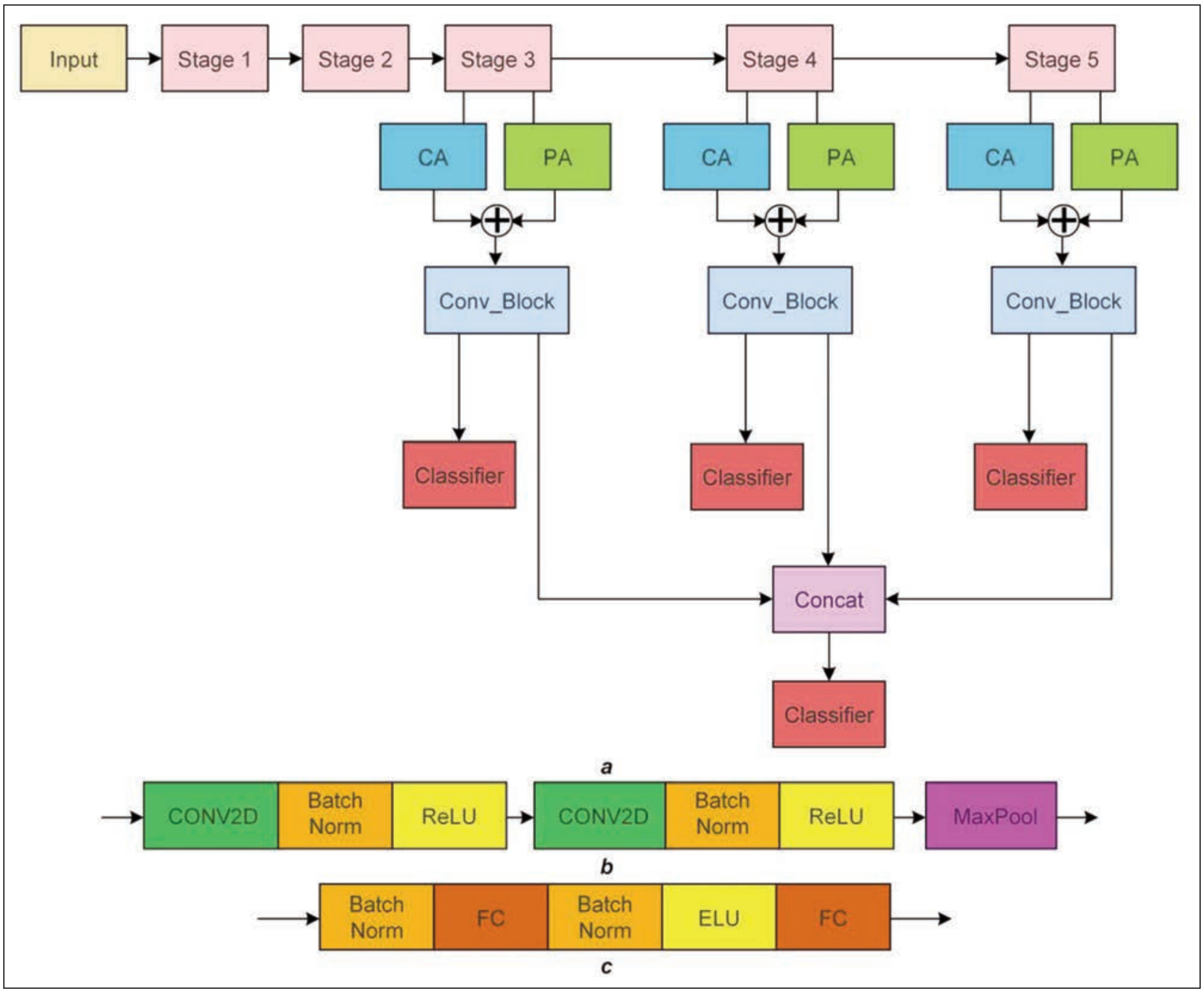


Fig. 3. MA-ResNet50 overall model diagram: *a* – architectural diagram of MA-ResNet50; *b* – Conv_Block architecture in MA-ResNet50; *c* – Classifier architecture in MA-ResNet50

information, and feature extraction in multiple stages can effectively utilize more complementary advantages of CNN features at different levels. Conv_Block represents a combination of two convolutional layers and a max pooling layer. The classifier represents two fully connected layers with a softmax layer at the end.

During training, the output from the corresponding classifier will be used for loss calculation and parameter update. For the training of the output of each stage and the output of the cascaded features, the loss is calculated using the Cross-Entropy (CE) between the ground truth label and the predicted probability distribution:

$$L = -\Sigma_{i=0}^{C-1} y_i \log(p_i) \tag{1}$$

where $p = [p_0, \dots, p_{C-1}]$ is a probability distribution, p_i denotes the probability that the sample belongs to the category i, $y = [y_0, \dots, y_{C-1}]$ is the one-hot representation of the sample label, as the sample belongs to the category i, $y_i = 1$, otherwise $y_i = 0$.

Channel attention module

The channel attention technique [15] is utilized increasingly frequently in the field of deep learning. Different channel-extracted features contain links with different degrees of tightness, and by collecting feature data from several channels, it is possible to highlight the interrelated image features. The channel attention module is shown in figure 4, *a*. We directly compute the channel attention map $X \in R^{C \times C}$ from the original features $M \in R^{C \times H \times W}$. Specifically, we reshape M into $R^{C \times N}$ and then perform matrix multiplication between M and the transposition of M. Finally, we apply the softmax layer to obtain the channel attention map $X \in R^{C \times C}$:

$$x_{ji} = \frac{exp\,(M_i \cdot M_j)}{\Sigma_{i=0}^{C} exp\,(M_i \cdot M_j)} \tag{2}$$

where x_{ij} denotes the influence factor of the i^{th} channel on the j^{th} channel. In addition, transpose X and do matrix multiplication with M and reshape the result as $R^{C \times H \times W}$, then multiply the result by the parameter α and then perform element summation operation with M to obtain the final result $F \in R^{C \times H \times W}$:

$$Fj = \alpha i = 1CxjiMi + Mj \tag{3}$$

where α gradually learns the weights from 0. From equation 2, the final feature F of each channel is a

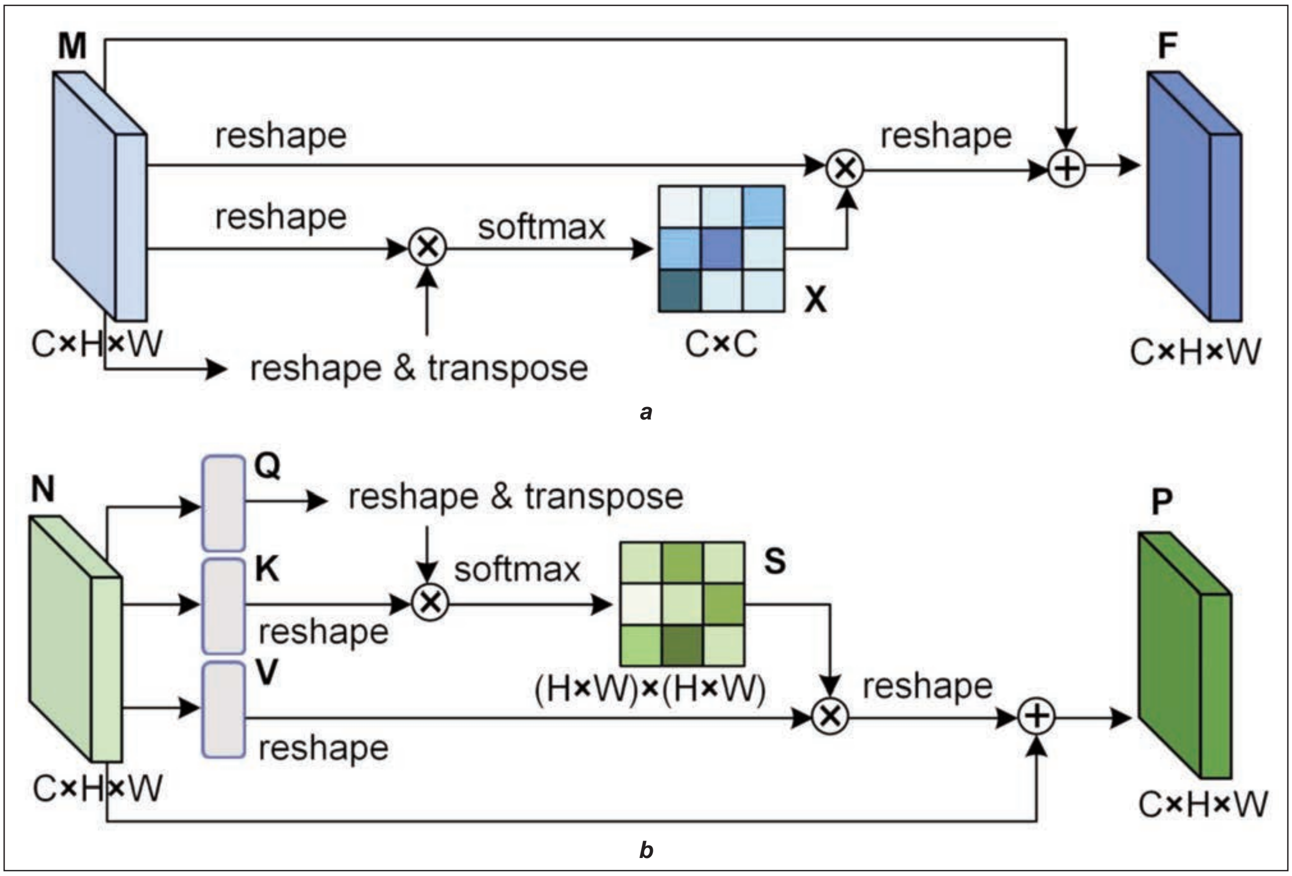


Fig. 4. Attention module: *a* channel attention module; *b* position attention module

weighted sum of the features of all channels and the original features, which models the long-term semantic dependency between feature mappings. It helps to enhance feature discriminability.

