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TEKSTİL VE KONFEKSİYON

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The Effects of Production Parameters on the Core Visibility Ratio of Dual-Core Yarns

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ABSTRACT

The aim of this work is to determine the effect of draft ratio and twist level on core visibility ratios of dual-core yarns. For this aim, different types dual-core yarns containing PET/Elastane were produced under controlled conditions. To objectively evaluate the visual quality of the dual-core yarns, the frequency of the core filaments appearing on the yarn surfaces was counted on dyed knitted fabrics produced with these yarns by using image processing algorithm. The results showed that the draft ratio and the twist coefficient were the important factors influencing the core visibility ratios of dual-core yarns. It was found that the core covering performances of the pre-treated dual-core yarns produced with the lowest twist coefficient in the study were more incomplete than the others. Moreover, it was seen that the higher draft ratio on PET filament led to well wrapping of sheath staples to core filaments for dual-core yarns.

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KEYWORDS

Dual-core yarn, pre-treated dual-core yarn, core visibility ratio, draft ratio, twist coefficient

1. INTRODUCTION

Core-spun yarn is composite yarn structure developed for utilizing properties of two or more fibre components at the same time with optimum level. The core-spun yarns consist of two different components; a sheath and a core. The core is generally a continuous monofilament or multifilament yarn, which imparts mechanical and functional properties such as strength, dimensional stability, and elasticity to produced core spun yarn. The sheath is staple fibres such as cotton, polyester, viscose etc. and these staple sheaths have been used to improve the wear comfort, in respect of the aesthetic, comfort and handle properties of the resultant yarns [1].

In general, core-spun yarns are classified depending on the raw material used at the yarn centre such as hard-core, soft-core. Hard core components such as PET, PA, filaments impart the functional properties such as higher breaking strength, shrinkage and good dimensional stability to resultant core spun yarns. Elastane filaments, as the example for soft core component can exhibit very high elongation (400-800 %) due to their chemical structure. The elastane content even at low usage rates of 3-5 % gives the properties such as shrinkage, better shape fitting, easy maintenance, high elasticity and good recovery to the fabric and garment.

Core-spun yarn properties are mainly influenced by the placement of components in the yarn structure, namely the position of the core filament, the distribution of the sheath staples on the yarn surface, cross sectional configuration, etc. If the core filament is firmly located in the centre of the yarn and well covered by the sheath-staples, the core-spun yarn is evaluated as high quality. Since the eccentric location of the core filament in the yarn axis or irregular covering of the sheath stables lead to bad appearance on the yarn surface, this type of core/sheath distribution is evaluated as yarn defect. Some studies have been

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performed regarding the effect of core-spun yarn structure and spinning parameters on core filament placement and the sheath staples strip-back from core filament phenomena [1-9]. These strip-back phenomena are called as barberpole by Sawhney [2] and it is concluded that strip-back occurs between core and sheath components because of two important reasons; nonconformity between core-spun yarn and core filament linear densities, insufficient twist level. Miao et al. [3] reported that core tension during production has a highly significant effect on sheath slipping resistance. Su et al. [4] showed that passing the spandex through the V-grooved roller and keeping a contact angle with the front top roller are beneficial to the cover effect of the elastic core-spun yarn. Babaarslan [5] concluded that core positioning has a direct effect on the structure, properties, and performance of core-spun yarns. Kim et al. [6] conceived a measuring system that operates on the machine vision along with programs for recognizing the surface defects and monitoring the measuring process. As a result of the measurement they made with this system, they found that the number of defects has decreases with the increase in twist level. Shanbeh et al. [1] described a method of decreasing the strip-back phenomenon of core-spun yarns. In the proposed method, before the production of these yarns, the core part was coated with a Methyl Methacrylate (MMA) binder using a purpose-built method based on the conventional pad-dry-cure (PDC) system. The obtained results showed the effectiveness of the method proposed for the improvement of the strip resistance of core-spun yarns after the abrasion process, as well as of the abrasion resistance and pilling of woven fabrics. Örtlek et al. [7] investigated the core visibility ratios of hybrid yarns containing copper wire which were produced with 5 different production methods at three different twist levels by using image thresholding method and they found that the production methods and the twist levels have impact on the core visibility ratio value of the hybrid yarns. Türksoy and Kılıç [8] used image processing technique to determine aesthetic differences of hybrid yarns manufactured by three different production methods (ring core-spun, siro core-spun, compact core-spun), and three different yarn counts (Ne 18, Ne 24, Ne 30) containing stainless steel (SS) wire and cotton fibres. Based on the core visibility ratio values of the core spun yarns, the best aesthetic performance in terms of hiding the stainless steel was obtained by siro core-spun method and Ne 18 count core-spun yarns.

In recent years, a new type of multicomponent core-spun yarn called as dual-core yarn has been developed in order to overcome a number of problems resulting from the high recovery property of elastane. Dual-core yarns are comprised of two core filaments; an elastane filament and a multifilament (such as PET, PA, PBT or T400®), covered by a staple sheath [10, 11]. Dual-core yarn production actually has a similar principle to that of the core-spun production. Dual-core yarns can be manufactured on modified conventional ring spinning machine in two different methods [10]. In the first method, previously combined two core threads are fed simultaneously, whereas in the second method, two core threads are fed separately into the centre of sheath fibre bundle. In this study, dual-core yarns produced with the first method were called as pre-treated dual-core (PDC) yarns while the yarns obtained with the second method were named as dual-core (DC) yarns. Many researchers have been focused on core-spun yarn properties [12-18] however very limited number of studies was found on the dual-core yarn properties.

The aim of this study is to determine the effect of draft ratio and twist coefficient on core wrapping quality of dual-core yarns. For this aim, two different dual-core yarns (PDC and DC) containing PET and Elastane were produced with the three different draft ratio and three different twist coefficients. To objectively evaluate the visual quality of the dual-core yarns, the frequency of the core filaments appearing on the yarn surfaces was counted by using image processing technique with a newly proposed approach. Finally, the results were statistically analysed in terms of the significance of independent parameters (draft ratio and twist coefficient) on core wrapping quality.

2. MATERIAL AND METHOD

2.1 Material

Pre-treated dual-core yarn and dual-core yarn samples having Ne 18/1 count were produced by using Rieter G33 conventional ring spinning machine modified with a positive feed roller system and a V-groove guide. For both yarn types, 100% Cotton fibers (30 % Turkmen Sawgin, 50 % Urfa Rollergin, 20 % USA Sawgin) were used as the sheath staple. The cotton fibers have the following physical properties; 29.21 mm fiber length, 82.9 UI (Uniformity Index), 32.5 g/tex strength, 7.91% elongation and 4.5 micronaire fineness. For the core component of pre-treated dual-core yarns, PET (36 filaments) filament having 55 dtex fineness and Elastane filament (Creora ®) with 44 dtex fineness were welded by intermingling process. Draft was applied to the combined filaments with the ratio of 3.5 during the intermingling process and obtained core component was named as gimped yarn. Gimped yarn was fed to the drafting system and positioned in front roller nip in terms of a standard V-grooved guide roller and covered by cotton fibres (Figure 1a).

Dual-core yarns were produced by using the same core and sheath components having the same fibre properties as pre-treated dual-core yarns. However, in dual-core spun yarn production, the core components of PET (36 filaments and 55 dtex) and Elastane (44 dtex) filaments were fed separately under control to the front roller in terms of a standard V-grooved guide roller and covered by cotton fibres (Figure 1b). The production parameters of multicomponent core-spun yarns are given in Table 1.

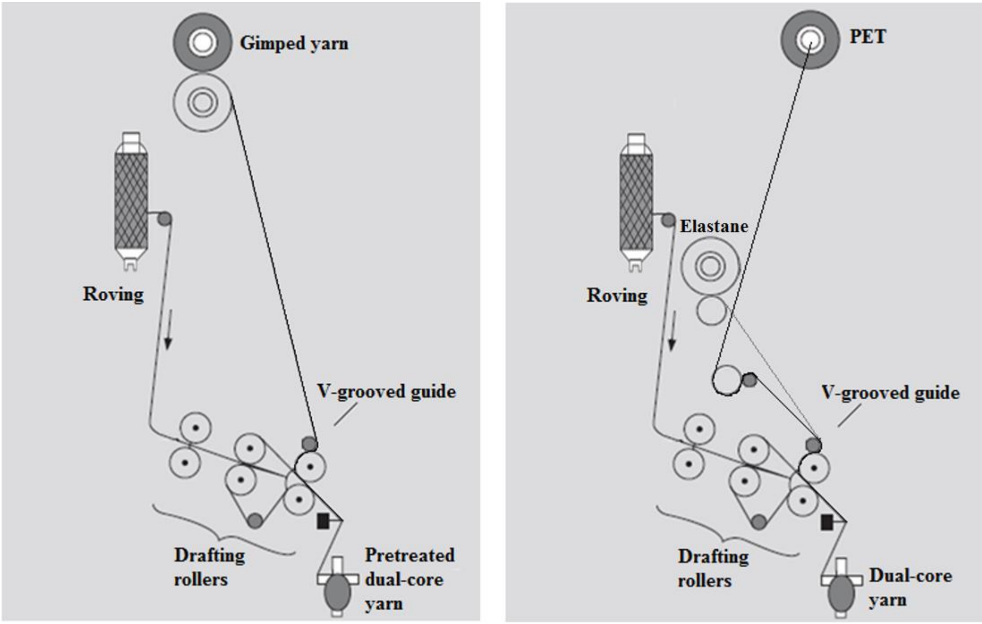


Figure 1. Pre-treated dual-core (a) and dual-core (b) yarn production

Table 1. The production parameters and codes of PDC and DC yarn samples

Sample Code	Twist Coefficient (α_e)	PET draft ratio	Elastane draft ratio	Gimped yarn draft ratio
PDC1	4	-	-	1.08
PDC2	4	-	-	1.03
PDC3	4	-	-	1.10
PDC4	3.5	-	-	1.08
PDC5	4.5	-	-	1.08
DC1	4	1.08	3.5	-
DC2	3.5	1.08	3.5	-
DC3	4.5	1.08	3.5	-
DC4	4	1.03	3.5	-
DC5	4	1.10	3.5	-
DC6	4	1.08	3.3	-
DC7	4	1.08	3.7	-

The visibility of core parts of PDC and DC yarns, which were produced with the different production techniques, was evaluated in the knitted fabric form. As a result of knitted fabric structure, core part of PDC and DC yarns, which is normally invisible, becomes visible. For this reason, single jersey knitted fabrics were manufactured with PDC and DC yarns on sample knitting machine by means of a sample circular knitting machine with 3.5" gauge, 22 feign and one feeder. Since the visibility of the core filament will be determined from the fabric surface, the fabric samples were performed the pre-treatment processes and dyed with reactive dyes. Thus, the cotton i.e. the sheath fibers were colored and the core filament remained as white color without getting dye pigments. So, the measurement success of the developed algorithm was improved. The fabric samples were evaluated with the corresponding yarn sample code in Table 1.

2.2 Method

It is considered that the improperly placed filaments or the bad sheath wrapping quality will exhibit different appearance and texture characteristic on the fabric surface. This difference in the fabric texture will result in different pixel values owing to having different light reflection characteristic and different colors. So, the wrapping quality of the dual-core yarns was evaluated in the knitted fabric form by an image processing based method, in this study.

For each yarn sample, seven fabric samples were produced from seven arbitrarily selected yarn copes. Ten image frames were acquired from different parts of each fabric by using Olympus digital microscope with ×15 magnification in ".tiff" format (Figure 2) and totally seventy image frames were obtained for each yarn sample. All lightening conditions and microscope adjustments were kept constant for all image acquisition processes.

Figure 2. Image acquisition with Olympus digital microscope

The algorithm given in Figure 3 was developed in order to determine the core filament visible ratios from the fabric surface. The algorithm was built in MATLAB environment. Firstly, the image frames acquired in RGB formant was converted to gray scale. RGB images consist of 3-D matrices. Three numerical values are assigned to each pixel in RGB images, each value corresponding to the red, green and blue (RGB) image channel component respectively. Since feature extraction and processing operations are typically applied on the converted grey scale version (2-D) of the image, RGB image frame should be converted to gray scale image using simple transform. Some unwanted external disturbance may occur during the image acquisition operation. These disturbance effects called as noise lead to variation of the signal from its true value in the image processing pipeline [19]. In order to obtain a robust image processing algorithm and achieve the required the success rate, the image frames are dedicated to noise removing filter. In this study, Wiener noise removing filter [20] was applied to reduce the disturbance effects from the image. Then, the image frame was converted to binary form by applying appropriate threshold level. The threshold value is determined by trial and error method. The binary image has two logical values; 1 (white) and 0 (black). The logical conversion of each pixel value is achieved regarding to being higher or lower than threshold value. In this study, the bad covered core filaments were seen on the fabric surface and they were converted white color after logical binary transformation. The other segments well wrapped by fibers were seen as black color. In order to differentiate foreground pixels (white) from the background pixels (black), erosion morphological operation is applied. In the erosion operation, the centre pixel of the structuring used as square in this study element was placed on each foreground pixel value 1. If any of the neighborhood pixels is background pixels' value 0, the foreground pixel is switched to the background. Thus, the visible core sections seen on the fabric surface were clearly distinguished. Finally, core visibility ratio (%) was calculated from the ratio of the foreground pixels' area to the total fabric sample area. The application result of the developed algorithm to a fabric sample image is given in Figure 4.

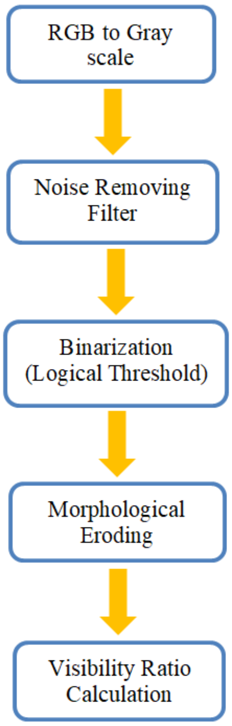
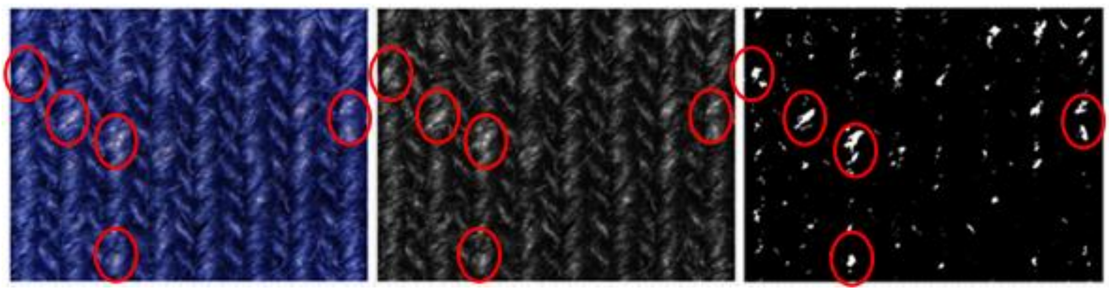


Figure 3. Core visibility measurement algorithm



(a) RGB image (b) Gray scale image (c) Eroded binary image

Figure 4. The image processing algorithm application

The significance of independent parameters; draft ratio and twist coefficient were analyzed by using one-way replicated analysis of variance (ANOVA) and the mean differences of subgroups were compared by using DUNCAN post hoc test at 0.05 level using SPSS 13.0 statistical package software.

3. RESULTS AND DISCUSSION

The core visibility ratio (CVR) of yarn samples was determined from dyed knitted fabrics by using image processing algorithm. The results were analyzed statistically and submitted in relation to the effect twist coefficient and draft ratio independent parameters. The effect of the twist coefficient and the draft ratio on the core visibility ratio values of the pre-treated dual-core yarns (PDC) and the dual-core yarns (DC) are shown graphically in Figure 5. As seen in Figure 5, the DC6 coded yarn has the lowest core visibility ratio whereas the PDC2 coded yarn has the highest core visibility ratio, in all yarn groups. According to the graph, the DC6 coded yarn produced with 4 twist coefficient, 1.08 PET draft ratio and 3.3 Elastane draft ratio can be said to well cover by the sheath-staples and to be the ideal yarn for core covering performance. In addition, when the graph is evaluated in general, it is seen that higher quality yarns in terms of high core coverage can be obtained with dual-core yarns according to the pre-treated dual-core yarn structure. It thought that higher bulkiness resulted from feeding with intermingling process of PET and Elastane filament may affect the core covering performance of pre-treated dual-core yarns negatively.

3.1 Analysis of Core Visibility Ratio of Pre-treated Dual-Core Yarns

In order to determine the significance of twist coefficient and draft ratio on core visibility or core covering properties of pre-treated dual core-spun yarn samples, variance analysis (ANOVA) of the measurement results were performed. According to ANOVA test, twist coefficients (tc); α_e=3.5, α_e=4.0 and α_e=4.5 and gimped yarn draft ratios (dr); 1.03, 1.08 and 1.1 have statistically significant effects (p_{tc} = 00.040 and p_{dr} = 0.002) on core visibility ratio of pre-treated dual-core yarn samples in 95% confidence interval. In order to compare the core visibility ratio results of the pre-treated dual-core yarn samples and determine which twist coefficient and gimped yarn draft ratio provide statistically significant difference, multiple comparison test (DUNCAN) was done (Table 2).

The DUNCAN test results of PDC1, PDC4 and PDC5 yarn samples are given in Table 2 for twist coefficient. As observed from the Table 2, there is no significant difference between the core visibility ratio of PDC1 and PDC5 yarn samples. However, there is a significant difference between PDC4 and other two samples; PDC5, PDC1 yarn samples. The highest core visibility ratio is seen in the PDC4 coded yarn that is produced with the lowest twist coefficient (α_e=3.5). The twist coefficient/level is an important factor affecting the frequency with which the core filaments show on the yarn surface. The position of the core filaments can be more frequently alter with the level of the twist coefficient. At a very low twist coefficient, twists seem to allow the core spun yarn to have a migration effect mainly due to the position change magnitude [6]. Moreover, Gharahaghaji et al. [21] stated that using a high level of twist helps to build up the required cohesion between the sheath and the core component. It is thought that the higher the CVR value of the pre-treated dual-core yarns produced with the lowest twist coefficient is related to these situations.

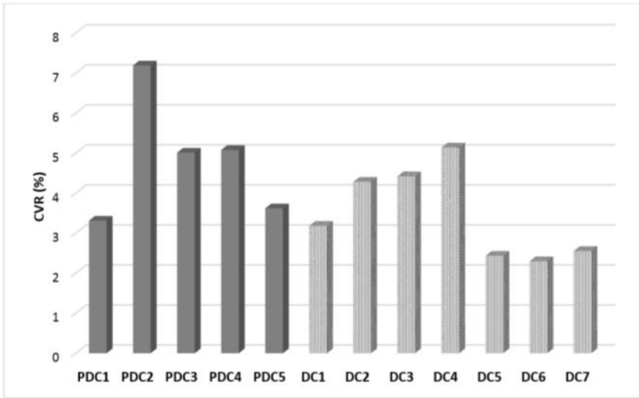


Figure 5. The average core visibility ratio values for pre-treated dual-core yarns (PDC) and dual-core yarns (DC)

Table 2. DUNCAN test results for core visibility ratio of pre-treated dual-core yarns with regard to twist coefficient and draft ratio

Process	**N**	**Subset**	
Twist Coefficient (α_e)		1	2
PDC1 (α_e=4)	7	3.31	
PDC5 (α_e=4.5)	7	3.62	
PDC4 (α_e=3.5)	7		4.93
Significance Level		0.625	1.000
Gimped Yarn Draft Ratio			
PDC1 (1.08)	7	1.93	
PDC3 (1.1)	7	2.57	
PDC2 (1.03)	7		5.20
Significance Level		0.458	1.000

When Table 2 is examined in terms of gimped yarn draft ratio, it is seen that there is a significant difference between PDC2 and other two samples; PDC1, PDC3. There is no significant difference between PDC1 and PDC3 samples. The lowest core covering performance is seen in the PDC2 coded yarn sample having 1.03 gimped yarn draft ratio. On the other hand, the best core wrapping performance is obtained with 1.08 core draft ratio among three different draft ratios.

3.2 Analysis of Core Visibility Ratio of Dual-Core Yarns

According to ANOVA result, the twist coefficient (tc), Elastane and PET draft ratios (edr and pdr) have significant effect (p_{tc} = 0.011, p_{edr} = 0.0001 and p_{pdr} = 0.001) on core visibility ratio of dual-core yarn samples. The DUNCAN test results of dual-core yarns according to the twist coefficient, Elastane and PET draft ratios are given in Table 3.

Table 3. DUNCAN test results for core visibility ratio of dual-core yarns with regard to twist coefficient, Elastane and PET draft ratios

Process	N	Subset	
Twist Coefficient (α_e)		1	2
DC1 (α_e=4)	7	3.18	
DC2 (α_e=3.5)	7		4.29
DC3 (α_e=4.5)	7		4.42
Significance Level		1.000	0.737
Elastane Draft Ratio			
DC6 (3.3)	7	2.30	
DC7 (3.7)	7	2.55	
DC1 (3.5)	7		3.18
Significance Level		0.229	1.000
PET Draft Ratio			
DC5 (1.1)	7	2.44	
DC1 (1.08)	7	3.18	
DC4 (1.03)	7		5.14
Significance Level		0.236	1.000

As submitted in DUNCAN test for twist coefficient (Table 3), there is no significant difference between DC2 and DC3 yarn samples. However, there is a significant difference between DC1 and other two samples; DC2 and DC3. Also, it can be said that that the highest core covering performances for the pre-treated dual-core and dual-core yarns are obtained with the middle twist coefficient (α_e=4). As shown Table 2 and 3, for both yarn types, the highest twist coefficient (α_e=4.5) resulted in staple fiber slippage over the filament fibers. It is thought that as core filaments are fed on the side of the spinning zone due to high twist, the wrapping of the sheath staples around the core filaments for both dual-core yarn type is not well and uniform.

When Table 3 is examined for elastane draft ratio, it is seen that there is no significant difference between DC6 and DC7 samples. On the other hand, DC1 results are significantly different from DC7 and DC6 samples. According to Table 3, it can be said that the highest core covering performance is obtained with DC6 coded dual-core yarn that is produced with 3.3 elastane draft ratio.

As shown in the Table 3, it is seen that there is no significant difference between DC5 and DC1 dual-core yarn samples in terms of PET draft ratio. It means that the draft ratio changes from 1.08 to 1.1 does not have significant effect on core wrapping level of sheath staple. However, DC4 sample is significantly different from DC1 and DC5 dual-core yarn samples. There is decreasing tendency in core visibility results of dual-core yarn samples with the increase in PET draft ratio value. This may be due to the fact that as the PET draft ratio is increased, the linear density of PET core component is getting finer, number of cotton sheath fibers increase and the core wrapping performance of the sheath fibers increase.

4. CONCLUSION

The aim of this study is to evaluate the aesthetic defects of different dual-core yarns containing PET/Elastane by using image processing technique in terms of production parameters. In order to determine the core visibility ratios of the pre-treated dual-core yarns (PDC) and dual-core yarns (DC) produced with different twist coefficient and draft ratio, single jersey knitted fabrics were manufactured from these yarns. Thanks to the knitted fabric structure and colored sheath fibers, core part of PDC and DC yarns became visible. Then, image processing technique was applied to the dyed knitted fabric samples acquired by using Olympus digital microscope and thus the image of the core filaments on the yarn surface became clear.

The results showed that the pre-treated dual-core yarns produced with the lowest twist coefficient (α_e=3.5) had the highest core visibility ratio. It can be revealed that the lower amount of twist on yarn structure leads to inadequate wrapping of sheath staples to core filaments. Moreover, this result indicates that the interlacing between the core filaments and the sheath staples decreases due to low twist coefficient and staple fiber slippage over the filament takes place more intensively. For pre-treated dual-core yarn samples, it was seen that the highest and lowest core covering performances were obtained with 1.08 and 1.03 core draft ratios, respectively. On the other hand, there was not any increasing or decreasing tendency in core visibility ratio with core draft ratio increase or decrease. So, it can be stated that the optimum core draft ratio is 1.08 for pre-treated dual-core yarn samples.

Since the dual-core yarn samples were produced by feeding two core filaments; Elastane and PET, the draft effect of these two core filaments were evaluated separately. For dual-core yarns, it was revealed that the core covering performance on the yarn surface improved with increase in PET draft ratio and the highest core covering performance was obtained with 1.1 PET draft ratio. This mean that the lower PET draft ratio leads to incomplete core coverage and may result in end breaks in the next stages of processing. When the effect of elastane draft ratio was investigated, it was seen that the highest core wrapping performance was obtained with 3.3 draft ratio. Apart from these, the results showed that the twist factor at 4 (α_e) gave the optimum core covering performances.

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Simulated Annealing Algorithm and Implementation Software for Fabric Cutting Problem

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ABSTRACT

The development of loom technology has significantly increased the efficiency of fabric output in the textile industry. Additionally, preventing the occurrence of defects during the manufacturing process on the fabric is not easy. Therefore, after the production is completed, the aim is deciding the cutting location of the product, which has the defect map, to increase the first quality product quantity by considering the customer quality parameters. In this article, a decision support system has been developed to help the inspector in the final stage which will also prevent losses. The utilized algorithm is the Simulated Annealing algorithm, which is well known and rendered good results for different types of problems in the literature. In the study, a sample problem is used to explain the adaptation of the algorithm to the problem, and the design of the experiments is deployed to obtain the best parameter values for the algorithm. Finally, the software, which is prepared to use the algorithm in the real production environment, is introduced and the results of the performance analysis are evaluated. The results demonstrated that the developed software is capable of making high ratio first quality fabric decisions within seconds.

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1. INTRODUCTION

Since textile is one of the most important actors in the fashion area, the manufacturers must be leading companies in such matters as production technology, delivery times, and quality levels to adapt to the ever-changing customer behaviors. In the last stage of the weaving industry, it is critical to decide the cutting locations of fabric, considering customer quality requirements, to boost firm profitability. Note that the prerequisite for conducting this study is registering the types and locations of defects on fabric into the database. In this study, defect detection is done by manual inspection. Then the collected data is transferred to the system database to obtain the defect map. The principal objective is to increase the resulting first quality fabric length. Those in the industry know that the profit loss from the first to the second quality is incredibly high. The focus of this study is to develop a decision support system that can solve this problem in seconds.

As the first attempt in the solution stage of the mentioned real production environment problem, a procedure was developed which splits the fabric in larger lengths into smaller subsections. The method proceeds considering the quality parameters of the customer company. The next step is to attain the highest quantity of first quality fabric from sub-parts obtained by the procedure. In order to solve the mentioned problem, Simulated Annealing (SA) metaheuristic is adapted to the cutting fabric problem in this paper.

SA algorithm is one of the well-known heuristic techniques based on the steps in the annealing process, which aims to ensure that the crystal structure is regular in the heat treatment of metals. Acceptance of bad solutions with some probability prevents convergence to local optimum points. As will be mentioned in the literature review, SA was applied to various problems, and good results were obtained. In the next step, SA's parameter values will be optimized, user interfaces will be developed, and performance evaluations will be made.

The main contributions of this research are evaluated regarding the methodology adopted and the application area. The first contribution is the recommended procedure

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for splitting the large woven parts into sub-parts to meet customer conformity. The second contribution is the application of the SA algorithm in a real production plant, which solves the real production area problems with high first quality ranges and in seconds.

This paper is organized as follows: Section 2 provides a literature review of cutting problems, which has a similar structure with the problem at hand. The problem description is made in Section 3. SA is presented in Section 4. Computational results are displayed in Section 5. The paper is finalized with the conclusion and future research directions in Section 6.

2. LITERATURE REVIEW

Despite the NP-hard structure of cutting problems (Brandao and Pedroso [1]), researchers usually develop heuristic methods. The main idea is, cutting the large objects into smaller items to meet customer demand. Optimization of these kind problems generally provides high economic savings. Cutting stock problems have been encountered in many production processes as wood, steel, meat, paper, and also in logistics applications such as cargo loading.

A literature review by Haessler and Sweeney [2] discusses the basic formulation and solution procedures for one- and two-dimensional cutting problems. In the study of Wäscher et al. [3], the cutting and packaging algorithms were grouped by considering the problem types and sizes (1, 2, 3 dimensional). The special cases of problems often involve not being able to include a specific group and can be grouped in the "other" class. The work in our paper, as will be elaborated later, will be referred to in the other group in the future, because of carrying many specific features. Some of the two-dimensional problems and their solutions in the literature are Rodrigo et al. [4], Fathy et al. [5], Andrade et al. [6], Cui and Zhao [7], Kim et al. [8], Afsharian et al. [9]. Javanshir et al. [10] focused on the field of readymade of the textile sector. The planning of cutting was to minimize total fabric consumption, which was compatible with the two-dimensional cutting problem, and the simulated annealing algorithm was used for the solution in their study.

Some studies in the literature related to the cutting problem can be compiled as follows.

In the study by Poltroniere [11], the cutting problem is studied in scheduling problems, and also machine setup time and scrap costs were considered simultaneously in the case. Heuristic methods were developed for the problem, and the calculation results were discussed. Arbib and Marinelli [12] developed an integer linear programming model and heuristic methods in another study where cutting operations were scheduled by taking into consideration the product delivery dates. In the paper of Araujo et al. [13], minimization of the number of parts and the number of different cutting patterns were considered, which are two objective functions that are contradictory to each other. A genetic algorithm was developed for the mentioned problem and tested on randomly generated and real data set. Another hybrid heuristic that minimizes the number of different cut shapes was also developed by Yanasse and Limeira [14]. In another study by Lai and Chan [15], the simulated annealing algorithm with artificial intelligence was developed for the cutting problem, and the algorithm was tested with random generated and real datasets. Another method that provides good and fast results for situations where there are a large number of pieces to cut was developed by Brandao and Pedroso [16].

The issue to be addressed in this paper is the one-dimensional cutting problem. Although the number of dimensions decreases, the constraints arising from the problem structure increase complexity. In the study of Afsharian et al. [9], these problem variants are called as “more specialized, less standardized” because of considering large defective objects. For the glass cutting problem, which can be classified in this category, the researchers developed a dynamic programming algorithm [17], mixed integer programming based algorithm [18], and genetic algorithm based solution [19]. The paper of Rönnqvist [20] provided an overview of wood flow in the forestry industry and some optimization models, including cutting problems. The problems in glass cutting, forest, steel, or textile industry might seem similar, but defect types, quality classes, different customers’ diverse requirements, make each problem type unique actually. In the study of Cherri et al. [21], an extensive literature review was made on the one-dimensional cutting stock problem that takes into account the usable leftovers, if large enough, to meet future demands. The study of Poldi and Arenales [22] carried out in this context, the situation of the subsequent periods was also taken into consideration. The range of products in the textile sector is extensive, and the main customers’ order variability decreases the possibility of re-using the product for future demands. So, the problem to be solved in this study also differs from the scope mentioned. The textile industry makes many problems special because of its natural structure. For example, again in the weaving sector, Eroğlu et al. [23] proposed a genetic algorithm for scheduling, which divided the jobs and assigned to machines simultaneously. The problem of cutting, which is encountered in the last stage of weaving and which will be discussed in this paper, has been studied rarely in the literature. The problem in the study, which was done by Özdamar [24], is compatible with the foundation stones of the problem in this paper. Özdamar [24] emphasizes the differences of the problem structure in her study, as summarized below.

Whitaker and Cammell [25] aimed to increase the total income by considering meat quantities in different sources besides meat cutting capacities. Meat is a function of variables such as meat, gender, amount of fat in the meat industry and includes causality. Sculli [26] discussed the effects of scratches on adhesive tape, and the total usable length to be divided into standard lengths became a random variable in the study. Sweeney [27] studied the trimming of multi-length strips of different quality classes in the master roll. In that study, the quality of the master roll to which small pieces were to be cut was predetermined. In all the studies in this paragraph, there are different quality classes and predetermined product lengths. However, in this study, a quality class will be obtained after cutting operation. So, to find the best cutting locations, so many criterions -e.g., as defect score, the number of the critical defect, maximum defect length, the size of the fabric itself- have to be considered as it will be discussed in the next sections.

Fabric defects are responsible for approximately 85% of defects in the garment industry [28]. This study tries to maximize the first quality product, which includes different kinds of defects. So, as a first step, the required information about defects (e.g., type, quantity, length, location) has to be collected to obtain the defect map. Although this defect map has already been available in this study, please note that there is extensive literature research on this context. Ngan et al. [29] studied on literature review on automated fabric defect detection methods proposed in recent years. These methods are mainly grouped by utilized methods as the spectral approach, model-based approach, learning approach (neural networks), and structural approach. The researchers also analyzed the strengths and weaknesses of these approaches. Mahajan et al. [30] also studied on review of fabric defect detection methodologies. In the study, defect detection methods are grouped into statistical, spectral, and model-based approaches.

Although the study in this paper is coincident with the problem structure defined by Özdamar [24], the model has to meet all the needs of the dynamic production environment. For this reason, the quality parameters of different customers must be carried out under the real system. Additionally, big parts' splitting procedure is developed, which runs primarily.

3. PROBLEM DESCRIPTION

Due to the lack of more recent work on this special topic, the problem instance in the study of Özdamar [24], is taken into consideration in this section to provide the integrity and show differences of this paper. In the problem, Figure 1a shows the piece of fabric that contains defects with different types and lengths. In our work, the new dimension added to the problem is due to the natural structure of the real problem. Table 1 shows that; the quality definitions of different customers are diverse. When the fabric in Figure 1a was cut in two places, as demonstrated in Figure 1b, quality levels of obtained fabric parts vary by customer. Evaluating these two parts, according to Customer A's criterion in Table 1, the first part defect score can be calculated using Formula (1). According to these computations, the first fabric part in Figure 1a can be graded as first quality according to the first criteria of Customer A's requirements. Similarly, the second part of the fabric can be graded as second quality according to the first criteria of Customer A's request. This calculation is demonstrated in Formula (2). However, the product must be able to meet all the criteria in Table 1 to get the quality grade.

