TEKSTİL VE KONFEKSİYON

VOL: 34, NO. 1
DOI: 10.32710/tekstilvekonfeksiyon.1121292

Strength and Elasticity Properties of Denim Fabrics Produced from Core Spun Yarns

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ABSTRACT

In parallel to the development of new fiber and yarn technologies, different fibers and yarns have been used in denim fabric production and breaking the market dominance of 100% cotton yarn in the denim market. In recent years, the use of elastane fibers for denim fabric production has rapidly increased thanks to their movement comfort. This study examines the strength and elasticity properties of denim fabrics containing core yarns. For this purpose, different weft yarns were used in the production of denim fabrics. While 100% cotton ring yarn was used as warp for all fabrics, cotton ring, cotton OE-rotor, cotton / PBT-elastane dual-core, cotton / elastane core and cotton-PET / elastane core yarns were used as weft. Within the scope of the study, tensile strength, tearing strength and bursting strength tests were carried out on denim fabrics. In addition, denim fabrics containing core spun yarns were tested for elasticity in the weft direction, which is the direction of core yarns used. When the results were examined, it was seen that tensile strength and breaking elongation are higher for the fabrics containing core yarn in general. Fabrics produced with dual-core yarns have the highest tearing strength values. In addition, the bursting strength values of fabrics containing core yarn are higher than fabrics without core yarn. It was seen that the elasticity values of denim fabrics produced using core yarn are generally above 50%. However, the highest growth values were seen in the fabrics with the highest elasticity.

ARTICLE HISTORY

Received: 25.02.2022
Accepted: 24.01.2023

KEYWORDS

Denim fabric, core yarn, dual-core yarn, fabric strength, elasticity, growth

1. INTRODUCTION

Denim fabrics, which were first produced in the 17th century, began to be widely used in the textile industry with the mass production in the middle of the 19th century [1,2]. Denim fabrics were preferred especially by farmers and for workwear used in mining industry in the first years of their production due to their high strength and high abrasion resistance. Due to the changing fashion perception over time and other features such as aesthetics and wearing comfort added to denim fabrics, the clothes produced from these fabrics have had a significant market share worldwide and still maintain their popularity. In parallel with the development of new fiber and yarn technologies, different fibers and yarns have also been used in the structure of denim fabrics, which used 100% cotton yarn at the beginning of their production [3]. In recent years, elastane fibers have taken their place among the fibers widely used in denim fabric production, especially due to the movement comfort they provide. The use of elastane core yarn in the fabric structure is one of the main processes applied to give elasticity properties to denim fabrics. In denim fabrics, elastane core yarns can be used in only one direction (weft or warp), as well as in both directions. In recent years, with the production of dual-core (double core) yarns, the use of these yarns in denim fabrics has become widespread. Core yarns, also called complex, compound, composite or hybrid yarn, can be defined as a combination of filament and staple fibers. For the production of core yarns, the filaments are fed into the yarn axis as “core” and staple fibers are used to wrap the core filaments as sheath [4,5]. Thanks to its core yarn structure, it is possible to benefit from the high-performance properties of the filaments (core) such as elasticity, movement comfort and strength, depending on the properties of the filaments, as well as the handle properties such as warmth, softness and comfort properties

To cite this article: Balci Kilic. G. 2024. Strength and Elasticity Properties of Denim Fabrics Produced from Core Spun Yarns. *Tekstil ve Konfeksiyon*, 34(1), 32-43.

like moisture absorption and air permeability of the staple fibers (sheath).

Although core yarn production is possible in different spinning technologies such as friction spinning, OE-rotor spinning, air-jet spinning and ring spinning, ring spinning is the most widely used spinning technology for core yarn production. The most important point for core-spun yarn production in all spinning technologies is positioning the filament at the center axis of the yarn. Core yarn can be produced by suitable modification on a conventional ring spinning machine. A feeding device (core spun attachment) is mounted on top of the front rollers. The core filament (or core yarn) passes the core spun attachment and is fed directly into the front roller, while the wrapping (sheath) fibre strand passes the back, middle and front roller [5,6] Due to the advantages of the composite structure, after the core yarns found a wide area of use, various studies were carried out to improve the properties of the core yarns and dual-core yarns were introduced in the 2000s. In the production of dual-core yarn, two separate filaments which have different performance properties are fed to the yarn axis. Generally, a polyester-based filament is preferred as the first core because of its high strength properties, while a polyurethane-based filament is preferred as second core due to its high elasticity properties. Today, the use of core (single and double core) yarns in denim fabric production is quite high and the number of studies in this field is increasing day by day. With the use of core yarn technology in denim construction, researchers firstly aimed to examine the effect of single-core yarns on the properties of denim fabrics [7-13]. In parallel with the developments in core yarn technology, studies focused on examining the effect of using dual-core yarn in denim fabric structure [14-16] and comparatively examining [17-23] the effects of single and dual-core yarns on the performance and elasticity properties of denim fabrics.

