Research Article • DOI: 10.2478/ftee-2023-0023 FTEE • 31(3) • 2023 • 14–21

Physical and Mechanical Properties of Cotton/Polyester Based Fibers for Shoe Uppers and Lining Products

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Abstract
The purpose of the study was to evaluate the physical and mechanical properties of various textile materials based on polyester and cotton for shoe uppers and lining. For that purpose, the influence of the ratio of a mixture of cotton and polyester fibers on the quality of the fabric was investigated. As a result, fabrics with the same composition but different yarn numbers differed from each other in specified properties. With an increase in the content of polyester, all specified properties increase except for vapor permeability, which makes it possible to correctly select the composition of fabrics for shoes.

Keywords
Textile, shoe, polyester, cotton, mechanical properties.

1. Introduction

Traditionally, shoes are made of leather, but there are other types of shoes. There are groups of consumers who prefer shoes made of alternative materials [1,2]. Currently, in the world of fabrics, polymers and rubbers have gradually replaced leather, which used to be the predominant material. Mixed cotton and polyester fabrics have a wide range of applications, including for shoes. Shoes have been used to protect the feet for thousands of years. The functions of the shoe are protection from the weather, warming the feet and support for daily activities. The decision to buy shoes depends on an attractive design in relation to the size of a high heel for women's shoes, as well as on the shape of shoes, bright materials and style [3].

Textile material from natural and synthetic fibers, nonwovens and other innovative forms, is used specifically for the manufacture of various parts of a shoe. Textile materials are a more economical and efficient way of replacing some costly traditional materials used to make footwear. They are used almost in all parts of footwear because of the developments of various types of nonwoven fabric and artificial leather [4]. Textiles can include cotton, nylon, viscose, polyester and wool. Cotton blends in the form of cotton yarn mixed with nylon are also common in shoe manufacturing [5]. The footwear design for articles of higher and medium-price class follows the trends and tendencies of haute couture, with everything a little bit more modest and simple, which usually presumes top design and high quality of the footwear, generally of natural leather exclusively, with other materials of certified quality and high quality of manufacture, including at the same time numerous special treatments, finishes, and innovations in industrial footwear production [6]. As for shoe materials, research has found that fabrics (78.8%) of medium thickness (71.2%) are the most preferred, followed by leather (15%) and plastic (6.2%). Both young and elderly participants agree that they prefer sports shoes made of textile materials as walking shoes, with a low heel height and laces as a fastener [7,8].

The shoe industry in developed countries is looking for solutions to reduce production costs to compete in the international market, such as replacing leather with fabrics, synthetic polymers and rubbers [9]. On the other hand, scientific and technical progress, globalization, striving for sustainable development, variety of applied technologies and materials, and more and more free flow of commodities, unfortunately often threatening users' health and safety, force the solving of problems of quality and certification of clothing and footwear. The following factors determine problems of clothing and footwear quality: quality of applied materials, innovative technological processes of manufacturing, as well as design and structural solutions that define functional values related to fashion and user comfort [10-12].

The design of shoes should be determined by the choice of upper shoe material, the curvature of the sole, weight, design and selection of lasts. Research shows that these are not independent options [13], since improper fitting of shoes can lead to illness or pain, the most responsible for which is the width of shoes, from which the elderly and adults suffer the most [14]. Leather is applied mainly to the upper part of shoes because of its ability to evaporate water into the environment [15]. When in contact with the skin, it is softer, can adapt to the foot, and has a lower tendency to fungus reproduction. Despite these properties, the use of leather in the market is declining due to its high price [16]. The widespread use of synthetic fabrics in sports shoes is due to the specific properties of the materials, such as flexibility, breathability/water vapor permeability, lower water absorption, rapid drying, low weight and especially low cost [17]. However, polyester fabrics are usually not as user-friendly because they cannot provide comfort properly, but this can be improved by mixtures with other fibers [18]. The literature [19,20] indicates some important attributes that influence the choice of materials for comfort, especially moisture transfer, breathability or vapor permeability, add tensile strength, thickness and shape. Moreover, well-known scientists have made a great contribution to determining the strength properties of threads and yarn [21,22].