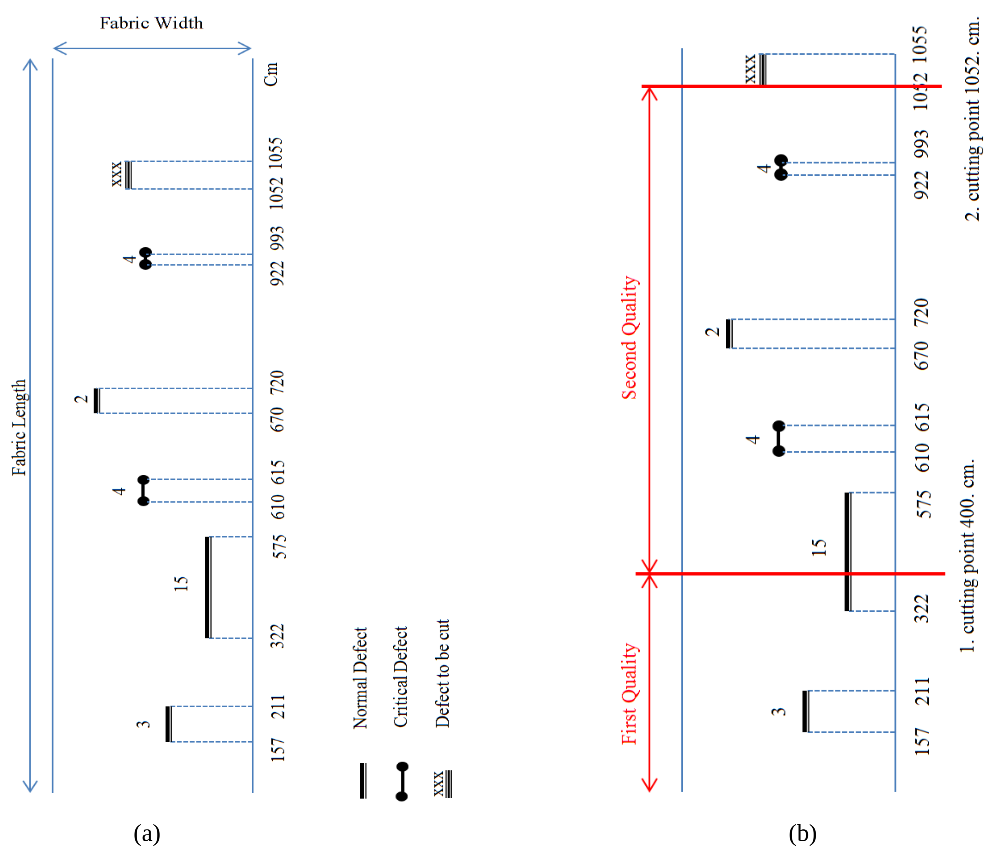

Figure 1 a. Piece of fabric with different types and length of defects **b.** Cutting points of fabric

Table 1. Different quality expectations of different customers

Criterion in a roll of fabric \ Quality Level	Customer A 1	Customer A 2	Customer A 3	Customer B 1	Customer B 2	Customer B 3
Defect score for each part	20	160	320	-	-	-
Critical defect quantity in 100 meter (m)	5	15	30	3	15	40
Maximum defect length (m)	3	300	300	1	300	300
Maximum part quantity	3	5	7	3	5	7
Minimum part length (m)	18	10	3	15	10	3
Maximum roll length (m)	300	300	70	150	300	300
Distance between two critical defects	5	0	0	3	0	0

First part defect score: $3+\frac{(400-322)}{(575-322)}*15 = 7.62$ (1)

Second part defect score: $\frac{(575-401)}{(575-322)}*15+4+2+4=20.33$ (2)

The contributions of the study in this article can be summarized as follows;

The real problem involves different quality expectations of different customers, and the solution must be able to respond to this demand. To solve the problem in the real production environment in seconds;

1. A procedure that splits large parts into smaller sub-parts is proposed;
2. SA algorithm is adapted to the more complex real problem;
3. The software is developed to respond to real production requirements.

The steps of the SA algorithm and the evaluation results are detailed in the next sections.

4. UTILIZATION OF THE SIMULATED ANNEALING ALGORITHM

One of the most critical points of the problem is meeting the customer demand both on quantity and quality basis. The aim is to increase the quantity of first quality fabric length by cutting the part from the detected points. The important point is to obtain the fabric that is compatible with the customer requirements. The solution to the problem is designed considering the following constraints. Note that these constraints are customer-specific, as indicated before.

- ✓ Defect score in 100 m^2 (area)
- ✓ The number of "main" defects in 100 meter (m)
- ✓ Maximum defect length
- ✓ Minimum length (m) between two defects
- ✓ Defect score in 100 m (length)
- ✓ The number of defects in 100 m
- ✓ Minimum part length (m) in a roll
- ✓ Maximum roll length (m)
- ✓ Minimum roll length (m)
- ✓ Clear zone in starting and ending of the fabric
- ✓ Non-defective zone in starting and ending of the fabric

4.1 Determining real sections

This stage emerged from the quality requirements of customers. In order to meet customer demands (maximum and minimum roll length), the fabric is needed to be split into subsections (real sections). The following example might be reviewed to explain the procedure; If we have 362 meter (m) fabrics, and we have constraints of "Maximum Roll Length" and "Minimum Part Length" for Customer B, as in Table 1, to find the minimum and the maximum number of actual sections, the following calculations are needed to be done. Please note, for Customer B, "Minimum Roll Length" is equal to "Minimum Part Length."

- ✓ Minimum Number of Section = Round-Up (Fabric Length / Maximum Roll Length) = Round-Up (362 / 150) =3
- ✓ Maximum Number of Section = Round Down (Fabric Length / Minimum Roll Length) = Round Down (362 /15) =25

Then, the algorithm finds the feasible solution by;

- ✓ Decreasing one by one from the maximum number of section to the minimum number of section,
- ✓ Making 10 000 trials in each stage,
- ✓ A feasible solution that provides constraints is found. Section quantity must be between the minimum and the maximum number of sections.

In this example, the number of real sections might be between 3 and 25, as calculated. There is not any restriction caused by loom in real sections for the studied factory. Consider Figure 2a, assume that the initial solution cuts the fabric into three real sections. Dashed lines in Figure 2 shows generated virtual cutting points. SA will be applied to each of sub-parts to generate these virtual points. Details of algorithms will be analyzed in the next subsections. Algorithms can be run as much as desired (parametric) for each real section. Figure 2a, Figure 2b and Figure 2c demonstrates different runs of an algorithm for a problem.

The first quality length of the fabric is determinative for selecting the best solution. After processing three runs, the section, which gives maximum first quality fabric length, can be chosen. Selected parts for the examined example are shown by ellipses in Figure 2.

4.2 Simulated Annealing Algorithm

Simulated annealing (SA) is a well-known metaheuristic that is developed by Kirkpatrick et al. [31] in the early 1980s. The working mechanism of the algorithm can be described as following: In the heat treatment of metals, all the molecules adjust themselves to the liquid phase by heating the metals to the melting point. If the cooling is done properly, the crystal structure becomes regular. In the SA, it is decided to go to which decision team while reducing the temperature continuously. It is a local progress method that works with the probability structure. Simulated annealing occasionally accepts worse solutions. This characteristic of simulated annealing helps it to jump out of any local optimums and converge to the global optimum point. The general steps of the algorithm can be summarized as follows;

Step 0: Set parameter values
- ✓ Initial Temperature: T_0
- ✓ Markov chain length (Number of iterations at the same temperature): L (ℓ is a counter for Markov chain length)
- ✓ Cooling rate: C (Recommended between 0.5-0.99)
- ✓ Number of iteration: k (The other criteria might be stopping temperature)
- ✓ Maximum number of iteration: K

Step 1: Create an initial solution
- ✓ $x^* = x^0$
- ✓ $Z(x^*) = Z(x^0)$
- ✓ ℓ=0, k=0

Step 2: Create a neighbor solution (x^1)
- ✓ Calculate $\Delta Z=Z(x^1)-Z(x^*)$
- ✓ We wish $\Delta Z<0$ in minimization problem (in maximization problem $\Delta Z>0$)

Process Step 3 or Step 4

If $\Delta Z<0$ (if the objective is minimization) (in maximization problem $\Delta Z>0$)

Step 3: Make the following assignments
- ✓ $x^*=x^1$
- ✓ $Z(x^*) = Z(x^1)$
- ✓ $\ell=\ell+1$, k=k+1

Else

Step 4: Move on a bad solution with a probability of "r" (r is a random number between 0-1)

If $e^{-\Delta Z/T}>r$ (in maximization problem $e^{\Delta Z/T}>r$)
- ✓ $x^*=x^1$
- ✓ $Z(x^*) = Z(x^1)$
- ✓ $\ell=\ell+1$, k=k+1

Else, continue from the previous solution

Step 5: If l = L make the following assignments;
- ✓ T=C*T
- ✓ $\ell=0$
- ✓ If k=K then stop

Else, go to Step 2

SA has been used as a very effective tool for solving many different types of problems ([15], [24]). Note that, defining initial and neighbor solutions are specific to the problem. For the different types of problems, T, C, L, and stopping criteria are algorithm-specific. There are different cooling strategies as stepwise or continuous temperature reduction.

The problem is adapted to the determination of cutting location in the weaving industry. Consider the example in subsection 4.1 and Figure 2; Start from any of the selected virtual cutting point (initial solution). Check objective function value and quality constraints. If necessary, according to the algorithm, merge the virtual cutting point with the next one (moving direction selection is made randomly). That is the neighborhood generation phase of SA. In subsection 5.1, a numerical example will be demonstrated to explain the methodology.

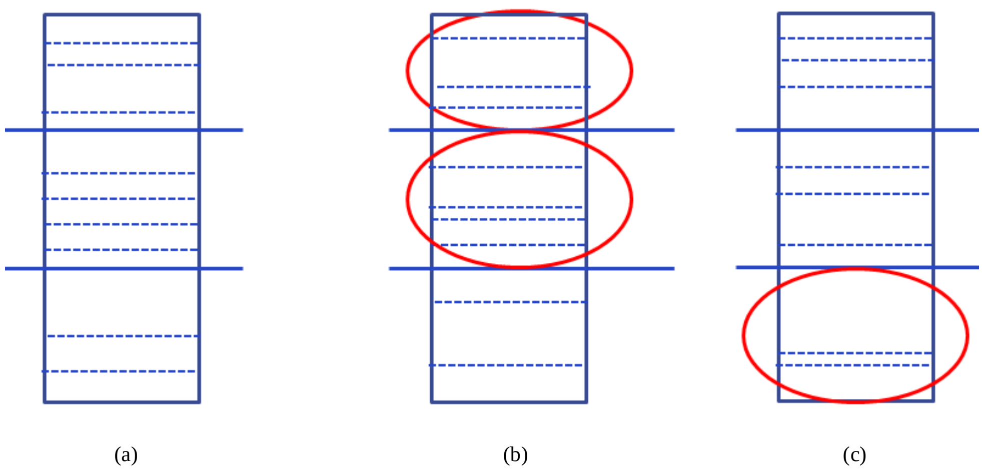

Figure 2. Three different runs of SA

5. COMPUTATIONAL RESULTS

5.1 Numerical Example

Consider the following example to explain the general concept of the problem. The proposed model splits fabric, which is 1 717 m in total length, into 14 real sections according to the procedure that was defined in Section 4.1. Each section's starting and ending points are shown in Table 2. The next step is applying SA to each of these sections.

Table 3 shows the defects of the first real section in Table 2. That defect map will be used to decide cutting points. The SA will be tried out to define cutting points. Please note, if the defect is in length, Score value, which is in the last column of Table 3, can be calculated as in Formulation (3);

$$\text{Score} = \text{Defect Score} * \text{Lenght of Defect} \quad (3)$$

Otherwise, if the defect is a point, Score is equal to Defect Score as stated in Formula (4);

$$\text{Score} = \text{Defect Score} \quad (4)$$

The SA will start the iterations from virtual cutting points. For example, the initial solution might be cutting the fabric virtually from 12nd, 59th, 105th, 200th meters. Then the SA iterations proceed. The algorithm will start iterations by merging the virtual subparts in the same quality level. If the virtual part is in the first quality, move backward or forward to get the bigger first quality part. However, consider all quality requirements of a customer while doing these operations. The backward or forward progress step is considered as 1cm. The first quality virtual cutting points of the first real section are shown in Table 4. According to the optimal solution in Table 4, the fabric has to be cut from 108.445th meter to get first quality fabric parts. Additionally, there must be some cut-offs from the end of the fabric to achieve customer quality requirements.

Table 2. Real sections of the total fabric

Real Section Nr.	Section Starting Point (m)	Section Ending Point (m)	Length of section
1	0.01	212.01	212.00
2	212.02	594.16	382.14
3	594.17	594.37	0.20
4	594.38	756.06	161.68
5	756.07	760.38	4.31
6	760.39	881.92	121.53
7	881.93	882.54	0.61
8	882.55	1031.1	148.55
9	1 031.11	1 034.42	3.31
10	1 034.43	1 039.97	5.54
11	1 039.98	1 043.35	3.37
12	1 043.36	1 489.07	445.71
13	1 489.08	1 490.23	1.15
14	1 490.24	1 716.99	226.75

Table 3. Defects of the first real section in Table 2

Defect ID	Defect Starting Point (m)	Defect Ending Point (m)	Length Between two defects	Length of defect	Score
0	0.01	5.35	7.22	5.34	38.02
1	12.57	12.57	2.27	0	1
2	14.84	14.84	2.25	0	1
3	17.09	17.09	2.08	0	2
4	19.17	19.17	4.65	0	1
5	21.3	23.82	4.04	2.52	10.08
6	27.86	27.86	1.49	0	1
7	29.35	29.35	4.48	0	1
8	33.83	33.83	1.34	0	1
9	35.17	35.17	14.33	0	1
10	49.5	49.5	6.71	0	2
11	56.21	56.21	6.74	0	1
12	62.95	62.95	21.72	0	1
13	84.67	84.67	2.69	0	2
14	87.36	87.36	4.7	0	1
15	92.06	92.06	6.09	0	2
16	98.15	98.15	13.1	0	2
17	111.25	111.25	3.19	0	1
18	114.44	114.44	4.85	0	1
19	119.29	119.29	2.11	0	4
20	121.4	121.4	7.95	0	1
21	129.35	129.35	13.62	0	1
22	142.97	142.97	4.42	0	1
23	147.39	147.39	2.76	0	1
24	150.15	150.15	6.71	0	3
25	156.86	156.86	9.66	0	1
26	166.52	166.52	8.02	0	3
27	174.54	174.54	6.48	0	1
28	181.02	181.02	2.71	0	1
29	183.73	183.73	15.57	0	1
30	199.3	199.3	3.41	0	3
31	202.71	202.71	4.65	0	2
32	207.36	207.36	2.97	0	1
33	210.33	210.33	1.68	0	1
34	211.54	212.01		0.47	1.88

Table 4. The best solution of SA for the first real section

Row Nr.	Quality	Starting Point of Cut (m)	Ending Point of Cut (m)	Length of Fabric
1	**0**	**0.010**	**5.350**	**5.340**
2	1	5.360	108.445	103.085
3	1	108.445	211.530	103.085
4	**0**	**211.540**	**212.010**	**0.470**

5.2. Design of Experiment (DoE) for parameter selection of SA

The main parameters and levels of parameters that affect the performance of the software are determined, as presented in Table 5.

Table 5. Experimented parameter values of the SA

Parameters	**Levels**
Markov chain length: L	1 000 ; 5 000 ; 8 000 ; 10 000
Stopping Temperature: T	0.6; 0.7
Cooling Rate: C	0.8; 0.97

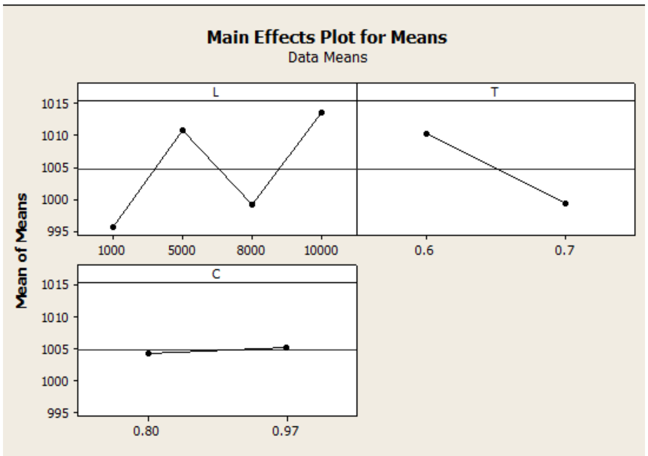

Figure 3. Main effects plot of the three factors

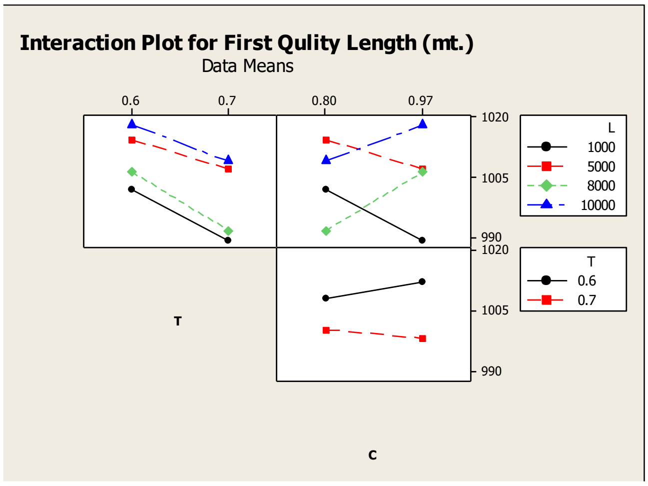

Figure 4. Interaction plot of L, T, and C

The experimental design that fits these levels is Taguchi L8 (4**12 **2). Minitab 16 is used for experimental design. The objective is to increase the first quality fabric length. According to the main effects plot in Figure 3, when L is equal to 10 000, T is equal to 0.6, C is equal to 0.97, SA yields the best performance regarding first quality length. According to the interaction plot in Figure 4, there is a significant interaction between parameters L and C. Figure 4 also indicates that the selected parameter value for L and C would be 10 000 and 0.97, respectively.

5.3. Performance of SA

The user interface of the algorithm can be seen in Figure 5. In application, it is easy to select customer quality requirements and the number of trials. The result section selects the best solution for each real section, as mentioned before. The values of SA parameters are parametric in the designed interface to present user-friendly and flexible software.

Table 6 summarizes the performance of SA. Because of quality constraints, data in Table 6 belong to the same customer. Each part (instance) has a length, total defect score, and total defect quantity, as shown in Table 6. The number of the trial (run) in SA is selected as 10 for each instance. All data in Table 6 has the following structure;

- ✓ Order lengths of instances are between 1 000 and 1 600 m.
- ✓ The total defect score of instances is between 100 and 300.

After running SA, discarded length for each instance can be found automatically. Then, first quality length, first quality percentage values in Table 6 can be calculated easily. The elapsed time of SA can be seen in the last column of Table 6. These values are in second, and elapsed time value is the summation of 10 runs duration. This computation performance is the most important feature of the utilized algorithm. Because of that, SA is developed to be a tool of optimization in the real production plant. Moreover, it has been already in use in many weaving factories as the decision support system that assists senior workers in cutting the fabric from the optimum location. Increasing the first quality fabric quantity will directly affect the total income of the factory.

The main purpose of the algorithm is to maximize the first quality product quantity considering the requirements of customers. Sometimes one defect may render the product unusable. That is why it is better to use defect score instead of the number of defects for comparisons. The defect score might be minimized by cutting schema. So, the best way to increase the first quality percentage is by cutting the fabric from the best place to decrease the defect score. The total defect score is divided by the length of fabric to reach a scaled defect score for each instance, as it is shown in Table 6. In order to show the relationship between the scaled defect score and the first quality percentage of each instance, the correlation analysis has been done by Minitab 16. According to results, the Pearson correlation coefficient between the scaled defect score and the first quality percentage is -0.569, which represents a negative relationship between the parameters. As scaled defect score increases, the first quality percentage decreases. The p-value is 0.004, which is less than the significance level of 0.05. The p-value indicates that the correlation is significant.

Table 6. Performance of the SA

Part ID	Length of Fabric (m)	Total Defect Score	Total Defect Quantity	First Quality Length (m)	Scaled Defect Score (Round-up)	First Quality Percentage (Round-up)	Elapsed Time (sec.)
1	1 415	300	170	1 145.18	0.22	81%	44.66
2	1 233	188	101	942.23	0.16	77%	33.21
3	1 382	190	114	1 208.08	0.14	88%	26.68
4	1 556	194	92	1 464.85	0.13	95%	22.25
5	1 122	201	61	1 018.43	0.18	91%	35.33
6	1 582	104	50	1 546.66	0.07	98%	4.28
7	1 093	186	52	1 012.25	0.18	93%	20.78
8	1 293	103	41	1 269.93	0.08	99%	4.34
9	1 566	123	52	1 545.25	0.08	99%	3.95
10	1 407	174	102	1 387.61	0.13	99%	4.62
11	1 308	182	68	1 208.13	0.14	93%	9.17
12	1 102	136	97	1 048.67	0.13	96%	7.63
13	1 201	151	103	1 154.15	0.13	97%	20.44
14	1 201	156	67	1 042.58	0.13	87%	12.39
15	1 208	147	80	1 186.04	0.13	99%	5.55
16	1 202	145	52	1 178.88	0.13	99%	6.66
17	1 152	147	51	953.64	0.13	83%	54.11
18	1 084	100	74	1 047.25	0.1	97%	8.19
19	1 101	179	132	1 057.11	0.17	97%	135.38
20	1 327	188	83	1 231.59	0.15	93%	26.39
21	1 034	184	105	904.86	0.18	88%	13.13
22	1 045	166	84	940.7	0.16	91%	6.34
23	1 195	176	69	1 132.93	0.15	95%	9.58
24	1 202	184	77	1 117.81	0.16	93%	2.83

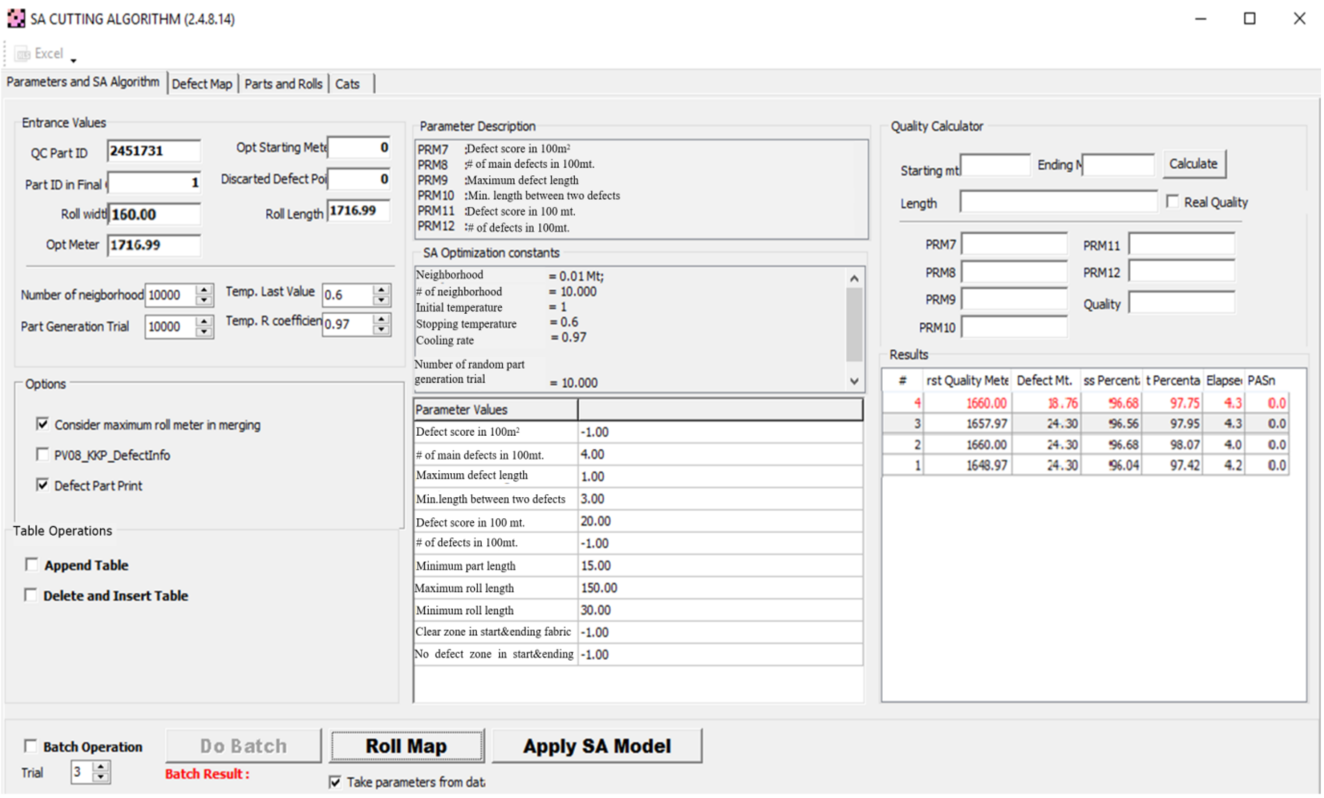

Figure 5. User interface of SA Application

6. CONCLUSIONS AND FUTURE DIRECTIONS FOR RESEARCH

In this paper, the Simulated Annealing algorithm is adopted to decide cutting points of large lengths of fabric in the weaving industry. All constraints of real production plant are included in the problem. First, to work on certain sized parts, which consider customers' requirements, the fabric is cut into real sections by following the steps of the proposed procedure. Second, after describing the methodology of SA, DoE is utilized to get better performance parameters. In the last phase, the user interface of SA is introduced, and the performance of the algorithm is analyzed. According to the achieved results, the SA can be used as the decision support system of the fabric cutting phase in the real production plant in the sense of both high first quality percentage rates and calculation time performance in seconds.

During the project, while progressing on SA, on the other side, the K-means algorithm was studied to find defect intensive regions and cut these regions off the part. SA performed better results than K-means for some tryouts. However, much more comparative analysis in terms of statistical evaluations and tests are required. So, as a future study, SA and K-means algorithms might be compared with different parameters. Another future research direction might be utilizing K-Means algorithm as an initial solution of SA. Mixed Integer Programming (MIP), which would include all requirements of different customers, might be developed to be used in the real production plant. Additionally, other well-known meta-heuristic techniques might be applied to the problem.

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Innovative Competency Analysis of the Turkish Technical Textile Sector Based on AHP and FCE Methods

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ABSTRACT

Today, it is known that successful companies in innovation applications have been maintaining their competitive power and even superiority in competition. In addition to successful innovation applications into practice, it is also necessary to analyze the innovation capabilities of enterprises on a regular basis. According to the findings based on these regular analyses and evaluations, the strengths and weaknesses of firms in innovation creation processes can be determined. In this respect, the data obtained through the field study, conducted with the technical textiles companies among the top 500 industrial enterprises in Turkey, is evaluated within the methods of AHP and FCE (Fuzzy Comprehensive Evaluation). According to the research result, the innovation capability of the Turkish technical textile sector is measured as "Fair level" and the factors that bring the innovation capability of the sector to this final result are explained one by one.

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KEYWORDS

Textile sector, technical textiles, innovation, Fuzzy Comprehensive Evaluation, Analytic Hierarchy Process

1. INTRODUCTION

In order for innovative applications to achieve success, it is necessary to regularly analyze the innovation capabilities of enterprises, as well as improving the working conditions, in the direction of *"Unmeasurable things cannot be managed and developed"*. By doing that, the weak and strong aspects of the enterprises' innovation creation processes can be identified and the continuity of the successful innovation processes can be ensured. The measurement of innovation power has been applied in the literature through different analysis techniques and in various sectors such as food and agriculture. However, the number of studies based on defining the components of innovation process evaluation in the textile sector, analysis of these factors, and analysis of innovation process management within the firm and sectoral-levels has remained limited in the literature. So far, no systematic research has been done on the innovation capability analysis of the technical textile sector. Therefore, it is thought that this study will contribute to the academic world by presenting the effects of innovation applications on firm success indicators in the technical textile sector, through concrete statistical data.

The Turkish technical textile sector has various advantages, such as being a sub-branch of an advanced textile industry which makes great contributions to total exports of the country, qualified human resource opportunities, well-established textile education institutions, a broad domestic market, advanced transportation network, well and modernly equipped laboratory infrastructure and also trade agreements with various countries. Looking at the commercial data of the Turkish technical textiles sector, it is observed that the volume of foreign trade in this area has increased significantly over the last five years. Imports of technical textiles increased to 1.4 billion dollars as of 2017, whereas, Turkey is technical textile exports reached 1.5 billion dollars in 2017. Therefore, Turkey's exports in this field has passed the imports during the latest years [1, 2].

Moreover, Turkish textile industry has acted as a supplier for many years in line with the customer demands. Thanks to the changing perspective of the developing technological infrastructure, well-educated workforce and the developing

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perspective of the sector managers, it is observed that the textile sector has become abler to direct customers and create new products and processes with its own possibilities and brain team. For these reasons, innovation culture has started to be more apparent in the textile industry in recent years and this situation has started to bring the results. The technical textile sector also benefits from the developing innovation culture in Turkey, like the textile sector as a whole in which it is one of the sub-branches. In the following periods, it can be said that the culture of innovation, that will become widespread in the sector, will be supportive of a wider range of innovative practices.

Due to this importance of the sector, the analysis of innovation capability of the firms operating in the Turkish technical textiles sector was carried out through the combination of the Analytical Hierarchy Process (AHP) and Fuzzy Comprehensive Evaluation Method (FCE). Based on the sample of the study, the advantages and disadvantages of the Turkish technical textiles sector in international competition were tried to be reflected and various suggestions were made in order to increase the innovation capability of the sector.

2. LITERATURE REVIEW

The European Commission regularly provides a comparative analysis of innovation performance in EU countries, other European countries, and regional neighbors. "Innovation Scoreboard" assesses relative strengths and weaknesses of national innovation systems. The measurement framework distinguishes between 27 different indicators in total. Countries fall into four performance groups, which are innovation leaders, strong innovators, moderate innovators and modest innovators. According to the innovation index obtained in 2018, countries such as Denmark, Finland, Luxembourg, the Netherlands, and Sweden are Innovation Leaders. Countries such as Bulgaria and Romania are in the class of Modest Innovators. In the context of this classification, Turkey is among the moderate innovative countries [3, 4].

Looking at patent and utility model applications, it is observed that 84 applications were made in the textile industry in 2016 and 86 applications were made in the clothing industry [5]. One of the reasons of this situation is that, while patent and utility model applications in the textile sector are generally based on the product and process innovation, the focus of the innovation applications in the clothing sector is mainly on design and branding activities. In addition, while in the past years, more patent and utility model applications were made in the textile products sector compared to clothing, the efforts and studies in the clothing industry have been fruitful in recent years and this situation has been reflected in the data in terms of the increase in these applications.

Innovation is a complex, nonlinear and a multidimensional process that is difficult to predict. For this reason, there is no single criterion and method that can identify and measure the properties of this holism. Examining both Turkish and international literature, the number of studies carried out in the field of innovation ability analysis of enterprises, especially at the national level, was found to be limited. On the other hand, studies related to innovation ability analysis in the technical textiles sector have been determined to be scarce.

The official standardization of innovation surveys was enabled after the preparation of the Oslo Manual by OECD and Eurostat. The latest version of the guide was translated into Turkish by TÜBİTAK [6]. In the literature, various innovation performance analysis studies were performed in the textile sector. In these studies, textile firms were evaluated within one sector or in combination with different sectors in terms of their innovation capability. In general, various criteria have been determined and field research has been carried out in order to obtain the data based on these criteria. In the evaluation of the obtained data, different methods have been applied. Balance scorecard method [7]; data envelopment technique [8]; factor and regression analysis [9]; multistage Delphi method and fuzzy logic method [10]; entropy weight rating, grey relational analysis [11]; parametric and non-parametric tests in accordance with social network analysis (SNA) [12] are some of examples of the utilized methods in the literature.

2. MATERIAL AND METHOD

A field research was carried out with the textile companies operating in the field of technical textiles, which are among the large-scale industrial enterprises of Turkey.

The data were obtained through face-to-face interview technique conducted with the companies using a questionnaire, which was arranged in accordance with the objectives. In addition, published statistics, research reports, theses, articles and papers constituted secondary data sources of the study. Considering the scope of the study, it was necessary to include the technical textiles companies, which are among the large-scale companies in Turkey that could allocate more budget to the innovation activities. For these reasons, the largest 1000 company list prepared by Istanbul Chamber of Industry (ISO), the list of companies operating in the technical textiles field prepared by ITKIB, the list of textile firms with R&D centers announced by Turkish Ministry of Industry, and other companies that were found suitable for the study by the experts working in the field of technical textiles were utilized in order to generate the sample of this study. Within the framework of the mentioned sample forming criteria, twenty technical textile companies were selected as the most suitable companies for data collection. In consequence of the negotiations, fifteen of these technical textile companies agreed to share data. These companies are located in the provinces of Kahramanmaras, Gaziantep, Bursa, Izmir and Tekirdağ in Turkey, and they operate technical textiles activities in various branches accepted all over the world, such as geotextiles, automotive textiles etc. [13].

Considering the scope of the study, a hierarchy of criteria was formed in order to analyze the innovation related activities exhibited by the companies operating in the field of technical textiles and to prepare the ground for the methods to be used in the analysis of the data. These criteria are shown in the Table-1 below.

Within the frame of the analysis, five main criteria were determined, namely, *innovation investment force, technology and human resources, communication opportunities, innovation environment and innovation production and management*. These main criteria are also divided into sub-criteria. The criterion of innovation investment force implies the size of the investment allocated to R&D activities in order to create innovative applications within the company. This criterion is divided into two groups: The ratio of the amount of budget allocated to R&D activities (%) = (Budget of the R&D activities/Total budget) and the ratio of the budget allocated to the training required for R&D personnel (%) = (Budget allocated to the education/ Total R&D budget). Technology and human resources criterion is divided into two subcriteria: The technology level of equipments used for R&D activities (Via verbal judgement set) and the ratio of R&D personnel to all personnel in the company (%). The criterion of communication opportunities is for determining the level of innovation-oriented communication across the company and it is divided into four sub-criteria: The level of innovation-oriented communication between the company departments, the level of innovation-oriented communication with suppliers, the level of innovation-oriented communication with customers, and the level of innovation-oriented communication with other institutions (public, university, industry, etc.). These criteria were evaluated through a verbal judgement set. Innovation environment means the evaluation of the environment in which the company is located, from the perspective of innovation. This criterion is divided into three sub-criteria: The Company's competitiveness in the entire Turkish technical textiles market, the state support for innovation provided to technical textile enterprises and the innovation-oriented cooperation level of the company with other institutions. These criteria were also evaluated through the verbal judgement set. Innovation production and management, which is the last main criterion, aims to determine the level of effective management of innovative activities and the transformation of these activities into commercial benefits within the company. This criterion comprises the following sub-criteria: The number of patents (numerical data), the number of utility models (numerical data), the number of industrial designs (numerical data), the number of the completed projects (numerical data), the number of scientific publications (numerical data), average new product development time (numerical data), the level of internal innovation incentive system (verbal judgement set) and commercial turnover ratio of the R&D activities (%) [13].

Table 1. The criteria used to analyze the innovation capability

Main criteria	Sub-Criteria
1. Innovation investment force	1. The ratio of the amount of budget allocated to R&D activities (%) = (Budget of the R&D activities/Total budget) 2. The ratio of the budget allocated to the training required for R&D personnel(%) = (Budget allocated to the education/ Total R&D budget)
2. Technology and human resources	1. The technology level of equipments used for R&D activities (Verbal judgement set) 2. The ratio of R&D personnel to all personnel in the company (%)
3. Communication opportunities	1. The level of innovation-oriented communication between the company departments (Verbal judgement set), 2. The level of innovation-oriented communication with suppliers (Verbal judgement set), 3. The level of innovation-oriented communication with customers (Verbal judgement set), 4. The level of innovation-oriented communication with other institutions (public, university, industry, etc.) (Verbal judgement set)
4. Innovation environment	1. The company's competitiveness in the entire Turkish technical textiles market (Verbal judgement set), 2. The state support for innovation provided to technical textile enterprises (Verbal judgement set), 3. The innovation-oriented cooperation level of the company with other institutions (Verbal judgement set)
5. Innovation production and management	1. The number of patents (Numerical data), 2. The number of utility models (Numerical data), 3. The number of industrial designs (Numerical data), 4. The number of the completed projects (Numerical data), 5. The number of scientific publications (Numerical data),

6. Average new product development time (Numerical data),
7. The level of internal innovation incentive system (Verbal judgement set),
8. Commercial turnover ratio of the R&D activities (%)

The combination of AHP, point allocation and FCE methods were utilized in realization of the innovation analysis of the Turkish technical textile sector, due to their advantages provided and their suitability for the study goal. By considering the above criteria, innovation ability analysis requires a combination of both qualitative and quantitative data, and selected methods are capable of adapting to this purpose. AHP and point allocation methods were used to determine the weights of all criteria. For this purpose, the criteria were asked to be compared in pairs by using the scale in the range of 1-9, which was developed by Satty [14] for the AHP method. The consistency of the matrices used within the method was tested by means of CR values. Moreover, within the scope of the study, evaluations were carried out depending on the multiple experts' opinion to avoid the bias that may be present. To perform the aggregation of these multiple ideas, arithmetic method is utilized. Although it is possible to combine these data with different methods, it has been observed that one of the frequently preferred methods in the literature is the arithmetic mean method [15, 16]. Another method of determining the relative weights of the criteria is the method of point allocation. In addition to the AHP method, this method is also included in the study because of the reason that innovation production and management criteria comprises eight sub-headings in total. Since the increase in the number of criteria will also result in the increase of the pair-wise comparisons, the responder is more likely to show distraction and reluctance, resulting from the extension of the questionnaire, could negatively affect the reliability of the questionnaire. In the most basic form, the method aims to determine the relative weights based on the distribution of a score between the criteria, conducted by the responder [17].