Position attention module

We developed the position attention module to model partial features, enriching contextual relations in the process. The position attention module encodes broader contextual information as local features, thus enhancing its representational capability [16]. The position attention module is shown in figure 4, *b*. Given a local feature $N \in R^{C \times H \times W}$, we first input it into the convolution layer to generate two new feature maps Q and K, respectively, where $\{Q, K\} \in R^{C \times H \times W}$. Then we reshape them into $R^{C \times N}$, where $N = H \times W$ is the number of pixels. After that, we perform matrix multiplication between the transpose of K and Q, and apply the softmax layer to compute the spatial attention map $S \in R^{N \times N}$:

$$s_{ji} = \frac{exp\,(Q_i \cdot K_j)}{\sum_{i=1}^{N} exp\,(Q_i \cdot K_j)} \qquad (4)$$

where s_{ij} denotes the influence factor of the i^{th} position on the j^{th} position. In addition, we input the features N into the convolution layer to generate a new feature mapping $V \in R^{C \times H \times W}$ and reshape it into $R^{C \times N}$. Then, we perform matrix multiplication between the transpose of V and S and reshape the result to $R^{C \times H \times W}$. Finally, the result is multiplied by the parameter β and then we perform the element summation operation with N to obtain the final result $P \in R^{C \times H \times W}$:

$$P_j = \beta \sum_{i=1}^{N} (s_{ij} V_i) + N_j \qquad (5)$$

where β is initially 0 and gradually learns to assign more weights [17]. From equation 4, it can be inferred that the resulting feature at each location is a weighted sum of the features at all locations and the original feature. Therefore, it has a global context view that enables superior contextual information aggregation based on the spatial attention graph.
Meanwhile, similar features with higher weights can play a mutually reinforcing role, thus improving intraclass compactness and semantic consistency.

EXPERIMENTS RESULTS AND ANALYSIS

Experiment settings

PyTorch with a version higher than 1.8 was utilized for the testing environment [18], and a single Tesla V100 GPU was employed for each experiment. The model was trained with 13366 images from 10 categories and tested with 5475 images. The ratio of training to test garment image data was 7:3. The only annotations utilized for training are the category labels on the images. During training, input images were resized to a size of 550×550 and randomly cropped to 448×448, and random horizontal flips were applied for data augmentation. During testing, the input images were resized to a size of 550×550 and cropped to 448×448 from the centre. For the optimization of model parameters, Stochastic Gradient Descent (SGD) was used as the model parameter optimizer. The momentum is 0.9 and the weight decay is 0.0005. Additionally, the newly added convolutional and fully connected layers' learning rates were initially set at 0.002 and decreased throughout training using the cosine annealing approach [19]. The learning rate of the pre-trained convolutional layer is kept at 1/10 of the newly added layer. For all models, they are trained for 300 epochs, and the batch size is 16.

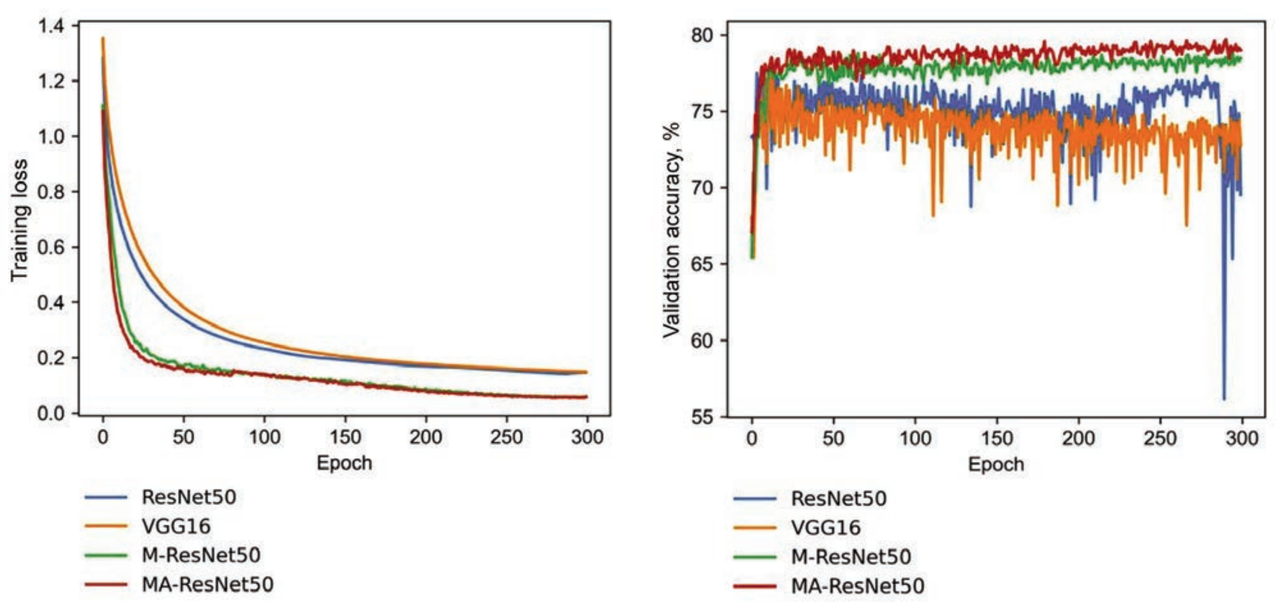
Results and analysis

This research compares the CNN classification models VGG16 [20] and ResNet50, which are often used for garment image classification, for analysis to confirm the efficacy of the MA-ResNet50 model. The second-hand clothing dataset is used to train each model until it converges, with all of the parameters being created from scratch. This process makes sure that all of the models are developed under the same circumstances. To visually track changes in the model's classification performance throughout the iterations, the training set is tested once for each iteration that is finished on the test set, and the classification accuracy is output and recorded.

The loss variation of several models on the dataset for used garments is illustrated in figure 5, *a*. It should be noted that the M-ResNet50 network model does not include an attention mechanism and just employs several stages for feature extraction. The M-ResNet50 and MA-ResNet50 models demonstrate a faster drop and convergence in loss values than the other three types of models. The loss curves of the two identical models, M-ResNet50 and MA-ResNet50, are comparable, and the change law and fluctuation range are almost the same. This experimental finding demonstrates that although the structure of the MA-ResNet50 model is more complex than the M-ResNet50 model and there are more parameters and calculations involved, it will not affect the rate at which the model loss value declines and converges when compared to commonly used models.

Figure 5, *b* represents the variance in model accuracy on the dataset for used garments. The classification accuracy is significantly improved by the M-ResNet50 model, which only adds multiple-stage feature extraction branches to the ResNet50 model's structure. This indicates that feature extraction in multiple stages significantly enhances the model's ability to extract features and that the richness of the features contributes to the improvement in classification performance. Figure 5, *b* also shows that the M-ResNet50 model is more stable than the ResNet50 model, with its accuracy curve fluctuating significantly less after roughly 25 iteration cycles. The attention process also strengthened the attractive features while weakening the detrimental ones, which might increase the accuracy of the model while maintaining its stability. According to the experimental results, the MA-ResNet50 model exceeds other deep convolutional networks in terms of classification accuracy.

For comparative trials, this study employed the DeepFashion clothes dataset [21], which has a reduced scene complexity, to further examine the scene applicability and application area of the MA-ResNet50 model. We utilized the DeepFashion dataset, which is a big publicly available apparel dataset established by the Chinese University of Hong Kong's Multimedia Laboratory. DeepFashion contains 800,000 photos, with 50 categories, 1,000 attributes, 4-8 key points, and paired characteristics of the same clothes, making it the largest visual fash-



a *b*

Fig. 5. Comparison of different models on second-hand clothing dataset:
a loss change curves; *b* accuracy change curves

Fig. 6. Sample graph of the DeepFashion dataset

ion analysis database that can be used to compare the classification performance of different deep learning algorithms.

The models were trained on 13112 photos from 10 categories and tested on 4477 images. On this dataset, four network models were evaluated. Table 2 presents the experimental results. In the table, represents the accuracy rate decreased when transitioning from simple to complicated scenarios. The experimental results demonstrate that: (1) The classification accuracy of the MA-ResNet50 model was 1.76% and 1.95% higher than that of the ResNet50 model on the DeepFashion and second-hand clothing datasets, respectively, and (2) When the complexity of the clothing scenes increased from low to high, both the ResNet50 model and the MA-ResNet50 model's accuracy slightly reduced, by 2.72% and 2.53% respectively. The experimental results prove that this model can improve the classification accuracy of clothing images in both simple and complex scenarios, and the classification accuracy of this model is more stable and can maintain high accuracy in complex scenes.

Table 2

COMPARISON OF CLASSIFICATION ACCURACY IN DIFFERENT DATASETS

Network model	**Second-hand clothing (%)**	**DeepFashion (%)**	**D_A (%)**
VGG16	77.46	77.71	0.25
ResNet50	77.74	80.46	2.72
M-ResNet50	78.79	81.19	2.40
MA-ResNet50	79.69	82.22	2.53

CONCLUSIONS

This research proposes a method based on an improved residual network to improve classification accuracy to optimize the effectiveness of second-hand clothes search engines and facilitate clothing transactions on second-hand platforms. Specifically, we introduce a location-attention module and a channel-attention module to capture global dependencies in the spatial and channel dimensions, respectively, and employ several stage branches to acquire CNN features at multiple levels. The attention module can efficiently gather a broad variety of contextual information for feature extraction in stages while also effectively exploiting the complementary capabilities of CNN features at different levels to provide more accurate classification results. The experimental results suggest that the modified residual network classification method outperforms the existing methods. The classification accuracy on the self-built dataset was 79.69% and 82.22% on the DeepFashion dataset, respectively. This result demonstrates this method's excellence and applicability. Furthermore, the solution proposed in this study offers a wide range of potential applications in the classification and recycling of the second-hand clothing market and thus contributes to textile sustainability.

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Authors:

TING CHENG[1], YUN ZHANG[2], WEIBO LI[3], JUNJIE ZHANG[4]

[1]Wuhan Sports University, School of Journalism and Communication, Wuhan 430073, China

[2]Wuhan Business University, School of Economics, Wuhan 430056, China

[3]Wuhan Textile University, Wuhan 430073, China

[4]Hubei Key Laboratory of Digital Textile Equipment, Hubei Provincial Engineering Research Center
for Intelligent Textile and Fashion, Wuhan Textile University, Wuhan 430073, China

Corresponding authors:

WEIBO LI
e-mail: leewb@wtu.edu.cn
JUNJIE ZHANG
e-mail: 2007086@wtu.edu.cn

Effect of walking speed on the evaporation coefficient of defence workwear

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ALFALEH AYMAN

ABSTRACT – REZUMAT

Effect of walking speed on the evaporation coefficient of defence workwear

The ripstop fabrics are highly appreciated in the military and defence workwear. One of the qualities requirements in defence clothing is quick evaporation. The effect of the wearer's walking speed on textile fabric evaporation during capillary rise was investigated in this study. To achieve this, two steps were taken: modelling the capillary considering evaporation and estimating the coefficient of evaporation using a program designed for image analysis. The walking speed was simulated by varying the air velocity from 0 m/s (non-walking) to 1 m/s (walking) and 2 m/s (running). Results conclusively demonstrated that the evaporation coefficient is directly relational to the water vapour in the surrounding air layer and is highly dependent on the aeration rate. Furthermore, liquid equilibrium front level and capillary diffusion were found to be inversely proportional to the walking speed. The walking speeds affected the indirect water amount on the fabrics and it was more difficult to evaporate liquid from the 100% cotton compared to 65% polyester/35% cotton.