Materials should have not only aesthetic appearance but also functional and physical and mechanical properties for wearable material [11,23]. Moreover, there has been an increase in the use of mixtures of fabrics such as polyester and cotton. Compared with 100% cotton, products made from a mixture of cotton and polyester have higher strength characteristics [24,25]. Polyester and cotton are mixed in different proportions depending on the purpose of the fabric, but the main problem in fiber mixing technology is the choice of their ratio in the mix.

The objective of the study was the evaluation of the physical, mechanical and structural properties of various polyester and cotton-based textile materials for shoe uppers and linings.

	Thickness, mm	Yarn number by warp	Yarn number by weft	Fabric composition*		Interlacing
№1	0.59	24/1	24/1	33%p	67%c	3/1
№2	0.52	24/1	24/1	65%p	35%c	2/1
№3	0.50	27/1	27/1	50%p	50%c	2/1
№4	0.69	27/1	27/1	52%p	48%c	2/2
№5	0.50	68/1	68/1	-	100%c	5/2
№6	0.71	24/1	24/1	35%p	65%c	3/1
№7	0.59	27/1	12/1	-	100%c	2/1
№8	0.71	24/1	24/1	20%p	80%c	3/1
№9	0.60	24/1	24/1	20%p	80%c	2/1
№10	0.30	50/1	50/1	-	100%c	1/1

p: polyester, c: cotton

Table 1. Composition and identification of the samples

2. Materials and Methods

2.1. Materials

In this study, fabrics were woven with mixed yarns for shoe uppers and lining. The following fabric samples woven from a yarn number were used as objects of research (12/1, 24/1, 27/1, 50/1, 68/1) for an experiment at the AZALA textile mill.

The compositions of the ten samples used in this study are given in Table 1.

2.2. Sample conditioning procedure

Tests of the samples were carried out after conditioning at 20 ± 2°C and 65% RH. The standard conditions for conditioning samples and conducting tests are established by the ISO 139 standard. Air at a temperature of 20°C and 65% relative humidity has a water vapor pressure of 1515 Pa, and when heated to 47 ± 2°C, the relative humidity in it will be 12.3-16.7%. Air at the maximum permissible limit of 22°C and 67% relative humidity has a vapor pressure of about 1700 Pa, and when heated to 50°C, its relative humidity ranges from 13.4 to 19.4%. If the relative humidity is required to be less than 10% and the temperature does not exceed 50°C, then the source air must have a water vapor pressure of less than 1230 Pa (which corresponds to 53% relative humidity at 27°C).

2.3. Determining the breaking strength and elongation

To study the tensile strength, determine the maximum force required for the destruction of the material, the breaking force (N) and elongation (%) of each fabric sample were determined by averaging the measured values using Statigraph L tensile testing equipment with computer control according to the ISO 5082-82 standard.

2.4. Method for determining the surface density

The surface density was measured according to the ISO 3801 standard. To determine the density from the point sample, rectangular 5 samples wer cut out from the warp and 5 from the weft with a size of 50x100 mm. Counting the number of yarns is performed by removing the warp and weft yarns with a needle or tweezers. From each elementary sample, 25 longitudinal yarns were pulled from each edge. The 50 yarns of the warp and weft obtained were weighed with an accuracy of 0.1 g.

The surface density of a piece of fabric is the mass of fabric, canvas or a piece of a product with an area of 1m^2. The surface density of a piece of fabric, cloth or a piece of a product (m_{AS}), in g / m, is calculated by the formula:

$$m_{as} = \frac{m_{AS}}{L_{AS} \cdot b_{AS}} \cdot 10^3 \quad (1)$$

Where, b_{AS} - the average width of a piece of fabric, canvas or a piece of a product, L_{AS} – length of a piece of fabric.

2.5. Water vapor permeability of the fibers

WVP tests were carried out using the TS EN ISO 14268 standard. Before the tests, all specimens were conditioned for 48 h in a standard atmosphere - 20/65 (temperature T= 20 ± 2°C, humidity RH= 65 ± 5%). A sample was placed over a vessel which contained a solid desiccant – calcium chloride. An experiment took typically not less than 16 h but not higher than 24 h. Then the vessel was weighed to determine the mass of moisture that had passed through the test piece and been absorbed by the desiccant. WVPs were calculated as a percentage of the mass difference.