Other method used was the fuzzy comprehensive evaluation (FCE). This method is developed mainly for the multi-stage, multi-variable and wide-area related problems [18, 19, 20, 21]. The basis of this method includes: a set of evaluation standards (*U)*, evaluation set (*V*), the fuzzy membership degree of appraisal of the factors *(r*), single-factor fuzzy evaluation matrix (*R)*, the weight set of the factors (*A*), the fuzzy comprehensive membership grade set (*B)* obtained by the combination of *A* and *R*. The evaluation set *V*, includes the entire possible judgment degrees, and is determined by the expert opinions in line with the criteria and the area studied, based on linguistic variables [22]. Similar with the evaluation set, various formulations and approaches exist in the literature for membership degrees of the factors that compose the matrix of *R*. It is observed that membership degrees of the factors (criteria) are shaped by experts according to the scope of study [18, 23, 24, 25]. In the frame of the method, decision-making matrices have been formed for the purpose of mathematical reflection of expert opinions. Based on the matrices obtained, fuzzy comprehensive evaluations were performed. In this way, both the "must haves" for a successful innovation management process and the current situation of the technical textile companies in innovation were determined and analyzed.

3. GENERAL FINDINGS OF THE RESEARCH

This part of the study was taken into consideration within the steps followed in the integrated use of AHP and FCE methods.

1. Determination of the evaluation factor set: Firstly, the factor set to be evaluated within the framework of the FCE method was determined. In other words, the hierarchical structure of the problem was determined to be used in the AHP method. In total, twenty-four factors, consisting of five main and nineteen sub-factors, are listed as follows: U= {U1, U2, ..., U24}={Innovation investment force, Technology and human resources, ..., The commercial turnover ratio of the R&D activities }

2. Determination of the factor weights: The factor weights were obtained via pair-wise comparisons of AHP procedure and the average weights were calculated based on the decision makers' appraisals, through the program of Expert choice 11. For the determination of the weights of innovation production and management criteria, SPSS-20 program was used for the point allocation method. The following table summarizes the criteria weights obtained in line with the opinions of the managers of fifteen companies included in the study (Table 2). The table is compiled according to the ranking of the main and sub criteria weights.

The innovation ability of technical textile companies is primarily driven by innovation production and management (27.7%), secondly by innovation environment (21.7%), third by technology and human resource (19.4%), fourth by innovation investment force (18.6%) and finally by the effectiveness of communication opportunities (12.7%). Therefore, in terms of companies, the tangible products obtained because of innovative activities, the conversion of these products into commercial benefits and the effective management of these factors constitute the most important criteria in constituting the innovation capability. All of the decision matrices obtained through pair-wise comparisons provide the rule of CR<0.10 for reliability. Therefore, it is possible to say that the data can be regarded as valid and reliable.

3. Determination of the evaluation set and standard membership degree of the evaluation set

Two types of evaluation sets were determined to obtain the judgments based on the verbal and quantitative data. This need arises from the fact that the criteria such as "the level of innovation-oriented communication with the suppliers of the company" criterion is subjected to verbal evaluation, while the criteria such as "number of the patents" need to be analyzed within numerical data. The evaluation set used to determine the entire possible verbal judgments is as follows: $V=\{v_1,v_2,v_3,v_4\}$ {Excellent, good, fair, poor}. These evaluation set degrees were assigned by the company managers. The membership degree set of the evaluation expressions above is as follows: u={1/excellent, 0.8/good, 0.6/fair, 0.1/poor}

Membership classifications for numerical data are determined in the light of the numerical data obtained from companies. The maximum and minimum values used in the creation of these membership classes and the number of these classes can be assigned and created by experts according to the former studies [26, 27, 28]. Accordingly, four equal-sized membership classes are categorized by taking the lower and upper values of the obtained data into account. For example, the upper value of data for the innovation investment force criterion is 15 and the lower value is 0.5. For this reason, the class size, which will include both limits and provide data distribution to four classes, is calculated as 3,5. Other classes were also formed according to this view. The table below shows the membership classifications of the main and the sub-criteria based on numerical data (Table 3).

Table 2. Innovation ability factor weights obtained through AHP

Factor sets	Weight sets of the factors
A (Main criteria): Innovation production and management, innovation environment, technology and human resources, innovation investment force, communication opportunities	A= (0.277, 0.217, 0.194, 0.186, 0.127)
A_1 (Innovation production and management): Commercial turnover ratio of the R&D activities, average new product development time, number of the completed projects, number of the patents, number of the industrial designs, the level of internal innovation incentive system, number of the utility models and the number of scientific publications	A_1=(0.209, 0.159, 0.148, 0.109, 0.107, 0.106, 0.100, 0.061)
A_2 (Innovation environment): The company's competitiveness in the entire Turkish technical textiles market, the innovation-oriented cooperation level of the company with other institutions and the governmental incentives for innovation provided to technical textile enterprises	A_2= (0.650, 0.195, 0.155)
A_3 (Technology and human resources): The technology level of equipments used for R&D activities and the ratio of R&D personnel to all personnel in the company	A_3= (0.617, 0.383)
A_4 (Innovation investment force): The ratio of the budget allocated to the training required for R&D personnel and the ratio of the amount of budget allocated to R&D activities and	A_4= (0.514, 0.486)
A_5 (Communication opportunities): The level of innovation-oriented communication with customers, the level of innovation-oriented communication between the company departments, the level of innovation-oriented communication with suppliers and the level of innovation-oriented communication with other institutions	A_5= (0.334, 0.267, 0.216, 0.182)

Table 3. Membership degree set of criteria based on numerical evaluation

Main Criteria	Sub-criteria	Membership degree set of numerical data			
		Excellent	**Good**	**Fair**	**Poor**
Innovation investment force	Budget of the R&D activities/Total budget (%)	10,8 and above	7.2-10.7	3.6-7.1	0-3.5
	Budget allocated to the Education/Total R&D budget (%)	36.3 and above	24.2-36.2	12.1-24.1	0-12
Technology and human resources	The ratio of R&D personnel to all personnel in the company (%)	4.8 and above	3.2-4.7	1.6-3.1	0-1.5
Innovation production and management	Number of the patents	30 and above	20-29	10-19	0-9
	Number of the utility models	6 and above	4-5	2-3	0-1
	Number of the industrial designs	9 and above	6-8	3-5	0-2
	Number of the completed projects	168 and above	112-167	56-111	0-55
	Number of scientific publications	30 and above	20-29	10-19	0-9

4. Establishing the single-factor fuzzy evaluation matrices (R): The evaluations of verbal expression-based factors were converted into fuzzy sets of the above-mentioned set of verbal judgments. In other words, the appraisal set of R can be considered as the fuzzy subset of V. In the creation of matrices, the membership degrees of the factors were utilized and they were formed by considering the secondary criteria related to their main criteria. Fuzzy R matrices formed in the light of the data obtained within the scope of the study considering the membership degrees of sub-factors, are shown below.

The matrix of R1 is shown below as an example, containing the normalized data for the innovation investment force criterion. This criterion comprises the ratio of the amount of budget allocated to R&D activities (R&D activities budget/total budget) and the ratio of budget allocated to the training required for R&D personnel (budget allocated to education/total R&D budget) based on the numerical data, as stated previously. Numerical data for the sub-criteria mentioned and membership classes (Table 2) based on the numerical data were utilized in forming this evaluation matrix. Similarly, the matrix (R2), which is created for the technology and human resource criterion, is shown below. This criterion covers level of equipments used for R&D activities (verbal judgement set) and the ratio of R&D personnel to all personnel in the company (%). Data resulting from the verbal evaluations, membership degree set of the evaluation expressions (Excellent, good, fair, good), numerical data and membership degree set of numerical data (Table 2) related to these criteria were utilized to form this matrix.

$$R_1 = \begin{bmatrix} 0.083 & 0 & 0 & 0.916 \\ 0.1 & 0.1 & 0.2 & 0.6 \end{bmatrix} \quad R_2 = \begin{bmatrix} 0.2 & 0.467 & 0.333 & 0 \\ 0.077 & 0.153 & 0.385 & 0.385 \end{bmatrix}$$

5. Determining the fuzzy comprehensive membership grade sets of the factors and the overall comprehensive membership grade of the hierarchy

At the primary level, the weights (A) and evaluation matrices (R) of all sub-criteria were multiplied for each main criteria and fuzzy membership sets were determined. Afterwards, at the secondary level, the most comprehensive fuzzy membership set of the hierarchy (B) was obtained via the weights of the main criteria and fuzzy comprehensive membership sets. For example, the fuzzy comprehensive membership set of the innovation investment force criterion (B_1) is shown as follows.

$$B_1 = A_1.R_1 = (0.514, 0.486) \bullet \begin{bmatrix} 0.083 & 0 & 0 & 0.916 \\ 0.1 & 0.1 & 0.2 & 0.6 \end{bmatrix} = (0.091, 0.049, 0.097, 0.763)$$

At the secondary level, the relative factor weights of the main criteria and the fuzzy comprehensive membership sets of each criteria were benefited in obtaining the most comprehensive fuzzy membership set of B.

$$B = (0.186, 0.194, 0.127, 0.217, 0.277) \bullet \begin{bmatrix} 0.091 & 0.049 & 0.097 & 0.763 \\ 0.153 & 0.347 & 0.353 & 0.147 \\ 0.19 & 0.606 & 0.163 & 0.041 \\ 0.143 & 0.543 & 0.208 & 0.106 \\ 0.138 & 0.192 & 0.099 & 0.569 \end{bmatrix}$$

$$B = (0.140, 0.324, 0.180, 0.356)$$

The next step is determining the numerical value of the innovation power of the Turkish technical textiles sector and defining the class in which this data corresponds to the judgment set. In order to make this assessment, the most comprehensive fuzzy membership grade of the data set was obtained with the help of the following formula. The formula used for this purpose is as follows: $F = B.u^T$, u^T: (1, 0.8, 0.6, 0.1). Here, "u" represents the membership degree set of the evaluation expressions.

$$F = (0.140, 0.324, 0.180, 0.356) \bullet \begin{bmatrix} 1 \\ 0.8 \\ 0.6 \\ 0.1 \end{bmatrix} = 0.543$$

6. Reaching the final judgment: The obtained value of "0.543" becomes included in the evaluation expression set of "Fair", which is the final and integrated evaluation result, by taking the distance between the evaluation result and the membership degree set of the evaluation expression into account. Therefore, in the light of the evaluations, it can be assumed that the innovation ability of the Turkish technical textiles sector performs at the fair level.

4. DISCUSSION, GENERAL EVALUATION AND CONCLUSIONS

The level of the integrated innovation ability of the Turkish technical textiles sector revealed in this study has been similar to the position of Turkey in innovation within the European countries, which was stated as the moderate class.

According to the opinions of the R&D managers, the area that needs to be given the most priority among the criteria that affect the innovation capabilities of technical textile companies is the innovation production and management in terms of the main criteria. Similarly, the commercial turnover ratio of the R&D activities becomes the most important and effective sub-criteria. This ratio ranges between 5% and 100% according to the data obtained from the companies and the average commercial turnover ratio of the R&D activities in technical textiles is 57.3%. Looking at the literature, this figure is defined as 55% on average in the fields of technology, industrial products and consumer goods in which the technical textiles sector takes place [29]. The data of this study becomes consistent with these results in the literature. One of the reasons why this ratio is stated higher than the average is that in some companies new product development processes are purely directed according to the customer requests. On the other hand, the limited commercial turnover ratio mainly stems from the following reasons. One of these reasons is the effort in realization of a large number of projects, however, not achieving success in the entire number. The other reason is that R&D activities in the technical textiles field are more backward compared to the conventional textiles products with a wider sales volume.

Average new product development time becomes of secondary importance. According to the data obtained within the scope of the study, this period ranges between 2 months and 15 months and the average duration of a new product development in technical textiles companies is 5.4 months. This criterion is followed by the number of completed projects. According to the survey carried out, this number ranges between 0 and 219 and technical textile companies have 62 completed projects on average. These projects include the partnerships conducted with the external stakeholders such as TUBITAK or universities, as well as the ones realized by internal resources, which last at least 6 months and implemented for innovations to be realized in company products, processes and services. It was observed that 75.3% of the innovative projects realized in technical textile enterprises were based on new product innovation, 16% on process innovation, 5.5% on organizational innovation and 3.2% on marketing innovation.

The patent, industrial design and utility model ownerships of Turkish technical textiles companies have lower significance levels in terms of enabling both commercial earnings and the innovation ability. It is observed that the number of patents varies between 0 and 37, and companies have 6 patents on average. It is observed that the number of industrial designs varies between 0 and 8, on average companies have only 1 certified industrial design. Looking at the number of utility models, it is observed that companies have an average of 1 utility model and this number varies between 0 and 5 within the technical textiles companies. In addition, it is stated that the products produced in Turkish technical textiles sector are mainly shaped in line with the feedback and requests of customers and therefore the companies in the sector prefer to carry out their activities towards customer demands rather than trying to meet the requirements of such certifications. According to the study, the ratio of the budgets allocated for innovation activities are above the general average in the companies with the highest number of patent ownerships. Correspondingly, their average product development times are below the general average, and the ratio of the new product developments turning into commercial benefits is above the average. Moreover, it is observed that technical textile companies have less demand for utility model applications because of the reason stated by them is that the protection period of utility models is less than patents and this kind of protection does not require a step of invention.

The presence of a system that encourages innovative activities is of less significance in terms of creating the innovation power of companies compared to other criteria and the systems that encourage innovative activities are carried out at a "good" level throughout the enterprises according to interviewed managers. However, the number of scientific publications has become the criterion that is considered to be least important in influencing innovation power. The reasons of this situation are that scientific publications play an important role in strengthening the prestige of companies, but cannot be turned into an advantage that is a priority for customers or provide commercial earnings. It is observed that the number of the scientific publications varies between 0 to 35, and on average, the companies have eight scientific publications.

The second most important main factor that constitutes the innovation power of enterprises is the environment of innovation in which the company is located. Technical textile enterprises participating in the study rate the competitiveness skills, the innovation-oriented cooperation level of the company with other institutions and the governmental incentives for innovation provided to technical textile enterprises as "good", within the evaluation set for classification. It has been determined that the technology level of the equipment utilized for R&D purposes is "good", throughout the large-scale technical textile enterprises participating in the study. The majority of the companies agree that the number of R&D personnel employed or the ratio of these personnel in total personnel is not an adequate data in formation of innovative activities solely. It was determined that this ratio changes between 0,4% and 6,1% in the technical textile companies participating in the study and the average ratio of R&D personnel is 2,33%.

One of the other criterion that enables companies to come to the forefront compared to their competitors in their innovation ability is their investment force. In the scope of the study, innovation investment of the companies was examined within two categories: The ratio of the amount of budget allocated to R&D activities (%)=(Budget of the

R&D activities/Total budget) and the ratio of the budget allocated to the training required for R&D personnel (%)=(Budget allocated to the education/Total R&D budget). According to the responses obtained from the companies interviewed, these two ratios have an effect on the innovation ability of companies at approximately equal levels. Technical textile companies allocate 2.46% of their general budgets to R&D and P&D activities on average. According to the firms' responses, this ratio ranges between 0.5% and 15%. The average R&D expenditure ratio of the technical textile companies obtained is above the R&D expenditure rate of Turkish GDP, which was 0.94 as of 2016 (30). Companies allocate 12,87% of their total R&D budget to the training expenses of R&D personnel. It is observed that the rate of the budget allocated to education varies between 0.03% and 50%. The last criteria that affects the innovation ability of technical textile companies is the effectiveness of the communication channels of the companies. In terms of the aspects of communication, innovation-oriented communication with customers takes place on the top amongst the communication channels.

Accomplishments of the sector will be able to make important contributions at both micro and macro levels. From this point of view, our companies need to gain a proactive structure, by directing the customers to their new offerings of latest innovations, rather than implementing the product and process improvements based only on the demands of customers. In this way, Turkish technical textile companies may become a pioneer in both domestic and foreign markets. Besides, the increase in innovation activities also stems from the increase in production and exports of the technical textile products. Similarly, the increase in production and exports is primarily due to the increase in consumption in the domestic market. Therefore, the compulsory usage of technical textiles in public places such as hospitals will provide significant advantages. In this regard, public procurement to be carried out in public areas such as medical and defense industries will enable domestic producers to move their existing facilities and productions to a more advanced level.

In addition to innovative applications, the regular implementation of innovation analysis inspections is also important in terms of sustainability of such applications. In order to be able to achieve this goal, information sources need to be constantly updated. In addition, the analysis of the data obtained because of the innovation analysis surveys together with additional economic indicators of the country, where the activities are carried out, will allow companies to analyze their innovation position in a healthier way. In addition, it has been observed that a database is needed for gaining detailed and concrete information about technical textile companies. This kind of a database that facilitates access to a range of information, such as the technical textiles branches of companies, product diversities etc., will be able to provide great advantages and communication opportunities for researchers, industrialists and retailers in both Turkey and abroad.

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Effect of Deposition Time on the Optoelectrical Properties of Electrospun PAN/$AgNO_3$ Nanofibers

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ABSTRACT

The aim of this study is to produce optically transparent nanofibers with adequate electrical conductivity for optoelectrical applications where transparency and conductivity are needed. Therefore, conductive polyacrylonitrile/silver nitrate (PAN/$AgNO_3$) nanofibers were produced by electrospinning with different deposition times ranging from 1 minute to 10 minutes. The effect of deposition time on the sheet resistance and optical transparency of the nanofibers were investigated. The surface characteristics, electrical properties and transmittance values of the electrospun mats were evaluated. Nanofibers with diameters under 700 nm were obtained. With the increasing deposition time, the sheet resistance and transparency of the samples were decreased. In order to figure out the optimum deposition time, the figures of merit of the samples were calculated. The figures of merit of the samples showed that the sample deposited for three minutes gave the best performance among the others. It was seen that conductive PAN/$AgNO_3$ nanofibers are promising for optoelectrical applications.

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KEYWORDS

Sheet resistance, optical transparency, polyacriylonitrile, silver nitrate, electrospinning, nanofiber

1. INTRODUCTION

Transparent conductive electrodes (TCEs), which conduct electrical current and transmit light, play important roles in many optoelectrical applications such as thin-film solar cells, liquid-crystal displays, light-emitting diodes, sensors, energy harvesting devices, field-effect transistors and photovoltaic devices. Two crucial parameters are expected from a good TCE: low sheet resistance and high optical transparency [1, 2].

Sheet resistance (Rs) (also known as surface resistivity) is the measurement of resistance across the surface of a material in contact with the electrodes. It can be defined as the electric current flowing across a surface as the ratio of DC voltage drop per unit length to the surface current per unit width and is expressed in ohms per square (Ω/sq) [3,4].

Optical transparency (T) is another important parameter to define a TCE. It can be defined as allowing light to pass through the material without being scattered. A good TCE should have high optical transparency with low sheet resistance [5, 6].

In order to meet these requirements, researchers have been investigated many conductive materials including indium tin oxide (ITO), metal oxides, carbon based materials like carbon nanotubes, graphene and graphite, metal nanowires etc. These materials are highly conductive as they have low resistance values depending on their production method, size and structure [7-10]. However, these materials also have disadvantages such as high cost/challenging production methods, rarity of the raw materials, or brittleness [5, 6]. This drives the search for an alternative material as TCEs.

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Nanofibers have gained attention due to their distinguishing properties such as high surface area per volume, low weight and high mechanical properties [11-14]. The electrical conductivity values of the nanofibers are increased due to the confinement [15]. Therefore, the interest for the usage of nanofibers in electrical applications are growing. Since thin film production for optoelectronic applications are difficult and costly, conductive nanofibers are an alternative for such applications. Electrospinning is the most used and well-known method for nanofiber production. The method involves fabrication of nano-scaled fibers from polymer solutions using electrical forces [11-14].

There are different methods to make conductive nanofibers by electrospinning including using intrinsically conductive polymers or adding a conductive compound into the non-conductive polymers [16].

Electrospinning of intrinsically conductive polymers (namely, polyaniline (PANI), polypyrrole (PPy), polythiophene, poly (3,4-ethylenedioxythiophene) (PEDOT)) for the production of TCEs have been thoroughly studied in several applications such as biosensors, biomedical applications, energy storage, etc [16-21]. Although these polymeric nanofibers show lower conductivities compared to ITO, carbon nanotubes, or graphene; there are also many studies on the improvement of their electrical properties. However, the processability of these polymers is challenging. They cannot be melt processed and are insoluble in most solvents [16-21].

Another approach to produce TCEs is to fabricate conductive electrospun nanofibers by adding a conductive component into a non-conductive polymer. In this method, the polymer called as “template polymer” carries the conductive component. Conductive component can be a metal (such as silver, copper, gold, etc.), carbon black nanoparticles, an ionic liquid, carbon fibers or nanotubes, conductive polymers or their combinations [16, 22-24].

Nanofibers with silver particles have application areas from antibacterial materials to conductive composites as they show high optical, antimicrobial, electronic and magnetic properties. They can be also used as fillers for composites to be used in electromagnetic shielding [25-27]. One of the challenges in adding silver particles into the nanofibers is to prevent the agglomeration of silver particles in the electrospinning solution. Generally, silver nitrate ($AgNO_3$) is added into the electrospinning solution and nanofibers are produced from $AgNO_3$/polymer solutions. The process is followed by a reduction treatment to form silver nanoparticles within the nanofibers. In literature, it was reported that the reduction treatment can be carried out by heating and/or chemical reduction or photo-reduction using UV irritation and chemical reduction is more effective compared to other methods [24, 28, 29]. The researchers also reported that the electrical properties of these structures may vary from hundreds of ohms to megaohms depending on nanofiber properties (thickness, diameter, fiber uniformity, distribution of the conductive component, etc.), solution properties (concentration of the components, homogenous solution preparation, etc.), electrospinning parameters (flow rate, applied voltage, distance between the needle and the collector, etc.) and reduction process (type and duration of the reduction, etc.) [24, 28]. Although, the properties of these structures are lower compared to highly conductive materials (ITO, metals, graphene, etc.), these values can be adequate for some special applications.

In this study the effect of deposition time on the sheet resistance and optical transparency of polyacrylonitrile/ silver nitrate (PAN/$AgNO_3$) nanofibers were investigated. For this purpose, PAN/$AgNO_3$ nanofibers were produced by electrospinning. PAN was chosen as template polymer due to its low cost and availability and $AgNO_3$ was chosen as conductive component due to its excellent electrical properties. Electrospun nanofibers were collected on glass substrates with different deposition times ranging from 1 minute to 10 minutes. The surface characteristics, sheet resistance and transmittance values of the electrospun mats were evaluated. The originality of this study is to establish a relationship between electrical and optical properties. Therefore, the figures of merit calculations, which define the performance of transparent conductive electrodes, were also added to the study in order to figure out this relationship and the sample with the optimum optoelectrical properties.

2. MATERIALS AND METHODS

2.1. Materials

In this study, commercially available polyacrylonitrile (PAN) (Mw: 200-240 kDa), N,N-dimethylformamide (DMF) (Sigma-Aldrich), silver nitrate ($AgNO_3$) (Tekkim Laboratory Chemicals) and sodium borohydride ($NaBH_4$) (Sigma-Aldrich) were used for the production of conductive nanofibers. All the chemicals were used without further purification.

2.2. Methods

A schematic view of the procedure followed in this study is given in Figure 1.

Solution preparation: A blend of PAN/$AgNO_3$ solution was prepared in DMF. In order to prepare PAN/$AgNO_3$ nanofibers, 7% wt. PAN was dissolved in DMF and stirred on a hot plate at 75 ˚C until it was dissolved completely. Afterwards, $AgNO_3$ was added into the PAN solution with a weight of 3% of the polymer and sonicated for 2 minutes using a Velp Scientifica OV5 homogenizer (OV5 Homogenizer, Velp Scientifica).

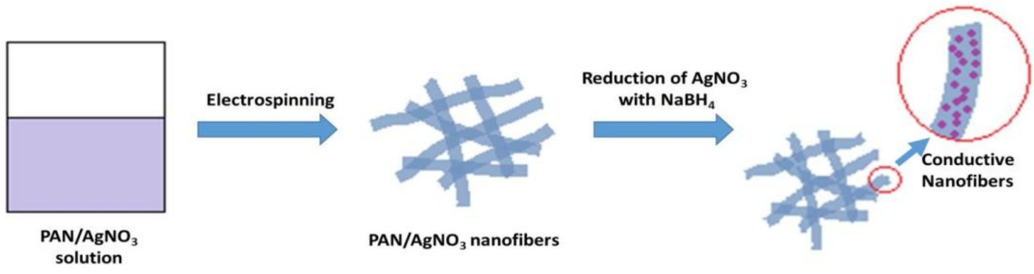

Figure 1. Schematic view of the procedure

Electrospinning of PAN/$AgNO_3$ solutions: In this study, electrospinning (Nanospinner NE300, Inovenso) was used to produce PAN/$AgNO_3$ nanofibers by using a single nozzle with an internal diameter of 0.8 mm at a flow rate of 1 ml/h. The applied voltage was 18 kV and the distance was kept at 13.5 cm. The nanofibers were collected on a glass slide placed on a rotating disc with a speed of 100 rpm. The schematic view of the electrospinning setup used in this study is given in Figure 2.

The duration of the deposition time directly affects the optical transparency and the thickness of the samples, which also affects the sheet resistance. Preliminary studies showed that under 1 minute of deposition time, the thickness and the sheet resistance values of the samples were too low to measure. Above 10 minute of deposition time the optical transparency values of the samples were too low for optoelectronic applications. Therefore, the duration of the electrospinning was kept between 1-10 minutes.

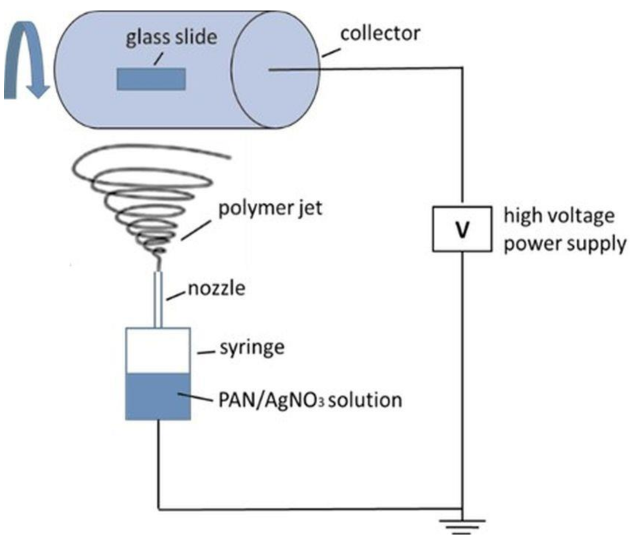

Figure 2. Schematic view of the electrospinning setup

Reduction process: In order to make PAN/$AgNO_3$ nanofibers conductive, a reduction process should be carried out. In the reduction process, $AgNO_3$ is reduced to Ag [16, 28-30]. In this study, a chemical reduction was performed after electrospinning by using $NaBH_4$ (1% wt. in water) to form silver nanoparticles within the fiber (Equation (1)). Thus, conductive nanofibers were obtained. Preliminary studies showed that reduction duration has a significant effect on the conductivities of nanofibers and the highest conductivity was achieved with longer durations [30]. Therefore, the same procedure was followed in this study. After reduction, the samples were dried at 40 °C for 2 hours in an incubator (Nüve-EN 025) and kept in room conditions for 2 days.

$$AgNO_3 + NaBH_4 \rightarrow Ag + H_2 + B_2H_6 + NaNO_3 \qquad (1)$$

Characterization of PAN/$AgNO_3$ nanofibers: A digital micrometer was used to calculate the thickness of the mats. The diameters and the morphologies of the nanofibers were examined by a Carl Zeiss Evo 40 scanning electron microscope (SEM). The sheet resistance values of the nanofibers were measured by a Four-Point Probe System (FPP 470-Entek Elektronik). Optical transparency values of the nanofibers were obtained by using a UV-visible spectrophotometer (Shimadzu- UV 3600 plus) with 0.1 nm resolution in the 280-2500 nm range. Specifically, the visible spectrum (380-750 nm spectrum band) was considered for each sample [31-33].

In this study, five sets of samples were produced from 1 min to 10 min. The thickness, the sheet resistance and the transparency measurements were performed on these samples. Average values for each sample were recorded.

Calculation of Figure of Merit: The figure of merit (Φ_{TC}) is a useful tool to compare the performance of transparence conductive coatings when their electrical sheet resistance and optical transmission are known. It is derived from optical transparency and sheet resistance values and it can be used to predict transparent electrode properties of a candidate material. Higher figure of merit results in a better quality of transparent conductive electrode [33-37]. The figure of merit is first introduced by Fraser and Cook to understand the performance of conductive and transparent films of $In_{2-x}Sn_xO_{3-y}$ [34]. They obtained the figure of merit simply by dividing optical transparency by sheet resistance of the film given in Equation (2),

$$\Phi_{TC} = \frac{T}{R_S} \qquad (2)$$

where T is the optical transmittance at 500 nm and Rs is the sheet resistance. The equation is modified by Haacke as described in Equation (3) [35],

$$\Phi_{TC} = \frac{T^x}{R_S} \quad (3)$$

where T is the optical transmittance at 550 nm and Rs is the sheet resistance. Values of x equal to 10, 20, and 100 lead to transmissions of 90%, 95%, and 99%, respectively. Since few applications require more than 90% transmission, Haacke settled on x=10 [36].

There are also other figures of merit calculations reported in the literature [36]. However, the figures of merit given in Equation (2) and (3) are useful functions for comparison purposes [33-37]. Therefore, in this study the figure of merit was obtained by using Equation (3).

3. RESULTS AND DISCUSSIONS

Results of mat thickness, sheet resistance, and transparency measurements and the figures of merit of the electrospun nanofibers are given in Table 1. The mat thickness was increased with the increasing deposition time, as expected. The lowest average value achieved was nearly 4 µm for the sample deposited for 1 minute, while the highest average value was almost 42 µm for the sample deposited for 10 minutes.

Changing deposition time doesn't have any effect on fiber morphology. It only changes the number of the nanofibers deposited on the glass slide. Figure 3 shows the general surface topography of the produced nanofibers before and after the reduction process. Randomly aligned, smooth nanofibers with uniform diameters were produced. The diameters of the nanofibers were around 700 nm. It was seen that the reduction process did not change or damage the nanofiber structure significantly.

Increasing the contact points between the nanofibers decreases the sheet resistance. With the increasing deposition time, the nanofiber amount and the number of contact points between the nanofibers increases leading to a decrease in the sheet resistance [38]. The sheet resistance values of the samples were changed in the range of 43.34 to 1.16 MΩ/sq depending on the deposition time. The lowest sheet resistance was achieved for the sample deposited for 10 minutes (Table 1). Electrical conductivity is inversely correlated to sheet resistance. Therefore, a decrease in the sheet resistance indicates an increase in the electrical conductivity [3, 4, 38].

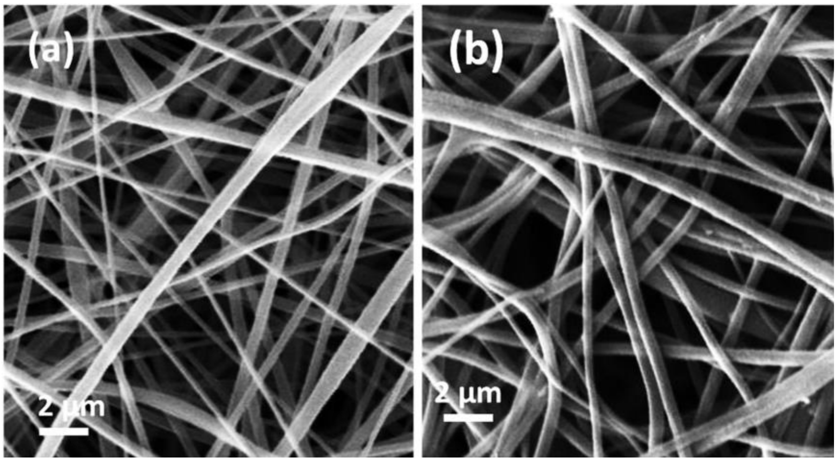

Figure 3. SEM image of the nanofibers a) before, b) after reduction with $NaBH_4$

Table 1. Experimental results

Deposition Time (min)	Mat Thickness (µm)	Sheet Resistance (Rs) (MΩ/sq)	Transmittance (T) (%)	Figure of Merit (Φ_{TC}) (1/Ω)
1	3.80±0.84	43.34±2.42	96.45±0.29	$156 \times 10^{-9} \pm 0.926 \times 10^{-9}$
2	7.40±1.82	26.49±8.07	94.57±1.05	$216 \times 10^{-9} \pm 3.96 \times 10^{-9}$
3	11.40±2.07	14.79±2.90	90.31±2.73	$242 \times 10^{-9} \pm 5.42 \times 10^{-9}$
4	15.80±2.28	9.78±1.65	80.44±6.25	$126 \times 10^{-9} \pm 7.80 \times 10^{-9}$
5	21.40±5.13	6.38±2.34	72.11±4.97	$5.51 \times 10^{-9} \pm 2.30 \times 10^{-9}$
6	24.80±6.06	5.07±1.49	69.94±4.40	$4.64 \times 10^{-9} \pm 2.26 \times 10^{-9}$
7	31.60±6.07	3.26±1.62	58.45±8.86	$1.83 \times 10^{-9} \pm 1.75 \times 10^{-9}$
8	34.80±5.40	2.82±1.38	55.08±8.35	$1.27 \times 10^{-9} \pm 1.14 \times 10^{-9}$
9	37.80±4.92	2.18±1.48	51.47±6.34	$0.663 \times 10^{-9} \pm 0.347 \times 10^{-9}$
10	41.80±4.32	1.16±0.98	46.31±2.70	$0.416 \times 10^{-9} \pm 0.288 \times 10^{-9}$

Transparency of the nanofibers is low. Therefore, an increase in the number of nanofibers in a defined area leads to a decrease in the transparency. Table 1 shows the change in optical transmittance values depending on the deposition time. The visible spectrum (380-750 nm spectrum band) was considered for each sample. Highest transmittance (~96%) was achieved for the samples deposited for 1 min and lowest transmittance (~46%) was achieved for the samples deposited for 10 min.