Keywords: *walking speed, evaporation coefficient, ripstop fabric, comfort*

Efectul vitezei de mers asupra coeficientului de evaporare al îmbrăcămintei de protecție

Țesăturile ripstop sunt foarte apreciate în îmbrăcămintea militară și de protecție. Una dintre cerințele caracteristicilor în îmbrăcămintea de protecție este evaporarea rapidă. În acest studiu a fost investigat efectul vitezei de mers a purtătorului asupra evaporării țesăturii textile în timpul procesului de capilaritate. Pentru a realiza acest lucru, au fost parcurși doi pași: modelarea capilarității luând în considerare evaporarea și estimarea coeficientului de evaporare, folosind un program conceput pentru analiza imaginilor. Viteza de mers a fost simulată prin varierea vitezei aerului de la 0 m/s (staționare) la 1 m/s (mers) și 2 m/s (alergare). Rezultatele au demonstrat în mod concludent că, coeficientul de evaporare este direct relațional cu vaporii de apă din stratul de aer din jur și este foarte dependent de rata de aerare. În plus, nivelul frontal al echilibrului lichid și difuziunea capilară s-au dovedit a fi invers proporționale cu viteza de mers. Vitezele de mers au avut un efect asupra cantității indirecte de apă pe țesături și a fost mai dificil să se evapore lichidul din țesătura din 100% bumbac, comparativ cu cea din 65% poliester/35% bumbac.

Cuvinte-cheie*: viteza de mers, coeficient de evaporare, țesătură ripstop, confort*

INTRODUCTION

Thermal discomfort can have a substantial impact on a worker's productivity. Continued exposure might cause fatigue, decreased productivity, and concentration. Employee dissatisfaction and absenteeism may also increase. Sweating increases proportionally to the thermal challenge degree to maintain thermo-physiological heat balance [1, 2]. The accumulated sweat on the skin's surface must be rapidly soaked up by the fabrics and drained to the external environmental air via wicking kinetics to avoid wetness and the uncomfortable fabric sticking to the body feeling. The dispersion of water vapour via textile textiles is critical to sustaining physical comfort. Creating and manufacturing comfortable textiles is a significant task for fibre, yarn, and fabric design [3].

The army and police train and exercise in extreme environmental conditions and may come into touch with water, which gets wet and makes the clothes bulkier and less comfortable. This reduces their effectiveness and endangers their lives. Therefore, one of the qualities needed in defence clothing is quick evaporation. Consequently, when designing workers' clothing, wicking and evaporation should be considered. Compared to civilians, soldiers are exposed to more environmental factors. The military protective fabric was primarily designed to safeguard soldiers from weather-related factors including wind, rain, and snow while also allowing them to move freely [4].

The following list of essentials can be used to summarize the main requirements of an advanced integrated combat clothing system: Physical requirements include weather resistance [5]; environmental requirements [6] include water repellency and windproofness; physiological requirements include comfort, minimum heat stress, low weight, and vapour permeability; and battlefield requirements include flame resistance, ballistic protection, good camouflage properties [7], and low noise generation [8].

Some of these needs could be in conflict. Enhancing environmental protection, in particular, may result in bodily issues such as heat stress and exhaustion. The military uniform restrictions imposed by battlefield situations may inhibit the soldier's operational efficiency. Low weight and bulk are typically sought for operating efficiency, but the level of protection provided by ballistic vests is lowered.

Depending on the necessities of the outfit, military uniforms are often fashioned from a range of textiles. Cotton, wool, nylon, and polyester are common textiles used in military uniforms. These textiles were chosen for their durability, comfort, and resistance to a variety of climatic situations [9]. Furthermore, to suit the requirements, military uniforms frequently integrate specialized qualities such as moisture-wicking properties, flame resistance, and camouflage designs [10, 11]. Because of their capacity to survive harsh environments, ripstop textiles are highly appreciated in military fabrics [12]. They contribute to ensuring the longevity of clothes and equipment, even during intense exercise.

The term "ripstop" refers to a weaving process that requires strengthening the fabric at regular intervals with strong reinforcing threads [12–14]. This keeps minor tears and rips from spreading and becoming larger.

Ripstop materials are frequently used in military uniforms for severe stress or abrasion, such as knees, elbows, and pockets. The use of ripstop materials extends the life of garments by reducing the risk of tears and holes.

The type of ripstop fabric used in defence applications varies based on the needs of the uniform. Polyester ripstop materials have suitable properties, such as strength and durability [15]. They are frequently used in military uniforms, outerwear, and equipment that require tearing and abrasion resistance. Cotton ripstop materials are less frequent in military uniforms, but they can be employed in particular situations. They have the comfort and breathability of cotton with the added durability of a ripstop weave [16].

The common wicking action via textile materials is caused by the constituted fibres [17–19].

Consequently, plenty of investigation has been carried out to figure out how capillary functions in textile materials. Based on major studies in this area, yarns have also been managed as a porous media [20–22], where the liquid movement in the textile fabric may be predicted using the Lucas-Washburn law, or as capillary pipes. But in the first case, common measurements like permeability are hard to calculate and need to be analytically estimated [23]. Like the preceding situation, fitting the experimental results provides data on the effective contact angle and average effective capillary radius. The average radius of a dynamic pore might change during wicking due to fibre swelling [24]. Some studies focused on fabric geometrical modelling to predict physical properties [25].

When studying capillary rise, surrounding airspeed is typically neglected, in contrast to water vapour transfer tests where the airspeed is almost equivalent to walking speed conditions [26, 27]. Textile fabric evaporation [28] was mostly studied when exploring drying or cooling [29–33]. Relative air humidity was shown to be a significant factor in the climate conditions that had the biggest impact on evaporation intensity [34]. Among the presented literature review, modelling the evaporation during capillary actions considering the walking speed is still lacking.

This paper explored the evaporation rate during capillary kinetics over plain ripstop fabric as a defence clothing considering walking speeds. A theoretic mathematical model of the capillary wicking considering evaporation based on the fabric geometrical layout. Investigations were done into how walking speed affected capillary kinetics. At various walking speeds, the evaporation coefficient was determined using experimental results.

EVAPORATION COEFFICIENT DETERMINATION

The capillary kinetics concept of water over the woven fabric was used as an extension mathematical model [35]. As illustrated in figure 1, the capillary rises from the infinite reservoir through a porous media, the evaporation will take place from the external porous media perimeter open to the evaporation.

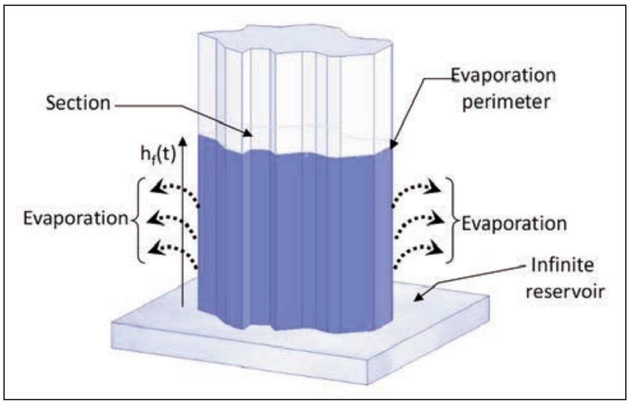

Fig. 1. Volatile liquid evaporation during capillary rise through porous media from infinite reservoir

An introduced physical parameter is presented in this model: the volume of the liquid evaporated from the textile fabric (Ω [m^3/s]) and the function of capillary front height ($h_f(t)$):

$$\frac{d\Omega}{dt} = -2\alpha W h_f(t) \tag{1}$$

where W is the textile fabric width in m and α is the intrinsic evaporation parameter of the liquid in m/s.

During the capillary rise, the liquid evaporates from the external walls. The evaporation surface will depend on the liquid front height and the width of the cross-section (S) of the porous media.

The liquid flow conservation on the wetting region Δh at a height h_f and section S gives:

$$\varepsilon S V_{h_f+\Delta h} = \varepsilon S V_{h_f} - 2\alpha W \Delta h \tag{2}$$

where V_{h_f} is the liquid front speed at the liquid front position h_f. By making Δh tend towards zero, the following expression is obtained:

$$\left(\frac{dV}{dt}\right)_t = -2\frac{\alpha W}{\varepsilon S} \tag{3}$$

In our case, the section S exposed to the evaporation is expressed as follows:

$$S = V \times t_h \tag{4}$$

Here t_h is the fabric thickness. So, the equation (3) could be written as follows:

$$\left(\frac{dV}{dt}\right)_t = -2\frac{\alpha}{\varepsilon t_h} \tag{5}$$

By integration between $h = 0$ and $h = h_f$ we have:

$$V_h = V_0 - 2\frac{\alpha h}{\varepsilon t_h} \tag{6}$$

Furthermore, the liquid front speed during capillary rise is:

$$V_h = \frac{dh_f}{dt} \tag{7}$$

And

$$V_0 = \frac{\left(\frac{R_D}{\tau}\right)^2}{8\mu h_f}\left(\frac{2\gamma_L\cos\theta}{R_D} - \rho g h_f\right) \tag{8}$$

The equation 8 corresponds to the liquid capillary rise without evaporation. So, combining equation 6 with the expressions of V_h and V_0 we obtain the capillary rise considering the evaporation equation:

$$\frac{dh_f}{dt} = \frac{\left(\frac{R_D}{\tau}\right)^2}{8\mu h_f}\left(\frac{2\gamma_L\cos\theta}{R_D} - \rho g h_f\right) - \frac{h_f}{\psi} \tag{9}$$

where $\psi = \frac{\varepsilon t_h}{2\alpha}$ is a function of liquid volatility and fabric construction parameters. It defines the liquid critical time to be evaporated from the fabric.