2.6. Structure of the fabric surface via Scanning Electron Microscope

The fabric surface was scanned using a JSM-6490LV Scanning Electron Microscope. The principle of operation of the microscope is based on the interaction of the electron beam with the surface of the object. The electron beam continuously scans the area of the object's surface, the image of which is formed by the microscope. Depending on which signal detector is currently on, the microscope generates a particular image. The microscope measures the length of the projection of geometric distances on a horizontal plane, i.e. the distance between the corresponding points on the flat and horizontally oriented surface of the object.

2.7. Statistical analysis

Physical and mechanical test results were evaluated statistically using One-Way ANOVA, a descriptive statistical test and the Duncan test by means of the SPSS 25 statistical software package. All data were represented as the mean for five independent measurements. A comparison of means was analyzed by the Duncan test and differences were considered significant when $p<0.05$.

3. Results and Discussion

3.1. Physical and mechanical indicators

Textile materials are diverse in thickness, weight, strength and other indicators. The purpose of the material, the design of the shoe and the scheme of the technological process depend on the properties of the material. Depending on the method of production and purpose of footwear, certain requirements are imposed on textile materials. The surface density, the number of yarns per 10cm, the breaking strength and the breaking elongation in the warp and weft of all fabrics are shown in Table 2. All tests were carried out in five repetitions.

Shoe fabrics, according to the "GOST 19196-93 Fabrics for shoes. General specifications", must have certain physical and mechanical properties for the upper part of the shoe and for linings made of cotton and mixed composition. For the intended manufacture of the upper part of casual shoes with a size of 50x200mm in the warp and weft, the breaking strength must be at least 736 N and 589 N, respectively. And also the breaking elongation at a break in the warp and along the weft must be at least 8% and 9%, respectively.

The textile material for linings and intermediate material should have the following physical and mechanical properties: a size of 50x200mm in the warp and weft, and a breaking strength of at least 215 N and 177 N, respectively.

The elongation at a break along the warp and weft must be at least 4% and 9%, respectively as well. From Table 2, Sample 1 proved that the arithmetic mean for the breaking load and breaking elongation in the warp/weft exceeds the standard indicators for shoes, which is suitable for the upper of shoes, with values of 951.4/548.8 N for the breaking load and 11.5/14.3% for the breaking elongation, respectively. After measuring the physical and mechanical properties of Sample 2, it can be seen that the mean of the breaking load and breaking elongation in the warp/weft was also suitable for shoe uppers. The values of the breaking load was 1414.0/1013.4 N and 24.4/16.3% for breaking elongation, respectively.

As in the discussion for Sample 1 and 2, Sample 3, 4, 7 and 8 are suitable for shoe uppers with higher values than in the standards. For Sample 6, only the weft direction had an acceptable value for the breaking load for shoe uppers. Sample 5, 9 and 10 had lower values than in the standards for the breaking load in both directions, which is not suitable for shoe uppers. For the breaking elongation, Samples 1, 2, 3, 4, 6, 7 and 8 had acceptable values of breaking elongation for shoe uppers. Samples 5 and 9 were not suitable according to the warp values (7.2% and 7.6%, respectively). Sample 10 was not suitable according to the weft direction, with 8.5%, which is lower than the 9% of the standard.

According to the values of Table 2 and the discussion for the lining materials, samples 5, 6, 9 and 10 were completely suitable for lining materials for both the breaking load and breaking elongation properties and also for warp and weft directions. The breaking load values were higher than 215 N and 177 N, and the breaking elongation values were better than 4% and 9%. The adequacy of the results can also be seen in Figure 1 and Figure 2.

The density values of the samples differ from 116.2 g/m^2 to 253.9 g/m^2. The highest density was for sample 1, and the lowest density was for Sample 10. Figure 2 also shows the density diagrams of the samples.

In 100% cotton with different yarn counts of 68/1 warp/weft (sample 5) and 50/1 warp/weft (sample 10) had the lowest breaking load and stretch index. Sample 7 - 27/1 warp 12/1 weft was the most durable among 100% cotton samples. The weft was also the most durable according to the index values. Samples 5 and 10 also had the lowest values for density according to Figure 3. It can be seen from each graph that fabrics with the same composition but with different numbers of yarns differed from each other in their physical and mechanical properties.

The Duncan test in the SPSS program was used to indicate whether there were any differences between the fabrics for physical and mechanical properties. For the surface density, it was observed that Sample 1 had the highest value; but also there were no differences between Sample 1, 3 and 8 statistically. Also, there are no differences between Sample 3, 8, 7 and 2. The other samples had completely different results from each other in statistical evaluation when $p<0.05$.