Optical transparency and sheet resistance are crucial for optoelectrical applications. A good optoelectrical device should have both high optical transparency and low sheet resistance. In this study, increasing the number of nanofibers decreases the sheet resistance and the transparency, as expected. Therefore, a good balance between sheet resistance and transparency should be achieved. The figure of merit (Φ_{TC}) can be used for this purpose [33-37]. In this study, the highest figure of merit was achieved for the samples deposited for 3 minutes indicating that they have better optoelectrical properties than the other samples (Figure 4, Table 1). This means that, 3-minute deposited nanofibers have the best performance within all the samples in terms of transparency and sheet resistance.

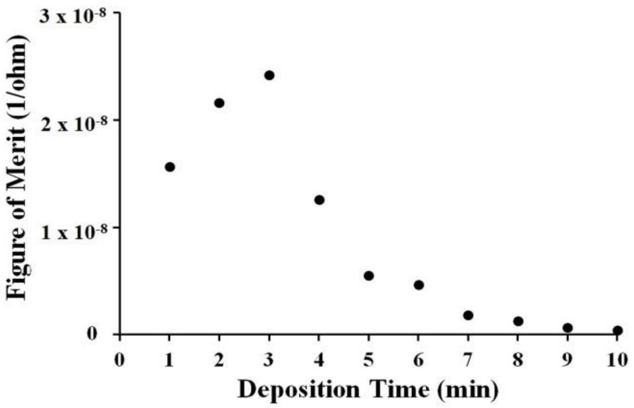

Figure 4. Figure of merit values of the samples

4. CONCLUSIONS

The significance of this study is to characterize the electrical and optical properties of the conductive PAN/$AgNO_3$ nanofibers. PAN/$AgNO_3$ nanofibers were produced by electrospinning with different deposition times ranging from 1 minute to 10 minutes and the effect of deposition time on the electrical and optical properties of PAN/$AgNO_3$ nanofibers was investigated.

PAN/$AgNO_3$ nanofibers with smooth surfaces were successfully produced. In order to obtain Ag within the fiber, a reduction process was performed. The samples were characterized in terms of their surface morphology, optical transparency and electrical conductivity.

With the increasing deposition time, the sheet resistance and the optical transparency of the samples were decreased. The lowest sheet resistance (1.16 MΩ/sq) was achieved for the sample deposited for 10 minutes. In addition, these samples gave the lowest optical transparency with a value of 46.31%.

In order to compare the performances of the samples, the figures of merit were calculated. The nanofibers deposited for 3 minutes gave the highest figure of merit value. This indicates that sample deposited for 3 minutes have the best optoelectrical properties.

This study shows that, electrically conductive and optically transparent nanofibrous surfaces can be successfully produced by electrospinning with the addition of $AgNO_3$ into the spinning solution. Although the sheet resistance values are relatively high, PAN/$AgNO_3$ nanofibers are promising for optoelectrical applications.

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Bending Properties of 3D I-Shaped Woven Composites

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ABSTRACT

This paper dealt with the bending properties of 3D (three-dimensional) I-shaped woven composites with basalt fiber filaments tows and epoxy vinyl resin. The 3D I-shaped woven fabrics with three different heights were woven on ordinary loom by reasonable design with low cost. The 3D I-shaped woven composites were fabricated by VARTM(vacuum assisted resin transfer molding) process. The bending tests were conducted on a microcomputer control universal testing machine (TH-8102S). The load-displacement and energy-displacement scatter plots were obtained from experimental tests. The results showed that the polynomial fitting formula were obtained by the calculation of least square method in the software of origin 8.0. Through the analysis of the mathematical equation and correlation coefficient of load-displacement and energy-displacement relationship.it was seen that the fitting effect of the curve was very good.The mathematical equation of this method can be used to simplify the calculation of load, energy from displacement.

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3D woven fabric, I-shaped composites, Mathematical equation, Bending properties

1. INTRODUCTION

I-shaped structure of cast-in-situ concrete structure occupies a large proportion in bridge construction. Although the well-designed and well-maintained concrete structure can withstand various loads during many years of operation, due to the role of heavy vehicles and the erosion of the environment, the concrete bridge deck needs frequent maintenance, and still need to be renovated and replaced. For these reasons, 3D (three-dimensional) I-shaped woven composites have been used to overcome these difficulties due to their excellent mechanical properties [1].

3D I-shaped textile structural composites were fabricated with 3D I-shaped textile fabrics used as reinforced phase and resin used as matrix phase. Most ordinary I-shaped composites were pressed with plate material, and the processing method was simple, but the integrity of the ordinary I-shaped composites is poor and it is easy to crack [2]. Compared with ordinary fabrics, the 3D woven fabric has good integrity and many advantages like larger thickness, rigidity and light weight [3]. So 3D woven technique is superior in manufacturing the I-shaped preform. 3D woven composite has gained extensive attention for its high impact resistance and damage tolerance, low delamination and structural integrity. Muhammad [4] studied the peel strength of T-shaped and H-shaped structures, and found that the mechanical properties of T-shaped and H-shaped interlocking structures are better than P-shaped and laminated structures compared with laminated structures. In weaving and designing, the 3D tubular woven fabric and other 3D woven fabric researched by our group also provide the basis for weaving the 3D I-shaped woven fabric of this paper [5].

I-shaped preform is a common structure used in engineering application like supporting structures on aircraft wings and ship decks. In the fabrication and the mechanical properties of 3D I-shaped composites, the mechanical behaviors of the I-shaped composites have been investigated extensively [6]. Zagon [7] studied the shear behavior of fiber reinforced I-shaped composites. A laminated composite beam with reduced proportions is proposed, but the wing of the I-shaped composite is a foam

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sandwich composite [8]. Zhou et al [9] studied the impact mechanical properties of 3D braided composite by setting three kinds of gas pressure. The results showed that the load, displacement and energy absorption increased with the increase of the shock gas pressure. Zheng et al[10] analyzed the bending properties of braided I-shaped composite. The results showed that the change of braiding parameters had a great influence on the properties of braided I-shaped composite. Even though a lot of researches had been done on the I-shaped composite, however, the bending properties of 3D I-shaped woven composites have not been reported comprehensively so far.

In terms of raw material selection, nowadays carbon fiber, kevlar fiber and glass fiber are mostly used in the preparation of composite materials. However, compared with these fibers, basalt fiber has the characteristics of high strength, high modulus, high temperature resistance, and compressive strength and shear strength, especially good environmental protection, and it can be completely biodegradable [11]. Therefore, basalt fiber is chosen as the raw material of 3D I-shaped woven composites. Many studies on basalt fiber reinforced composites have been done before [12]. But few studies have been done on 3D I-shaped woven composites with basalt fibers. The paper studied the bending properties of 3D I-Shaped woven composites with basalt fibers.

2. MATERIAL AND METHOD

2.1 Material

800tex basalt fiber filaments tows from Zhejiang Shijin Basalt Fiber Co., Ltd, (Zhejiang, China) were chosen as weft and warp yarns. Epoxy vinyl resin (V-118) from Wuxi Qianguang Chemical Co., Ltd, (Wuxi, China) was used as matrix. Loom in the lab (SGA 598) from Tongyuan Textile Machinery Co., Ltd, (Jiangyin, China) was used for weaving samples; VARTM molding system was used for molding; universal system prototype (QG-5A) from Kaya Industrial Co., Ltd, (Shanghai, China) was used for cutting samples, and universal testing machine (TH-8102S) from Suzhou Tuobo Machinery Equipment Co., Ltd (Suzhou, China) was used for testing, muffle furnace (SRJX-4-13A) from Zhejiang Xinnuo Instrument Co., Ltd (Shaoxing, China) was used for testing fiber volume fraction.

2.2 Fabrication of 3D I-shaped Woven Composites

Most of the 3D woven fabrics are designed by the common design method, that is, to directly design the warp section of the fabric, and then draw the pattern map according to the warp section. The thickness of the fabric designed by this method will be limited by the number of heald frames. Therefore, in the design process, in order to make the beam height of 3D I-shaped woven fabric not affected by the number of heald frames of loom, the method of multiple pattern board weaving is used for design and weaving, that is, flattening reduction method [13]. The specific weaving sketch of 3D I-shaped woven fabric was shown in the Figure 1. From Figure 1, it can be seen that the shape structure of A1 and A3 were same, so the same weaving structure was assigned to A1 and A3, therefore the same warp structural drawings and chain drafts utilized in this paper were to weave the structure of A1 and A3. The shape structure of A2 was different from A1 and A3, so using different warp structural drawings and chain drafts in this paper was manufactured the structure of A2. At the same time, the size of A1 was equal to A3, the size of A2 was designed according to requirements. In this paper the lengths of A2 was set to 20 mm, 40 mm, and 60 mm respectively.

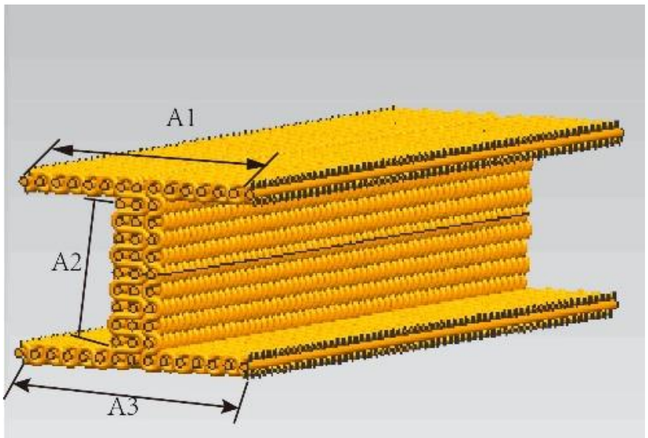
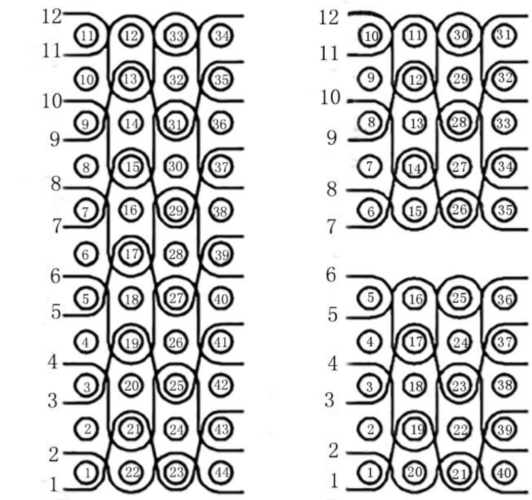


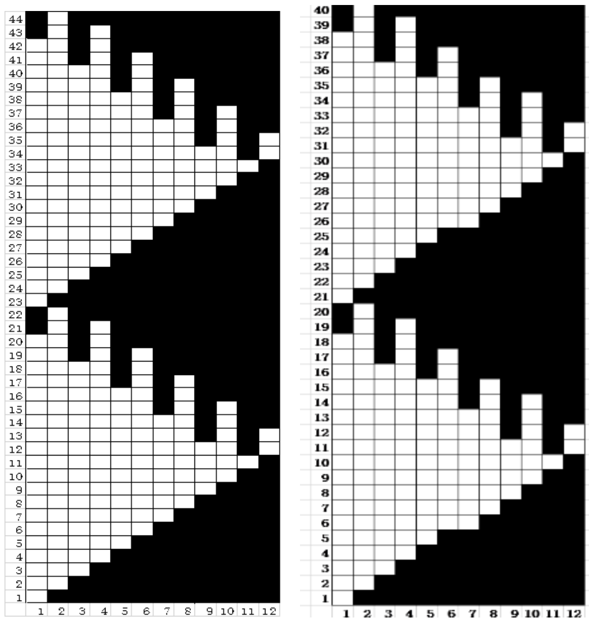
Figure 1. Specific weaving sketch of 3-D I-shaped woven fabric

3D I-shaped woven fabric belongs to multiple layers binding structure. Since the height of 3D I-shaped woven fabrics is determined by the weaving length of the A2, so the warp structural drawings and chain drafts were all same, just changing the weaving length of A2. The warp structural drawings of 3D I-shaped woven fabrics with three different heights are shown in Figure 2, as seen in Figure 2, (a) was warp structural drawings of A2, (b)was warp structural drawings of A1 and A3. According to the warp structure drawing, the chain draft of 3D I-shaped woven fabric with three different heights was drawn, as shown in Figure 3. As shown in Figure 3, (a)was the chain draft of A2, and (b) was the chain draft of A1 or A3.



(a) Warp structural drawings of A2 (b) Warp structural drawings of A1 or A3

Figure 2. Warp structural drawings of 3D I-shaped woven fabrics with three different heights Note: The line was warp yarn and the circle was weft yarn



(a) Chain drafts of A2 (b) Chain drafts of A1 or A3

Figure 3. Chain drafts of 3D I-shaped woven fabrics with three different heights

Note: The black rectangles are warp interlacing point and the white rectangles are weft interlacing point, the numbers in vertical directions are weft numbers and numbers in horizontal directions are warp numbers.

The weaving parameters of 3D I-shaped woven fabrics were shown in Table.1 The following are loom parameters for loom.

(1) width: 20 inches

(2) color selection: Manual

(3) number of heald frames: 16 pages; (standard configuration)

(4) coiling: manual or automatic;

(5) beating up device: manual;

(6) heald lifting frame: computer PLC control, pneumatic opening;

(8) power supply: rated power supply 220 V, frequency 50Hz;

(9) overall dimension (mm): 1300 × 980 × 1510; weight: 180kg; power: 1KW

In order to produce the same heights of three different 3D I-shaped woven composites, the weaving parameters were all same except the heights of A2. For the same thickness, the bending properties, energy absorption properties and fiber volume fraction of different heights could be compared.

The 3D I-shaped woven composites were manufactured by VARTM process. And, the role of its principle and structure of each part could be seen in literatures[14]. The proportion of Epoxy vinyl resin, curing agent and accelerating agent was 400:5:5. In order to decrease the porosity in composite, the vacuum pressure in the bag was about 0.1MPa before resin injection. The epoxy vinyl resin was injected into the preform by VARTM technique. The curing condition included normal temperature(about 20 degrees Celsius) for 3h, then 80℃ for 8h. As shown in Figure.4, the 3D I-shaped woven composites were cut into the testing length of 120 mm. The thickness of the flanges was 30 mm, and the heights of 3D I-shaped woven composites were 20 mm, 40 mm, 60 mm respectively, which could be compared.

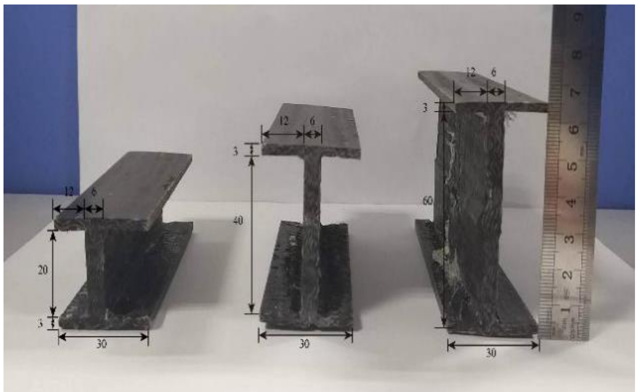


Figure 4. 3D I-shaped woven composites with three different heights Note: The unit of the dimensions is mm indicated in this figure.

2.3 Characterization of 3D I-shaped Woven Composites

The test was conducted using ISO 178:2001, and using a computer controlled universal testing machine (TH-8102S). The testing speed was 10 mm/min.

In this paper the energy absorption properties were evaluated by Energy-displacement scatter plots which were obtained by integrating the area of the load-displacement scatter plots curves in origin 8.0.

Fiber volume fraction is the ratio of fiber volume divided by composite volume and depending on the density of the constituent materials in a 3D I-shaped woven composites

In this paper the fiber volume fraction of the 3D I-shaped woven composites were achieved by burning method in muffle furnace which can be referred to the well-known standard ASTM D3171.

The fiber volume fraction is calculated by using the following formulas.

$$V_{\text{Resin}} = \frac{(W_1 - W_2)}{\delta_{\text{Resin}}} \quad (1)$$

$$V_1 = \frac{V_{\text{Resin}}}{V} \times 100 \quad (2)$$

$$V_2 = (1 - V_1) \times 100 \quad (3)$$

V is the total volume of the sample, δ_{Resin} is the resin density (the data provided by the supplier is 1.7g/cm^3), V_{Resin} is the volume of resin, W_1 is the weight of sample before burning, W_2 is the weight of sample after burning, V_1 is the resin volume fraction, and V_2 is the fiber volume fraction.

Therefore, the experimental data obtained from the burning method in this paper were shown in Table 2.

Table 1. Weaving Parameters of 3D I-shaped Woven Fabrics

Heights /mm	Linear density/tex	Layer number of yarns		Weaving density /root /10cm	
	Warp/weft yarns	A1,A3	A2	Warp density	Weft density
20/40/60	800	5	11	480	1180

Table 2. Fiber volume fraction of 3D I-shaped Woven Composites

Heights/mm	V/cm^3	W_1/g	W_2/g	V_1/%	V_2/%
20	2.880	5.328	3.081	41.8	58.2
40	4.488	8.097	4.677	44.8	55.2
60	4.968	9.433	5.515	46.4	53.6

2.4 Origin 8.0 Numerical Fitting

Although the testing process of bending test was relatively simple, it had large number of data to be measured in the experiment. The best method was the least squares method. Its advantage was that it accurately fit the curve linearly or non-linearly, but it had large amount of computation and complexity, and it was difficult to realize the artificial calculation through numerous formulas. Origin 8.0 software just used the least squares method to fit the data non-linearly according to load-displacement and energy-displacement scatter plots, which had been used by many scholars.

3. RESULTS AND DISCUSSION

This research investigated the bending properties of 3D I-shaped woven composites. First, 3D I-shaped woven fabrics with three different heights were woven on ordinary loom by reasonable design with low cost. Then 800tex basalt filaments were used as weft and warp yarns. And the 3D I-shaped woven composites were fabricated by VARTM(vacuum assisted resin transfer molding)process. The bending test was carried out on the microcomputer control universal testing machine (TH-8102S). The load-displacement and energy-displacement scatter plots were obtained from experimental test. Finally the software of Origin 8.0 was used to fit the load-displacement and energy-displacement scatter plots. The results showed that the polynomial fitting formulas were obtained by the calculation of least square method in origin 8.0.

3.1 Analysis of Load-displacement Curves

The bending properties of 3D I-shaped woven composites under three-point bending test were evaluated by load-displacement scatter plots and energy-displacement scatter plots. By observing the load-displacement scatter plot, the method of 8-orders polynomial fitting was finally adopted. The load-displacement scatter plots were obtained from experimental data, and then fitted by least square method in software origin 8.0. The load-displacement scatter plots and fitting curves of 3D I-shaped woven composites with three different heights were shown in Figure.5.

After that the polynomial fitting formula could be obtained by the calculation of least square method in origin 8.0. The mathematical equation of fitting curve and correlation coefficient of load-displacement relationship were shown in Table.3. From the correlation coefficient in Table 3, it could be seen that the fitting effect of the curve was very good. The fitting results depended on the correlation coefficient “R”. The value range of “R” was $0 < R \leq 1$, and the value was to 1 and the consistent was good of the curve and formula. This mathematical equation of fitting curve could be used to simplify calculation of load from displacement.

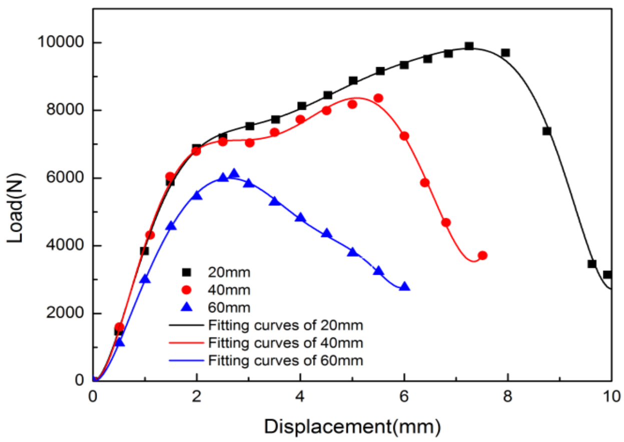


Figure 5. Load-displacement scatter plots and fitting curves of 3D I-shaped woven composites with three different heights

It could be seen from Figure.5 that the maximum load of the composites decreased gradually with the increase of the height of 3D I-shaped woven composites. This was mainly because the center of gravity of the composites increased with the increase of the heights, and the ability endure the damage decreased in the bending process. And analysis of Figure.5 showed that all three fitting curves could be divided into three stages. At the beginning, the fitting curves were almost linear, this indicated that bonding situation was good between resin and fiber. So, the composites exhibited linearly elastic performance. Secondly, the curves no longer presented straight lines and the slope of curves decreased with the increase of displacement. This was because the contact surface area increased with the increase of displacement between the samples and indenter, and the resin began to destroy. Finally, at the peak, the curve began to decline rapidly and the composites began to have shear destruction.

Table 3. Mathematical Equation of Fitting Curve and Correlation Coefficient of load-displacement relationship

Heights/mm	Mathematical Model Equation of Fitting Curve	Correlation Coefficient
20	$Y=-15.434+263.249x+8522.060x^2-6912.590x^3+2532.792x^4-507.943x^5+57.632x^6-3.474x^7+0.086x^8$	0.99676
40	$Y=6.070-178.334x+9402.190x^2-7280.569x^3+2455.145x^4-434.173x^5+42.215x^6-2.234x^7+0.055x^8$	0.99510
60	$Y=-2.005-165.9005x+7612.0445x^2-7157.535x^3+3674.481x^4-1190.124x^5+231.693x^6-24.267x^7+1.043x^8$	0.99722

This also could be seen from the load-displacement curves that with the increase of displacement, the load reached the maximum, the fracture of composites became more severe. It showed that the curves were fluctuant and the peak load decreased during the three different heights and after damage initiation, the composites rigidity was degraded gradually according to the specified damage evolution law. This was because that the uninterrupted fiber fracture and resin rupture emerged in the process of bending. And the bending damage was mainly focused on the junction between the top flange and the web.

It also could be seen from Figure.6 that the bending properties of the 3D I-shaped woven composites with 20 mm was the best, because the composite with the heights of 20mm had bigger rigidity and bigger maximum bending load comparing to the composites with the heights of 40mm and 60mm. And the bending properties of the 3D I-shaped woven composites with the height of 60 mm was the worst, and the bending properties of the 3D I-shaped woven composites with the height of 40 mm was between the both.

3.2 Analysis of Energy-displacement Curves

The energy absorption behavior of textile composites has been an attractive research topic in recent years, so in this paper the energy-displacement scatter plots were obtained from experimental data, and by observing the energy-displacement scatter plot, the method of 3-orders polynomial fitting was finally adopted, then fit by least square method in software origin 8.0. The energy-displacement scatter plots and fitting curves of 3D I-shaped woven composites with three different heights were shown in Figure.6.

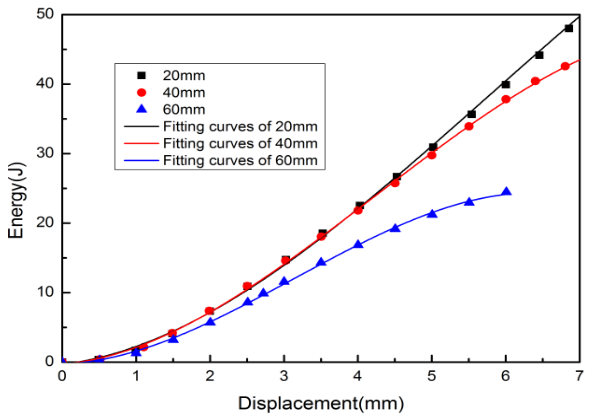


Figure 6. Energy-displacement scatter plots and fitting curves of 3D I-shaped woven composites with three different heights

And the mathematical model equation of fitting curve and correlation coefficient of load-displacement relationship were shown in Table.4. This mathematical equation of fitting curve could be used to simplify calculation of energy from displacement. From the correlation coefficient in Table 3, it was seen that the fitting effect of this curve was good. From Figure 6, the energy absorption value increased with the decrease of the height of 3D I-shaped woven composites, the bending properties and energy absorption properties of 3D I-shaped woven composites were in proportional to each other. This conclusion was consistent with the previous studying results in this aspect by other scholars[15]

Energy absorption is also an important index of cushioning performance and impact resistance of composites in the bending process. So the cushioning performance and impact resistance of 3D I-shaped woven composites increased with the decrease of height. This was mainly because the center gravity of composites increased with the increase of height, there was a three-point bending failure mode in the composites, which was compression failure on the upper surface, tension failure on the lower surface and shear failure on the web surface. Therefore, the energy absorption mechanism was the expansion of cracks in the 3D I-shaped woven composites and the increase of the compression area of the composites.

3.3 Analysis of Fiber Volume Fraction

From Table 2, it was seen that the fiber volume fraction of the 3D I-shaped woven composites with the height of 20 mm, 40 mm, 60 mm were 58.2%, 55.2%, 53.6% respectively. It showed that the fiber volume fraction decreased with the increase of the heights of 3D I-shaped woven composites. Combining with Figure 5 and Figure 6, the results showed that the increasing fiber volume fraction improved the bending properties of the 3D I-shaped woven composites. This conclusion was consistent with the previous studying results in this aspect by other scholars [16-17].

3.4 Analysis of Failure Mode and Failure Mechanism

The trend of 3D I-shaped woven composites with different heights is similar and the failure mode and failure mechanism are the same. Therefore, the failure mode and failure mechanism of the 3D I-shaped woven composites with the height of 20 mm were explained as an example.

The overall and partial enlargement photographs of 3D I-shaped woven composites with the height of 20 mm were shown in Figure. 7. As seen in Figure 7, (a) was the overall and partial enlargement failure modes on the top flange of the composites, (b) was the overall and partial enlargement failure modes of the bottom flange of the composites, and (c) was the overall and partial enlargement failure modes on the web of the 3D I-shaped woven composite.

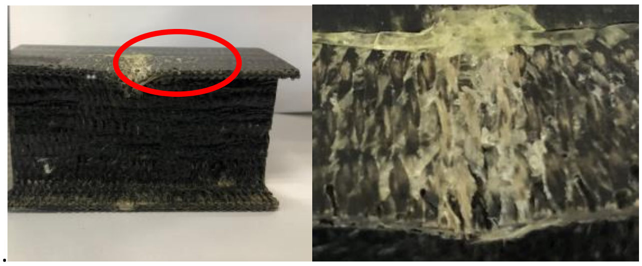
Table.4 Mathematical Equation of Fitting Curve and Correlation Coefficient of energy-displacement relationship

Heights/mm	Mathematical Equation of Fitting Curve	Correlation Coefficient
20	$Y=-297.397+1222.219x+1424.755x^2-82.105x^3$	0.99946
40	$Y=249.761+785.854x+1747.292x^2-138.098x^3$	0.99964
60	$Y=-242.158+302.282x+1725.884x^2-183.167x^3$	0.99897

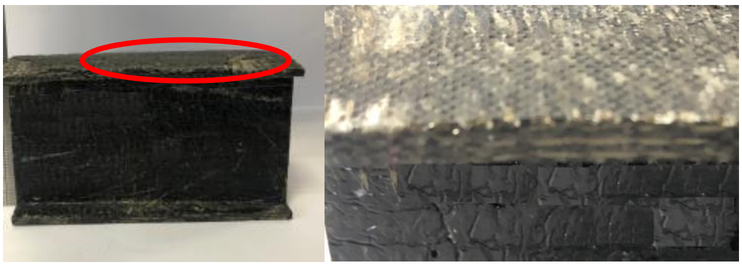
From Figure. 7, the bending failure modes showed that the 3D I-shaped woven composites was a typical bending failure modes with the compression failure in the top flange and tensile failure in the bottom, there was also shear failure in the web. Then, the bending failure modes of 3D I-shaped woven composite with 40 mm and 3D I-shaped woven composite with 60 mm were similar to 3D I-shaped woven composite with 20 mm.

In the aspect of damage, at the beginning, the damage distribution was mainly focused on the point where the pressure head located and the two fixed edges. Subsequently, with the increase of displacement, the damage area increased gradually. The damage of the top flange and the bottom flange were both serious, and damage in the web was next to the flange, this was because the stress wave spread from the top flange to the web, and at the same time the force in the reinforcement inclined forward to the web. This was due to the complex weaving structure in the reinforcement, which had be explained in the part two of this paper.

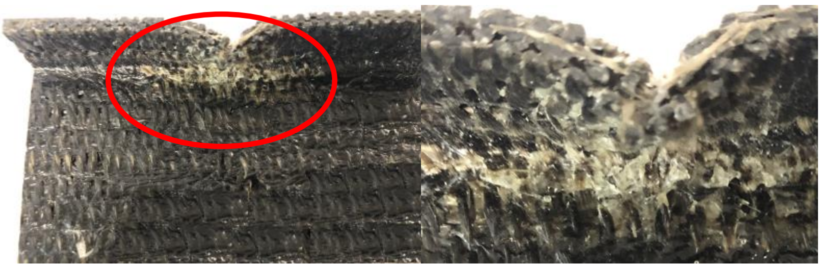
With the increase of the height, the destruction of the composites was worse, but there was no lamination in the 3D I-shaped woven composites. It was clear that the 3D I-shaped woven composites had high delamination resistance. There were cracks appearing in the direction of the web in the 3D I-shaped woven composite, this was mainly caused by the low fracture toughness of epoxy resin.



(a) The overall and partial enlargement failure modes on the top flange of the composites



(b) The overall and partial enlargement failure modes of the bottom flange of the composites



(c) The overall and partial enlargement failure modes on the web of the 3D I-shaped woven composite

Figure 7. Failure modes of overall and partial enlargement photographs of 3D I-shaped woven composites with the height of 20mm

4. CONCLUSION

From the results of this study, the following conclusions were drawn：

1. 3D I-shaped woven fabrics with three different heights were woven on ordinary loom by reasonable design with low cost processing.

2. The 3D I-shaped woven composite with 20 mm has the maximum load. The 3D I-shaped woven composite with 60 mm has the minimum load. The 3D I-shaped woven composite with 40 mm has the load between the two. The bending properties of 3D I-shaped woven composites increased with the decrease of height.

3. Through the analysis of origin 8.0 fitting results, it showed that the polynomial fitting formula could be obtained by the calculation of least square method in origin 8.0. And it could be seen that the fitting effect of the curve was better. This mathematical equation of fitting curve could be used to simplify the relationship between load, energy and displacement.

4. The 3D I-shaped woven composites has excellent mechanical properties. In the test process, the composites showed good interlaminar shear strength, no delamination and splitting phenomenon. And, the height of the 3D I-shaped woven fabrics utilized as the reinforced composites were different, and the bending properties of composite made of 3D I-shaped woven fabrics also showed a big difference, but all of them had same failure modes and failure mechanism.

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A Study on the Parameters Effecting Yarn Snarling Tendency

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ABSTRACT

The yarn is subjected to many internal stresses due to the raw material and yarn spinning steps used. When the yarn is relieved of the stresses it is subjected to, the yarn reacts inversely to the rotation defined as yarn liveliness. Yarn liveliness, may cause the spirality problem especially in the structure of knitted fabrics. The aim of this study is to investigate the effect of yarn spinning system, yarn count and twist coefficient on the tendency of yarn snarling. In this study, yarns were produced using 100% cotton materials, in five different spinning systems, taking two different twist coefficients into consideration, and in two yarn counts. Yarn liveliness values of samples were measured by Kringel Factor Meter Test Apparatus. As the twist coefficient of the yarns increases and the yarn becomes thicker, the snarling tendency increases. However, the highest yarn liveliness values were seen in the compact spinning system.

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Yarn liveliness, snarling tendency, twist effect, yarn properties

1. INTRODUCTION

Every stage in yarn production creates tension on the yarn structure. The main reason for this stress is the twist [1, 2]. Every twisted yarn is being subjected to a permanent torque force on them. As soon as the yarns are released from this torque force, they start to snarl on themselves. The term of yarn liveliness, also referred to as twist liveliness or yarn snarling can be explained by the deterioration of the internal balance of the yarn as a result of the torsional force. The important point here is that the bending rigidity is direct proportional to the twisting resistance. That is, the more twist is given to the yarn, the greater the force shown against the twist [2].

Except some extreme cases, the snarl of the yarn on itself causes some problems. Particularly on the bobbin transfer stage, it causes disruption such as breaking by yarn liveliness. In the weaving step, it causes problems during the weft thread stroke. Due to the yarn liveliness, it causes the yarns to be mixed during the weft yarn stroke. This, results in machine downtime and loss of efficiency. It also causes problems for knitted fabric structures, which directly affect the quality of the fabric such as spirality. In knitted fabric structures, the yarn liveliness creates loops that are bent to right or left with the “θ” angle. This is called spirality problem of knitted fabrics [3]. The liveliness created by the twist causes a tension-induced break of the yarn during the skein dyeing of the yarn [4].

It has been found in the studies conducted by many researchers that some parameters directly affect the formation of yarn liveliness. Lord concluded that, the lower the twist, the easier it will be to get rid of the internal tension caused by twisting. The diameter of the yarn here is an important parameter. Because of the decrease in diameter of the yarn, the forces applied on the edges will become tighter. Thus, with this pressure on the fibers, it will be difficult to get rid of the effect of twisting [5]. Araujo and Smith concluded that vacuum steaming reduced the tendency of the snarling. It was concluded that the yarn liveliness values decreased gradually with the increase in

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the vacuuming period, but not completely eliminated [6]. Kadoğlu investigated the effect of twist coefficient and spinning system on yarn liveliness. Accordingly, it is stated that there is a direct correlation between twist coefficient and liveliness. Besides, the snarling tendency of the open end yarns was significantly lower than the ring spinning system [7]. Primentas designed the Prianic tester to examine the yarn liveliness. In addition, it is emphasized that the measuring apparatus significantly reduces the operating time compared to other methods [8]. Marmaralı stated in her study that relationship between twist factor and spirality to be directly proportional between these two parameters. Therefore, with the increase of the twist factor, the yarn liveliness increases and this increases the spirality [9]. Üreyen in study of yarn liveliness, he stated that as the twist coefficient increased, the yarn liveliness increased however as yarn count decreased, the liveliness values decreased [3]. Çelik did not use the standard loading weight of the Kringel Factor Meter, which is a measuring instrument for yarn liveliness. Instead of this, loading weight for each yarn number is calculated by the formula (yarn tex) x 10 mg. Accordingly, results of long staple fiber spinning showed that, yarn liveliness increased as the twist coefficient increased, but number change was not statistically significant. The highest Kr values were found to be in the compact, ring and siro-spun system, respectively. Stapel fiber spinning results showed that, the highest Kr values were found in the compact system and the lowest Kr values were in the open end system. In addition, there is a direct correlation between the yarn count and twist coefficient and the liveliness values [2]. Çelik and Kadoğlu studied yarn liveliness tendency of staple yarns and the results demonstrated that raw material, spinning system, yarn count, twist coefficient and steam process significant on yarn liveliness properties [1]. Çelik et al. have found that the effects of yarn count, twist coefficient and raw material on the yarn liveliness of siro spun yarns are significant. According to this, the liveliness values of acrylic yarns were found higher than that of wool yarns. Furthermore, the liveliness values of siro spun yarns were lower than the ring yarns [10]. Xu et al. have designed a computer aided measuring instrument that can automatically measure yarn liveliness. The twist tester is a recommended objective test instrument to measure the number of yarn snarl turns with image analyse [11]. Şardağ and Özdemir observed that the effect of vacuum has a significant effect on the yarn liveliness and decreases the liveliness. It was determined that the lowest liveliness values occurred in viscose fibers and the highest snarling tendency in staple polyester yarns. Additionally, as the twist coefficient increased and the yarn become coarser, the liveliness values increased [12, 13]. Bilir and Şardağ investigated performance characteristics of the Tencel® and cotton blended yarns. As a result, it was found that the amount of Tencel® fiber in the yarn had no direct effect on the yarn liveliness [14].