In the literature, there are limited studies on comparison for ring, OE-rotor, core-spun, and dual-core spun yarns on denim fabrics' strength and elasticity properties. In this study, ring, OE-rotor, core-spun (two different sheaths), and dual-core spun yarns at the same linear density (Ne 24/1) were produced. These yarns used as weft yarns to make different denim fabrics at the same construction and weaving machine. The same yarn (Ne 24/1, ring) is used as warp in all fabrics. Within the scope of this study, the strength properties of denim fabrics were examined in terms of tensile, tearing and bursting strengths, which are the most important strength parameters for fabrics. Furthermore, elasticity properties were measured by using the two most widely used different test methods and the results were examined comparatively. In addition, elasticity and hysteresis behaviors of denim fabrics containing core yarn under low stresses were also analyzed. It is thought that this study will contribute to the literature in terms of analysing the bursting strength of denim fabrics under the effect of multi-directional forces and comparing two commonly used elasticity test methods. Within the scope of the study, it is also aimed to examine the contribution of the second core to the mechanical and elasticity properties by comparing two different core yarns (with different sheath fibers) and dual-core yarn.

2. MATERIAL AND METHOD

2.1 Material

Within the scope of the study, denim fabrics containing different types of core yarns were produced. Cotton ring yarns were used as warp and cotton ring, cotton OE-rotor, cotton / PBT-elastane dual-core, cotton / elastane core, and cotton-PET / elastane core yarns were used as weft. Figure 1 shows the production of dual-core yarns. Properties of the fibers and yarn production parameters are shown in Table 1. Physical and mechanical properties of yarns are shown in Table 2. The properties of denim fabrics produced with fancy twill (Figure 2) weave structure are given in Table 3.

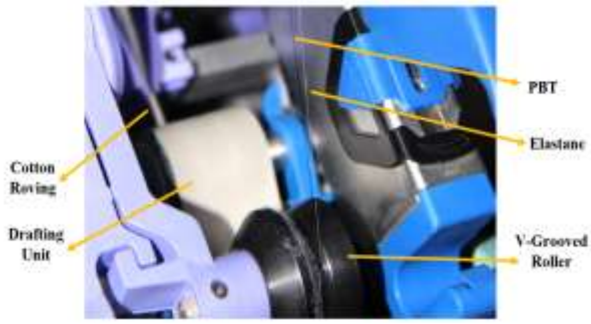

Figure 1. Cotton / PBT-elastane dual core ring yarn production

Table 1. Properties of the fibers and yarn production parameters

Parameter	Specification
Cotton fiber	Staple length: 27.8 mm, Fineness: 4.45 mic., Tenacity: 27.8 gf/tex, Elongation: 6.9%
PBT fiber	24F55dtex
Elastane	78 dtex
Polyester (used in sheath blend)	1,3 dtex 38 mm
Elastane draft ratio	3.5
Production Parameters	Sliver: Ne 0.12, Roving: Ne 0.70, Yarn twist: 900 T/m

Table 2. Physical and mechanical properties of yarns

Sample Code	CVm %	Thin Places -50%	Thick Places +50%	Neps +200 %	H	sH	Breaking load (cN)	Breaking elongation (%)
Ring	14.46	1.5	207.5	256.5	5.21	1.25	362.54	8.05
OE-rotor	14.77	27.5	88.0	307.0	4.74	1.19	259.08	7.92
Cotton+Core (Elastane)	9.51	0.0	6.0	6.5	4.77	0.88	349.22	10.14
Cotton+Dual Core (Elastane-PBT)	11.41	0.0	61.0	57.5	4.79	1.11	393.66	16.23
Cotton/PET+Core (Elastane)	14.25	1.0	190.5	127.5	6.18	1.35	366.18	12.82