Considering the evaporation at equilibrium $\frac{dh_f}{dt} = 0$ and $h_f = h_{eq}^{ev}$. Solving the equation 9 gives the following form of the equilibrium front height:

$$h_{eq}^{ev} = \frac{-1 + \sqrt{1 + 4\frac{4\tau^2\mu}{\gamma_L\psi\cos\theta\, R_D} \times \left(\frac{2\gamma_L\cos\theta}{\rho g R_D}\right)^2}}{2\frac{4\tau^2\mu}{\gamma_L\psi\cos\theta\, R_D} \times \frac{2\gamma_L\psi\cos\theta}{\rho g R_D}} \tag{10}$$

Here $\frac{2\gamma_L\cos\theta}{\rho g R_D}$ is the liquid height equilibrium without evaporation defined by the Jurin law.

Considering equations 10 and 1, the evaporation coefficient α is determined as follows:

$$\alpha = \frac{\varepsilon t_h(2R_D\gamma_L\cos\theta - \rho g R_D^2 h_{eq}^{ev})}{16\mu\tau^2(h_{eq}^{ev})^2} \tag{11}$$

where R_D is the dynamic equivalent capillary radius (m), τ – the capillary channel tortuosity, μ – the liquid viscosity (N·s/m^2), h_{eq}^{ev} – the liquid front equilibrium height with evaporation consideration, ρ – the water density (Kg/m^3), g – the acceleration of gravity (m/s^2), μ – the water viscosity (N·s/m^2), θ – the equilibrium contact angle, γ_L – the water surface energy (N/m).

Equation 11 contains the contact angle as a liquid/fibre interaction, the physical properties of the liquid (μ, γ_L) and the fabric structural parameters (t_h, ε, τ and R_D). All of these parameters should be evaluated to determine the coefficient of liquid evaporation from textile fabrics.

Thus, it exists a maximum liquid front position which does not correspond to a balance between gravity and capillary forces but to a kinetic balance due to the evaporation of the liquid. The greater the evaporation, the smaller the equilibrium height will be.

The effective dynamic average pore radius R_D is expressed as follows [24]:

$$R_D = \frac{2\gamma_L\cos\theta}{\rho g h_{eq}^{ev}} \tag{12}$$

MATERIALS AND METHODS

Experimental device

In the experimental device (figure 2), a steel ruler and lab jack were, respectively, employed in the device to measure the wicking front level and elevate the liquid reservoir containing the wicking liquid. An installed gap plate was introduced on the reservoir's top side to allow fabric penetration and capillary ascent while minimizing liquid evaporation from the reservoir.

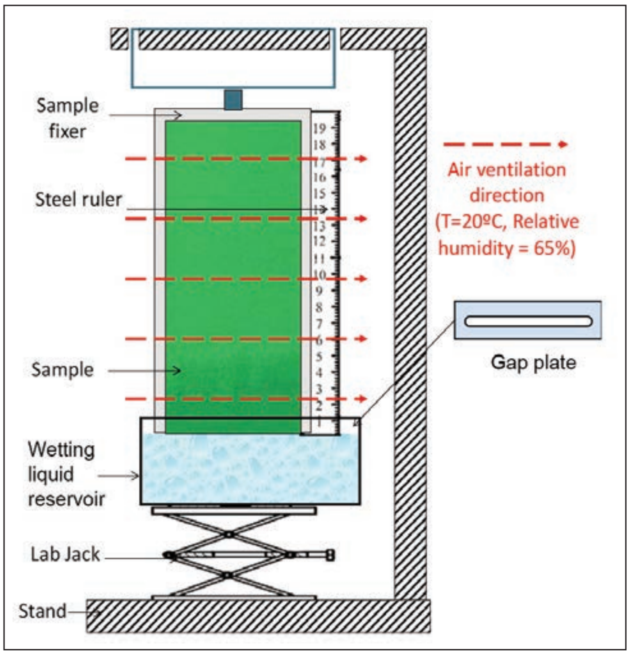

Fig. 2. Capillary rise experimental setup considering evaporation

The capillary liquid front was observed and measured at various periods by capturing images with a CCD camera on frequently. The capillary rise and time were captured until equilibrium was established. The photos were adjusted in Photoshop for brightness, size, cropping and calibration. MATLAB software was used to monitor the liquid front position using grayscale images. The contrast of each grayscale photo was attuned using histogram equalization, subsequent in lower grey levels visible in the contrast-adjusted photo. Wetted regions were represented by the image's dark sections, while non-wetted areas of the fabric were transparent. The photo threshold level was determined for binarization.

Used weaving fabric

The Rip-stop fabric pattern design as illustrated in figure 3, was woven using the rapier Dornier weaving machine HTV/HTVS/PTV with the Bonas ZJ2 jacquard mechanism.

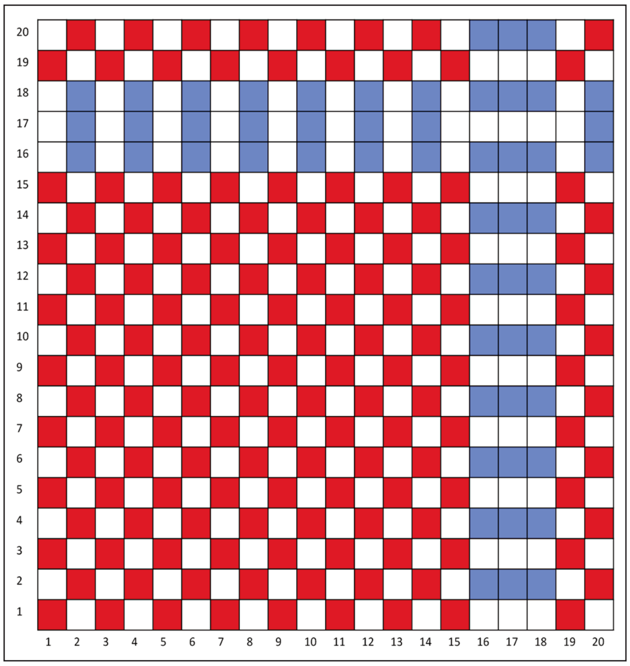

Fig. 3. Rip-stop fabric pattern design

The woven fabric thickness was evaluated using the ISO 5084:1996 standard [36]. The mass per unit area, warp and weft densities were measured according to the ISO 7211-6:2020 standard [37].

The woven fabric structural parameters are presented in table 1.

Experimental test conditions

The used wetting liquid was distilled water; with a density of 998.29 kg/m^3, a dynamic viscosity of 0.001003 N·s/m^2, a surface energy of 0.0725 N/m, a contact angle $\cos\theta = 0.97$ in the case of cotton fibre 100% cotton fibre and $\cos\theta = 0.94$ in the case of polyester fibre. The polyester fibre is a hydrophobic polymer with a low contact angle. Generally, synthetic fibres are smooth, resulting in a low contact angle [18].

Different air speeds were used to assess the effect of a wearer's walking speed on capillary rise evaporation. The air speeds tested were 0 m/s, 1 m/s, and 2 m/s referring respectively to non-walking, walking and running speeds.

All experimental tests were conducted under a standard atmosphere of 65±2% relative humidity and 20±2ºC. Tested fabrics were conditioned for 24 hours before testing and each capillary rise test was repeated three times.

RESULTS AND DISCUSSIONS

Based on figure 4, it can be observed that the walking speed of workers has an impact on capillary rise. The equilibrium liquid front decreases as the walking speed increases and is caused by the evaporation that occurs from the open-pores sample. The walking speed is closely related to the water vapour diffusion layer, which is proportional to the evaporation rate. When the capillary front level is small, the impact of walking speed and air ventilation on liquid evaporation remains insignificant for short periods. For cotton, the height of the capillary front stands fewer than 20 centimetres with a standard deviation of 0.58 and a CV of 2.95%, however, for polyester, a front level of fewer than 6 cm with a standard deviation of 0.24 and a CV of 1.62% does not disturb evaporation. With time passing the liquid speed becomes lower caused by the gravitational forces decelerating the capillary rise rate. At equilibrium, in the case of the polyester fabric the liquid reaches the maximum height of 44.8±1.2 cm with a CV of 1.84% for the non-walking speed (0 m/s). During the walking speed of 1m/s, the equilibrium front height was 40.4 ±1.5 cm with a CV of 3.63% compared to 31.5±2.7 cm with a CV of 4.71% for the running speed (2 m/s). According to the statistical results of the presented standard deviation and CV values, it is clear that the air mobility caused by the increase in walking speeds affects the stability of the equilibrium height. The statistical values during the running speed are higher than walking and non-walking speeds.

The same phenomenon was found in the case of the cotton fabric. However, the effect of the walking speeds on the equilibrium height was less noticed as for the cotton fibre it is more difficult to evaporate liquid where the amount of the direct water (more difficult to be evaporated) compared to polyester. As illustrated in figure 4, the equilibrium heights were found to be 35.1±0.3 cm with a CV of 0.92%, 32.7±0.7 cm with a CV of 1.12% and 28.4±1.1 cm

Table 1

USED SAMPLES STRUCTURAL PARAMETERS

Sample code	Fibber	Yarn number (Nm)	Mass per unit area (g/m^2)	Warp count (threads/cm)	Weft count (threads/cm)	Thickness (mm)
Ribstop-PC	65% Polyester, 35% Cotton	25	215±4	24±2	24±3	0.56±0.03
Ribstop-CT	100% Cotton		210±3	24±1	24±2	0.55±0.02

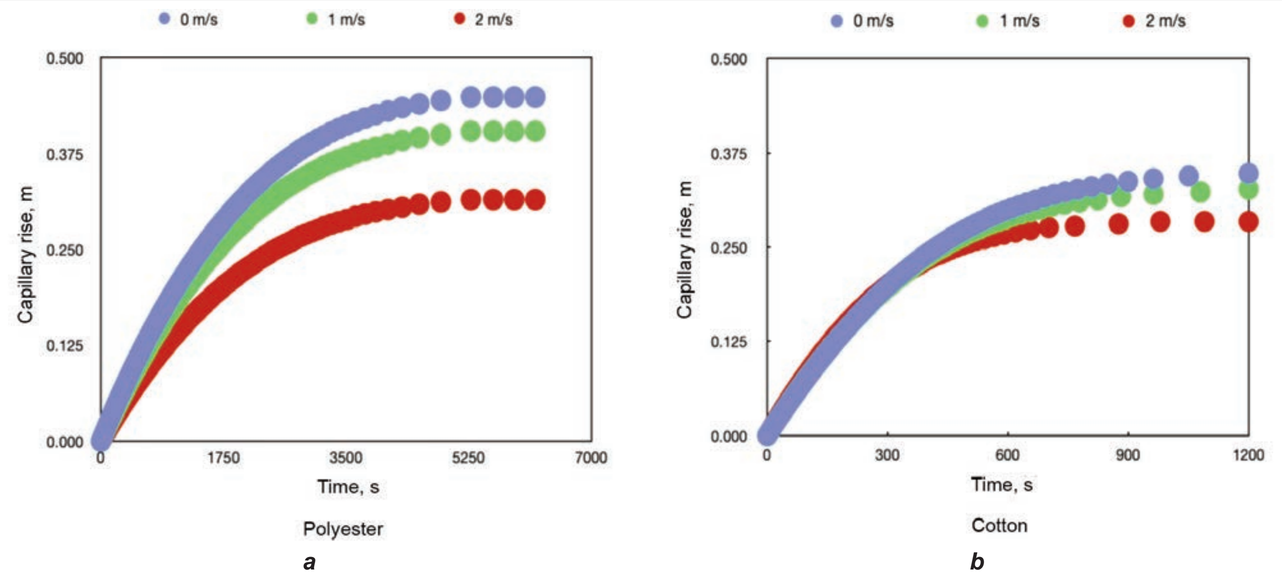

Fig. 4. Effect of walking speed on the capillary rise (20°C and 65% of relative humidity: standard environmental conditions): *a* – Ribstop-PC; *b* – Ribstop-CT