In this study, 100% cotton raw material was used as roving and sliver. Ring, compact, siro, compact siro and rotor spinning systems were preferred as spinning systems. The yarns were produced in two different yarn counts and by using two different twist coefficients. In addition, the results were analysed statistically by variance analysis. Although thick yarns have been studied in previous articles, this study is interested in thin yarn count (30/1 and 40/1 Ne) liveliness properties. The main reason for this prefer is the high amount of energy in thick yarns that cause the yarn to snarl [15]. However, in this study it is examined that whether thin yarns have the same effect as thick yarns or not. In addition, the twist coefficients of 3.6 and 4.2 have been preferred and a new perspective has been introduced especially for the yarns used in the knitted fabric industry. The aim of this study is to examine the yarn liveliness in different spinning systems, especially investigation of liveliness characteristics of the compact siro yarn system contrast to the previous studies. In this way, 5 different yarn structures were examined, which is the originality of the study, in order to investigate the effect of thin yarn counts on the snarling tendency for these systems.

2. MATERIAL AND METHOD

The main purpose of the study is to examine the effect of spinning systems, yarn count and twist on the yarn liveliness. In this context, 100% combed cotton raw material was used as sliver (0.1 Ne) for open-end spinning and as roving for other systems (0.8 Ne). Pinter Merlin SPA 1803 was used for the production of ring and siro spun yarns. For siro spun system, double roving was fed into the machine and the apparatus to keep the roving at the same distance. Rieter K45 spinning machine was used for compact and compact siro spinning processes. In the production of compact siro spun, the machine's original siro spinning system was used. The Rieter R40 Open End spinning machine was used for OE-Rotor yarns. The machine parameters are given in Table 1. In order to examine the effect of the yarn count, 30/1 and 40/1 Ne were choosen. In addition, α_e= 3.6 and α_e= 4.2 twist coefficients were applied to investigate the effect of yarn twist coefficient.

On the Rieter R40 spinning machine 90000 rpm rotor speed and 7750 rpm opening roller speed were fixed for all yarn types, in order to be able to investigate the effects of twist coefficient and yarn count. 33 XT-BD type rotor with a diameter of 40 mm and a circumference of 104 mm was used. As opening roller, B174 DN type opening roller was chosen.

While ring, rotor and compact spinning systems can work with all examples, 40/1 Ne yarns couldn't produced for siro and compact siro systems. This is because the draft value to be applied is too high and not within the machine limits.

Subsequently yarns were conditioned for 24 hours at 20°C±2 and 65±5% RH. Vacuum steam process was not applied to the samples and measurements were made on crude yarns.

In this study, Kringel Factor Meter yarn liveliness test apparatus, which is shown in Figure 1 was used. The plate-front of this test apparatus is divided into 10 parts. These 10 parts are available in 5 sections, each containing 0.2 units (Figure 1). The movement of this system is provided by the three-stage control button located in the upper right corner of the device. The yarn is passed through the first clamp when the button is in the free position. After that the button is adjusted to compress the 1st clamp and the yarn is compressed. After the yarn is placed in the test apparatus, weights of 450 mg for each number are separated from the yarn holders on the underside of the plate and hung on the yarn. The yarn depending on the liveliness it has, it comes to a fixed position and the expression read on the plate gives the liveliness value of the yarn. This value is defined as the Kr (Kringel) value of the yarn. The higher the Kr value, the higher the liveliness value of the yarn [16].

The measurement results were statistically evaluated in 95% confidence limits. Variance analysis (ANOVA) was used to examine the effect of the spinning method on all parameters. To deduce whether the parameters were significant or not, p values were examined. According to the homogeneity of variances, Duncan or Dunnett tests and F values and α = 0.05 significance were evaluated. The t-test was applied to determine the effect of yarn number and twist coefficient on yarn properties.

Table 1. The machine parameters

		Ring	Compact	Siro Spun	Compact Siro
Spindle speed (rpm)		12.000	12.000	12.000	12.000
Ring diameter (mm)		40	40	40	40
Traveller number	30/1 Ne	45 (3/0)	45 (3/0)	45 (3/0)	45 (3/0)
	40/1 Ne	31,5 (6/0)	31,5 (6/0)	31,5 (6/0)	31,5 (6/0)

Table 2. The quality tests for yarn samples

Yarn tests and standards	Measurement tool	Number of measurement
Yarn tenacity (TS 245 EN ISO 2062)	Lloyd yarn tenacity tester	5 yarn samples/10 tests for each cops/bobbins
Yarn elongation at break (TS 245 EN ISO 2062)	Lloyd yarn tenacity tester	5 yarn samples/10 tests for each cops/bobbins
Yarn twist test (TS 247 EN ISO 2061)	Zweigle D315 tester	5 yarn samples/10 tests for each cops/bobbins
Yarn unevenness test (ISO 16549)	USTER tester 5	5 yarn samples/1 tests for each bobbins(The measurement length was 1000 m cops/bobbins)
Yarn count (TS 244 EN 150 2060)	USTER tester 5	5 yarn samples/1 tests for each bobbins (The measurement length was 1000 m cops/bobbins)
Yarn liveliness test	Kringel factor meter yarn liveliness test apparatus	5 yarn samples/10 tests for each cops/bobbins

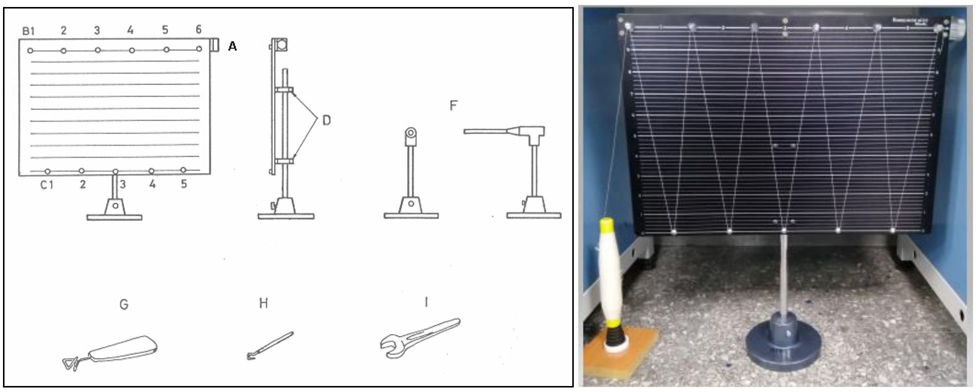

Figure 1. Kringel factor meter yarn liveliness test apparatus [15]

3. RESULTS AND DISCUSSION

In this part yarn count, yarn tenacity, yarn breaking elongation, Uster unevennesses, twist values and yarn liveliness tests results were given in (Table 3-6).

3.1 Influence of twist coeffifient on yarn liveliness

The effect of the twist coefficient on yarn liveliness was found statistically significant (Figure 2, Figure 3 and Table 7). Considering the same spinning system and yarn count, it was seen that as the twist coefficient increases the values of liveliness (Kr) also increases.

Table 3. Properties of 40/1 Ne yarn samples

	Ring		Compact		Open end	
Twist coefficient (α_e)	**3.6**	**4.2**	**3.6**	**4.2**	**3.6**	**4.2**
Yarn count (Ne)	40.43	39.58	39.01	40.07	39.38	39.49
(%CV)	(2.12)	(0.86)	(1.20)	(2.50)	(0.92)	(0.96)
Tenacity (cN/tex)	11.7	11.89	15.26	15.64	10.21	10.97
(%CV)	(7.81)	(9.09)	(6.6)	(6.69)	(4.59)	(4.19)
Elongation at break (%)	7.39	6.93	9.06	8.95	8.41	8.02
(%CV)	(8.8)	(9.58)	(3.63)	(8.74)	(4.73)	(8.19)
Uster %CV	13.52	17.38	13.7	13.37	4.56	4.47
Thin places/km	126.2	176	5.4	2.6	104	121
Thick places/km	375	415	87.8	27.6	92	135.6
Neps/km	240	209	73	51	18	24
Yarn hairness (H)	4.98	4.77	3.55	3.42	4.56	4.47

Table 4. Properties of 30/1 Ne yarn samples

	Ring		Compact		Open end		Siro		Compact siro	
Twist coefficient (α_e)	**3.6**	**4.2**	**3.6**	**4.2**	**3.6**	**4.2**	**3.6**	**4.2**	**3.6**	**4.2**
Yarn count (Ne)	29.84	28.27	28.27	29.64	29.88	29.24	28.91	29.04	29.38	28.93
(%CV)	(1.21)	(1.96)	(1.18)	(4.23)	(2.51)	(1.55)	(1.93)	(2.33)	(0.85)	(1.05)
Tenacity (cN/tex)	13.42	15.95	16.53	17.09	10.43	12.02	14.95	16.03	16.63	18.43
(%CV)	(4.85)	(4.39)	(3.36)	(5.17)	(3.51)	(2.76)	(9.17)	(2.40)	(5.23)	(5.59)
Elongation at break(%)	8.68	9.09	9.65	10.2	8.49	9.57	9.44	10.12	9.4	9.96
(%CV)	(6.38)	(2.62)	(3.23)	(3.14)	(4.45)	(2.98)	(4.07)	(4.17)	(4.27)	(3.35)
Uster %CV	14.03	14.35	11.22	12.18	11.44	12.59	14.1	15.42	13.32	14.26
Thin places/km	8.2	11.2	3.4	1.2	59.8	70.4	17	79.60	5	11.6
Thick places/km	89.6	116	26.8	13	11.4	62	74.4	108.2	94.9	146.8
Neps/km	106.2	146.8	29	22.8	24.2	22	87.8	104.2	70.6	114.8
Yarn hairness (H)	5.34	5.03	3.85	3.66	5.16	5.13	5.18	4.82	3.56	3.3

Table 5. Twist values of yarn samples

System	Yarn count (Ne)	Twist coefficient (α_e)	T/m (theoric)	T/m (measured)	T/m (%CV)
Ring	30/1	3.6	776.88	825.04	2.48
	30/1	4.2	906.37	943.19	3.02
	40/1	3.6	897.07	933.97	2.97
	40/1	4.2	1046.58	1037.18	5.13
Open end	30/1	3.6	776.88	776.88*	-
	30/1	4.2	906.37	906.37*	-
	40/1	3.6	897.07	897.07*	-
	40/1	4.2	1046.58	1046.58*	-
Compact	30/1	3.6	776.88	840.73	3.67
	30/1	4.2	906.37	956.25	1.73
	40/1	3.6	897.07	962.53	3.54
	40/1	4.2	1046.58	1113.32	3.70
Siro	30/1	3.6	776.88	804.21	2.86
	30/1	4.2	906.37	878.78	3.47
Compact siro	30/1	3.6	776.88	758.37	3.13
	30/1	4.2	906.37	849.79	3.78

*** The theoric number of twists for open-end rotor yarns are taken.**

Table 6. Yarn liveliness values of all samples

Twist coefficient (α_e)		30/1 Ne 3.6	30/1 Ne 4.2	40/1 Ne 3.6	40/1 Ne 4.2
Ring	Kr	4.44	4.88	4.25	4.66
	% CV	1.82	1.76	2.17	2.16
Compact	Kr	4.69	4.91	4.52	4.80
	% CV	1.13	3.09	1.28	1.17
Open-end	Kr	2.80	3.17	2.26	3.00
	% CV	2.55	3.11	3.92	4.04
Siro	Kr	4.36	4.72	-	-
	% CV	1.07	1.11	-	-
Compact siro	Kr	4.16	4.62	-	-
	% CV	2.1	1.1	-	-

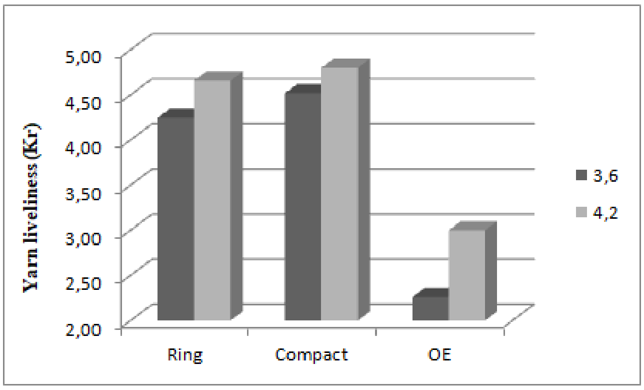

Figure 2. Influence of twist coefficient on 40/1 Ne samples

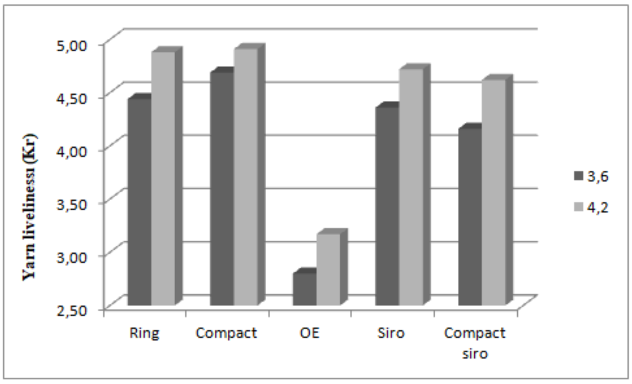

Figure 3. Influence of twist coefficient on 30/1 Ne samples

Table 7. The results of statistical analyses

Factor	Dependent variable = Kr value	F	Significance*
Twist coefficient	30/1 Ne Ring	4.693	0.000*
	30/1 Ne Open end	0.000	0.000*
	30/1 Ne Compact	6.171	0.000*
	30/1 Ne Siro	0.297	0.000*
	30/1 Ne Compact siro	16.613	0.000*
	40/1 Ne Ring	16.287	0.000*
	40/1 Ne Open end	1.641	0.000*
	40/1 Ne Compact	0.969	0.000*

* Significant for α =0.05 level.

Although high twist strength increases, the yarn is caused to be rotated in the opposite direction. This can be explained by the reaction of the yarn in order to elimination the torsion strain that it is subjected to during twisting step. Hence, the higher twist coefficient, get greater the tendency of the yarn to snarling. This is consistent with the results of previous studies of Primentas; Çelik; Kadoğlu and Üreyen.

3.2 Influence of yarn count on yarn liveliness

Statistical analysis of data showed that different yarn counts create different twist liveliness values of long staple yarns for α=0.05 (Figure 4 and Table 8).

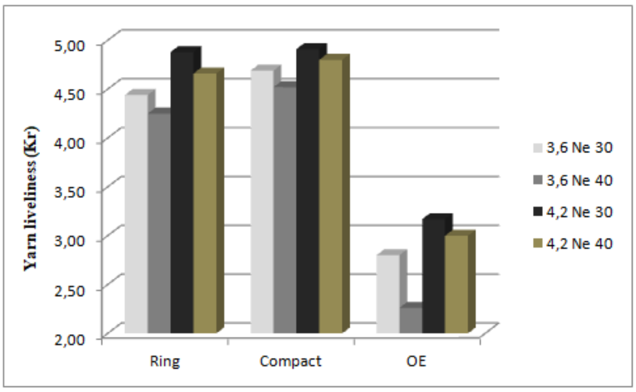

Figure 4. Influence of yarn count on yarn liveliness

Table 8. The results of statistical analyses

Factor	Dependent variable = Kr value	F	Significance*
Yarn count	α_e =3.6. Ring	9.624	0.000*
	α_e =4.2. Ring	10.034	0.000*
	α_e =3.6. Open end	0.042	0.000*
	α_e =4.2. Open end	1.138	0.000*
	α_e =3.6. Compact	0.281	0.000*
	α_e =4.2. Compact	13.956	0.001*

* Significant for α =0.05 level.

Accordingly, the value of Kr increases as the yarn becomes coarser. This is explained by the accumulation of more energy in yarns. A coarse yarn count gets more amount of energy than a fine yarn count on a unit length of yarn, hence drawing forth a higher yarn liveliness value as well. As the energy accumulated on the yarn increases, the tendency to snarl will be higher. This is consistent with the results of previous study of Üreyen.

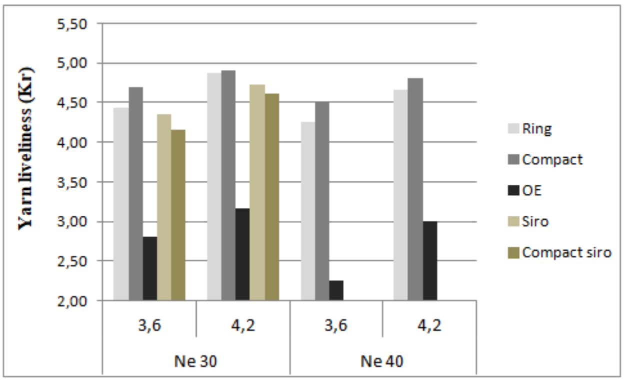

Figure 5. Influence of yarn count on yarn liveliness

3.3 Influence of spinning system on yarn liveliness

When the results of the spinning system were analyzed (Figure 5, Table 9-13) the effect of the spinning system on the yarn liveliness was found statistically significant.

Table 9. The results of statistical analyses

Factor	Dependent variable = Kr value	F	Significance*
Spinning system	30/1 Ne. α_e =3.6	1162.333	0.000*
	30/1 Ne. α_e =4.2	1106.974	0.000*
	40/1 Ne. α_e =3.6	3762.285	0.000*
	40/1 Ne. α_e =4.2	2958.273	0.000*

* Significant for α =0.05 level.

Table 10. Yarn liveliness values of 30/1 Ne, α_e =3,6 samples Duncan test

Spinning systems	Measurements	α_e =3,6				
		1	2	3	4	5
Open end	250	2,8008				
Compact siro	250		4,1592			
Siro	250			4,3628		
Ring	250				4,4396	
Compact	250					4,6880
Significance		1,000	1,000	1,000	1,000	1,000

Table 11. Yarn liveliness values of 30/1 Ne, α_e =4,2 samples Duncan test

Spinning systems	Measurements	α_e =4,2			
		1	2	3	4
Open end	250	3,1668			
Compact siro	250		4,6224		
Siro	250			4,6996	
Ring	250				4,8828
Compact	250				4,9140
Significance		1,000	1,000	1,000	0,316

Table 12. Yarn liveliness values of 40/1 Ne, α_e =3.6 samples Duncan test

Spinning systems	Measurements	α_e =3,6		
		1	2	3
Open end	250	2,2560		
Ring	250		4,2476	
Compact	250			4,5180
Significance		1,000	1,000	1,000

Table 13. Yarn liveliness values of 40/1 Ne, α_e =4.2 samples Duncan test

Spinning systems	Measurements	α_e =4.2		
		1	2	3
Open end	250	3.0024		
Ring	250		4.6588	
Compact	250			4.7900
Significance		1.000	1.000	1.000

It is seen that the lowest liveliness values for 30/1 Ne yarn samples exist in the open end system, followed by compact siro, siro, ring systems and the highest values in the compact spinning system. Similarly, on the 40/1 Ne yarns it was observed that the lowest snarling tendency was observed in rotor yarns and the highest values were in compact yarns. As it is known open-end yarns have certain fibre belts on yarn surface. Therefore, open-end yarns have the lowest liveliness. Siro and compact siro yarns are stable in comparison to ring and compact systems. Thus, the snarling tendency is not very high. In compact yarns, the settlement of the fibers in the yarn structure is higher. Due to the excess of fibers added to the yarn structure according to this system, the torsional force to be created by the fibers is higher than other yarns. So, the yarn liveliness values of compact yarns are higher. This is consistent with the results of previous study of Kadoğlu and Çelik.

3.4 Influence of the other yarn parameters on yarn liveliness

It has been observed that yarn liveliness increases with increasing yarn strength in some yarn types (Table 3-5). However, this increase was not found in all yarn types and was not statistically significant.

As a result, it is not possible to decide a relationship between tenacity and liveliness. On the other hand, it was not observed any significant relation between the hairiness and irregularity of yarns over the yarn liveliness characteristic.

4. CONCLUSION

The yarn acquires tension due to both twisting and spinning processes. It has the desire to get rid of this tension even when it is released as a yarn or fabric. In this study, the evaluated parameters are concentrated on the yarn twist coefficient, yarn count and spinning system. In the experimental part, the yarn liveliness was investigated with the Kringel Factor Meter Tester. The data obtained are evaluated and the results are stated below:

- The effect of twist coefficient on yarn liveliness was found significant. As the twist coefficient increases in the same yarn count and system, the snarling tendency of the yarn, i.e. the yarn liveliness values, increase. This result is in parallel with many studies. (Kadoğlu; Primentas; Üreyen; Çelik; Şardağ and Özdemir).
- If an association is made between the yarn liveliness and the yarn count, yarn count also has a significant effect on the yarn liveliness. According to these results, in the same twist coefficient 30/1 Ne yarn liveliness values were higher than 40/1 Ne samples. As a result, it has been seen if the yarn becomes coarser the liveliness increases. The similar results were seen in the study conducted by Üreyen.
- On the other hand, the effect of spinning system on yarn liveliness is also significant. The liveliness values of the 30/1 Ne samples can be ranked as compact, ring, siro, compact siro and open end rotor, respectively. Similarly, yarn liveliness values of 40/1 Ne samples were found compact, ring, open end rotor, respectevly. All these results were compared to the other studies by Kadoğlu; Çelik. This result is consistent with many other studies.

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Bleaching of Fabrics Produced from Casein Fibers

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ABSTRACT

The pH of milk fibers, which can be obtained even from the protein of sour milk, is compatible with the human body. Besides being ecological, they have biodegradable properties. In this paper the influence of different bleaching conditions with hydrogen peroxide and thioureadioxide (TUDO) on the whiteness of casein fiber fabric was investigated. Bleaching was carried out both conventionally and with microwave energy. Whiteness, bursting strength, hydrophilicity, and chemical oxygen demand (COD) values were determined and compared. The structures of the untreated and treated casein fabrics were investigated with Fourier transform infrared spectroscopy (FTIR) and scanning electron microscopy (SEM). The effect of bleaching on the structure of casein fabric was investigated with scanning electron microscopy (SEM). The loss of strength in milk fiber based fabrics which have been bleached with peroxide in acidic medium is less than the loss in bleaching in basic medium. Microwave energy can produce whiteness levels obtained by conventional method in much shorter periods. Strength losses are also less. The air permeability test results show that the air permeability of casein fiber based fabric samples decreases with increasing processing temperature and processing time. Careful selection of process temperature and duration is important for milk fibers as well as for wool fibers. When working with milk fibers it is recommended to test the dimension peroxide bleaching change according to the process conditions.

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KEYWORDS

casein fabric, milk fiber, peroxide bleaching, thioureadioxide, microwave

1. INTRODUCTION

The raw materials utilized for the preperation of regenerated protein fibers might be milk, soybean, peanut and zein [1]. Fast development of cheaper synthetic fibres with outstanding mechanical characteristics in the early sixties had effect on the commercial manufacture of regenerated protein fibres that was totally discontinued in the middle of the 1960s [2]. Casein fiber is one of the regenareted protein fibers of milk protein origin. Lanital is developed as the first commercial casein fiber [3]. Various casein fiber brands such as Aralac, Caslen (USA), Lactofil, Casolana (Netherlands), Cargan (Belgium), Tiolan, Tiocell (Germany), Silkool (Japan), Fibrolane (Great Britain) have been manufactured in various countries [4-6]. The original Lanital (France) has been improved and produced under various trade names such as Merinova (Italy) and Wipolan (Poland) [7].

Fibrolane (Great Britain) and Merinova (Italy) are formed by dissolving casein in sodium hydroxide and then by extrusion into an acid / salt bath. The fibres formed in this way is stretched as tow and partially stabilised by formaldehyde treatment [1]. The process requires a lot of water [8]. New methods have been found in recent years to produce these fibers in a more environmentally friendly manner and a new process is developed without the use of formaldehyde [8]. A newly developed process for the production of casein fibers without formaldehyde is described in a recent patent [9], but these fibers are not yet available commercially. In the study carried out by Bier et al., casein fibers were produced according to two different approaches, using water and heat or sodium hydroxide. In both ways, relatively flexible fibers and textile coatings were gained [10].

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Casein fibers have a certain similarity to sheep's wool. It is a phospho-protein built up from a number of amino acids [11]. The general properties of regenerated protein fibres include the wool like attributes of resilience, warmth and soft handle. The strength of regenerated protein fibers is lower than of wool fibres. Casein fibers have no cystine linkage, which leads to a more open structure [1].

Milk protein fiber is comfortable and has excellent water transportation and air-permeability [12]. These biodegradable and renewable fibers have also better resistance to attack by microorganisus such as bacteria and fungus. Besides its antimicrobial activity casein fibers is healtier [12]. Their smooth structure makes them feel similar to silk, and the high moisture absorption lets the fibers swell and makes them softer and thus especially attractive for people with skin diseases. Additionally, they can easily be dyed and age only slowly [10]. Casein can also be extracted from "non-food milk", i.e. waste which cannot be used in the food industry. For this reason casein fiber would be a sustainable alternative to other natural fibers. The usage of casein fiber is expected to increase in the near future due to its eco-friendly footprints [13].

In the study carried out by Lei et al. wearabilities, tensile property, appearance property and abrasive resistance of milk protein fiber plain knitted fabric were tested [14]. According to the research casein fiber can be regarded as an ideal fiber fabric used as underwear in spring, autum and winter [14]. In the study carried out by Rathinamoorthy thermal comfort and moisture management characteristics of knitted casein fabric have been evaluated and compared with cotton fabric for the application of undergarment [15].

First concepts of MW use for textile finishing processes emerged in the 1970s when cellulosic fabrics were treated with Durable Press finishing agents and healed in a microwave oven [16]. Textile finishing using microwave heating has been reported by several authors [17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28]. Microwave heating has proven to be more rapid, uniform and efficient than other heating methods [29]. Furthermore it is a clean and environmentally friendly technology.

In the study carried out by El-Kheir et al., microwave irradiation was used to reduce consumption of energy and time during bleaching of wool fabrics with hydrogen peroxide [30].

In this study, bleaching process of fabrics produced from 100% casein fibers was investigated. Hydrogen peroxide and thioureadioxide (TUDO) were used for bleaching. Bleaching was carried out using conventional method and microwave energy. The whiteness / yellowness, strength and hydrophilicity values of the treated samples were determined and the results were compared.

2. MATERIAL AND METHOD

2.1 Material

100 % casein milk fiber yarn (32/1 Ne) single jersey knitted fabric (140 g/m2) is used in this study. 100 % casein milk fiber yarn is obtained from China. The whiteness degree of greige un-treated casein milk fiber fabric was 56.91 Stensby.

2.2 Method

Scouring process, at 40°C for 10 minutes, was applied to greige milk fabrics twice before any bleaching operations in order to remove any possible impurities which could be found on the surface of the fabric. Hydrogen peroxide bleaching operations were applied to casein (milk) fabrics using Ataç Lab Dye HT sample dyeing machine via exhaustion process. In all bleaching processes, 0.5 g/l nonionic wetting agent was added to the bleaching bath (Table 1).

Peroxide bleaching of wool under mild acidic conditions (pH 5–6) can also be carried out using a peracid activator such as Prestogen W (BASF). As wool sustains some damage in the presence of alkali, this method is useful for bleaching delicate fabrics. In the bleaching processes of milk fibers, as in wool fiber, bleaching in acidic medium was carried out microwave energy assisted reductive and hydrogen peroxide bleaching processes were carried out using Arçelik MD 565 model microwave oven (900 watt) via exhaustion process. Casein milk fiber fabrics were bleached with microwave energy assistance for 1, 3 and 5 minutes. Bleaching liquor are prepared at room temperature and poured into closed glass container. After 1minute microwave energy application, bleaching liquor was started to boil and after 5 minutes of application all liquor was evoparated.

Table 1. Hydrogen peroxide used for casein fiber bleaching and their processing detail

Peroxide bleaching under alkaline conditions		**Peroxide bleaching under acidic conditions**	
Hydrogen peroxide (35 %)	10, 15, 30, 45,65 ml/l	Hydrogen peroxide (35 %)	10, 30, 45, 65, 90, 120 ml/l
Temperature (°C)	50, 60, 70, 80, 90ºC	Temperature (°C)	60, 80, 90°C
Time (minutes)	45, 60, 90, 120	Time (minutes)	60
pH	pH 9	pH	pH 5
liquor ratio	1:40	liquor ratio	1:40
nonionic wetting agent	0.5 g/l	nonionic wetting agent	0.5 g/l
stabilizer	1 g/l	Prestogen W	2, 6, 9, 13, 18, 24 g/l

2.3 Analysis and Testing

Following various abovementioned bleaching treatments, the whiteness (Stensby value) and yellowness (E313 YI) of the casein fiber fabrics were determined using a Datacolor 600 spectrophotometer. The hydrophilicity property of bleached and untreated control casein milk fiber fabrics was measured as the time, in seconds, of water absorption of the specimen according to TS 866 standard. Moreover, bursting strength properties of bleached milk knitted fabric was carried out in accordance with ISO 13938-2, using an SDL Atlas M229P bursting tester, under the standard laboratory conditions (20±2 C; 65±2% relative humidity).

Test fabrics were tested for their air permeability on FX 3300 air permeability tester (Textest A.G, Switzerland) according to EN ISO 9237 standard.

The surface morphologies of bleached casein fabrics were examined by using scanning electron microscopy (SEM, Zeiss EVO 40). Before the test, the samples were coated with a thin gold film layer to increase the conductivity.

The infrared analysis was performed using a Infrared Spectrometer (FT-IR) with diamond universal ATR accessory in ATR mode. Waste bleaching floats were measured according to closed reflux method for Chemical Oxygen Demand (COD). The conventional and microwave assisted bleaching of casein milk fiber fabrics was compared according to the test results.

3. RESULTS AND DISCUSSION

3.1 Conventional Bleaching of Casein Fabric

Effect of pH

According to bleaching results to determine optimum pH value, peroxide bleaching at pH 5 and pH 9 gave the highest whiteness values. Bleaching at pH 11 causes the whiteness of the fabric samples produced from milk fiber to decrease and yellowing of the samples (Table 2). As it is known that the liberation of HO^{2-} ion at higher pH (above 10.8) is so quick that it becomes unstable with the formation of oxygen gas which possesses no bleaching character. At higher pH conditions, hydrogen peroxide is not stable and henceforth a stabiliser is often added in the bleaching bath [1].

Effect of temperature

Bleaching process was applied to milk fibers at 50˚C, 60˚C, 70˚C, 80˚C, 90˚C at pH 9 where the highest whiteness degree was obtained. Figure 1 shows the measured whiteness and yellowness values of casein fabrics.

It is observed that the whiteness values of the samples increase slightly with increasing peroxide concentration, time and process temperature (Figure 1). However, these increases are not observed at 90°C. In the bleaching process at 90˚C, whiteness of milk fiber based fabrics remains at low levels even at high hydrogenperoxide concentrations. Process temperature, time and hydrogen peroxide concentration as well as the pH of the liquor; are the most important factors affecting the bleaching degree and fiber damage. Increasing them more then enough not only increases the damage to the fibers but also reduces the degree of whiteness obtained. The decrease in whiteness at 90°C is thought to be due to the high processing temperature. At 5 different pH and 2 different temperatures, milk fiber-based samples were treated with only water for 60 and 120 minutes without adding any chemicals to the liquor and their whiteness degrees were measured (Figure 2).

According to Figure 2, whiteness value decreases as the temperature and processing time of the milk fibers are increased. Temperature and pH value selection is important when working with milk fibers. After pH 9, yellowing is observed in the fibers.

In order to observe the effect of heat treatment, milk fibers were exposed to dry heat for 5 minutes at different temperatures. From 90 ºC, the degree of whiteness starts to decrease and the yellowing increases with increasing temperature (Figure 3).

Table 2. The effect of pH on whiteness and yellowness degree

	60 ⁰C							
	pH 5		pH 7		pH 9		pH 11	
H_2O_2	Whiteness degree (Stensby value)	Yellowness Index (E313 YI)	Whiteness degree (Stensby value)	Yellowness Index (E313 YI)I	Whiteness degree (Stensby value)	Yellowness Index (E313 YI)	Whiteness degree (Stensby value)	Yellowness Index (E313 YI)
15 ml/l	62,05	13,99	60,69	15,34	62,83	13,9	20,70	39,74
30 ml/l	63,30	13,78	61,57	14,91	64,83	12,71	14,02	43,61

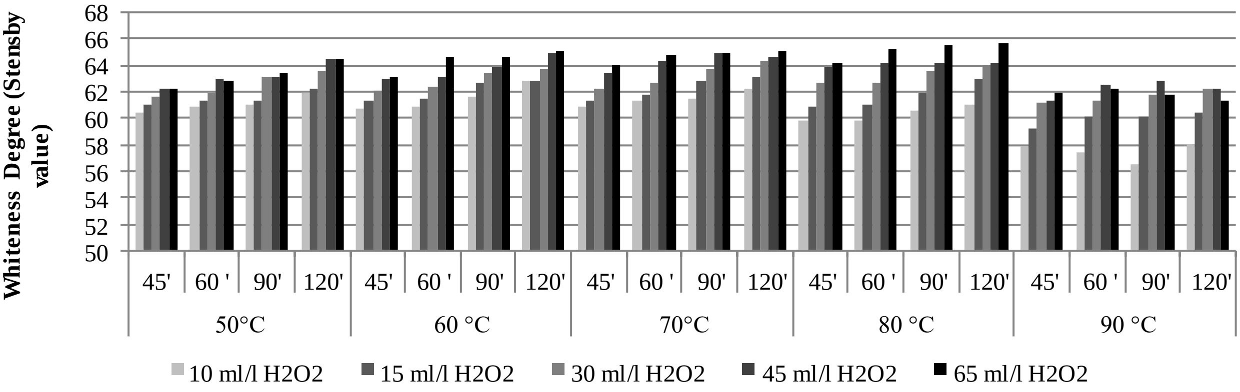


Figure 1. Whiteness and yellowness values of milk fibers after hydrogen peroxide bleaching at 50 ºC, 60 ºC, 70 ºC, 80 ºC, 90ºC

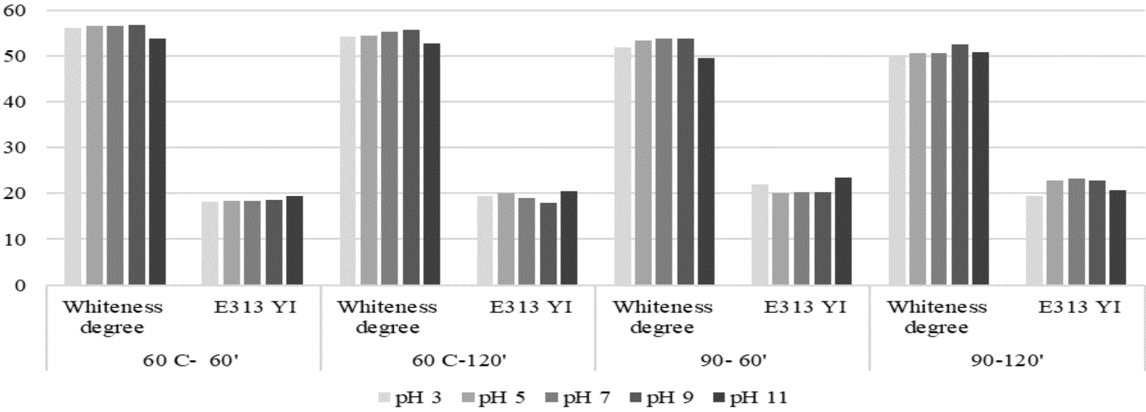


Figure 2. Effect of process temperature on whiteness degree and yellowness index of casein fabric

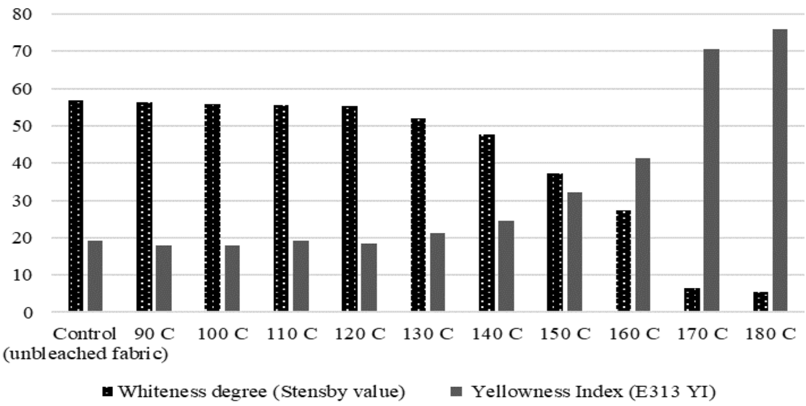


Figure 3. Effect of heat treatment on whiteness degree and yellowness index of casein fabrics

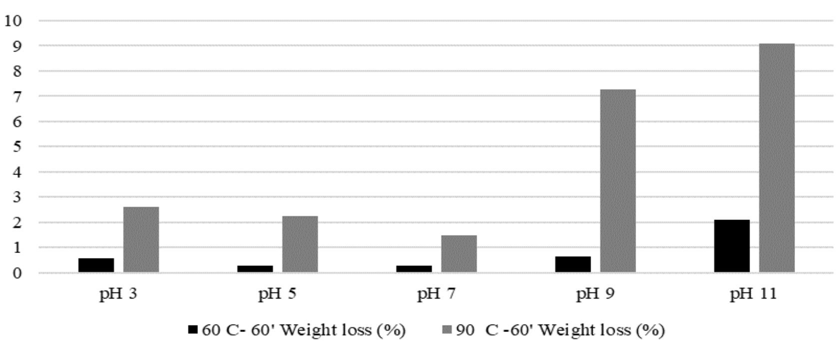


Figure 4. Weight loss of casein fabric at different pH and temperature

At pH 3 and pH 9, weight losses in milk fibers increase. The increase in temperature also supports the increase in weight losses (Figure 4). The weight losses at 90°C at all pH values are considerably higher than at 60°C. Whilst the pH values where milk fibers had the lowest weight loss were pH 5 and 7, slightly higher whiteness values were obtained at pH 9. Therefore, the processing conditions of 120 minutes at 50°C (Stensby value 64,44) and 120 minutes at 60°C (Stensby value 64,89) with 45 ml/l hydrogenperoxide at pH 9 are set as reference for subsequent bleaching processes.