Table 3. Production parameters of denim fabrics

Parameter	Definition		
Warp Yarn	Ne 24/1 ring	100% cotton	
	Ne 24/1 ring	100% cotton	
	Ne 24/1 OE-rotor	100% cotton	
Weft Yarn	Ne 24/1 dual core-spun	Sheath: 100% cotton	Core: Elastane (78 dtex)+PBT (55 dtex)
	Ne 24/1 core-spun	Sheath: 100% cotton	Core: Elastane (78 dtex)
	Ne 24/1 core-spun	Sheath: 50% cotton, %50 polyester	Core: Elastane (78 dtex)
Weave Structure	5/1/1/1 3 Fancy Twill Step 4		
Reed Count	70/4		
Loom width (cm)	215		
Warp Setting (ends/cm)	34		
Weft Setting (picks/cm)	25		

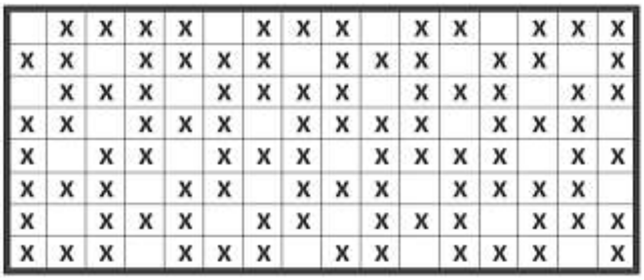

Figure 2. Weave pattern for 5/1/1/1 fancy twill

2.2 Method

In the study, unit weight, warp and weft densities and thickness values were measured to determine the post-production structural properties of denim fabrics. Fabric unit weight tests were carried out according to TS EN 12127 [24] and warp and weft densities were measured by TS 250 EN 1049-2 [25] standards. Fabric thickness measurements were made with R&B Fabric Thickness Tester under 5 g/cm^2 pressure according to TS 7128 EN ISO 5084 [26]. In order to examine the effect of different weft yarns used in denim fabrics on the dimensional properties of the fabrics, dimensional stability test was conducted (TS EN ISO 3759) [27]. For the analysis of dimensional properties, fabric width measurements were also carried out before and after washing. To determine the mechanical properties of the fabrics, tensile and tear strength tests were performed on the Instron 4411 multi-purpose strength tester according to TS EN ISO 13934-1 [28] and TS EN ISO 13937-2 [29] standards, respectively. The bursting strength of denim fabrics was also analyzed within the scope of the study. As it is known, unlike other strength tests, fabric is exposed to multidirectional force effects in bursting strength tests. Considering the purpose and usage area of denim fabrics containing elastane core, one of the main performance features expected from these fabrics is providing comfort of movement. Especially in the knee part of denim trousers, the fabric is under the effect of multi-directional forces, and the bursting strength test is one of the best tests to simulate forces in daily use. In the study, bursting strength tests were performed with the James Heal Truburst2 device according to the hydraulic method (diaphragm method) as described in TS EN ISO 13938-1 standard [30]. The measurement area for bursting strength tests performed with the diaphragm method is 50 cm^2. During the test, the fluid (air) pressure applied to the fabric placed on the elastic rubber (diaphragm) is increased regularly to reach the average bursting strength determined in the preliminary trials in 20±5 seconds, and as a result, the fabric bursting strength (kPa) and height at burst (mm) values are determined. Elasticity is another very important performance feature for elastane core denim fabrics. Elasticity properties of denim fabrics are commonly determined according to ASTM D3107-07 [31] and BS EN 14704-1 [32] standards. In this study, tests were carried out in accordance with both test methods in order to determine the elasticity and growth properties of fabrics and the results were analyzed. According to ASTM D3107-07 standard, the sample width is reduced to 50 mm by removing the thread along the length from the opposite edges of the fabric cut in certain sizes (60 mm x 560 mm). At least 250 mm long reference points are marked on the sample, centering the center point as much as possible (O1) (Figure 3.a). A 1.36 kg (3 lb) block is attached to the tip of the cut specimen and tension is applied three times for 5 seconds. After the fabric is exposed to the applied tension for the fourth time for 30 minutes, the distance (A) between the reference points is measured and recorded (Figure 3.b) and the elasticity value of the fabric (%) is determined according to Equation (1). In order to determine the permanent elongation (growth) value of the fabric, the tension on the fabric is removed and the fabric is laid on a flat surface without tension and the distance (B) between the reference points is measured (Figure 3.c). The growth values at the end of the specified periods (such as 30 minutes, 1 hour, 2 hours etc.) are calculated according to Equation (2).