Sample №	Number of yarns per 10cm of warp	Number of yarns per 10cm of weft	Breaking strength in warp direction (N)	Breaking strength in weft direction (N)	Breaking elongation in warp direction (%)	Breaking elongation in weft direction (%)	Surface density (g/m²)
1	330.0±0.0	220.0±0.0	951.4±33.2	548.8±43.8	11.5±0.3	14.3±0.1	253.9±1.1
2	309.4±1.7	211.8±5.2	1414.0±153.1	1013.4±32.3	24.4±0.4	16.3±0.2	246.5±1.3
3	356.8±10.5	264.2±2.5	1311.9±96.0	1003.8±46.2	19.1±0.6	21.6±0.3	250.6±1.9
4	320.2±1.5	200.8±1.8	1218.2±88.0	857.2±39.8	20.3±0.2	21.7±0.3	225.4±.1.9
5	457.0±16.1	344.4±3.0	488.0±41.8	306.4±12.6	7.2±0.6	11.4±0.8	122.9±5.8
6	311.8±12.3	216.0±3.2	903.7±89.6	570.1±55.2	13.0±0.4	15.4±1.2	234.8±6.1
7	305.4±10.3	153.4±2.4	750.7±13.7	722.5±39.6	11.5±0.6	14.5±0.2	246.6±2.4
8	331.2±1.8	211.2±1.3	1310.3±52.1	670.3±13.0	10.3±0.1	11.7±0.2	250.5±1.1
9	292.0±1.6	119.6±1.1	719.4±1.5	381.4±42.4	7.6±0.4	11.7±0.9	208.2±0.8
10	295.6±0.5	264.0±0.0	336.0±5.6	276.6±19.9	11.7±0.1	8.5±0.2	116.2±1.5

Table 2. Physical and mechanical parameters of samples

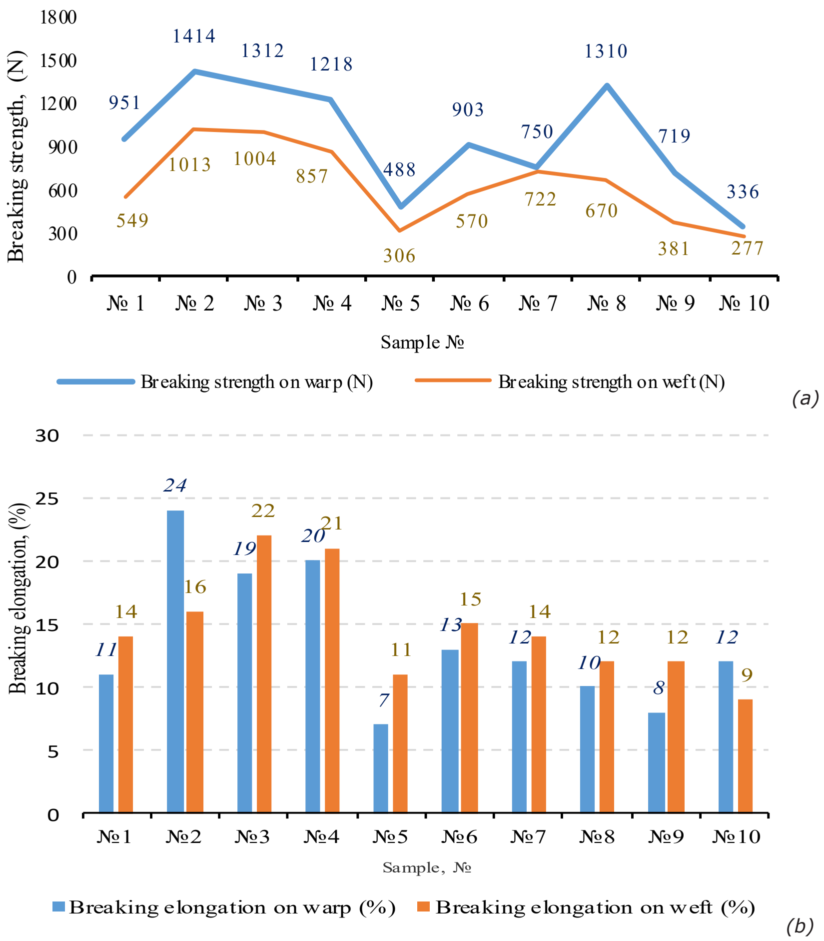

Fig. 1. a) Breaking strength, b) Breaking elongation of samples in the warp and weft directions