Peroxide bleaching under acidic conditions

During hydrogen peroxide bleaching in acidic medium in presence of Prestogen W, the highest whiteness degree (65.31) could be achieved at a temperature of 60°C and 90 ml/l hydrogenperoxide concentration. Increasing the process temperature does not improve the whiteness degree. The use of peroxide concentrations greater than 90 ml/l also does not provide a significant improvement in whiteness (Table 3).

The highest whiteness degrees and processing conditions obtained by bleaching milk fibers with hydrogen peroxide (H_2O_2) are given together in Figure 5.

Table 3. Whiteness values of mik fibers bleached in acidic medium with hydrogen peroxide (H_2O_2)

H_2O_2 (%35)	60 ^{0}C		80 ^{0}C		90 ^{0}C	
	Whiteness degree (Stensby value)	Yellowness Index (E313 YI)	Whiteness degree (Stensby value)	Yellowness Index (E313 YI)	Whiteness degree (Stensby value)	Yellowness Index (E313 YI)
10 ml/l	60,74	16,78	59,67	16,81	57,82	17,27
30 ml/l	62,06	15,48	62,71	14,19	61,41	14,67
45 ml/l	62,31	15,28	63,03	13,99	62,02	14,4
65 ml/l	63,07	14,72	63,56	13,6	62,75	14,04
90 ml/l	65,31	12,88	64,31	12,58	63,72	13,27
120 ml/l	65,02	11,71	64,54	12,79	64	12,9

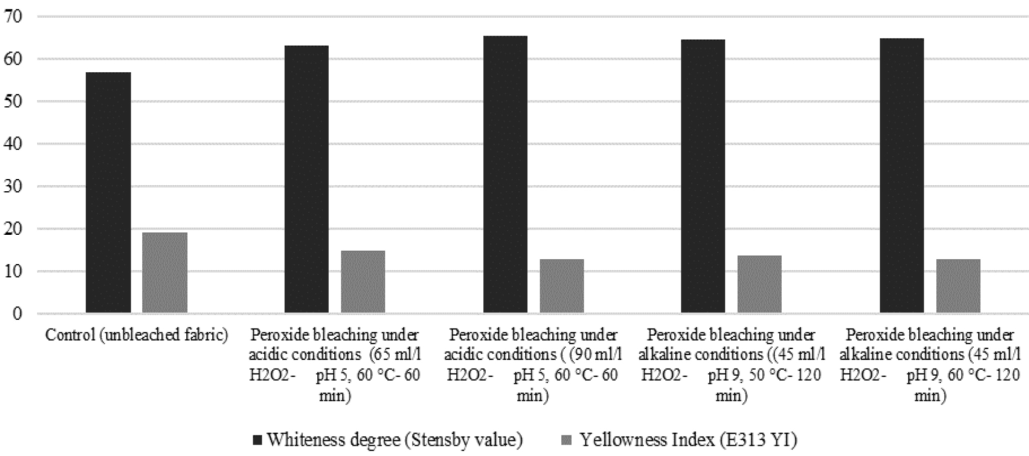


Figure 5. Peroxide bleaching of casein fabric under acidic and alkaline conditions

TUDO bleaching

Highly reductive sulfinate iedons, which are formed through the hydrolysis of tiouredioxide at high temperatures and neutral and alkali baths into sulfinate anions and urea, provide reductive bleaching (Figure 6) [31].

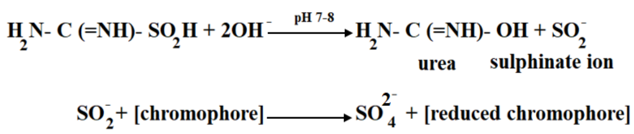


Figure 6. TUDO’s reaction mechanism [1]

TUDO was used in three different pH values as 5, 7 and 10 at recommended temperature 90°C. The whiteness degrees obtained at pH 10 were higher than the whiteness degrees obtained at pH 7. At a TUDO concentration of 10 g/l, the whiteness of the milk fibers increased to 67.22 Stensby in 60 minutes at 90ºC (Figure 7). The rate of degradation of TUDO increases with increasing pH and temperature and decreases with increasing concentration [1]. If the concentration is further increased, the degree of whiteness decreases. 64 Stensby value could be achieved at pH 5 at high concentrations such as 30 g/l. The degrees of whiteness measured at pH 5 and pH 7 are similar (Figure 7).

Samples of knitted fabrics made of milk fiber were treated at TUDO concentrations of 10 g/l and 20 g/l where high whiteness was measured at 90°C for 30 minutes. According to the results of 60 minutes, the whiteness of the samples was lower (Figure 8).

Two-stage bleaching process

Wool is often bleached in two-stage process, one being an oxidative step followed by reductive bleach. Hydrogen peroxide is usually used to perform the oxidiative stage, at pH 8-10, followed by a treatment with reduction agents such as thiourea dioxide, hydrosulphite [32]. Two-step bleaching results for casein fibers were also investigated.

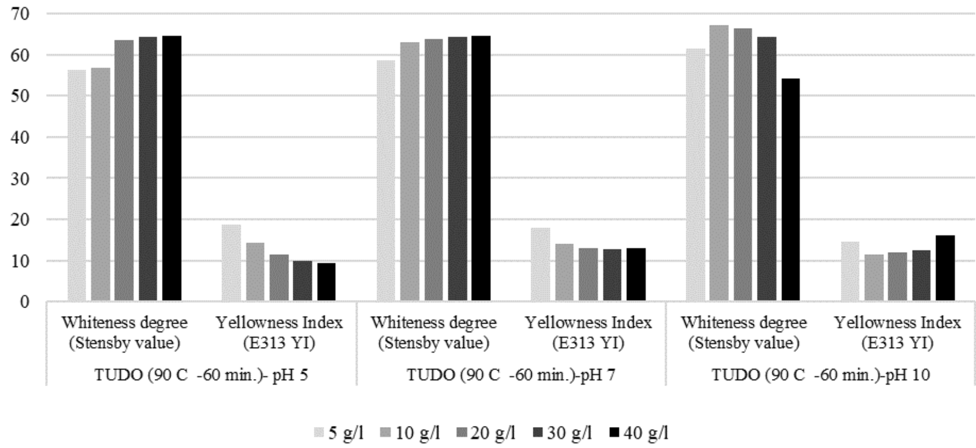


Figure 7. Graph of the whiteness and yellowness values of samples treated with TUDO (thiourea dioxide) at different pH values

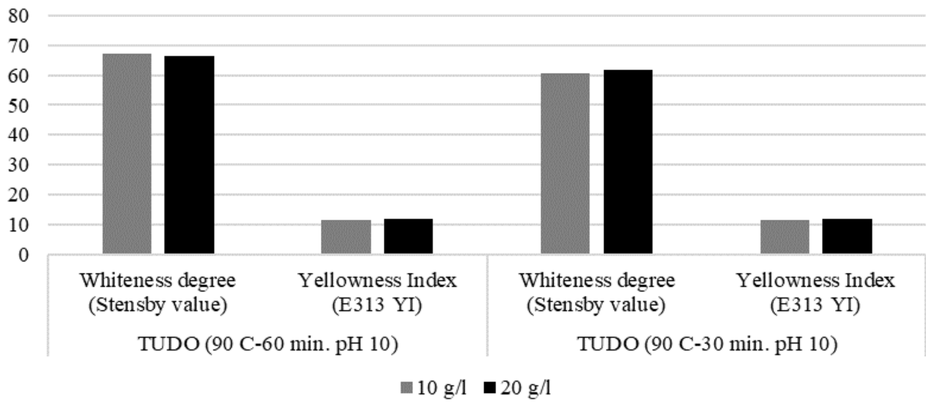


Figure 8. Effect of time on whiteness values of samples treated with TUDO at 90°C

Table 4. One and two stage bleaching process

		Whiteness degree (Stensby value)	Yellowness Index (E313 YI)
	Control (unbleached fabric)	**56,91**	**19,21**
one stage bleaching	Peroxide bleaching under acidic conditions (65 ml/l H2O2- pH 5, 60 °C- 60 min)	63,07	14,72
	Peroxide bleaching under acidic conditions (90 ml/l H2O2- pH 5, 60 °C- 60 min)	65,31	12,88
	Peroxide bleaching under alkaline conditions (45 ml/l H2O2- pH 9, 50 °C- 120 min)	64,44	13,68
	Peroxide bleaching under alkaline conditions (45 ml/l H2O2- pH 9, 60 °C- 120 min)	64,89	12,75
	TUDO bleaching (10 g/l TUDO-pH 10-90 °C- 60 min)	67,22	11,36
two stage bleaching	Peroxide bleaching under acidic conditions (65 ml/l H2O2-pH 5, 60 °C- 60 min) after TUDO	65,22	11,55
	Peroxide bleaching under acidic conditions (90 ml/l H2O2- pH 5, 60 °C- 60 min) after TUDO	67,03	10,85
	Peroxide bleaching under alkaline conditions (45 ml/l H2O2- pH 9, 50 °C- 120 min) after TUDO	66,93	10,85
	Peroxide bleaching under alkaline conditions (45 ml/l H2O2- pH 9, 60 °C- 120 min) after TUDO	67,3	10,27

Although two-step bleaching with TUDO after peroxide bleaching increases the whiteness of casein based fabrics compared to single-step bleaching, 67.22 Stensby whiteness can be achieved in one step with TUDO. Given that the two-step process is both costly and time-consuming and does not provide very high whiteness degrees, two-step bleaching for milk fibers may not be the correct mode of operation (Table 4).

3.2 The Microwave-Assisted Bleaching of Casein Fabric

As a result of the experiments carried out according to the conventional method, 100% milk fiber samples were bleached with the help of microwave energy based on the process conditions giving the highest whiteness values. The whiteness, yellowness and hydrophility values of the samples treated with microwave energy in shorter periods were compared with the results obtained in the conventional method.

The whiteness values of the samples bleached by microwave energy do not reach the whiteness values measured in the conventional method. However, it should be noted that the processing time is 5 minutes (Table 5).

As in the classical method, two-step bleaching has also been applied in bleaching processes carried out by using microwave energy. Reduction bleaching followed by peroxide bleaching in acidic media increases the whiteness degree of the samples (67.21 Stensby). With a bleaching time as short as 10 minutes, an increase of whiteness of up to 10 points can be achieved with respect to the whiteness of the unbleached fabric (56.91). The hydrophilicity of the samples improves with respect to the unbleached fabric.

After the bleaching with hydrogen peroxide (61.81 Stensby) in alkal medium by using microwave energy, the whiteness degree (65.97 Stensby) of the sample which was treated with reductive bleaching increased by 3 points. The hydrophilicity values also improved compared to the unbleached fabric (Table 5).

4. Test and Analysis Results of Casein Fabrics

Evaluation of bursting strength of casein fabrics

In addition to achieving a good degree of whiteness during the pre-treatment processes, it is important not to damage the fibers. The bleaching processes can damage the fibers more or less. For this purpose, the strength values of the samples with the best whiteness degree were also investigated. Fabric samples produced from milk fiber suffer more or less chemical damage after bleaching, and the degree of damage to the fibers may vary depending on the bleaching agent and the method applied.

When the bursting strength values of the bleached samples were compared; the loss of strength in the acidic medium peroxide bleaching process is less than the loss in the basic medium bleaching process. In the basic environment, the damage of milk fiber-based samples is slightly higher, despite their similar whiteness values (Table 6). It was determined that the weight loss of the samples treated with water only in the basic medium was higher than the loss of the samples treated with acidic medium.

Table 5. Microwave-assisted bleaching of casein fiber fabric

		1 min		**3 min**		**5 min**		
		Whiteness degree	**Yellowness Index**	**Whiteness degree**	**Yellowness Index**	**Whiteness degree**	**Yellowness Index**	**Hydrophilicity * (s)**
one stage bleaching	Peroxide bleaching under acidic conditions (90 ml/l H2O2- pH 5)	60,31	15,88	61,73	16,01	**63,47**	14,01	17"
	Peroxide bleaching under alkaline conditions (45 ml/l H2O2- pH 9)	59,55	16,4	61,38	15,99	**61,81**	15,18	36"
	TUDO bleaching (10g/l TUDO- pH 10)	58,82	16,08	60,91	13,98	**62,2**	12,62	32"
two stage bleaching	Peroxide bleaching under acidic conditions (90 ml/l H2O2- pH 5) after TUDO (10g/l TUDO- pH 10)					**67,21**	**10,46**	**21"**
	Peroxide bleaching under alkaline conditions (45 ml/l H2O2- pH 9) after TUDO (10g/l TUDO- pH 10)					**65,97**	**11,22**	**25"**

* Hydrophilicity values of samples treated with microwave for 5 minutes.

Table 6. Bursting strength values of 100% milk fiber fabrics

	Whiteness degree (Stensby value)	Bursting strength (kPa)	Weight loss (%)	Hydrophilicity (s)
Control fabric (unbleached)		**290,2**		**90**
Conventional bleaching				
Peroxide bleaching under acidic conditions (65 ml/l H2O2- pH 5, 60 °C- 60 min)	63,07	269,6	12,73	38
Peroxide bleaching under acidic conditions (90 ml/l H_2O_2- pH 5, 60 °C- 60 min)	65,31	253,9	14,18	26
Peroxide bleaching under alkaline conditions (45 ml/l H_2O_2- pH 9, 50 °C- 120 min)	64,44	231,7	10,93	45
Peroxide bleaching under alkaline conditions (45 ml/l H_2O_2- pH 9, 60 °C- 120 min)	64,89	240	9,1	31
TUDO bleaching (10 g/l TUDO, pH 10-90 °C- 60 min)	67,22	276,5	12,23	17
Bleaching with microwave				
Peroxide bleaching under acidic conditions (90 ml/l H_2O_2- pH 5, 5 min)	63,47	272.3	12,45	17
Peroxide bleaching under alkaline conditions (45 ml/l H_2O_2- pH 9, 5 min)	61,81	259,6	10,35	36
TUDO bleaching (10 g/l TUDO, pH 10, 5 min)	62,20	270,5	8,28	25

Bursting strength values of samples subjected to bleaching by peroxide with the help of microwave energy are slightly higher than those measured in the classical method (Table 6). This is thought to be due to the fact that the processing time is considerably shorter than the conventional method. Reductive bleaching is the opposite; bursting strength values of bleached samples in the presence of microwave energy with reductive bleaching agents are slightly lower than the conventional method. During the reductive bleaching process with microwave energy, the temperature of the liquor can be reached to boiling temperature within 5 minutes of treatment time, on the contrary in the conventional method; the process is carried out at a constant temperature of 90°C. Although the process time in microwave bleaching is short, it is thought that the increase in temperature during the process might have slightly increased the strength losses of the samples. In the strength, loss values of milk fiber based knitted fabrics the increase in the weight of milk fiber based knitted fabrics due to the process temperature is effective. As the processing time and temperature increase, the dimensional stability of the milk fiber based fabrics changes, the fabrics shrink and their weights are increased (Figure 9).

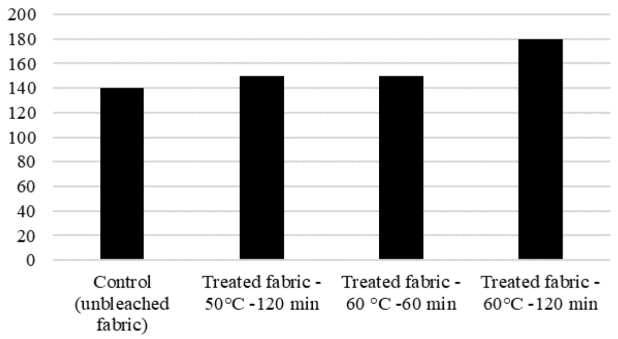


Figure 9. Weight changes of milk fiber based fabrics under different processing conditions

The increase in the thickness of the fabrics also confirms that the fabrics were shrunk (Table 7).

Evaluation of air permeability of casein fabrics

Figure 10 indicates the air permeability results. The air permeability of all bleached casein fabrics decreased compared to the control fabric. In this case, it is confirmed that, depending on the processing conditions, the fabrics are shrunk, compacted and therefore the air permeability of the fabrics is reduced.

Table 7. Thickness test results of milk fiber based knitted fabrics

	Fabric thickness (Leipzig Nr.7880)	(micron)
Control fabric (unbleached)		4
Peroxide bleaching under acidic conditions	(90 ml/l H2O2- pH 5, 60 °C- 60 min)	4,1
Peroxide bleaching under alkaline conditions	(45 ml/l H2O2- pH 9, 60 °C- 120 min)	4,2
TUDO bleaching	(10 g/l TUDO-pH 10-90 °C- 60 min)	4,8

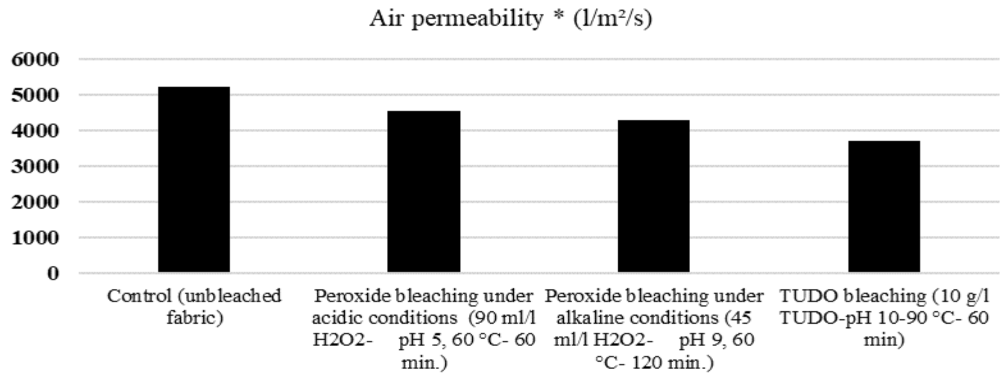


Figure 10. Air permeability test results of milk fiber based knitted fabrics

Evaluation of SEM and FTIR analysis of casein fabrics

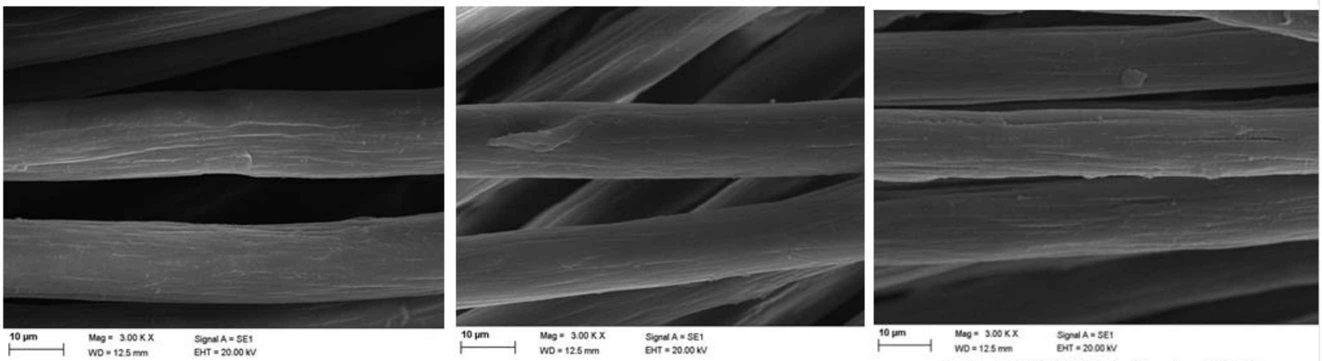
Figure 11 shows SEM images of bleached milk fibers with peroxide and TUDO in acidic and basic media. Strips are observed on the surface of the fibers treated in basic medium.

The absorption peak at 1647 cm^{-1}, represents C=O structure in amide I bond which confirms the presence of protein. Peak at 1530 cm^{-1} represents strong amide II bond which is formed due to N-H bonding of C-N-H group [15].

Amide I (1658 cm^{-1}) and Amide II (1538 cm^{-1}) peaks are characteristic peaks peaks for casein fibers in the FTIR spectrum [2]. FTIR-ATR analysis shows that there is no bulk change in bleached casein fabrics compared to control fabric (Figure 12).

Chemical oxygen demand (COD)

In order to investigate the environmental impacts of the recipes giving the best whiteness degree, the Chemical Oxygen Demand (COD) measurements of wastewaters were measured by using Closed Reflux, Titrimetric Method and the results are given in Table 8 below.



a) 90 ml/l H_2O_2 (60°C - 60 min- pH 5) b) 45 ml/l H_2O_2 (60°C - 120 min- pH 9) c) 10 g/l TUDO (90°C - 60 min- pH 10)

Figure 11. SEM images of bleached milk casein fabric samples. a) Peroxide bleaching under acidic conditions, b) Peroxide bleaching under alkaline conditions c) TUDO bleaching

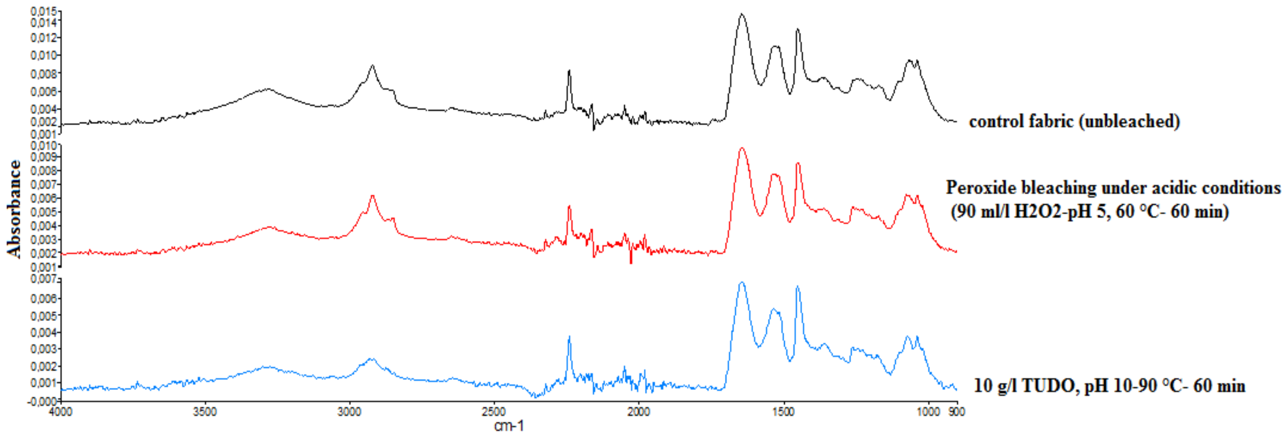


Figure 12. FTIR–ATR Analysis of milk casein fabric samples

Table 8. COD values measured according to Closed Reflux, Titrimetric Method of bleaching liquors of conventional method

	Chemical Oxygen Demand (COD)
Peroxide bleaching under acidic conditions (90 ml/l H_2O_2- pH 5, 60 °C- 60 min.)	12,55 g/l
Peroxide bleaching under alkaline conditions (45 ml/l H_2O_2- pH 9, 60 °C- 120 min)	6,77 g/l
TUDO bleaching (10 g/l TUDO-pH 10-90 °C- 60 min)	1,26 g/l

The environmental problems of the textile industry are based on the amount of wastewater and the chemical load of these wastewaters, energy consumption and waste air emissions. Environmental problems associated with hydrogen peroxide bleaching result from the use of strong complexing agents (stabilizers) [33]. The COD measurements of the wastewaters were measured by using the Closed Reflux Colorimetric Method to examine the environmental impacts of the recipes giving the best whiteness degree. When COD values were examined; It can be said that the most ecological bleaching method is reductive bleaching because it has the lowest COD value. TUDO, which provides the best whiteness degree with the classical method in this study, stands out with its more ecological feature.

4. CONCLUSIONS

Milk fibers, which can be obtained even from the protein of sour milk, provide an comfortable feeling due to the compatibility of the pH value with the human body, have bright colors due to their good dyeing ability and have ecological properties as well as biodegradable properties which makes the fiber an advantageous choice. In this study, whiteness, yellowness, hydrophilicity and strength properties of milk fiber fabrics were investigated before and after different bleaching processes. According to the process conditions whiteness value measured in 120 minutes at a concentration of 45 ml/l H_2O_2 at pH 9 at 50°C in peroxide bleaching made in alkaline medium is 64,44 Stensby, on the other hand whiteness value measured in 120 minutes at a concentration of 45 ml/l H_2O_2 at 60°C is 64,89 Stensby. Since the measured whiteness values are very close to each other, 50 and 60˚C have been determined as the optimum temperatures. On the other hand in the bleaching with H_2O_2 in acidic environment, the best whiteness levels were determined as 65,31 Stensby at 60ºC for 60 minutes at a concentration of 90 ml/l and 63.07 Stensby at 60ºC for 60 minutes at a concentration of 65 ml/l.

The loss of strength in milk fiber based fabrics which have been bleached with peroxide in acidic medium is less than the loss in bleaching in basic medium.

Air permeability test results show that air permeability decreases with increasing process temperature and process time of milk fiber based fabric samples. It should be noted that the size stability of the milk fiber fabrics may vary depending on the processing conditions. It is recommended to carefully select process temperature and duration and test the dimension change in milk fibers as well as wool fibers. Microwave treatment has significant advantages for bleaching of fabrics produced from casein fibers as microwave is a clean, environmentally friendly, efficient heating technology.

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Digital Supplier Selection for a Garment Business Using Interval Type-2 Fuzzy TOPSIS

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ABSTRACT

The aim of this study was to use the interval type-2 fuzzy TOPSIS method to select the best supplier among a number of suppliers digitized by Industry 4.0 for a company operating in the garment industry. The interval type-2 fuzzy TOPSIS method involves an interval of type-2 fuzzy sets and can model uncertainties very well to solve fuzzy multi-criteria decision making problems. Alternatives were listed based on closeness indexes, and the best digital supplier was selected based on sensitivity analysis. This is the first study to use the model in question to select the best digital supplier for a company. We, therefore, believe that it will contribute to the literature. It is recommended that the model in question be used in other industries as well.

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KEYWORDS

Industry 4.0, Digital Supply Chain, Fuzzy TOPSIS, Garment Industry

1. INTRODUCTION

Revolution is a rapid, radical and noteworthy change in a certain area [1]. The Industrial Revolution was one of the most important revolutions in world history. The first phase of the Industrial Revolution was the First Industrial Revolution in the eighteenth century, in which human power was replaced by steam power resulting in a dramatic transformation in production. The second phase was the Second Industrial Revolution in the twentieth century which witnessed the integration of electricity into production, marking the onset of mass production. The third phase was the Third Industrial Revolution in which advanced automation systems were introduced to production in the 1970s. Today, we are on the verge of the fourth phase, which is the Fourth Industrial Revolution, involving smart factories that autonomously run entire production processes [2, 3].

The Industrial Revolution has provided limitless multiplication of goods and services [4]. Thus, enterprises and countries that quickly adapt to new industrial production concepts have achieved significant progress. Benefiting from the First Industrial Revolution very efficiently, western countries, the USA and Japan monopolized production for a long time and achieved high competitiveness while others generally turned into open markets [5, 6, 7]. However, developed countries have lost their competitive advantages to underdeveloped and developing countries in the early 2000s due to aging population and high labor costs etc. [8]. Developed countries such as the US, Germany and the United Kingdom had traditionally outsourced their production to developing countries. They have, however, been adversely affected by the global economic crisis in 2008, and therefore, started to reshore their production back [6, 9]. Germany was the first to execute it. In 2011, German Kagermann argued that the integration of sensors, embedded-connected systems, digitization and information-communication technologies into production promotes smart production, which can provide competitive advantage against low-cost manufacturing in Asia [7, 10, 11, 12]. The

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German National Science and Engineering Academy developed this idea and defined it as Industry 4.0 in 2013 [8]. Industry 4.0 is based on such technologies as smart robots, big data, internet of things (IoT), 3-D printing and cloud etc. [13, 14].

The Internet-based high automation in Industry 4.0 production connects machines, computers, suppliers and customers in real time [15, 16]. Thus, each machine is independently and autonomously involved in production, adapt themselves to new demands, monitor production processes, predict the current situation, analyze data, perform tasks by themselves, and report or solve possible operation and maintenance issues. Smart devices can be placed on production lines to minimize production costs or disruptions, artificial smart technologies can shorten decision-making processes, data can be shared with systems and related parties in real time, and interface can be used to interact with people [7, 9, 15, 16, 17].

In Industry 4.0, while production is fast and modular production principle, zero defective and high quality production is planned with flexible production lines [7, 15]. The expected advantages of Industry 4.0 are as follows: A decrease in production (10-30%), material, logistics (10-30%) and quality management (10-20%) and labor and investment costs; faster production, processing, delivery and launch of new products; more flexible business processes; higher sensitivity to customer demands; customized production; difficulty of imitation; high quality, competitiveness and efficiency (approx. 4.1% annually) [10, 18, 19]. Ovacı [6] maintains that enterprises that invest in Industry 4.0 can see a return on investment within three to five years. Dalenogare et al [10] concludes that Industry 4.0 will change the competition rules of production, the structure of industries and customer relations. Today, Industry 4.0 is used in automotive, telecommunication, health products, household appliances, electronics, machinery and textile/ garment sectors [6, 7].

The garment sector is a branch of industry which statistically analyzes the demand for clothing and meets that demand through mass production [20]. The garment sector emerged in developed European countries and North America which witnessed the Industrial Revolution. Those countries had monopolized the production of ready-to-wear garments for a long time. After the Second World War, Japan and the Far East countries turned to garment exports using cheap labor and transferring technology, which resulted in developed countries outsourcing their garment production to developing Asian countries [21]. They have also inspired developing countries such as Turkey to invest in the sector. This has led to the globalization of the sector, intensification of competition and reduction in profit margins [22]. In that environment, it became imperative for ready-to-wear companies wishing to dominate the market to create powerful and responsive supply chains to provide efficient operations and the best value to customers [23]. Although it is assumed that the mechanical mass production and labor-intensive structure of today's garment industry will prevent it from quickly adopting new technologies [24], ready-to-wear companies have already started to integrate such smart systems that provide decision and support such as Expert Systems (ES), Genetic Algorithms (GA), Artificial Neural Networks (ANN), Knowledge-Based Systems (KBS), Decision Support Systems (DSS), Fuzzy Logic Systems, Hybrid Systems into their supply chains to achieve competitive advantage [25]. They have also started to use artificial intelligence (AI), Internet of Things (IoT), 3D printing, wearable and soft engineering, intelligent logistics, nanotechnology, advanced materials, biotechnology, BPM (business process management), virtual reality (VR), augmented reality (AR), cyber-physical systems (CPS), cyber security, big data (BD), autonomous robots, cloud computing and simulation technologies, which constitute the basis of the Industrial Revolution 4.0, of which we are on the verge [26, 27, 28]. Those new technologies have digitized supply chains and increased the need for collaborating with digital suppliers.

With the development of information communication technologies, digitalization has spread to every field. In the future, digitalization is expected to become more widespread. Under these circumstances, it can be said that the adaptation time of the enterprises will determine their future success. This can be achieved through the digitization of the suppliers that directly affect the performance of the enterprises. In the apparel industry where information technologies are not used much, the importance of digitalization has been realized and digitalization has started. Accordingly, digital supplier selection is a new topic in the clothing sector as in many other sectors and there is not enough academic studies in this field.

The aim of this study was, therefore, to select a supplier that used Industry 4.0 technologies most effectively for a company operating in the garment industry. An Interval type-2 fuzzy TOPSIS (IT2F-TOPSIS) method, which is a multi-criteria decision making method modeling uncertainties accurately, was used.

Different from the T2F AHP method, the IT2F-TOPSIS method does not require pairwise comparison matrices, which makes calculations easier. Moreover, the IT2F-TOPSIS method yields more accurate results because it does not have a hierarchical structure.

The rest of the study is organized as follows; the second section of the study explained the digital supply chain. The third section briefly addressed the IT2F-TOPSIS method and presented the algorithm steps. The fourth section evaluated the alternative suppliers. The last section presented the findings of the research and made evaluations.

Digital Supply Chain

A supply chain (SC) consists of suppliers, manufacturers, distributors and external resources and all processes involved in the production of software and components [29, 30]. It is a global system of complex interconnected networks that are widely distributed geographically [29]. Supply chain used to be a purely operational logistic function that once gave information to sales or production and focused on production lines and delivering products. Today, it has become an independent supply chain management (SCM) function managed by a separate unit in some companies [31]. SCM means having the right customers at the right place and time [30]. SCM operations involve systems that manage the flow of information, materials and services from suppliers to end consumers, and are important for business operations. They, therefore, have a significant impact on costs and profits [32]. However, intense competition in global markets reduces companies' capacity to use their supply chains to achieve workflow. SC managers are desirable for cheaper, better and faster product. However, traditional supply chains can be more costly, complex and vulnerable [30]. To overcome these challenges, there has been a paradigm shift towards what is today known as Industry 4.0, which has led to the automation and digitalization of supply chain functions including supply, production and distribution [30, 31, 32]. The digitization has significantly altered SCM behavior and led to the introduction of the concept of digital supply chain (DSC) [33].