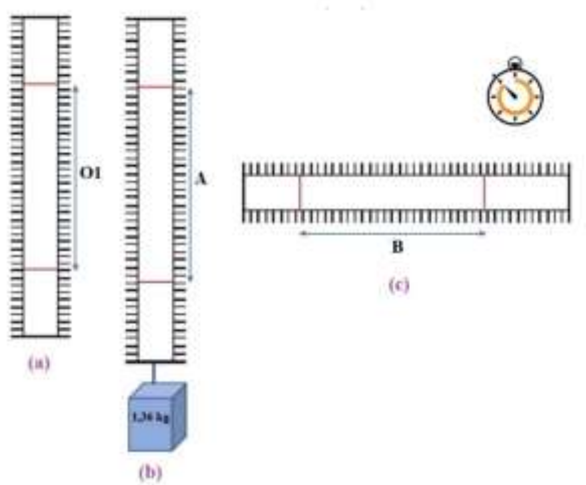

Figure 3. Calculation of fabric elasticity and growth (ASTM D3107-07)

$$Elasticity\ (stretch)(\%) = \left(\frac{A-O1}{O1}\right) x\ 100 \quad \text{Equation (1)}$$

$$Growth\ (\%) = \left(\frac{B-O1}{O1}\right) x\ 100 \quad \text{Equation (2)}$$

Where O1 denotes the distance between the reference points, A denotes the distance between reference points after a load has been applied to the sample for a specified period of time and B denotes the distance between the reference points for the specified times after the load on the sample is removed.

According to BS EN 14704-1 Method A, the sample cut in dimensions of 50 mmx300 mm is placed between the jaws of the strength tester. The measuring length is 200 mm, and the test speed is 100 mm/min. Reference points showing the measurement length are marked on the sample and placed between the jaws. A load of 6 N/cm is applied to the sample for 5 cycles. Then the sample is placed on a flat surface and the distance between the reference points is measured after a certain time (1 min and 30 min). Elasticity (%) and growth (%) values are calculated in accordance with the standard.

In order to compare the elasticity test methods, the elasticity (%) value calculated according to the ASTM D 3107-07 standard was also calculated according to the BS EN 14704-1. In addition, elastic recovery (%) values for both methods were calculated and analyzed.

In the study, elasticity (mm/N), stiffness (mm), plasticity (µm) and hysteresis (J) parameters were measured using the EMTEC TSA (Tissue Softness Analyzer) device to determine the elasticity and hysteresis behavior of denim fabrics under low stress. Table 4 and Figure 4 gives the parameters that EMTEC TSA device measures.

The tests in the study were carried out under standard atmospheric conditions (20±2 ºC temperature and 65±4% relative humidity) specified in TS EN ISO 139. According to the standards, five fabric samples were tested for all tests.

3. RESULTS AND DISCUSSION

Within the scope of the study, the effect of different weft yarns on the properties of denim fabrics was investigated. Statistical analyzes were performed using the SPSS 24 program with a confidence interval of 95%.

3.1 Structural Properties (Unit Weight, Weft and Warp Density and Fabric Thickness)

The unit weights of denim fabrics before and after washing are given in Figure 5. When Figure 5 is examined, while there was no significant difference between the unit weights of denim fabrics produced using cotton (ring and OE-rotor) weft yarns, the differences between the unit weights of denim fabrics produced using core and dual-core weft yarns are quite high and statistically significant (p=0.00). When elastane core yarn is used as weft yarn in denim fabrics, an increase of 16%-26% was observed in fabric unit weights. The results are in line with the studies by Erbil et al. (2021) and Üte (2019). The reason of this situation is that the shrinkage values of the fabrics produced from core yarns containing elastane are quite high after washing as seen in Figure 6. The highest difference in unit weights belongs to denim fabrics produced from cotton+elastane single-core weft yarns, which has the highest shrinkage values.

The weft and warp density (/cm) and thickness (mm) values of denim fabrics after washing are given in Table 5. When examined, it is seen that warp density and fabric thickness values of denim fabrics produced from cotton ring and OE-rotor weft yarns are lower than fabrics produced from core yarns (p=0.00). The main reason for this is the lower packing density values of core yarns [18,34]. Therefore, since these yarns can be compressed more due to air gaps between fibers and the forces caused by the fabric shrinkage they are exposed to after fabric production, they will show a denser placement in the fabric structure.