Table 4

THE WICKING PROPERTIES OF THE USED FABRICS					
Sample	**R_D (µm)**	**Total porosity (%)**	**Walking speed (m/s)**	**h_{eq}^{ev} (m)**	**α (m/s)**
Ribstop-PC	3.11	83.2±2.3	0	0.448±0.001	$1.762±0.007 \cdot 10^{-08}$
			1	0.404±0.002	$2.783±0.028 \cdot 10^{-08}$
			2	0.315±0.003	$3.497±0.093 \cdot 10^{-08}$
Ribstop-CT	2.45	76.5±1.8	0	0.351±0.002	$2.974±0.011 \cdot 10^{-08}$
			1	0.327±0.005	$4.682±0.084 \cdot 10^{-08}$
			2	0.284±0.007	$5.813±0.067 \cdot 10^{-08}$

with a CV of 1.41%, respectively during walking speeds of 0 m/s, 1 m/s and 2 m/s. Comparing the presented statistical values, the equilibrium heights in the case of the cotton fabric are more stable compared to the polyester ones. It could be said that the walking speed does not affect the direct water amount evaporation during the capillary rise.

The difference between polyester and cotton fabrics' capillary kinetics is due to the amount of direct and indirect water in the fibre. Cellulosic fibre has a greater proportion of direct water, which is difficult to evaporate, compared to polyester fibre [38].

When designing comfortable fabrics, it is important to consider the phenomenon of evaporation. The surface of the textile that is opened to evaporation and in contact with the surrounding air must be carefully sized to effectively evacuate sweat through the fabric and allow evaporation into the surrounding air. If the surface is too small, evaporation may not occur as efficiently. The evaporation coefficients can be determined based on the water equilibrium front level and considering evaporation based on equation 11. All the wicking parameters are shown in table 2. The results for different walking speeds are also presented in table 2.

Based on figure 4, it is noticeable that the evaporation coefficient is directly proportional to walking speed. This means that when walking at high speed, the air around us is not fully saturated, allowing for greater vapour mobility and more water to evaporate. It is noticed that the evaporation coefficient for 100% cotton was $2.974±0.011 \cdot 10^{-08}$ m/s, which is greater than the $1.762±0.007 \cdot 10^{-08}$ m/s for 65% polyester/35% cotton at non-walking speed (0 m/s).

Additionally, when running at 2 m/s, the difference in evaporation coefficient values between 100% cotton and 65% polyester/35% cotton was even more significant, with 100% cotton having a coefficient of $5.813±0.067 \cdot 10^{-08}$ m/s and 65% polyester/35% cotton having a coefficient of $3.497±0.093 \cdot 10^{-08}$ m/s.

The moisture equilibrium isotherms exhibit hysteresis during sorption and desorption cycles, signifying structural modifications of the fibre due to water interaction. It's worth noting that while cotton absorbs quickly, it dries slower than other materials due to hysteresis during wetting [38].

CONCLUSIONS

This study explored the water evaporation during the capillary rise of two ripstop woven fabrics made of 65% polyester/35% cotton and 100% cotton. The coefficient of evaporation rate was determined from the equilibrium liquid front level through an image analysis developed program. Based on the developed mathematical model of the capillary kinetics it was established that the evaporation coefficient is a function of various fabric construction parameters (tortuosity, dynamic equivalent pore's radius, thickness and porosity), the water's physical properties (water viscosity and surface energy) and the contact angle resulting from liquid/fibre interaction. The effect of walking speeds (0 m/s as non-walking, 1 m/s as walking and 2 m/s as running speed) was considered, and it was figured out that the evaporation coefficient is directly related to the water vapour diffusion layer and is directly related to the walking velocity. It was found that the walking speeds have an effect on the indirect water amount on the fabrics and it is more difficult to evaporate liquid from the 100% cotton compared to 65% polyester/35% cotton.

Nevertheless, the purpose of this study is to gain insight into the subject and to lay the groundwork for future research. The influence of different air directions on evaporation during wicking will be investigated in future studies.

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Author:

ALFALEH AYMAN

College of Engineering and Computing, Mechanical and Industrial Engineering Department, Umm Al-Qura University,
Al-Khalidiya District Al-Qunfudhah City 28821, Kingdom of Saudi Arabia

Corresponding author:

ALFALEH AYMAN
e-mail: Affaleh@uqu.edu.sa

Sectoral analysis of textile and composite industries for value-added manufacturing: a regional study

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MEHMETKARAHAN
ALİ ARI
AHRARİ MAZYAR

ABSTRACT – REZUMAT

Sectoral analysis of textile and composite industries for value-added manufacturing: a regional study

This study aims to determine the main competitive features of the textile and composite industry in the Bursa region, the centre of Türkiye's composite and technical textile production, analyse its development, and define, evaluate, and explore how it can be transformed into value-added elements to increase its efficiency. Adding value to textiles and composites using these competitiveness traits is key to the industry's continued development and prosperity. Value-added products' unique qualities, capabilities, and benefits set them apart from commodity items. The study determined that traditional textile producers would face the most difficulties in the transformation. Textile companies whose technical textile production is below 50% of their total production make up the second group. Companies producing composite materials stated that Research and Development opportunities and quality and technical competence are the two biggest challenges. However, companies producing composite materials are considering transforming their applications in the fields of automotive, renewable energy, defence industry, aviation, and space. As a result, organizations wishing to succeed in the highly competitive and ever-changing composites market must prioritize various aspects of competitiveness.

Keywords: *composite materials, technical textiles, competitiveness, Bursa*

Analiza sectorială a industriei textile și a compozitelor pentru producția cu valoare adăugată: un studiu regional

Acest studiu își propune să determine principalele caracteristici competitive ale industriei textile și a compozitelor din regiunea Bursa, centrul producției textilelor tehnice și a compozitelor din Turcia, să analizeze dezvoltarea acesteia și să definească, să evalueze și să exploreze modul în care poate fi transformată în element cu valoare adăugată, care să-i sporească eficiența. Adăugarea de valoare textilelor și compozitelor folosind aceste caracteristici de competitivitate este cheia dezvoltării și prosperității continue a industriei. Calitățile, capacitățile și beneficiile unice pe care le oferă produsele cu valoare adăugată le deosebesc de articolele de bază. Studiul a stabilit că producătorii tradiționali de textile s-ar confrunta cu cele mai multe dificultăți în procesul de transformare. Companiile de textile a căror producție de textile tehnice este sub 50% din producția totală reprezintă a doua grupă. Companiile producătoare de materiale compozite au declarat că oportunitățile de cercetare și dezvoltare, calitatea și competența tehnică sunt cele mai mari două provocări. Cu toate acestea, companiile producătoare de materiale compozite iau în considerare transformarea aplicațiilor lor în domeniile auto, energie regenerabilă, industria de apărare, aviație și spațiu. Prin urmare, organizațiile care doresc să reușească pe piața compozitelor extrem de competitivă și în continuă schimbare trebuie să acorde prioritate diferitelor aspecte ale competitivității.

Cuvinte-cheie*: materiale compozite, textile tehnice, competitivitate, Bursa*

INTRODUCTION

When nations invest in their composite industries, they help spur economic growth and development. The composite business has evolved and changed throughout the years, from the dawn of hand weaving to the present day, when it is incredibly mechanized and technologically advanced, to suit the ever-changing demands of customers and market conditions. Businesses are under increasing pressure to differentiate themselves from competitors, reduce expenses, and provide customers with high-quality items that meet their demands and expectations as the industry has experienced unprecedented levels of competition in recent years [1–4].

Innovation is a critical component of success in the composite industry. The key to success in a cutthroat market is coming up with ground-breaking new products that not only satisfy but also exceed customer expectations. Innovations can take several forms, such as providing funding for research and development, collaborating with designers and other industry experts, or showcasing the most recent trends and technology [5, 6]. Businesses can differentiate themselves from competitors and carve out a unique position in the market by focusing on innovation. Innovations in the textile sector include new fibres and materials, cutting-edge production methods, and sophisticated digital technology. Examples of newly produced fibres that provide improved sustainability and performance attributes include Tencel and recycled polyester [7–9]. Innovations in digital printing have allowed designers to create intricate and detailed patterns and designs, and developments in automation and robotics are transforming manufacturing processes by making them faster, more effective, and cheaper [10–12].

One of the most important factors in staying competitive in the composite industry is speed-to-market. Since customer tastes and market circumstances are always evolving, businesses that can introduce new items efficiently stand a better chance of succeeding [13–15]. This might be accomplished with the help of investments in supply chain optimization, methods for quick product development, and efficient production processes. Quick action and adaptation to changes in demand and market conditions put businesses in a better position to win market share and sustain an advantage over rivals [16–18].

The main objective of this research is to identify, evaluate and investigate how the important competitiveness features of the sector can be transformed into valuable products to promote the growth and progress of the textile and composite industry. These efforts will include a comprehensive approach to identify and evaluate potential opportunities in the sector, thereby enabling the identification of strategic steps and innovative solutions that are critical for industrial development. In this context, in-depth research will be conducted in various areas to analyse both technological and market-oriented changes and increase the industry's future growth potential. This study will be an important step in increasing the competitiveness of the composite and technical textile industries and moving towards sustainable success. Additionally, this research will explore ways of collaboration and partnership in the industry. In an increasingly connected world, collaboration is key to unlocking new opportunities and accelerating innovation. A synergistic ecosystem has been created in the Bursa region of Türkiye that encourages creativity, efficiency, and sustainable growth by encouraging partnerships between manufacturers, suppliers, researchers, and policymakers. The findings of this study will serve as a road map for industry stakeholders and guide them towards sustainable success in the dynamic environment of the textile and composite industries. By identifying key competitiveness characteristics and translating them into actionable strategies, we can move the industry forward, stimulating economic growth, job creation, and technological advancement. This research effort is not merely an academic exercise; it is a call to action to unite all stakeholders in the pursuit of a vibrant, resilient, and competitive textile and composites industry.