DSC encourages companies to rethink their supply chain design to meet customer needs and expectations for the improvement of procurement and service quality [34]. It differs from traditional supply chains as the latter focus mainly on minimizing manufacturing, transport and logistics costs. DSC is a customer-centric platform model that uses and maximizes real-time data flowing from different sources and helps businesses collaborate by integrating the entire supply network [35, 36, 37].

DSC has an outstanding performance that makes customers very satisfied because it makes demand stimulation, simulation, matching, detection and management possible for the maximization of performance and minimization of risks and ensures timely delivery of products and quick and easy return at the end of their life cycle [35, 38, 39]. DSC and high digitized operations can increase annual productivity and revenues by 4.1% and 2.9%, respectively [40].

DSC operations consist of such technologies as autonomous robots, AR, additive manufacturing (AM), AI, high-tech sensors, cloud computing, IoT, autonomous vehicle, mobility and Big Data Analytics (BDA) as shown in Figure 1. [40, 41].

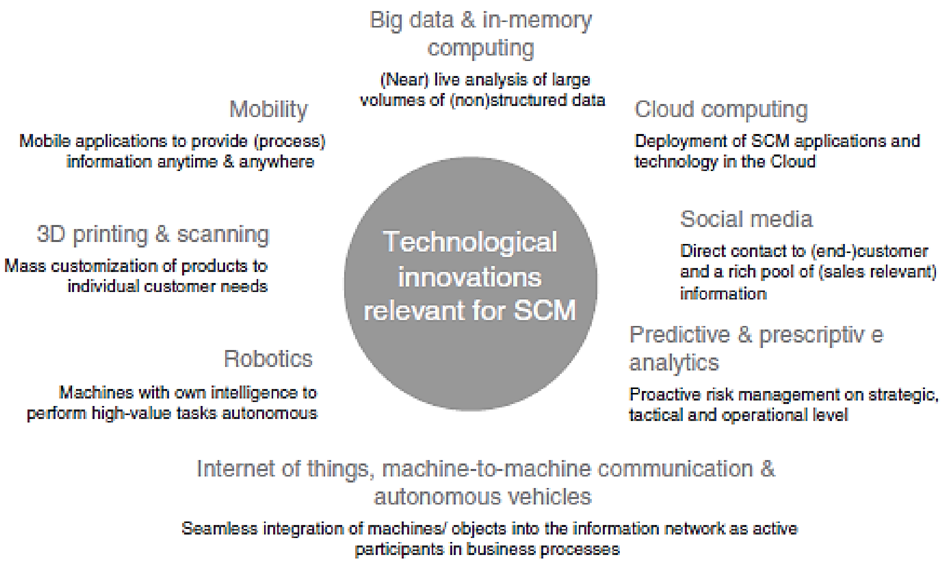

Figure 1. Innovations in supply chain management [37]

AM describes the use of 3D technologies in different stages of SC to achieve production flexibility, fast delivery, individualized product and less inventory [41]. It is a decentralized manufacturing technique that transforms the distribution network. It reduces the complexity and load of a product or supply chain, provides flexibility for the production of a variety of products and renders the supply chain more efficient. 3D printers help reduce the amount of stock throughout the supply chain and also simplify some manufacturing processes of technology (For example, a module can be printed using a single 3D operation instead of several components that require different supply chains) [42].

Driverless transportation systems (DTSs) minimize human errors, and thus, provide greater operational reliability and enhance storage and logistics efficiency and lower costs. DTSs can be used for decades and integrated with smart technologies that provide precise positioning, guidance, route optimization, machine diagnostics or real-time monitoring. These technologies can also support such warehouse operations as safer loading of goods, more efficient inventory management or faster collection cycles, and therefore, have a positive effect on SCM operations as well. These technologies also help operators with product delivery, storage and dispatch, reduce the number of accidents, enhance transportation visibility and help truck drivers [41].

Information technologies (ITs) play a critical role in the effective management of supply chains. They provide communication and data transfer and improve supply chain performance, and thus, integrate suppliers, processes and customers. One of the most significant developments in information technologies is IoT. The term IoT was coined in 1999 by Kevin Ashton. IoT is defined as the network of a series of physical and virtual objects connected through a network that enables communication, detection, interaction and data collection and exchange [30]. An increase in the number of IoT devices results in an increase in the number of participants and actors in supply chains. The peak of IoT is an output of supply chain systems characterized by low energy consumption and cost and sometimes long term and different levels of physical accessibility [29]. It helps to maximize the effectiveness of operations across supply chain partners [32], resulting in high transparency (supply chain visibility) and integrity control in supply chains (right products at the right time, place, quantity and cost) [43]. It also helps monitor the logistics operations where asset tracking or transit components are complex [32]

Today, a huge amount of data is being collected in various domains including technology-oriented data sources such as enterprise resource planning (ERP) systems, distributed manufacturing environments, orders and shipment logistics, social media, customer buying behavior, product life cycle operations, global positioning systems (GPS), radio frequency identification (RFID) technology, monitoring, mobile devices and surveillance cameras. Enterprises are, therefore, interested in large data sets characterized by 4V (volume, variety, velocity, and veracity). The bigger the data, the harder it is to manage and analyze it. Recent studies on BDA have developed tools and techniques to help make data-driven supply chain decisions [44]. BDA operations in SCM are used in procurement processes, dynamic vehicle routing, logistics, inventory management, order collection and storage [41].

Cloud computing (a.k.a. cloud) refers to the use of a remote server network to access shared resources such as data servers, storage, applications, and other services. Cloud computing allows supply chain users to store and process their data in a private cloud or on a third-party server, which makes the data easily accessible from almost anywhere. It also enables companies and individuals to minimize infrastructure and maintenance costs in information technology [45]. Digitization is also used to support routine resource acquisition activities such as procurement and assessment. Digital indirect procurement processes (maintenance or repair services, travel booking, office furniture or supplies) reduce uncoordinated procurement transactions [41].

Today, delivery of products can last for weeks or even months. To know where products are at any given time, they should be visible and transparent within supply chains, and therefore, they should be geographically positioned. RFID tags and GPS are used to track physical objects and send that information to a central data center. Those systems, which are fixed on products themselves or on transport units (e.g. containers), collect a large amount of data on weather, traffic, or telemetry of transportation vehicles [37].

Robots can be used in manufacturing, logistics, retail operations etc. Smart robots in retail or warehouse are used for cycle counting (also in supermarkets) or logistic and collection operations. Flying robots can be used to transport goods and packages to hard-to-reach areas. For example, Amazon conducted its first drone delivery test in the U.K. [41]. Many companies from different sectors are also investing in digitizing business operations and supply chains. For example, DHL, a large logistics service provider, follows trends that will affect the logistics industry in the future. DB Schenker, another logistics service provider, is investing in a digital mobility laboratory. Such airlines as THY, Lufthansa and Emirates with strong cargo operations are expanding paperless e-freight offers with data cleaning for customers. Monsanto, an agricultural company, is investing in sensor technology to digitize its agricultural operations. Amazon and Alibaba, global retailers, are investing in drones and robotics for product transportation and delivery [46].

Type-2 fuzzy sets

Decision-making processes involve uncertainties, which are generally due to excessive number of decision making criteria, system behavior, and most importantly, decision-makers' preferences. Decision-makers make subjective and linguistic judgments, which do not yield accurate results. Uncertain set theory has been integrated in decision-making methods to deal with uncertain linguistic judgments. Although most of the methods use type-1 fuzzy sets (T1FSs) to model decision-makers' uncertain linguistic judgments, those sets are not suitable for modeling words [47] because words mean different things for different people.

Type-2 fuzzy sets (T2FSs) are used to overcome this problem because they treat uncertain linguistic judgments appropriately and have fuzzy membership functions, in which the degree of membership of each element belongs to a set. Thus, the modeling of an uncertainty is not limited to linguistic variables in T2FSs but also takes part in the definition of membership functions [48, 49]. The concept of T2FSs was first presented as an expanded and extended version of classical T1FSs [49]. T2FSs is used especially when a full membership function cannot be defined for a fuzzy set. Those sets are, therefore, very effective in overcoming uncertainties [47].

The membership functions of T1FSs are two-dimensional whereas those of T2FSs are three-dimensional. The new third dimension of T2FSs provides additional degrees of freedom and allows uncertainties to be modeled. Therefore, if T1FSs are considered to be a first degree approach to uncertainties in the real world, then type-2 fuzzy sets can be regarded as a quadratic approach to uncertainty. T2FSs are capable of performing well in the presence of noisy inputs and in case of uncertainty on linguistic data, the meanings of which may vary from expert to expert.

The membership functions of T1FSs are net sets. Therefore, when the meanings of criteria are ambiguous, evaluators have different views, resulting in a noisy evaluation environment. T1FSs, therefore, fail to provide effective decision support. In such cases, the problem can be modeled using T2FSs with membership functions of T1FSs [49]. As is known, linguistic information, usually from expert knowledge, does not provide information on the form of membership functions. In such cases, the effect of linguistic or numerical uncertainties can be mitigated by T2FSs as opposed to T1FSs. T2FSs involve more uncertainties and yield more accurate and robust results than T1FSs. Interval T2FSs are easier to calculate, and therefore, used by most applications. Interval T2FSs are used in real-world multi-criteria decision-making (MCDM) problems [50].

Interval type 2 fuzzy TOPSIS methodology

The fuzzy TOPSIS method developed by Hwang and Yoon (1981) is also widely used in MCDM problems. The fuzzy TOPSIS method is based on the concept that the chosen alternative should have the shortest distance from the positive-ideal solution and the longest distance from the negative-ideal solution. There are many studies using this method to solve MCDM problems. However, the fuzzy TOPSIS method is not always appropriate to represent uncertainties because it is based on T1FSs [51, 52].

Chen and Lee [53] expanded the classical TOPSIS method and developed the interval type-2 fuzzy TOPSIS method involving T2FSs to solve fuzzy multi-criteria decision-making problems. The IT2F-TOPSIS method uses T2FSs to solve fuzzy multi-criteria decision-making problems, and therefore, provides more rationality and flexibility to calculate the weights and values of criteria [54]. Some of the studies using the IT2F-TOPSIS method are as follows:

WASPAS and type-2 fuzzy TOPSIS method were used to select a car sharing station [49]. Interval type-2 AHP and TOPSIS methods were used to select an appropriate ship loader type in maritime transport [50]. IT2F-TOPSIS method was used to select a material [55], a new route from five different destinations for one airline [48] a green supplier [56], a supplier [51] and RFID for warehouses [52] and to assess supplier performance for an airline [57] and investment projects for development agencies [58].

The steps of the IT2F-TOPSIS method are as follows. Lee and Chen [54] presented the concept of ranking values of trapezoidal interval T2FSs. Let be an interval type-2 fuzzy set (Figure 2),

where

$$\tilde{\tilde{A}}_i = \left(\tilde{A}_i^U . \tilde{A}_i^{L,}\right) = ((a_{i1}^U, a_{i2}^U, a_{i3}^U, a_{i4}^U; H_1(\tilde{A}_i^U), H_2(\tilde{A}_i^L))).$$

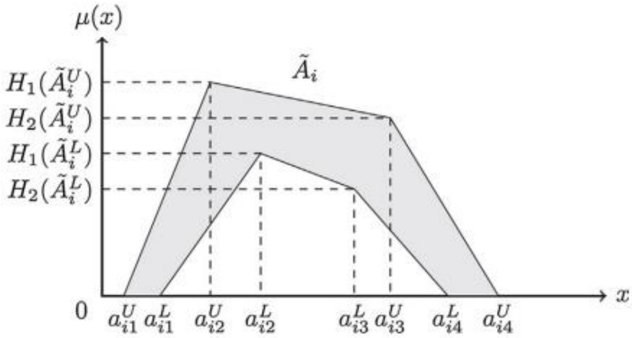

Figure 2. A trapezoidal IT2FSs [53]

The ranking value   of the trapezoidal interval type-2 fuzzy set   is defined as follows [54]:

$$\begin{aligned} Rank(\tilde{\tilde{A}}_i) = {} & M_1\left(\tilde{A}_i^U\right) + M_1\left(\tilde{A}_i^L\right) + M_2\left(\tilde{A}_i^U\right) + M_2\left(\tilde{A}_i^L\right) + M_3\left(\tilde{A}_i^U\right) + M_3\left(\tilde{A}_i^L\right) \\ & -\frac{1}{4}\left(S_1\left(\tilde{A}_i^U\right) + S_1\left(\tilde{A}_i^L\right) + S_2\left(\tilde{A}_i^U\right) + S_2\left(\tilde{A}_i^L\right) + S_3\left(\tilde{A}_i^U\right) + S_3\left(\tilde{A}_i^L\right) + S_4\left(\tilde{A}_i^U\right) + S_4\left(\tilde{A}_i^L\right)\right) + \\ & H_1\left(\tilde{A}_i^U\right) + H_1\left(\tilde{A}_i^L\right) + H_2\left(\tilde{A}_i^U\right) + H_2\left(\tilde{A}_i^L\right) \end{aligned} \quad (1)$$

Where $M_p(\tilde{A}_i^j)$ denotes the average of the elements a_{ip}^j and $a_{i(p+1)}^j$, $M_p(\tilde{A}_i^j) = (a_{ip}^j + a_{i(p+1)}^j)/2,\ 1 \le p \le 3,\ S_q(\tilde{A}_i^j)$ denotes the standard deviation of the elements a_{iq}^j and

$a^j_{i(q+1)}$, $S_q(\tilde{A}^j_i)=\sqrt{\frac{1}{2}\sum_q^{q+1}\left(a^j_{ik}-\frac{1}{2}\sum_{k=q}^{q+1}a^j_{ik}\right)^2}$, $1\le q\le 3$, $S_4(\tilde{A}^j_i)$ denotes the standard deviation of the elements $a^j_{i1}, a^j_{i2}, a^j_{i3}, a^j_{i4}$, $S_4(\tilde{A}^j_i)=\sqrt{\frac{1}{4}\sum_{k=1}^{4}\left(a^j_{ik}-\frac{1}{4}\sum_{k=1}^{4}a^j_{ik}\right)^2}$,

$H_p(\tilde{A}^j_i)$ denotes the membership value of the element $a^j_{i(p+1)}$ in the trapezoidal membership function $\tilde{A}^j_i$, $1\le p\le 2$, $j\in\{U,L\}$, and $1\le i\le n$.

In Eq. (1), the summation of $M_1(\tilde{A}^U_i), M_1(\tilde{A}^L_i), M_2(\tilde{A}^U_i), M_2(\tilde{A}^L_i), M_3(\tilde{A}^U_i), M_3(\tilde{A}^L_i), H_1(\tilde{A}^U_i), H_1(\tilde{A}^L_i), H_2(\tilde{A}^U_i)\, and\, H_2(\tilde{A}^L_i)$ are referred to as the basic ranking score, where we deduct the average of $S_1(\tilde{A}^U_i), S_1(\tilde{A}^L_i), S_2(\tilde{A}^U_i), S_2(\tilde{A}^L_i), S_3(\tilde{A}^U_i), S_3(\tilde{A}^L_i), S_4(\tilde{A}^U_i)\, and\, S_4(\tilde{A}^L_i)$ from the basic ranking score to give the dispersive interval type-2 fuzzy set a penalty, where $1\le i\le n$.

Assume that there is a set X of alternatives, where $X=\{x_1,x_2,\ldots,x_n\}$, and that there is a set F of attributes, where $F=\{f_1,f_2,\ldots,f_m\}$. Assume that there are k decision-makers $D_1, D_2,\ldots,$ and D_k. The set F of attributes can be divided into two sets F_1 and F_2, where F_1 denotes the set of benefit attributes while F_2 denotes the set of cost attributes, $F_1\cap F_2=\phi$, and $F_1\cup F_2=F$. The proposed method is now presented as follows:

Step 1: Construct the decision matrix Y_p of the *pth* decision-maker and construct the average decision matrix $\overline{Y}$, respectively, as follows:

$$Y_p=(\tilde{f}^p_{ij})_{mxn}=\begin{matrix} & x_1 & x_2 & \cdots & x_n \\ \begin{matrix} f_1\\ f_2\\ \vdots\\ f_m\end{matrix} & \multicolumn{4}{c}{\begin{bmatrix} \tilde{\tilde{f}}^p_{11} & \tilde{\tilde{f}}^p_{12} & \cdots & \tilde{\tilde{f}}^p_{13}\\ \tilde{\tilde{f}}^p_{21} & \tilde{\tilde{f}}^p_{22} & \cdots & \tilde{\tilde{f}}^p_{23}\\ \vdots & \vdots & \vdots & \vdots\\ \tilde{\tilde{f}}^p_{31} & \tilde{\tilde{f}}^p_{m1} & \cdots & \tilde{\tilde{f}}^p_{mn}\end{bmatrix}}\end{matrix} \tag{2}$$

$$\overline{Y}=\left(\tilde{\tilde{f}}_{ij}\right)_{mxn}, \tag{3}$$

where, $(\tilde{\tilde{f}}_{ij})=\left(\frac{\tilde{\tilde{f}}^1_{ij}\oplus\tilde{\tilde{f}}^2_{ij}\oplus....\oplus\tilde{\tilde{f}}^k_{ij}}{k}\right)$, $\tilde{\tilde{f}}_{ij}$ is an interval type-2 fuzzy set, $1\le i\le m, 1\le j\le n, 1\le p\le k,$ and k denotes the number of decision-makers.

Step 2: Construct the weighing matrix W_p of the attributes of the pth decision-maker and construct the average weighing matrix $\overline{W}$, respectively, as follows:

$$W_p=(\tilde{\tilde{w}}^p_i)_{1xm}=\begin{bmatrix}\tilde{\tilde{w}}^p_1 & \tilde{\tilde{w}}^p_2 & \cdots\tilde{\tilde{w}}^p_m\end{bmatrix}, \tag{4}$$

$$\overline{W}=(\tilde{\tilde{w}}_i)_{1xm}, \tag{5}$$

where $\tilde{\tilde{w}}_i=\left(\frac{\tilde{\tilde{w}}^1_i\oplus\tilde{\tilde{w}}^2_i\oplus....\oplus\tilde{\tilde{w}}^k_i}{k}\right)$, $\tilde{\tilde{w}}_i$ is an interval type-2 fuzzy set, $1\le i\le m, 1\le p\le k,$ and k denotes the number of decision-makers.

Step 3: Construct the weighted decision matrix $\overline{Y}_w$,

$$\overline{Y}_w=(\tilde{\tilde{v}}_{ij})_{mxn}=\begin{matrix} & x_1 & x_2 & \cdots & x_n \\ \begin{matrix} f_1\\ f_2\\ \vdots\\ f_m\end{matrix} & \multicolumn{4}{c}{\begin{bmatrix} \tilde{\tilde{v}}_{11} & \tilde{\tilde{v}}_{12} & \cdots & \tilde{\tilde{v}}_{13}\\ \tilde{\tilde{v}}_{21} & \tilde{\tilde{v}}_{22} & \cdots & \tilde{\tilde{v}}_{23}\\ \vdots & \vdots & \vdots & \vdots\\ \tilde{\tilde{v}}_{m1} & \tilde{\tilde{v}}_{m2} & \cdots & \tilde{\tilde{v}}_{mn}\end{bmatrix}}\end{matrix}, \tag{6}$$

where $\tilde{\tilde{v}}_{ij}=\tilde{\tilde{w}}_i\otimes\tilde{\tilde{f}}_{ij}$, $1\le i\le m$, and $1\le j\le n$.

Step 4: Based on equation (1), calculate the ranking value $Rank(\tilde{\tilde{v}}_{ij})$ of the interval type-2 fuzzy set $\tilde{\tilde{v}}_{ij}$, where $1\le j\le n$. Construct the ranking weighted decision matrix $\overline{Y}^*_w$,

$$\overline{Y}^*_w=\left(Rank(\tilde{\tilde{v}}_{11})\right)_{mxn}, \tag{7}$$

where $1\le i\le m$, and $1\le j\le n$.

Step 5: Determine the positive ideal solution $x^+ = (v_1^+, v_2^+, \ldots\ldots v_m^+)$ and the negative-ideal solution $x^- = (v_1^-, v_2^-, \ldots\ldots v_m^-)$, where

$$v_i^+ = \begin{cases} \max_{1 \le j \le n}\{rank(\tilde{\tilde{v}}_{ij})\}, & if \ f_i \in F_1 \\ \min_{1 \le j \le n}\{rank(\tilde{\tilde{v}}_{ij})\}, & if \ f_i \in F_2 \end{cases} \tag{8}$$

and

$$v_i^- = \begin{cases} \min_{1 \le j \le n}\{rank(\tilde{\tilde{v}}_{ij})\}, & if \ f_i \in F_1 \\ \max_{1 \le j \le n}\{rank(\tilde{\tilde{v}}_{ij})\}, & if \ f_i \in F_2 \end{cases} \tag{9}$$

where F_1 denotes the set of benefit attributes, F_2 denotes the set of cost attributes, and $1 \le i \le m$

Step 6: Calculate the distance $d^+(x_j)$ between each alternative x_j and the positive ideal solution (PIS) x^+ as follows:

$$d^+(x_j) = \sqrt{\sum_{i=1}^{m}(Rank(\tilde{\tilde{v}}_{ij}) - v_i^+)^2} \tag{10}$$

where $1 \le j \le n$. Calculate the distance $d^-(x_j)$ between each alternative x_j and the negative-ideal solution (NIS) x^-, as follows:

$$d^-(x_j) = \sqrt{\sum_{i=1}^{m}(Rank(\tilde{\tilde{v}}_{ij}) - v_i^+)^2} \tag{11}$$

where $1 \le j \le n$.

Step 7: Calculate the relative degree of closeness $C(x_j)$ of x_j with respect to the positive ideal solution x^+, as follows:

$$C(x_j) = \frac{d^-(x_j)}{d^-(x_j) + d^+(x_j)}, \tag{12}$$

where $1 \le j \le n$.

Step 8: Rank the values of $C(x_j)$ in a descending sequence, where $1 \le j \le n$. The larger the value of $C(x_j)$, the higher the preference of the alternative x_j, where $1 \le j \le n$.

2. MATERIAL AND METHOD

2.1 Material and Method

The aim of this study was to select the best supplier among a number of suppliers for a company that has been operating in the Turkish garment industry and selling women's, men's, children's and baby clothes under its own brand in over 1000 stores in over 40 countries for 30 years. The company makes very little of the products that it sells. But instead, they are manufactured by domestic and foreign apparel manufacturers. The company has a very large supply network that maintains its production structure and wants to select the best supplier (digital supplier) using Industry 4.0 technologies to overcome the problems of communication and supply chain management. To this end, IT2F-TOPSIS method, which is a multi-criteria decision making method, was used. The literature review in Section 2 (Digital Supply Chain) was used to determine the criteria for digital supplier selection. The company experts (IT specialist, supply chain manager, quality manager, sales-marketing manager) were also consulted for their opinions. Alternative digital suppliers were determined by the company, and a hierarchical selection model was developed given in Figure 3.

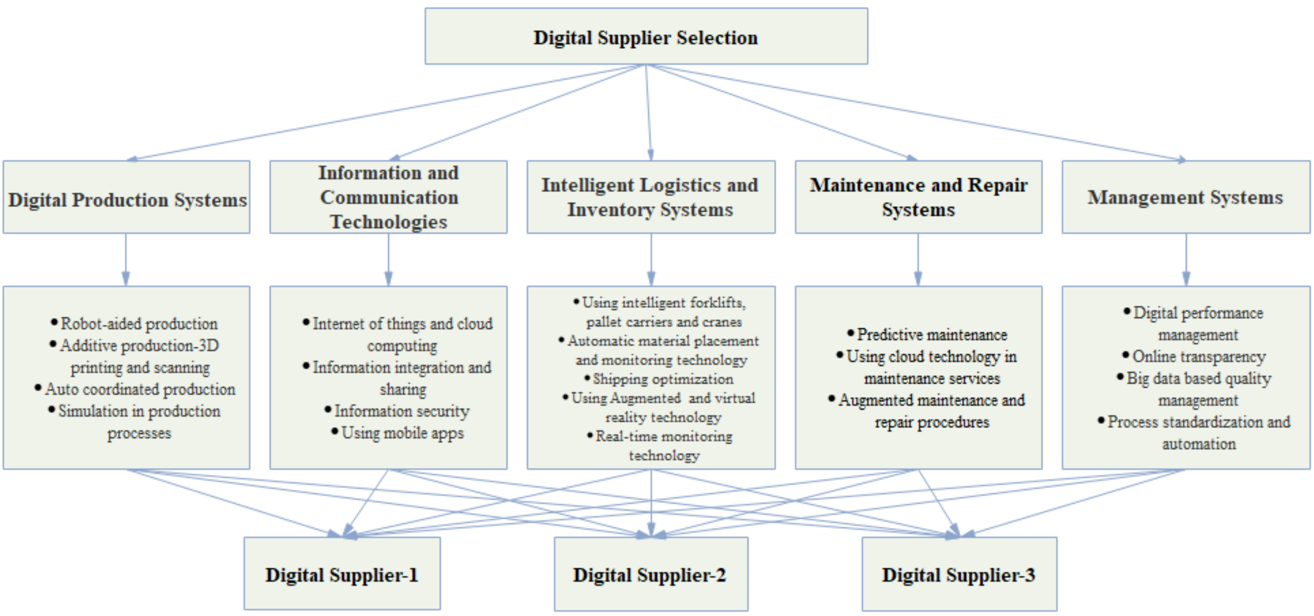

Figure 3. Hierarchical model for the selection of the best digital supplier

In order to evaluate the suppliers and the criteria, a team of 5 persons working in the purchasing, quality and production departments of the company was organized. They are university graduates and have been working in the company for at least 5 years. In addition to their expertise, the team also has extensive knowledge in digital technologies. A team of five people consisting of the company's own experts and experts in digital technologies were formed. Based on the team's feedback, the selection criteria and alternatives were evaluated according to the above-described steps of the IT2F-TOPSIS method.

Step 1: The criteria used in the selection of DS were assessed using the linguistic terms in Table 1 based on the team's feedback, and the resulting weight matrix is given in Table 2.

Table 1. Linguistic terms and interval T2FSs

Linguistic terms	Interval T2FSs
Very Low (VL)	((0, 0, 0, 0.1; 1, 1), (0, 0, 0, 0.05; 0.9, 0.9))
Low (L)	((0, 0.1, 0.1, 0.3; 1, 1), (0.05, 0.1, 0.1, 0.2; 0.9, 0.9))
Medium Low (ML)	((0.1, 0.3, 0.3, 0.5; 1, 1), (0.2, 0.3, 0.3, 0.4; 0.9, 0.9))
Medium (M)	((0.3, 0.5, 0.5, 0.7; 1, 1), (0.4, 0.5, 0.5, 0.6; 0.9, 0.9))
Medium High (MH)	((0.5, 0.7, 0.7, 0.9; 1, 1), (0.6, 0.7, 0.7, 0.8; 0.9, 0.9))
High (H)	((0.7, 0.9, 0.9, 1; 1, 1), (0.8, 0.9, 0.9, 0.95; 0.9, 0.9))
Very High (VH)	((0.9, 1, 1, 1; 1, 1), (0.95, 1, 1, 1; 0.9, 0.9))

Table 2. Linguistic assessment of digital supplier selection criteria and weight matrix

Criteria	Linguistic terms	IT2FSs
Digital Production Systems (DPS)		((0.68,0.78,0.78,0.9,1,1) (0.69,0.78,0.78,0.84,0.9,0.9))
Robot- aided production (RAP)	H	((0.7, 0.9, 0.9, 1; 1, 1), (0.8, 0.9, 0.9, 0.95; 0.9, 0.9))
Additive production-3D printing and scanning (AP)	M	((0.3, 0.5, 0.5, 0.7; 1, 1), (0.4, 0.5, 0.5, 0.6; 0.9, 0.9))
Auto coordinated production (ACP)	VH	((0.9, 1, 1, 1; 1, 1), (0.95, 1, 1, 1; 0.9, 0.9))
Simulation in production processes (SPP)	MH	((0.5, 0.7, 0.7, 0.9; 1, 1), (0.6, 0.7, 0.7, 0.8; 0.9, 0.9))
Information and Communication Technologies (ICT)		((0.8,0.95,0.95,1,1,1) (0.88,0.95,0.95,0.98,0.9,0.9))
Internet of things and cloud computing (ICC)	H	((0.7, 0.9, 0.9, 1; 1, 1), (0.8, 0.9, 0.9, 0.95; 0.9, 0.9))
Information integration and sharing (IIS)	VH	((0.9, 1, 1, 1; 1, 1), (0.95, 1, 1, 1; 0.9, 0.9))
Information security (IS)	VH	((0.9, 1, 1, 1; 1, 1), (0.95, 1, 1, 1; 0.9, 0.9))
Using mobile apps (UMA)	H	((0.7, 0.9, 0.9, 1; 1, 1), (0.8, 0.9, 0.9, 0.95; 0.9, 0.9))
Intelligent Logistics and Inventory Systems (ILIS)		((0.74,0.9,0.9,0.98,1,1) (0.82,0.9,0.9,0.94,0.9,0.9))
Using intelligent forklifts, pallet carriers and cranes (IFC)	H	((0.7, 0.9, 0.9, 1; 1, 1), (0.8, 0.9, 0.9, 0.95; 0.9, 0.9))
Automatic material placement and monitoring technology (AMP)	H	((0.7, 0.9, 0.9, 1; 1, 1), (0.8, 0.9, 0.9, 0.95; 0.9, 0.9))
Shipping optimization (SO)	VH	((0.9, 1, 1, 1; 1, 1), (0.95, 1, 1, 1; 0.9, 0.9))
Using Augmented and virtual reality technology (AVR)	MH	((0.5, 0.7, 0.7, 0.9; 1, 1), (0.6, 0.7, 0.7, 0.8; 0.9, 0.9))
Real-time monitoring technology (RTM)	VH	((0.9, 1, 1, 1; 1, 1), (0.95, 1, 1, 1; 0.9, 0.9))
Maintenance and Repair Systems (MRS)		((0.5,0.7,0.7,0.9,1,1) (0.6,0.7,0.7,0.8,0.9,0.9))
Predictive maintenance (PM)	MH	((0.5, 0.7, 0.7, 0.9; 1, 1), (0.6, 0.7, 0.7, 0.8; 0.9, 0.9))
Using cloud technology in maintenance services (CTM)	MH	((0.5, 0.7, 0.7, 0.9; 1, 1), (0.6, 0.7, 0.7, 0.8; 0.9, 0.9))
Augmented maintenance and repair operations (AMR)	MH	((0.5, 0.7, 0.7, 0.9; 1, 1), (0.6, 0.7, 0.7, 0.8; 0.9, 0.9))
Management Systems (MS)		((0.75,0.72,0.72,0.78,0.8,0.8) (0.66,0.72,0.72,0.75,0.72,0.72))
Digital performance management (DPM)	VH	((0.9, 1, 1, 1; 1, 1), (0.95, 1, 1, 1; 0.9, 0.9))
Online transparency (OT)	H	((0.7, 0.9, 0.9, 1; 1, 1), (0.8, 0.9, 0.9, 0.95; 0.9, 0.9))
Big data based quality management (BQM)	MH	((0.5, 0.7, 0.7, 0.9; 1, 1), (0.6, 0.7, 0.7, 0.8; 0.9, 0.9))
Process standardization and automation (PSA)	VH	((0.9, 1, 1, 1; 1, 1), (0.95, 1, 1, 1; 0.9, 0.9))

The arithmetic mean of the weights of the sub-criteria was determined to calculate the weights of the main criteria [59].

Step 2: Three alternative digital suppliers were assessed using the linguistic terms (Table 1) again based on the team's feedback, and the resulting decision matrix is given in Table 3.

Step 3: After linguistic evaluation of alternative digital suppliers, these linguistic evaluations are converted to their corresponding Interval T2FSs on the scale in Table 1, which developed by Lee and Chen [54] and used in the interval type-2 fuzzy TOPSIS method. The converted matrix is given in Table 4.

After the decision matrix was developed, $\tilde{\tilde{f}}_{ij}$ values were calculated using equation (3), and the fuzzy decision matrix was obtained as illustrated in Table 5.