For the breaking strength in the warp direction of the fabrics, it was observed that Sample 2 had the highest value and there were differences among the others. Sample 3, 8 and 4 were in second place, and there were no differences between them. When looking at the weft direction, Sample 2 had the highest value again; but also there were no differences between Sample 2 and 3 statistically. The other samples had completely different results from each other, except for Sample 6 & 1 and Sample 5 & 10. Sample 6 & 1 and Sample 5 & 10 showed similarities for each group statistically. It can be said that Sample 2 is more advantageous than the others for breaking strength in both directions.

For the breaking elongation in the warp direction of the fabrics, it was observed that Sample 2 had the highest value and there were differences among others for the breaking strength. The other samples had completely different results from each other, except for Sample 10, 7 & 1 and Sample 9 & 5. These samples are similar to each other according to the Duncan test. When looking at the weft direction, Sample 4 had the highest value; but also there were no differences from Sample 3 statistically. The other samples had different results from each other, except for Sample 7 & 1 and; Sample 9, 8 & 5. These samples are again similar to each other for each group, statistically.

The wear comfort of textile products is an important factor determining consumer satisfaction in selecting clothing. The property of water vapor permeability (WVP) of fabrics is closely related to wear comfort. The term WVP is defined as “the steady water vapor flow in unit time through unit area of a body, normal to specific parallel surfaces” in a standard testing atmosphere. Invisible moisture (water/perspiration) in the form of vapor

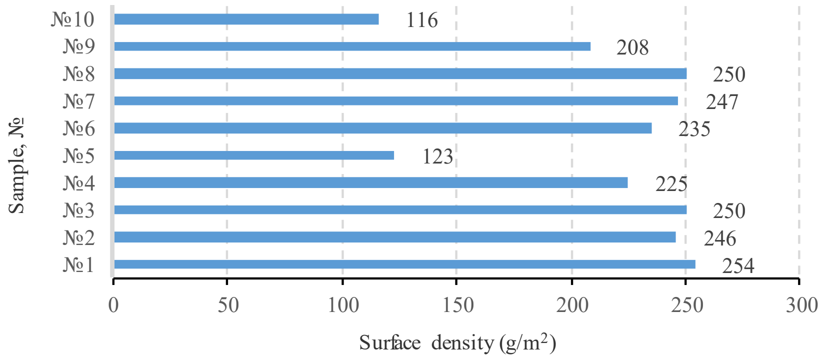

Fig. 2. Surface density of samples

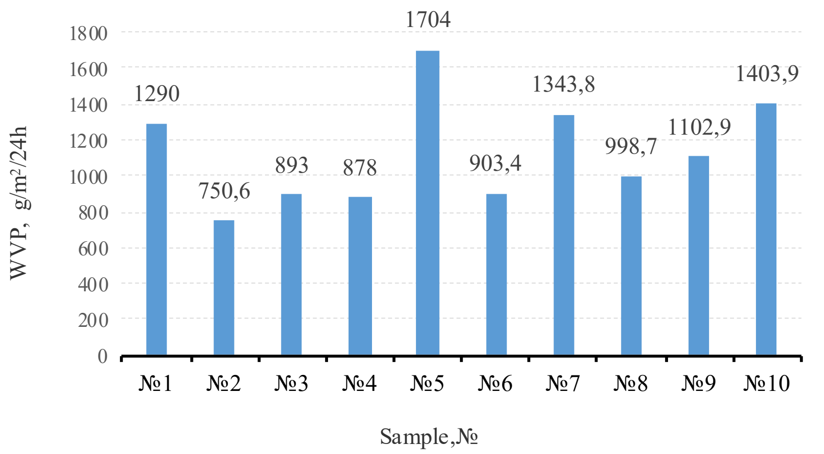

Fig. 3. WVP values of the fabrics

passes through the air gap between yarns in the fabric from the inner to the outer layer. With a high rate of moisture transmission of fabrics, perspiration will not be accumulated on the skin surface. And thus, the skin can be maintained dry and in comfort when users are wearing the fabrics. This property is directly correlated to the hot-wet comfort of the manufactured article by allowing rapid removal of excess moisture and is therefore particularly appreciated in footwear products [26]. The results and Figure 3 indicate the relatively higher WVP values in cotton-based fibers.