METHODOLOGY

The diagnostic study into the needs of the companies that are the Centre's potential customers consisted of two phases. In the first phase, 140 companies were visited by 3 Junior Non-Key Experts to fill out a questionnaire, while in the second phase, 50 companies selected from the 140 using two objective scoring tools were visited for deep diagnostic interviews by 2 Senior Non-Key Experts and the Key Expert 2 who are experts in Technical Textiles and Composites.

Questionnaire

A draft questionnaire was prepared first, in close cooperation with the End Recipient of Assistance (ERA) (i.e. BTSO, formally, BUTEKOM in practice). It was tried out during a pilot phase with leading companies in the textile and composite sectors. The questionnaire was then fine-tuned for effective data collection. The long questionnaire for the screening phase consists of nine modules with a total of 91 questions:

- Activity/Production (8 questions)
- Supply/Sales (17 questions)
- Human resources (10 questions)
- Research and Development (R&D) (24 question)
- Quality (5 questions)
- Sustainability (2 questions)
- Value chain (8 questions)
- Transformation (7 questions)
- Clustering (10 questions).

Due to the high non-response rate and time limitations, a shortened version was adapted from the long version with 73 questions.

The definition of organizations mentioned in the study is given below:

- Bursa Chamber of Commerce and Industry (BTSO): BTSO aims to meet the common needs of its members, facilitate their professional activities, ensure the development of the sector, ensure the superiority of honesty and trust in the interaction of members with each other and with the public, and maintain professional discipline and harmony (Türkiye).
- Bursa Technology Coordination and R&D Centre (BUTEKOM): To lead the work in national and international organizations (fairs, seminars, R&D project markets, etc.) and to convey the information in the organizations to corporate and expert members (Türkiye).
- Bursa Technical Textile and Composite Materials Cluster (BUTEXCOMP): Bursa Technical Textile and Composite Materials Cluster is an innovation cluster that brings together companies producing textiles, technical textiles and composite materials, sub-industry companies, academic and research institutions and public institutions, reflecting the entire sectoral value chain (Türkiye).

Sampling

The companies to be visited for the first phase study were selected using rational sampling strategies from a database of 2734 companies from the company register provided by BTSO. The companies were established in Bursa, with at least one staff on the payroll.

A pilot sample of 20 companies was selected to try out the questionnaire. Selection was skewed towards larger companies, as those are more likely to engage in technical textile and composite production. A first sample of 175 companies was then randomly selected using a stratified method. However, when it was found that the non-response rate was much higher than expected, a second (144 companies) and third (80 companies) sample were taken to which a turnover threshold was applied. The high non-response rate of the first sample was attributed to the busy schedules of company owners or related high-level managers and the larger number of companies of smaller sizes included in the first sample that had already ceased their activities or showed no interest in transformation and participation in the project activities. In the second and third samples, smaller companies with a low turnover were not included.

Execution of the study

The TAT backstopping team took care of the first step of a successful company contact. It was found that filling out the questionnaires was very time-consuming, such that questionnaires could usually not be completed in a single visit. Different departments of larger companies (Research and Development (R&D), Human Resources, financial, etc.) were needed to complete the questionnaire to complicate matters further. It was thus often necessary to leave the partially filled questionnaire at the company to be completed later. Considerable efforts were spent on follow-up to retrieve the filled-out questionnaires, which was not always successful. As a result, the visits to 140 different companies resulted in 102 questionnaires that could be used for statistical analysis and an additional 18 partially filled questionnaires.

Scoring schemas

Two scoring schemas for the selection of companies to be visited in the second phase were developed in close collaboration with ERA. The first scoring schema focuses on companies that are likely to be the best customers for the centre, with reasonable R&D capability for the production of medium-high tech products of the company that fit in the BUTEXCOMP project's focus on prototyping and new production development skills. This scoring schema focuses on production/export (Technical Textile (TT)/Composites, target sector, production technology, export, and attendance to fairs), general structure of human resources (educational attainments, availability of engineers), R&D (ideas, R&D, Product Development and design centre or units, innovation outputs, application or use of scientific funds), and cooperation readiness (quality, transformation, cooperation and clustering intention). The second scoring schema, derived from the first, targets companies that are most interested in transforming more high-tech products but do not have such capabilities yet. The main difference between the schemas is that the second schema does not take into account existing skills in R&D and Technical Textiles/Composites, but only the potential and willingness to obtain such skills (i.e. to transform).

Execution of the second phase study

The semi-structured questionnaire for the second phase is made up of questions to diagnose companies' limitations and challenges regarding prototyping and new product development. It focuses on companies' needs and plans for prototyping and new product development considering their technology levels, the decision-making process for new product development, obstacles for developing new ideas and challenges in R&D processes, new product development projects, project teams' needs, their skill and knowledge gaps and needs, marketing strategies, transforming to technical textile and composites, clustering perceptions etc. The questionnaire is a tool to explore the companies' needs related to the purpose of the Project.

ANALYSIS OF QUESTIONNAIRES RESULTS

Firmography

102 fully completed questionnaires were collected despite 140 companies being visited as part of the diagnostic study's initial phase (18 partially filled questionnaires were also received). The companies visited were divided into 4 groups: those of companies only active in classical textiles (26 companies), companies that produce technical textiles, but less than 50% of their total turnover (24 companies), companies that obtain more than 50% of their turnover from technical textiles (18 companies) and companies active in the production of composites (34 companies). Some companies (6) produce both technical textiles and composites; these were considered textile companies. This group was too small to give statistically significant results so was not studied as a separate group.

While exactly two-thirds (66.7 percent) of the companies that visited and completed the survey produced textile products, about 9 percent of these companies also produced composite materials (figure 1).

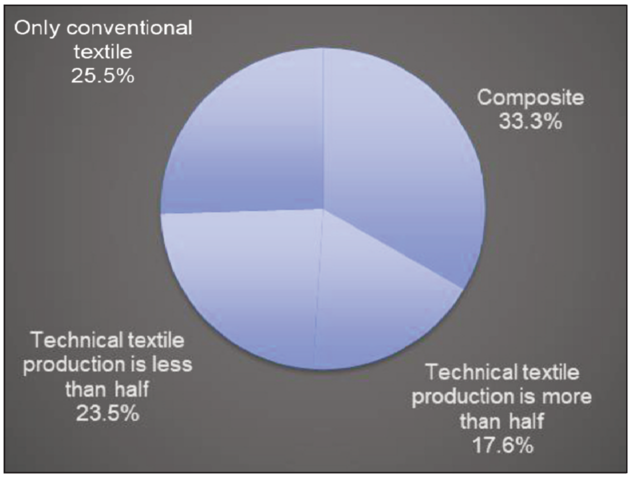

Fig. 1. Distribution of companies by production areas (%) [19]

One-fourth of the companies said they only make traditional textiles. The proportion of enterprises producing technical textiles among all those visited is 40.9 percent.

The majority of technical textile manufacturers claimed that technical textiles accounted for less than half of their total output. Regardless of size, the technical textile production rate among the companies that visited and produced technical textiles was calculated to be 28 percent.

Development and Transformation

The companies claimed that they intended to expand their current capacity but they also appeared to be highly keen to invest in new sectors (figure 2). They thus pursue possibilities to simultaneously preserve the current status and get access to the advantages and income of new areas. More than three-quarters of the visited companies emphasized that they intended to change and make investments in the new fields. Due to the need for new technologies and composite materials, intentions for investment and transformation in new areas are higher especially in companies producing technical textiles and composite materials than in companies that only produce traditional textiles. Additionally, it is intended to increase production capacity in businesses that only create traditional textiles and composite materials.

Uncertainty and high investment costs are used by companies as excuses and justifications for not planning investments or transformations yet. Additional factors have been put forth as the lack of knowledge about the industry that will be investing in and the laws, particularly for businesses making technical textiles and composite materials.

More than three-quarters of the companies assert that, with adequate support, they can produce a product with higher quality and high added value (figure 3). This rate is higher in businesses that produce more than half of their output as technological textiles and composite materials.

Companies declared their intentions to invest or change in practically every sector (table 1). While investment or transformation to clothing items are at the forefront in companies that manufacture only traditional textiles, home textiles and automotive and transportation textiles are at the forefront in companies that produce less than half of their production in technical textiles, and automotive and transportation textiles and industrial textiles are at the forefront in companies that produce more than half of their production in technical textile. In addition, companies

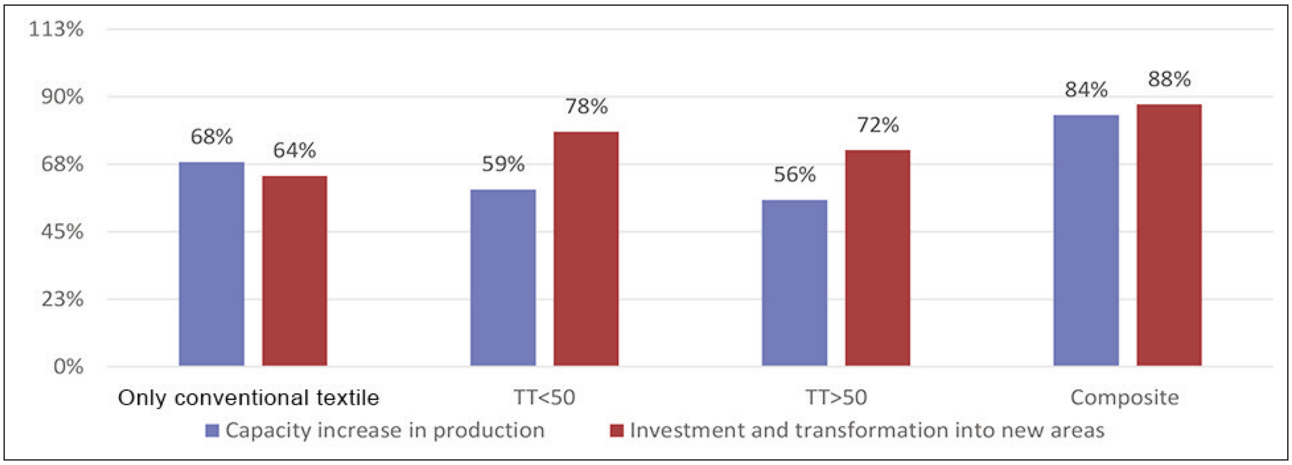

Fig. 2. Capacity increase in production, investment in new areas and transformation plans of companies (%)