Table 3. Linguistic assessment of alternative digital suppliers and decision matrix

Main Criteria	Sub-Criteria	Alternatives Digital Suppliers		
		DS-1	DS-2	DS-3
DPS	RAP	L	L	M
	AP	VL	VL	VL
	ACP	L	L	MH
	SPP	L	L	M
ICT	ICC	ML	ML	M
	IIS	ML	ML	MH
	IS	ML	M	H
	UMA	ML	MH	H
ILIS	IFC	ML	MH	H
	AMP	ML	ML	H
	SO	L	M	H
	AVR	VL	L	L
	RTM	L	M	MH
MRS	PM	L	ML	ML
	CTM	VL	L	ML
	AMR	VL	VL	ML
MS	DPM	L	ML	H
	OT	L	ML	H
	BQM	L	ML	MH
	PSA	ML	M	H

Table 4. Converting the evaluation of alternatives into interval type-2 fuzzy numbers

Main Criteria	Sub-Criteria	Alternatives Digital Suppliers		
		DS-1	DS-2	DS-3
DPS	RAP	((0, 0.1, 0.1, 0.3; 1, 1), (0.05, 0.1, 0.1, 0.2; 0.9, 0.9))	((0, 0.1, 0.1, 0.3; 1, 1), (0.05, 0.1, 0.1, 0.2; 0.9, 0.9))	((0.3, 0.5, 0.5, 0.7; 1, 1), (0.4, 0.5, 0.5, 0.6; 0.9, 0.9))
	AP	((0, 0, 0, 0.1; 1, 1), (0, 0, 0, 0.05; 0.9, 0.9))	((0, 0, 0, 0.1; 1, 1), (0, 0, 0, 0.05; 0.9, 0.9))	((0, 0, 0, 0.1; 1, 1), (0, 0, 0, 0.05; 0.9, 0.9))
	ACP	((0, 0.1, 0.1, 0.3; 1, 1), (0.05, 0.1, 0.1, 0.2; 0.9, 0.9))	((0, 0.1, 0.1, 0.3; 1, 1), (0.05, 0.1, 0.1, 0.2; 0.9, 0.9))	((0.5, 0.7, 0.7, 0.9; 1, 1), (0.6, 0.7, 0.7, 0.8; 0.9, 0.9))
	SPP	((0, 0.1, 0.1, 0.3; 1, 1), (0.05, 0.1, 0.1, 0.2; 0.9, 0.9))	((0, 0.1, 0.1, 0.3; 1, 1), (0.05, 0.1, 0.1, 0.2; 0.9, 0.9))	((0.3, 0.5, 0.5, 0.7; 1, 1), (0.4, 0.5, 0.5, 0.6; 0.9, 0.9))
ICT	ICC	((0.1, 0.3, 0.3, 0.5; 1, 1), (0.2, 0.3, 0.3, 0.4; 0.9, 0.9))	((0.1, 0.3, 0.3, 0.5; 1, 1), (0.2, 0.3, 0.3, 0.4; 0.9, 0.9))	((0.3, 0.5, 0.5, 0.7; 1, 1), (0.4, 0.5, 0.5, 0.6; 0.9, 0.9))
	IIS	((0.1, 0.3, 0.3, 0.5; 1, 1), (0.2, 0.3, 0.3, 0.4; 0.9, 0.9))	((0.1, 0.3, 0.3, 0.5; 1, 1), (0.2, 0.3, 0.3, 0.4; 0.9, 0.9))	((0.5, 0.7, 0.7, 0.9; 1, 1), (0.6, 0.7, 0.7, 0.8; 0.9, 0.9))
	IS	((0.1, 0.3, 0.3, 0.5; 1, 1), (0.2, 0.3, 0.3, 0.4; 0.9, 0.9))	((0.3, 0.5, 0.5, 0.7; 1, 1), (0.4, 0.5, 0.5, 0.6; 0.9, 0.9))	((0.7, 0.9, 0.9, 1; 1, 1), (0.8, 0.9, 0.9, 0.95; 0.9, 0.9))
	UMA	((0.1, 0.3, 0.3, 0.5; 1, 1), (0.2, 0.3, 0.3, 0.4; 0.9, 0.9))	((0.5, 0.7, 0.7, 0.9; 1, 1), (0.6, 0.7, 0.7, 0.8; 0.9, 0.9))	((0.7, 0.9, 0.9, 1; 1, 1), (0.8, 0.9, 0.9, 0.95; 0.9, 0.9))
ILIS	IFC	((0.1, 0.3, 0.3, 0.5; 1, 1), (0.2, 0.3, 0.3, 0.4; 0.9, 0.9))	((0.5, 0.7, 0.7, 0.9; 1, 1), (0.6, 0.7, 0.7, 0.8; 0.9, 0.9))	((0.7, 0.9, 0.9, 1; 1, 1), (0.8, 0.9, 0.9, 0.95; 0.9, 0.9))
	AMP	((0.1, 0.3, 0.3, 0.5; 1, 1), (0.2, 0.3, 0.3, 0.4; 0.9, 0.9))	((0.1, 0.3, 0.3, 0.5; 1, 1), (0.2, 0.3, 0.3, 0.4; 0.9, 0.9))	((0.7, 0.9, 0.9, 1; 1, 1), (0.8, 0.9, 0.9, 0.95; 0.9, 0.9))
	SO	((0, 0.1, 0.1, 0.3; 1, 1), (0.05, 0.1, 0.1, 0.2; 0.9, 0.9))	((0.3, 0.5, 0.5, 0.7; 1, 1), (0.4, 0.5, 0.5, 0.6; 0.9, 0.9))	((0.7, 0.9, 0.9, 1; 1, 1), (0.8, 0.9, 0.9, 0.95; 0.9, 0.9))
	AVR	((0, 0, 0, 0.1; 1, 1), (0, 0, 0, 0.05; 0.9, 0.9))	((0, 0.1, 0.1, 0.3; 1, 1), (0.05, 0.1, 0.1, 0.2; 0.9, 0.9))	((0, 0.1, 0.1, 0.3; 1, 1), (0.05, 0.1, 0.1, 0.2; 0.9, 0.9))
	RTM	((0, 0.1, 0.1, 0.3; 1, 1), (0.05, 0.1, 0.1, 0.2; 0.9, 0.9))	((0.3, 0.5, 0.5, 0.7; 1, 1), (0.4, 0.5, 0.5, 0.6; 0.9, 0.9))	((0.5, 0.7, 0.7, 0.9; 1, 1), (0.6, 0.7, 0.7, 0.8; 0.9, 0.9))
MRS	PM	((0, 0.1, 0.1, 0.3; 1, 1), (0.05, 0.1, 0.1, 0.2; 0.9, 0.9))	((0.1, 0.3, 0.3, 0.5; 1, 1), (0.2, 0.3, 0.3, 0.4; 0.9, 0.9))	((0.1, 0.3, 0.3, 0.5; 1, 1), (0.2, 0.3, 0.3, 0.4; 0.9, 0.9))
	CTM	((0, 0, 0, 0.1; 1, 1), (0, 0, 0, 0.05; 0.9, 0.9))	((0, 0.1, 0.1, 0.3; 1, 1), (0.05, 0.1, 0.1, 0.2; 0.9, 0.9))	((0.1, 0.3, 0.3, 0.5; 1, 1), (0.2, 0.3, 0.3, 0.4; 0.9, 0.9))
	AMR	((0, 0, 0, 0.1; 1, 1), (0, 0, 0, 0.05; 0.9, 0.9))	((0, 0, 0, 0.1; 1, 1), (0, 0, 0, 0.05; 0.9, 0.9))	((0.1, 0.3, 0.3, 0.5; 1, 1), (0.2, 0.3, 0.3, 0.4; 0.9, 0.9))
MS	DPM	((0, 0.1, 0.1, 0.3; 1, 1), (0.05, 0.1, 0.1, 0.2; 0.9, 0.9))	((0.1, 0.3, 0.3, 0.5; 1, 1), (0.2, 0.3, 0.3, 0.4; 0.9, 0.9))	((0.7, 0.9, 0.9, 1; 1, 1), (0.8, 0.9, 0.9, 0.95; 0.9, 0.9))
	OT	((0, 0.1, 0.1, 0.3; 1, 1), (0.05, 0.1, 0.1, 0.2; 0.9, 0.9))	((0.1, 0.3, 0.3, 0.5; 1, 1), (0.2, 0.3, 0.3, 0.4; 0.9, 0.9))	((0.7, 0.9, 0.9, 1; 1, 1), (0.8, 0.9, 0.9, 0.95; 0.9, 0.9))
	BQM	((0, 0.1, 0.1, 0.3; 1, 1), (0.05, 0.1, 0.1, 0.2; 0.9, 0.9))	((0.1, 0.3, 0.3, 0.5; 1, 1), (0.2, 0.3, 0.3, 0.4; 0.9, 0.9))	((0.5, 0.7, 0.7, 0.9; 1, 1), (0.6, 0.7, 0.7, 0.8; 0.9, 0.9))
	PSA	((0.1, 0.3, 0.3, 0.5; 1, 1), (0.2, 0.3, 0.3, 0.4; 0.9, 0.9))	((0.3, 0.5, 0.5, 0.7; 1, 1), (0.4, 0.5, 0.5, 0.6; 0.9, 0.9))	((0.7, 0.9, 0.9, 1; 1, 1), (0.8, 0.9, 0.9, 0.95; 0.9, 0.9))

Table 5. Fuzzy decision matrix

Main Criteria	Alternatives Digital Suppliers		
	DS-1	DS-2	DS-3
DPS	(0,0.08,0.08,0.25,1,1) (0.04,0.08,0.08,0.16,0.9,0.9)	(0,0.08,0.08,0.25,1,1) (0.04,0.08,0.08,0.16,0.9,0.9)	(0.3,0.4,0.4,0.53,1,1) (0.35,0.4,0.4,0.46,0.9,0.9)
ICT	(0.1,0.3,0.3,0.5,1,1) (0.2,0.3,0.3,0.4,0.9,0.9)	(0.25,0.45,0.45,0.65,1,1) (0.35,0.45,0.45,0.55,0.9,0.9)	(0.55,0.75,0.75,0.9,1,1) (0.65,0.75,0.75,0.83,0.9,0.9)
ILIS	(0.04,0.16,0.16,0.34,1,1) (0.1,0.16,0.16,0.25,0.9,0.9)	(0.24,0.42,0.42,0.62,1,1) (0.33,0.42,0.42,0.52,0.9,0.9)	(0.52,0.7,0.7,0.84,1,1) (0.61,0.7,0.7,0.77,0.9,0.9)
MRS	(0.23,0.3,0.3,0.4,1,1) (0.27,0.3,0.3,0.35,0.9,0.9)	(0.03,0.13,0.13,0.3,1,1) (0.08,0.13,0.13,0.22,0.9,0.9)	(0.1,0.3,0.3,0.5,1,1) (0.2,0.3,0.3,0.4,0.9,0.9)
MS	(0.03,0.15,0.15,0.35,1,1) (0.09,0.15,0.15,0.25,0.9,0.9)	(0.15,0.35,0.35,0.55,1,1) (0.25,0.35,0.35,0.45,0.9,0.9)	(0.65,0.85,0.85,0.98,1,1) (0.75,0.85,0.85,0.91,0.9,0.9)

Step 4: Then, a weighted fuzzy decision matrix given in Table 6 was obtained using equation (6).

Table 6. Weighted fuzzy decision matrix

Main Criteria	Alternatives Digital Suppliers		
	DS-1	DS-2	DS-3
DPS	(0,0.06,0.06,0.23,1,1) (0.03,0.06,0.06,0.14,0.81,0.81)	(0,0.06,0.06,0.23,1,1) (0.03,0.06,0.06,0.14,0.81,0.81)	(0.18,0.31,0.31,0.47,1,1) (0.24,0.31,0.31,0.39,0.81,0.81)
ICT	(0.08,0.29,0.29,0.5,1,1) (0.18,0.29,0.29,0.39,0.81,0.81)	(0.2,0.43,0.43,0.65,1,1) (0.31,0.43,0.43,0.54,0.81,0.81)	(0.44,0.71,0.71,0.9,1,1) (0.57,0.71,0.71,0.8,0.81,0.81)
ILIS	(0.03,0.14,0.14,0.33,1,1) (0.08,0.14,0.14,0.24,0.81,0.81)	(0.18,0.38,0.38,0.61,1,1) (0.27,0.38,0.38,0.49,0.81,0.81)	(0.38,0.63,0.63,0.82,1,1) (0.5,0.63,0.63,0.72,0.81,0.81)
MRS	(0.12,0.21,0.21,0.36,1,1) (0.16,0.21,0.21,0.28,0.81,0.81)	(0.02,0.09,0.09,0.27,1,1) (0.05,0.09,0.09,0.17,0.81,0.81)	(0.05,0.21,0.21,0.45,1,1) (0.12,0.21,0.21,0.32,0.81,0.81)
MS	(0.02,0.11,0.11,0.27,0.8,0.8) (0.06,0.11,0.11,0.19,0.65,0.65)	(0.11,0.25,0.25,0.43,0.8,0.8) (0.17,0.25,0.25,0.34,0.65,0.65)	(0.49,0.61,0.61,0.76,0.8,0.8) (0.5,0.61,0.61,0.68,0.65,0.65)

Step 5: A ranked weighted decision matrix (Table 7) was calculated using equation (1).

Table 7. Ranked weighted decision matrix

Main Criteria	Alternatives Digital Suppliers		
	DS-1	DS-2	DS-3
DPS	3.97	3.97	5.41
ICT	5.20	6.03	7.68
ILIS	4.44	5.77	7.21
MRS	4.84	4.17	4.80
MS	4.24	5.05	6.46

Steps 6: Positive and negative ideal solutions (Table 8) were calculated using equations (8) and (9).

Table 8. PIS and NIS

Main Criteria	Positive ideal solution	Negative ideal solution
DPS	5.41	3.97
ICT	7.68	5.20
ILIS	4.44	7.21
MRS	4.84	4.17
MS	6.46	4.24

Step 7: The distance of each alternative to the positive (d^+) and negative (d^-) ideal solutions was calculated using equations (10) and (11). Closeness indexes $C(x_i)$ were calculated using equation (12) and shown in Table 9.

Table 9. Distance of each alternative to PIS and NIS and closeness indexes

Alternatives Digital Suppliers	d+	d-	$C(x_i)$	Ranking
DS-1	3.625	2.857	0.441	2
DS-2	2.997	1.856	0.383	3
DS-3	2.777	3.68	0.570	1

According to the closeness indexes, the preferred order of alternative digital suppliers were ranked as DS-3, DS-1 and DS-2. Afterwards, a sensitivity analysis was performed depending on the scenarios given in Table 10 to determine whether the ranking of alternatives would be different according to different criteria weights. The results are given in Figure 4.

Table 10. Combinations of scenarios with different criteria weights

Scenarios	Combinations
Scenario 1	Current
Scenario 2	DPS Very Low, The Rest current
Scenario 3	ICT Very Low, The Rest current
Scenario 4	ILIS Very Low, The Rest current
Scenario 5	MRS Low, The Rest current
Scenario 6	MS Very Low, The Rest current
Scenario 7	DPS Very High, The Rest current
Scenario 8	ICT Very High, The Rest current
Scenario 9	ILIS Very High, The Rest current
Scenario 10	MRS Very High, The Rest current
Scenario 11	MS Very High, The Rest current

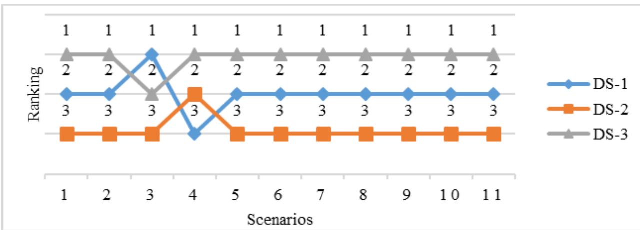

Figure 4. Changes in sensitivity analysis results

The sensitivity analysis results show that DS-3 is the best digital supplier in all scenarios, except for Scenario 3, where the weight of criterion ICT was changed. This result indicates that the IT2F-TOPSIS results are sensitive and that supplier DS-3 is the most suitable digital supplier.

3. RESULTS AND DISCUSSION

In recent years, companies have been using competitive strategies to survive in the market, to meet the changing needs of their customers and to ensure sustainable development in the business world. They adopt Industry 4.0 technologies such as autonomous robots, 3D printing, IoT, BDA, cloud computing, augmented reality, cyber physical systems and simulation in order to create an innovative business environment. These technologies have fundamentally changed business processes and models and SCM. Consequently, the traditional supply chain has been transformed into DSC, which has started to improve the overall performance of companies.

The use of digital smart systems in DSC renders supply chains more transparent and efficient. Real-time analysis and evaluation in DSC helps companies make better and faster decisions to meet customer needs. It also reduces costs and risks and helps companies make their supply chain management more efficient and useful than before.

DSC will be much more effective in the next two and three years. The expected advantages of DSC are up to a 30% reduction in operating costs, a 75% less loss on sale and up to 75% reduction in inventory. Parent companies, therefore, want to work with suppliers that use digital technologies in all their activities.

The aim of this study was to determine the supplier using digital technologies most effectively among a number of suppliers of a company operating in the garment sector in Turkey and working with numerous domestic and foreign suppliers. Supplier selection involves numerous criteria. The IT2F-TOPSIS was, therefore, the method of choice in this study because it is an MCDM method that analyzes uncertainties better than IT1FSs. The best DS was chosen as a result of the evaluations made according to the application steps of the method. As a result, the benefits of the company in the case of working with this selected supplier are listed below:

- Information flow between the supplier and the company will be manageable, resulting in more workflow and collaborations.
- Integration between the supplier and the company will make purchasing processes more predictable and resulting in optimum stock control, and thus, low inventory costs.
- The company and the supplier will have more mutual data collection opportunities and analyze data to find solutions to various problems.
- Preventive maintenance activities carried out by the supplier will increase the efficiency of the lines, enabling the company to meet demands without delay.
- In conclusion, Industry 4.0 technologies will increase the flexibility, quality and efficiency of suppliers and reduce their costs and improve their decision-making processes. In this way, companies will be able to make customized products, design virtual clothing, meet customer demands more rapidly and launch new products and services more frequently. This improvement will move companies towards better levels of performance in terms of quality, flexibility and cost.

Finally, the study is the first study in the literature to determine a DS. The sensitivity analysis results show that the selection model and method are sensitive. Therefore, companies that wish to select and assess the best supplier among their suppliers that use industry 4.0 technologies can use the selection model and method proposed in this study.

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Measurement Control of Ready-Made Garments with Image Analysis Methods

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ABSTRACT

In the ready-made clothing industry accurate garment measurement is one of the most important points for the right fitting of the apparel. Garments should be produced to the determined size by the customer or the enterprise. Although, the measurement control of the final product is made by trained operator, the factors such as gradually loose of attention, fatigue and stress could cause faults that could lead to lack of quality and waste of time. In this sense, developing and using objective, fast and economic measurement control systems in terms of both cost effectiveness and the reliability of the controls has become a must. The purpose of the study is to design a system and develop an algorithm to control the measurements of garments automatically. This study, which is determined that image analysis method can be used in measurement control of ready-made garments, will be a new measurement control method in the literature and an example for similar studies. By benefiting from the image analysis methods, measurement mistakes likely to result from the operator will be prevented and the results will be made more reliable.

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KEYWORDS

ready-made garments, quality control, image analysis methods, measurement control

1. INTRODUCTION

In apparel industry, measurement control is extremely critical in terms of being an important criterion affecting cloth fitting. Ready-made garments, where physical appearance and body fit are extremely important, should be produced to the determined size by the customer or the enterprise.

For apparel products, fit of the garments is one of the most important parameters affecting the customer satisfaction and the buying decision [1]. Manufacturers should keep control of their finished garments measurements and remove or repair the products exceeding the specified tolerances. Because measurement problems are an important issue affecting the quality of the product.

However, finished and semi-finished products may be subjected to conditions that may cause measurement deviations at all stages of production. Measurement problems in the product may be caused by incorrect methods or applications in various departments, or material properties. Storage conditions and methods that do not conform to the structural properties of the fabric or auxiliary materials may cause tension or shrinkage on the fabric. In the cutting section; at the process of fabric control, fabric laying, cutting, sorting and sewing preparation, working with methods that are not suitable for fabric properties negatively affect the dimensions of the products. In the sewing section; wrong machine settings, false sewing techniques, and operator application errors result in deviations in measurement. In the ironing section; incorrect ironing setting, operator's lack of information, lack of skill or carelessness can cause differences in measure. And finally, in the quality control and packaging department; storage method of finished products and storage errors (storage environment, moisture content, etc.) can cause problems in the measurements. To keep measurements under control, semi-finished and finished garments are measured in line and final control stage of the production.

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The efficiency of the measurement control which is under the responsibility of quality control operator is affected by the knowledge and skills of the employee as well as by physical (tiredness, attention etc.) and mental structures (stress, unwillingness, depression, etc.). The cognitive and affective behaviour of the operator can cause errors, losses of time and quality during the control and decision stages.

Acceleration of the entry into storage of finished products towards the end of the production process, the approach of the shipment date, customers pressures, the differences between planned and actual targets create stress and pressure on the quality control department which is the most critical department.

In the final control department, the product's measurement controls are performed according to the locations and positions specified in the measurement table, unless specific criteria or methods are specified by the customers. It is necessary that measurement deviations must not be out of determined tolerances. However, all measurements of all products cannot be controlled in terms of lack of time and labor costs. Therefore, critical measurements (chest width, length, etc.) are often checked by simple random sampling.

Considering the importance of measurement control; it should not be ignored that the intense tempo and stress in the enterprises affect the efficiency, accuracy and effectiveness of the measurement control. Measurement controls should be performed carefully and accurately to ensure that the product can be produced in desired specifications and to ensure customer satisfaction. In this sense, developing and using objective, fast and economic measurement control systems in terms of both cost effectiveness and the reliability of the controls has become a must.

The purpose of the study is to design a system and develop an algorithm to control the measurements of garments automatically. The system will be simple, portable and easily adaptable to computers. The measurement control system will enhance product quality and result in improved productivity to meet both customer demands and reduce costs associated with off-quality. The employment cost will be reduced by automatic control of measurement, where deviations in measurements will be evaluated objectively. A database of the measurements can be formed and they can then be analysed realistically. Consequently, statistical evaluation of measurements can be achieved.

Today, visual analysis systems are used as a fast and effective method in the controls of various products in textile and ready-made clothing industry. The use of image analysis to replace human vision is now wide spread in industrial manufacture; there are many benefits in reducing fatigue and improving speed, consistency and cost effectiveness. The image analysis system is referred to realising visual function of human, i.e. realizing the recognition of three- dimensional objective world, by means of computer [2].

Nowadays, picture processing has many applications in different fields such as textile industry, garment industry and measurement. Among the uses are: automatic measurement of coverage factor, control of thread defects, measurement of length and diameter of thread and fibers, measurement of shining index, investigation of the thickness of the cloth and its other features, measurement of torsion angle of cloth and measurement and modelling the body [3].

Image processing techniques in textile sector are used for the purpose of structural investigation, classification, defect detection and quality control in fibre, yarn and fabric surfaces. In line with technological developments, the number and variety of the studies carried out in the literature is getting increased. Upon the review of the related literature, it is likely to see that image analysis methods were studies into various fibres, yarns, woven and knitted fabrics, nonwoven fabrics at a large scale but were not studied into the ready-made garments at an adequate number.

Chen [2] used the fuzzy edge-detection algorithm to detect the edges of garment, and found the key corner points based on Freeman chain codes. Cao et al [4] adopted median filter algorithm to eliminate the garment image noise and is used a fast fuzzy edge-detection algorithm to detect the edge of garment image; and invoked a new corner-detection algorithm based on Freeman code to locate the corner points. Li et al [5] proposed an automatic garment measurement approach using image recognition. A garment template is introduced to recognize garment types and feature points, which are used to calculate the garment sizes. Roknabadi et al [3] made a new device to take human body’s measures in cloth using image processing. Their method based on image processing which can extract the main measurements of the body based on Muller method. In the related literature, the studies carried out into garments highlight the efficiency of this method.

In this study Faster Region-based Convolutional Neural Network was used instead of other object detection algorithms as it has better process time and accuracy and it is more current and accepted algorithm.

The purpose of the current study was to find an answer to the question of whether the use of image analysis method was effective in the measurement control of the finished ready-made garments for the first time, in the light of the studies conducted in the literature [6].

2. MATERIAL AND METHODS

As the current study is one of the first research and development one carried out into the use of image analysis method on ready-made garments, the sampling group was determined as a round-necked and short-sleeved white T-

shirt by paying attention to the fact that it is a simple model to be studied and to the need that the product should have suitable model and colour in taking a photography and processing the image. The research was carried out in two stages as the pilot study and basic application.
In both studies, the applications were made through image processing programs that were developed for the research. As the data processing and building neural network, Tensorflow framework was used for the edge detection and the camera having an imaging capacity of at least 8.0 megapixel in order to obtain programs and images that was developed for the quality control of the T-shirts.

In order to run the system that was developed; it is necessary to have

1. A camera or digital CMOS (digital camera) having an imaging capacity of at least 8.0 megapixel to obtain the images

2. Tensorflow for edge detection. Faster Region-based Convolutional Neural Network was used instead of other object detection algorithms because that recently, Faster RCNN has better process time and accuracy. Faster RCNN was supported with Inception network.

3. Python program for distance calculation.

4. OpenCV Library for getting image as data.

The first trials were made in a lab in the research. A fixed platform was formed in order to conduct the control of the product and image reception processes. The camera that was planned to receive the images over the product was fixed on the platform adjacent to the light source. For lighting, softone light bulbs and fluorescent lamps were used. The picture of testing apparatus is given in Figure 1 and the main units of the system applied in the research are given in Figure 2.

The program processes over pixels. First, the distance between the pixels is calculated as shown in Equation (1). According to Equation (2), product of actual width and ratio of pixel distance to resolution gives actual distance.

(x1,y1) = Coordinates of edge 1

(x2,y2) = Coordinates of edge 2

Actual Width = Real life distance

Resolution's width = Image Dimension

Pixel distance $= \sqrt{(x1 - x2)^2 + (y1 - y2)^2}$ (1)

Actual Distance = (Pixel Distance / Resolution's width) x Actual width (2)

The camera takes the picture at 65cm height and with the right angle. After the picture of the T-shirt was given as an input to neural network, neural network detects related edge and their coordinates. The program determines the measurement by calculating distance using by equations respectively Equation 1 and Equation 2.

The example of the flow graphics of measurement scanning is given in Figure 3.

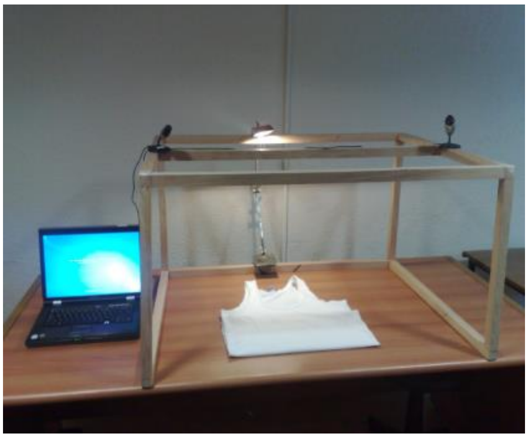

Figure 1. Testing apparatus

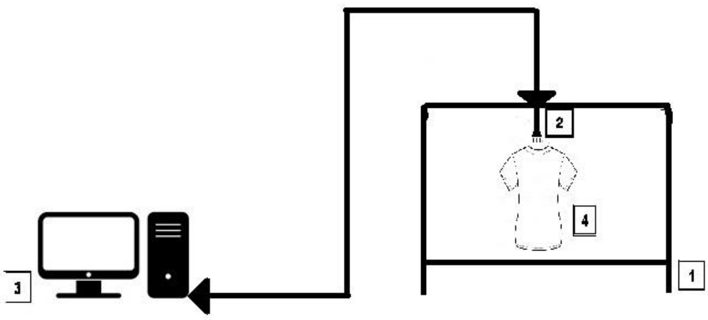

Figure 2. Main units of the system applied in the research (1) The structure allowing the electro mechanic system standstill, (2) Camera and light source, (3) Pre-trained model included machine, (4) T-shirt.

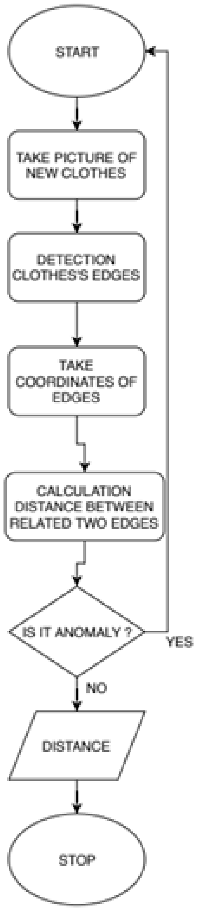

Figure 3. Flow Graphic of Measurement Scanning

In the study, 43 T-shirts were measured by the operator and the program. T-shirt measurement positions referenced in this research are shown in Figure 4.

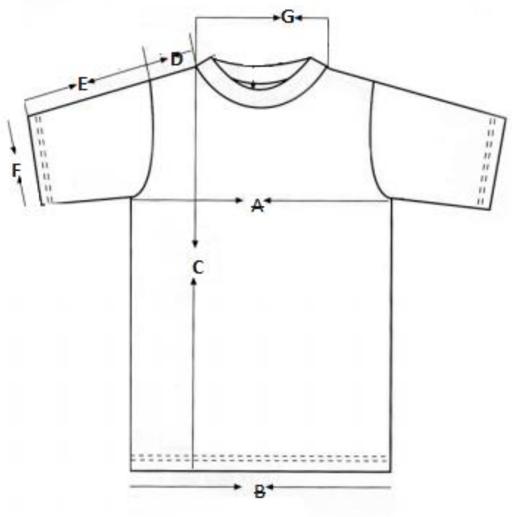

Figure 4. Measurement positions of T-shirts A: Chest B: Hem (hemline) C: Front Length D: Shoulder Width E: Sleeve Length F: Sleeve Opening G: Neck Opening.

The T-shirt measurement of the operator is shown in Figures 5 and 6.

Figure 5. Operator's chest measurement

Figure 6. Operator's front length measurement

Picture of clothes is taken from pre-built, fixed platform. Taken image is given to neural network to edge detection. After neural network detects edges with tags and coordinates, software written in python calculate distance between two related edges. If output is outlier, it would be better to separate it for manual measurement. Because that, even if we have a very high success rate, we cannot rule out low errors. So, we preserve our system 10 times faster and more reliably. If the output is not anomaly, the distance will save and the process continues with new clothes.

3. RESULTS AND DISCUSSION

In the study carried out over the products chosen randomly in a determined work flow and time interval, the measurement results obtained with the program developed for the research were compared with the measurement results measured by the operators.

In statistics, mean absolute error (MAE) is a measure of difference between two continuous variables. In this study, they are; if we take human measurements as bayesian error, worker measurements as true values and software results. As shown in the table above, there are very small differences between the software results and the actual human measurements we accept. If the error rate is assumed to be directly proportional to the accuracy, the accuracy is expected to be high. As shown in the table above, accuracy has met the expected value.

Table 1. MAE&Accuracy

	Mean Absolute Error	Accuracy
Chest Width	0.267442	99.9394
Hem Width	0.0418605	99.9997
Front Length from Shoulder	0.0465116	99.9997
Neck Opening	0.027907	99.9989
Right Shoulder Width	0.0302326	99.9985
Left Shoulder Width	0.0372093	99.9976
Right Arm Width	0.0162791	99.9997
Left Arm Width	0.0953488	99.9912
Right Sleeve Opening	0	100
Left Sleeve Opening	0	100

As measurement results of the operator and the program have almost same values (99% accuracy) on 43 samples, lines are overlapping in any graphics. So, no graphics is needed because of high accuracy.

The data obtained in the current study was analysed with the package program of SPSS 15.0. The frequency and percentage distributions of the data were given. The normality test of the measurement values made by operator and the program regarding the T-shirt were analysed and it was found that not all measurement values came from normal distribution ($p<0.05$).

The evaluation of the normality test of the measurement results is given in Table 2.

During the analysis of the difference between the non-normally distributed variables at the end of the normality test of the data, Mann Whitney U Test, which is not parametric in pair groups, was used.

Whether there was a difference between the measurements by both the operator and the program over the T-shirts was evaluated with Mann Whitney U Test. The data obtained for each measurement part were evaluated separately. The comparison of the operator and the program results for shoulder width is given in Table 3.

Upon the comparison of the operator and the program results for the measurements of the chest width of the product, it was found that there was no significant difference between the measurements at the significant level of $p>0.05$ as measurement means were the same ($\bar{x}$=38,9cm) and $p=0.542$.

At the end of the applications, the measurement results of products' chest, hem (hemline), front length from shoulder, neck opening, right-left shoulder width and right-left sleeve opening obtained with the operator and the program were compared and no significant difference was found between the measurements ($p>0.05$).

While making a comparison between the dependent variables, WilcoxonSign Test was used in non-normally distributed variables. As for the differences between the groups, significance level was regarded 0.05 and in the case of $p<0.05$, there became a significant difference between the groups and when it was $p>0.05$, there did not become a significant difference between the groups.

In order to determine whether there was a compliance between the difference of the measurements taken by the operator and the program of the measurement parts which had a similarity in terms of the method and place of making measurement on the product, WilcoxonSigh test was used. The comparison of the differences of the chest width and hem width is given in Table 4.

Table 2. The normality test of the measurement results

		Normality Test		
		Kolmogorov-Smirnov Test		
		Test Statistics	Degree of Freedom	P
Chest Width	Operator	0,214	43	0,000*
	Program	0,200	43	0,000*
Hem (hemline) Width	Operator	0,259	43	0,000*
	Program	0,210	43	0,000*
Front Length from Shoulder	Operator	0,237	43	0,000*
	Program	0,177	43	0,002*
Neck Opening	Operator	0,235	43	0,000*
	Program	0,174	43	0,002*
Right Shoulder Width	Operator	0,247	43	0,000*
	Program	0,188	43	0,001*
Left Shoulder Width	Operator	0,329	43	0,000*
	Program	0,241	43	0,000*
Right Arm Width	Operator	0,315	43	0,000*
	Program	0,289	43	0,000*
Left Arm Width	Operator	0,392	43	0,000*
	Program	0,263	43	0,000*
Right Sleeve Opening	Operator	0,463	43	0,000*
	Program	0,463	43	0,000*
Left Sleeve Opening	Operator	0,419	43	0,000*
	Program	0,419	43	0,000*

*p<0,05

Table 3. Comparison of operator and program results for the shoulder width measurement

Measurement Part		Mann Whitney U Test								
		n	Mean	Median	Minimum	Maximum	SS	Mean Rank	U	p
Shoulder Width	Operator	43	38,9	39,0	37,5	40,0	0,5	41,9	856	0,542
	Program	43	38,9	39,0	37,4	40,0	0,5	45,1		
	Total	86	38,9	39,0	37,4	40,0	0,5			

p>0,05

Table 4. Comparison of chest and hem (hemline) differences

Wilcoxon Sign Test													
							Negative Rank		Positive Rank		Ties	Z	P
Measurement Place	n	Mean	Median	Min.	Max.	SS	N	Mean Rank	N	Mean Rank	n		
Chest	43	-0,016	0,000	-0,500	0,500	0,131	11	10,1	9	10,9	23	-0,253	0,800
Hem	43	-0,019	0,000	-0,500	0,400	0,110							

p>0,05

There was no significant difference between chest width and hem width differences as p= 0,800 (p>0.05). It was found that the measurements complied with each other.

At the end of the applications, right-left shoulder width, right-left arm length and right-left sleeve opening of the products were compared and it was also found that the measurements complied with each other (p>0.05).

In the light of the findings, it was accepted that the results of the measurement controls by the program are true. It was also found that the measurement results obtained with the program was at the same reliability as those obtained by the quality control operator. It was determined in the applications that the measurement control process applied by the control operator on the ready-made garment at the final control could be made through image analysis method. The data obtained showed that the deviations in the measurement control were within tolerable limits. It is a striking feature in terms of the efficacy of the program.

4. ADVANTAGES, DISADVANTAGES AND DIFFERENCES

In a day, both working speed and accuracy are depending on worker's performance. It was observed that the efficiency of workers have been decreased towards end of the day. There are many factors which trigger this situation; worker's mood, tiredness, health problems. This study mainly aimed that this problem and success is supported with results. Adding computer vision was a step in reducing dependence on the employee. Another step that increases speed and accuracy is the calculation by the computer. Thus, dependence on human variable efficiency has disappeared.

Because garment products are more complex due to many factors such as pattern and colour, the system may have difficulty. Basic models have been selected for this experiment since it is one of the first researches. The solution is to re-train the pre-trained model with these complex garments. The model learns with the data set it is trained in and does not make mistakes easily from data set it learns.

When other studies in this field are examined, it is seen that edge detection algorithms similar to this study are used. Unlike other algorithms, Faster RCNN is more current and more accepted algorithm. This allows the study to remain up-to-date and to build a faster architecture using today's technological facilities to the fullest. Besides these, Inception network allows deeper network which means algorithm which has used could work on more complex process and provides to choose filter size.

5. CONCLUSIONS

Ready-made clothing industry is a production field vulnerable to defect formation because of its variety of both raw material and supplementary materials and the stages of model and production and with its intensive labour structure. For that reason, it is necessary that quality control automation that would be established for the defect detection for the ready-made garments should offer effective solutions and that the sophisticated and effective defect detection algorithms of the programs to be prepared which require expertise should be created.

In the light of the studies that have been carried out up till now, the current study which was determined that it was the first study carried out to show that image analysis method could be used in the measurement control of the finished ready-made garments will take its place as a new quality control method in the literature and will be a sample for the similar studies in the sector. By benefiting from the image analysis methods in the measurement control, measurement mistakes likely to result from the operator during the measurement will be prevented and the results will be more reliable. The application and evaluation of the measurement process will be taken from the operator's initiative and systematic evaluation and reporting will be possible. For that reason, it is recommended to improve the study and carry out researches into software being able to a make concurrent warning and reporting. It is also recommended to carry out some studies and improvements into system by taking into consideration of putting such limitations as model, quality parameters, to use special technologies to be applied in interlude controls in different departments of the ready-made clothing businesses and also in the control of different ready-made garments.

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