3.2. SEM image indicators

The surfaces of the fabrics were visualized using scanning electron microscopy (SEM) to make a comparison between the test samples. Figure 4 (1-10) shows the structures of fibers with different compositions and at different magnifications.

In Sample 1 the surface of the fabric that is scanned is very dense. The fibers make up the weight of the yarn equal to 12.25 microns on average. In Sample 2, the surface of the fabric, turned out to be dense. A visible diagonal scar was formed on the surface of the fabric. The fibers make up the weight of the yarn on average, equal to 11.40 microns. In Sample 3 the surface of the fabric is bound by a report of 2/1, which is dense and soft to the touch. The fibers make up the weight of the yarn, equal to 18 microns on average. In Sample 4, a 2/2 derivative plain weave is the main rep. In the numerator, the degree of gain is in the direction of the base of single overlaps of the first base of the rapport yarn, while in the denominator, the degree of gain is in the direction of the base of single overlaps of the second main rapport yarn. The fabric is soft; and fibers in the yarn average 16.8 microns. In Sample 5, the periodic repeating pattern of the weaves, is constructed from a number of yarns of 5/2. Satin and satin weave make it possible for a very clear printing pattern on the surface and wear resistance of the fabric. The arithmetic mean diameter of the fiber was equal to 18 microns. SEM images of Sample 6 proved that twill weave 3/1 with a pattern of diagonal parallel ribs has a high tear resistance because it has less yarn interweaving per area and the load falls on two threads at once. The diagonal of the fiber was equal to 15 microns. Sample 7 also proves that in twill weave 2/1 with a pattern of diagonal parallel ribs, the diagonal of the fiber is equal to 18 microns. An SEM view of Sample 8 shows that twill weave has a wide application. It is distinguished by pronounced diagonal lines that run along the width of the fabric. The fabric has more yarn per unit area, fewer weaving points and better weave coverage. The arithmetic mean for the diameter of the fibers is 17 microns. Sample 9 also has pronounced diagonal lines that run along the width of the fabric. The fabric has more yarns per unit area, fewer weaving points and better weave coverage. The arithmetic mean for the diameter of the fibers is 19 microns. SEM images of Sample 10 demonstrated the simplest type of weave in which the warp and weft threads overlap each other in every two consecutive overlaps with the least possible rapport. Thus, the rapport of the base was equal to the rapport of the weft. The arithmetic mean for the diameter of the fibers was 19 microns.

Based on the results of this study, it was found that the strength of yarn made from a mixture of cotton and polyester fibers increases with an increase in the content of polyester fibers in the fiber mixture. Fayzullaev et al. (2021) also investigated the effect of changes in the percentage of polyester fiber on the breaking strength and elongation at break and found similar results [25]. Kumpikaitė et al. (2019) aimed to find the relation between the tensile properties of yarns and woven fabrics for different natural raw material and found that the breaking strength in the weft of fabrics containing 86% cotton/14% polyester + 100% flax is higher than for 100% combed cotton + 100% flax fabrics. The opposite results, however, were found for elongation [27].