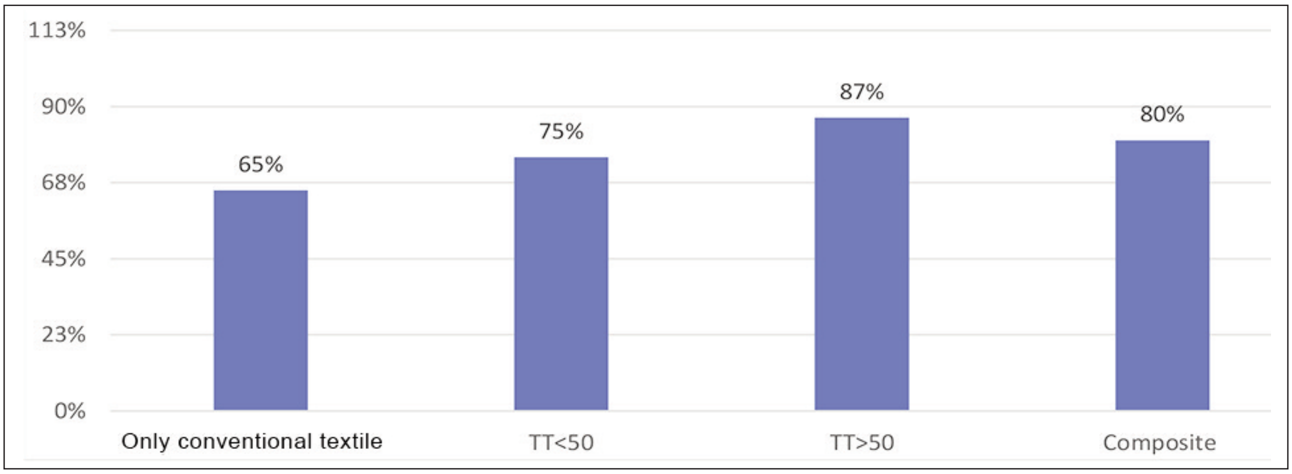

Fig. 3. Ownership of qualified and high added value products

Table 1

SECTORS WHERE INVESTMENT OR TRANSFORMATION IS PLANNED (TECHNICAL TEXTILES)				
Sector	**Traditional textile only (%)**	**TT<50 (%)**	**TT>50 (%)**	**Composite (%)**
Agrotech	15.8	0.0	14.3	0.0
Medtech	21.1	23.8	28.6	0.0
Hometech	36.8	66.7	21.4	0.0
Oekotech	31.6	23.8	28.6	0.0
Clothtech	63.2	23.8	21.4	0.0
Geotech	10.5	4.8	14.3	0.0
Packtech	0.0	0.0	7.1	0.0
Protech	26.3	33.3	14.3	0.0
Indutech	21.1	23.8	35.7	14.3
Sportech	31.6	19.0	21.4	0.0
Mobiltech	31.6	47.6	42.9	42.9
Buildtech	10.5	14.3	28.6	0.0

have reported that they are planning investments or transformation in the fields of health and environment. Those who create technical textiles said they planned to invest in home textiles, even though traditional textile companies intend to invest in technical textiles used in clothing. Investment or transformation is desired in the automotive, transportation, and environmental textile industries by businesses that make composite materials.

Companies are considering investment or transformation in the areas of automotive and transportation applications, renewable energy applications, the defence industry, and aerospace industry applications related to composite materials (table 2). Technical Textiles used in these areas are often used in composite material. Therefore, investment or production increase in technical textile production will bring about an increase in composites.

Although it changes by sub-sectors, the most significant hurdles in transformation are access to qualified human resources, entry into new markets, and funding (figure 4). Besides most companies reported

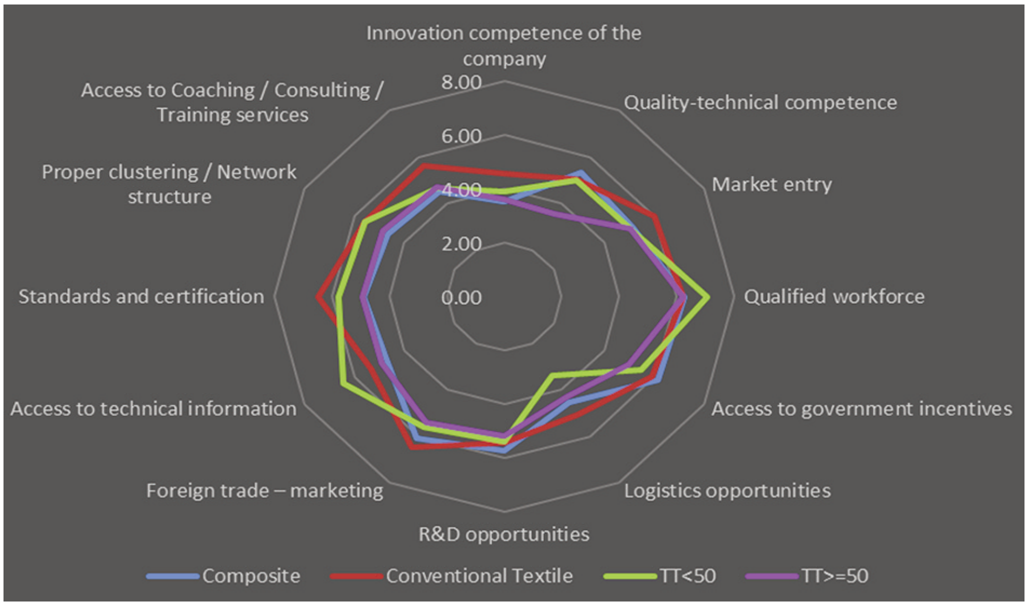

Fig. 4. Challenges in transformation by sectors (out of 10)

Table 2

SECTORS WHERE INVESTMENT OR TRANSFORMATION IS PLANNED (COMPOSITE)				
Sector	**Traditional textile only (%)**	**TT<50 (%)**	**TT>50 (%)**	**Composite (%)**
Electrical and electronic applications	0.0	20.0	33.3	11.1
Infrastructure/pipe/tank applications	0.0	20.0	33.3	7.4
Construction applications	16.7	40.0	16.7	0.0
Automotive and transportation applications	16.7	60.0	50.0	70.4
Marine applications	16.7	0.0	33.3	14.8
Renewable energy applications	66.7	80.0	33.3	7.4
Defence industry	16.7	60.0	50.0	37.0
Aerospace industry applications	16.7	0.0	50.0	48.1
Sports and entertainment equipment	16.7	40.0	16.7	11.1

about difficult access to coaching, consultancy and training services on the subject matter.

It has been noted that conventional textile manufacturers would experience the most difficulty in transformation. The second group is textile companies with technical textile production of less than 50% of their whole production. While conventional textile manufacturers claim that the most significant obstacles are a qualified workforce and access to technical knowledge; technical textile producers below the 50% threshold reported that difficulty in marketing, standards and certification, entrance to markets, and access to coaching, consultancy, and training services are most challenging issues. It shows that they are currently in the transformation phase. Even though the problems are evaluated similarly in enterprises that produce more than half of their output in technical textiles, however, their levels are lower. Companies that make composite materials stated that R&D opportunities and quality & technical competence are the two biggest challenges.

Challenges were also evaluated specifically for sub-sectors of the Conventional Textile sector (figure 5). The most important three challenges were reported as access to a qualified workforce, access to technical information, and standards and certification.

The first three most challenging sub-sectors are workwear fabric and apparel, followed by garment and upholstery fabric manufacturing companies. For the workwear fabric and apparel sub-sector, the ranking for the sector is similar to the overall ranking. However, for the garment sub-sector foreign trade and marketing were reported as being the most significant challenge.

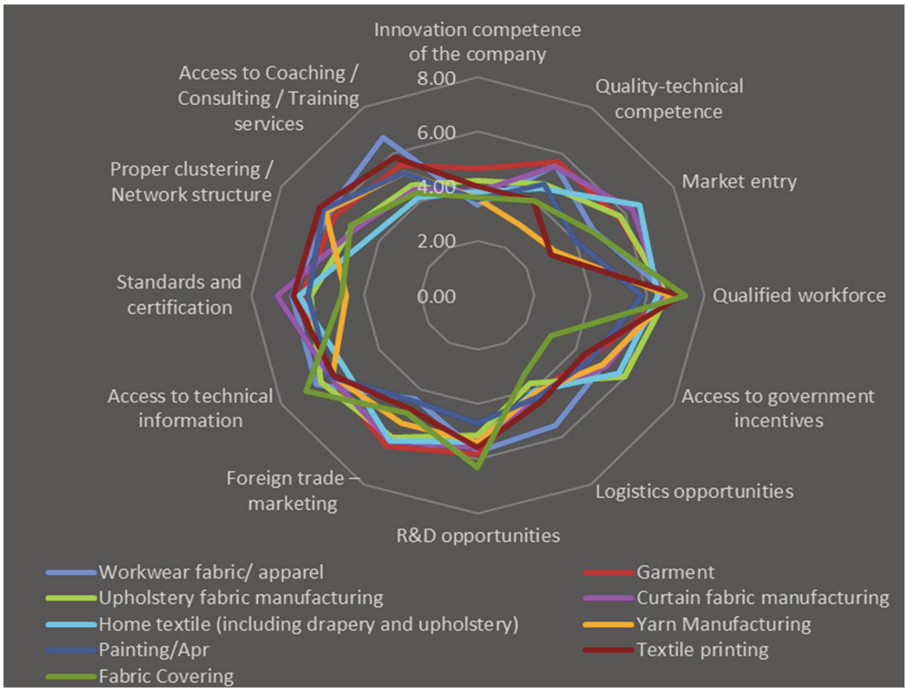

Fig. 5. Challenges in transformation for sub-sectors of conventional textile (out of 10)