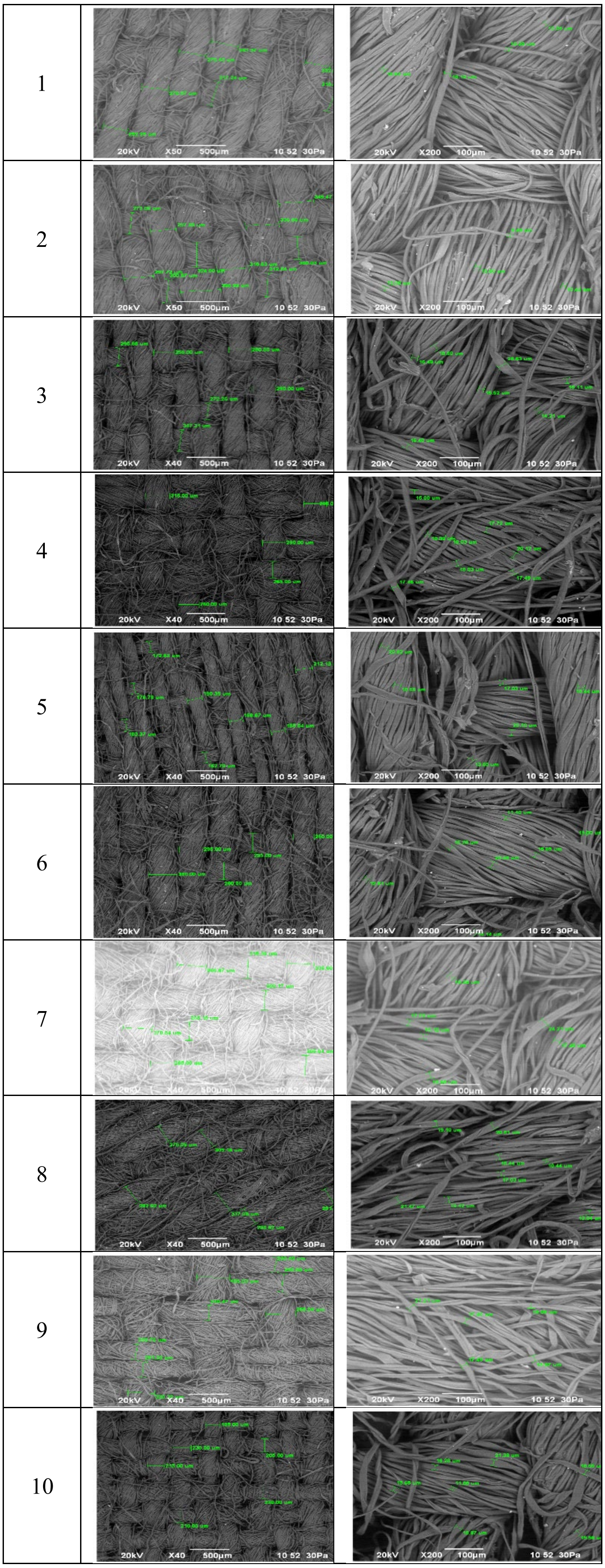

Fig. 4. Structure of the samples 1-10

It is known that the values of the surface density of the fabric affect the weight of the fabric in a positive direction, while the amount of yarn affects it in a negative direction. It can be seen from the studies that the most important parameter when changing the width of the fabric is the type of connection in the fabric braid. The most important parameter of tensile strength is the the density of the weft. On the other hand, it is possible to neglect the weaving factor parameter for this because of the very small effect. It can be seen that the number of connections of layers of fabrics positively affects the tensile strength of all fabrics [28]. According to the results by Makhotkina et al. (2019), a mixed material consisting of 20% cotton-80% polyester has a breaking load in the warp and weft of 1548/697 N [29]. Hence, it can be summed up that the more polyester in the fabric, the higher the breaking strength; but there is s increased rigidity, and poor deformability and flexiblility, and it does not allow air to pass, which does not meet hygiene standards. That's why, the cotton ratios of wearable materials should be increased also taking into consideration the physical and mechanical conformity. In other studies, the ratio of polyester was generally higher than for cotton for obtaining heat-protective properties for an active recreation suit [28,29]. However, in our study, samples of cotton and polyester fabrics were woven for shoes and tested for outdoor activities. Further studies should be conducted on mixed fabric for a better understanding of wear comfort properties.

4. Conclusions

As a result of the studies conducted, it can be seen that fabrics with the same composition but different yarn numbers differ from each other in physical and mechanical properties. It is proved from the research that fabrics № 1, 2 & 8 have high indicators for surface density, while fabrics № 2, 3 & 4 have the best breaking strength and breaking elongation according to the indicators. With an increase in polyester content in the fabric, the breaking load and elongation increase, and the fabric also has an increased surface density, which allows its use for the upper of shoes. With the same composition, an increased composition of cotton in the yarn mixture, changing the weave can achieve the desired result for shoe linings, especially in WVP. Mixed cotton and polyester fabrics when applied to the lining could also be mentioned to improve the comfort of shoes, as cotton absorbs moisture, and polyester brings appropriate attributes such as durability, fast drying, low weight and low cost.

Declaration of Conflicting Interests

The author(s) declare no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

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