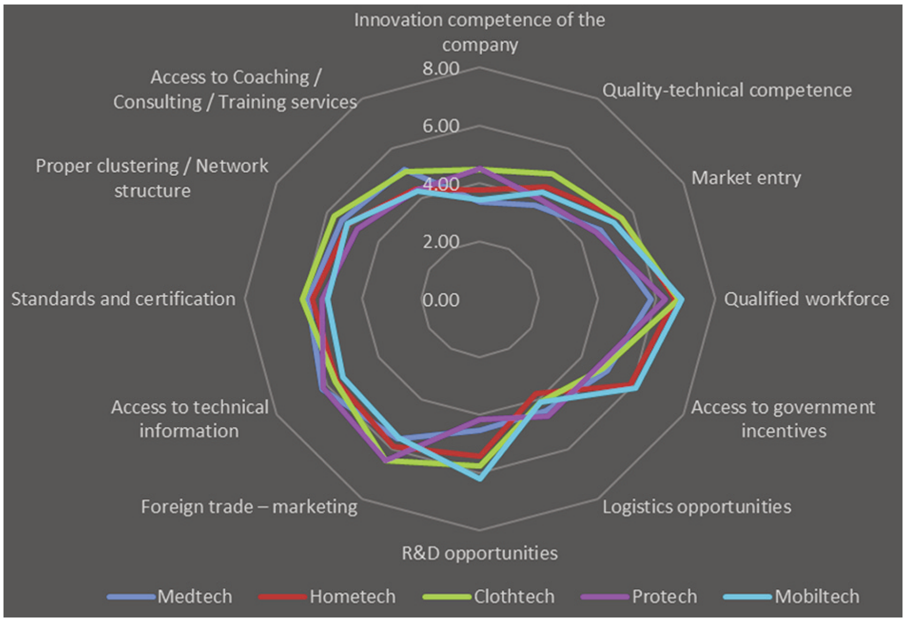

Fig. 6. Challenges in transformation for sub-sectors of technical textile (out of 10)

Figure 6 shows the challenges for the technical textile sub-sectors. Almost the same challenges are valid for the sub-sectors of the technical textile manufacturers. Access to a qualified workforce was reported to be the main challenge by all sub-sectors, especially Mobiltech and Clothtech. The difficulties for marketing and exporting come second for all sub-sectors. Specifically, Clothtech and Protech subsectors reported these challenges too. The challenge for access to technical information was reported by Medtech and Protech sub-sectors.

The great majority of businesses want to collaborate with companies outside their industry (f). The businesses whose main product is technical textiles showed the most desire for cooperation, followed by the companies that produce composite materials. Overall, 88 percent of the enterprises visited expressed a desire to be a part of the projected Technical Textile and Composite cluster in Bursa (figure 8). Once more,

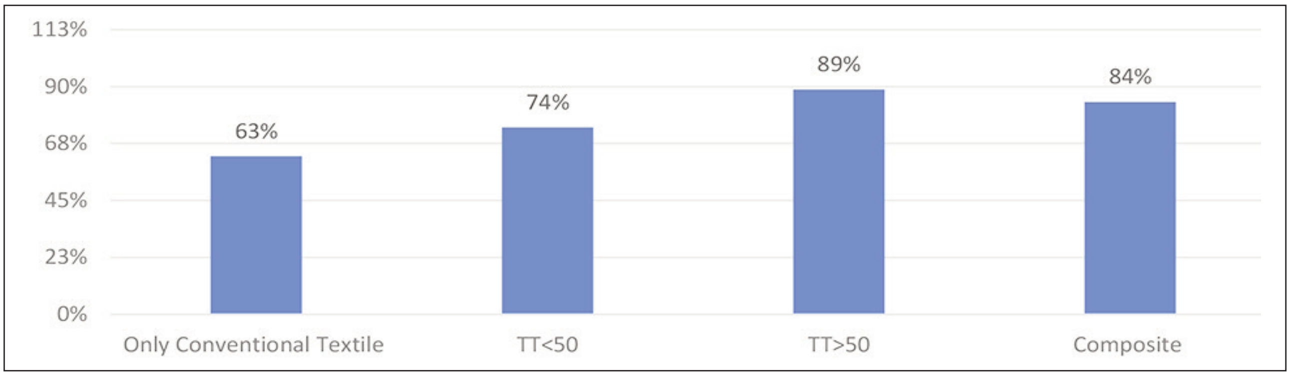

Fig. 7. Desire for commercial cooperation with companies outside their field

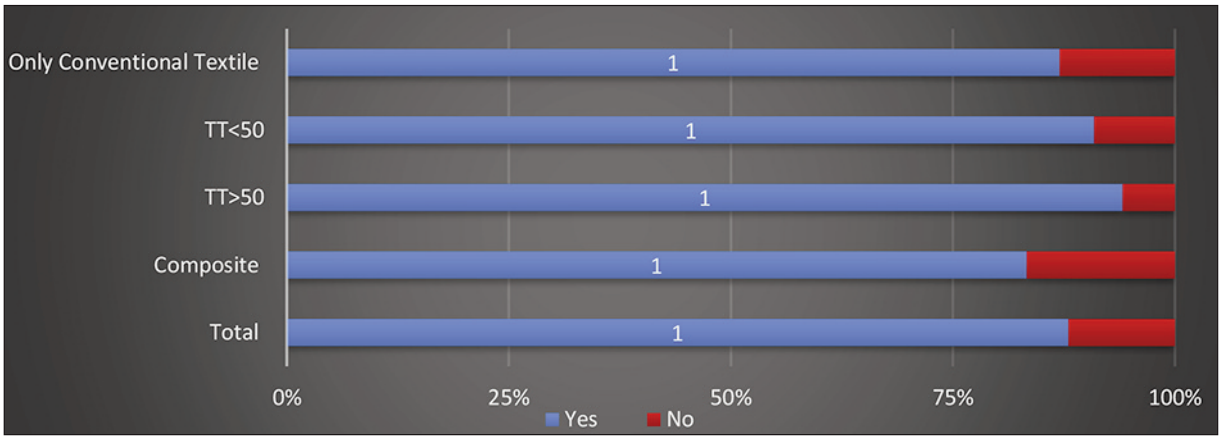

Fig. 8. Desire to be included in the cluster to be established in Bursa (%)

the rate is highest in companies that manufacture technical textiles. Companies that make traditional textiles have also expressed an interest in joining this cluster. This point demonstrates the desire for change as well.

Companies mainly agreed that the clustering plan would deliver benefits such as testing and R&D facilities, incentives and support, and joint sales marketing (table 3). In terms of benefits, business partnership venture capital comes to the fore in companies that only produce traditional textiles. Companies that produce more than half of their products as technical textiles discussed receiving incentives, whereas those that produce less than half of their products as technical textiles discussed receiving technical support, consulting, testing, and R&D facilities. Companies that make composite materials are also highly motivated to benefit from post-clustering technical support and consulting. At the same time, this situation will enable the companies to act more easily in this regard towards the raw material suppliers or representatives in the cluster.

Table 3

BENEFITS OF A CLUSTERING STRATEGY

Sector	Traditional textile only (%)	TT<50 (%)	TT>50 (%)	Composite (%)
Joint sales-marketing	63.6	54.5	55.6	55.2
Input/raw material supply	36.4	50.0	50.0	34.5
Technical support consultancy	50.0	72.7	66.7	65.5
Shared centres	31.8	59.1	50.0	41.4
Testing / R&D facilities	72.7	72.7	72.2	48.3
Incentive support	68.2	68.2	77.8	44.8
Publicity/promotion	50.0	54.5	38.9	34.5
Joint venture/joint venture capital	72.7	45.5	44.4	41.4
No benefit	4.5	4.5	11.1	10.3
Other (please specify)	4.5	9.1	16.7	10.3

CONCLUSIONS

Research on the key competitiveness characteristics of the textile and composite industry and their development potential towards value-added products has reached the following conclusions:

- Fully two-thirds (66.7%) of the companies that visited and completed the survey produce textile products, while approximately 9% of these companies also produce composite materials. One-quarter of the companies said that they only produce traditional textile products. The rate of enterprises producing technical textiles among those visited was 40.9%.
- Companies expressed their intention to augment their current capacity, while also displaying a strong inclination to invest in emerging industries. Over 75% of the companies assert that they are capable of manufacturing superior quality and higher value-added products with adequate assistance.
- Companies have declared their intention to invest or modify operations in nearly every industry. The objective is to enhance the production capacity of enterprises exclusively engaged in the manufacturing of conventional textiles and composite materials.
- Companies often employ uncertainty and high investment costs as rationales for deferring investment planning or transformation initiatives. It has been observed that traditional textile producers would face the greatest challenges in terms of transformation. Companies in the textile industry that produce less than half of their goods as technical textiles are classified as the second group.
- Composite material manufacturers are contemplating investing in or transitioning to various sectors, including automotive and transportation, renewable energy, defence, and aviation and space industries, specifically composite materials.
- The primary barriers to transformation, which may differ across sub-sectors, include limited availability of skilled personnel, challenges in entering new markets, and difficulties in securing financing.
- Traditional textile producers are expected to encounter the greatest challenges during the transformation. The second group consists of textile companies whose production of technical textiles accounts for less than 50% of their overall production.
- 88% of the businesses visited expressed their desire to be part of the Technical Textile and Composite cluster envisaged in Bursa.
- Composite material manufacturers have identified research and development opportunities, as well as quality and technical competence, as their primary challenges.
- The sub-sectors of technical textile manufacturers face similar challenges. The main issue across all sub-sectors, particularly mobile technology and fabric technology, is the reported lack of access to skilled labour.
- Composite material manufacturers are also strongly inclined to seek advantages from post-cluster technical assistance and consultation. This will also facilitate companies in taking prompt actions towards raw material suppliers or representatives within the cluster.
- Innovation, rapidity to market, cost competitiveness, product quality, branding and marketing, sustainability, social responsibility, and talent management are some of the ways a business can cut costs, differentiate itself from competitors, meet customer needs and expectations, and avoid falling behind the competition. By prioritizing these traits, companies can create profitable and long-lasting businesses that can thrive in the fast-paced, highly competitive textiles industry.

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Authors:

MEHMET KARAHAN[1,2], ALİ ARI[3], AHRARİ MAZYAR[4]

[1]Vocational School of Technical Sciences, Bursa Uludag University, 16059, Bursa, Türkiye
e-mail: mkarahan@uludag.edu.tr

[2]Butekom Inc.,umlupinar OSB District, 2nd Cigdem Street No:1/4, 16245, Osmangazi, Bursa, Türkiye

[3]Department of Weapon Industry Technician, Vocational School of Higher Education, Ostim Technical University, 06374, Ankara, Türkiye

[4]Textile Engineering Department, Faculty of Engineering, Bursa Uludag University,
Gorukle Campus, Bursa, Türkiye

Corresponding author:

ALİ ARI

e-mail: ali.ari@ostimteknik.edu.tr