Table 4. Explanations of the parameters measured by EMTEC TSA [33]

Parameter		Definition
D	**Stiffness or "in-plane stiffness" or "stretch"**	(lower value = higher stiffness)
E	**Elasticity (mm/N)**	the higher the value, the more elastic is the material, the lower the value, the less flexible.
H	**Hysteresis (J)**	the higher the hysteresis, the more energy is generated during the recovery of the material.
P	**Plasticity or "Fitting" (µm)**	the closer the value to zero "0", the better the recovery of the material. P gives an information about the recovery characteristics of a fabric: to what extend does a material bounce back into its original position after deformation with a defined load.

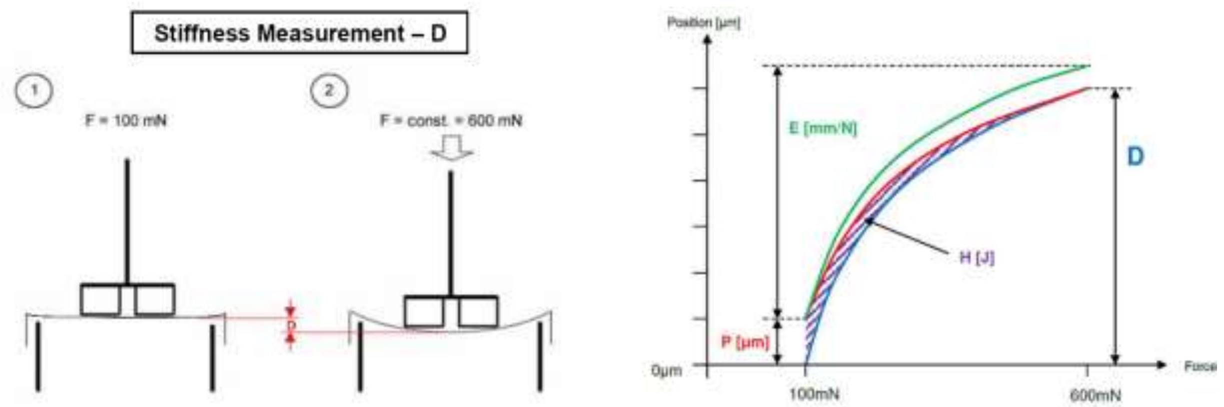

Figure 4. Measurement of the stiffness, elasticity, hysteresis and plasticity values [33]

Table 5. Density and thickness values of denim fabrics

Sample code	Weft density (/cm)	Warp density (/cm)	Fabric thickness (mm)
Ring	24.4	39.8	0.54
OE-rotor	24.4	38.8	0.57
Cotton+Dual Core (Elastane-PBT)	24.6	56.8	0.79
Cotton+Core (Elastane)	24.6	55.8	0.76
Cotton/PET+Core (Elastane)	24.6	55.8	0.75

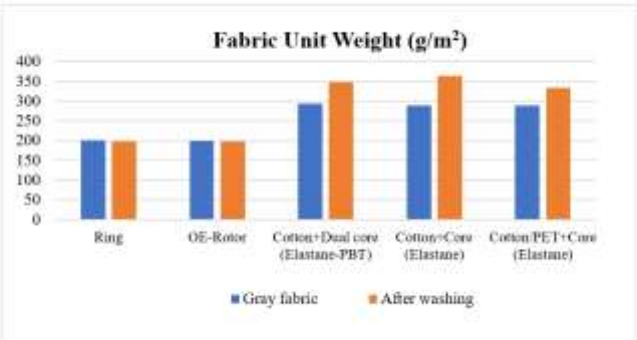

Figure 5. Fabric unit weights (g/m^2) before and after washing

3.2 Dimensional Properties

When the dimensional change values of denim fabrics are examined, it is seen that denim fabrics containing single-core and dual-core weft yarn are quite higher than denim fabrics containing 100% cotton ring and 100% cotton OE-rotor weft yarn, as in unit weight test results (Figure 6). Positive dimensional stability test results indicate the fabric elongation for the measured test direction, and negative results indicate shrinkage for the measured test direction, and it is seen that there is shrinkage in both directions for all fabrics in general (except for the cotton ring and cotton OE-rotor warp direction). It is seen that the dimensional change (shrinkage) in the weft direction is quite high (between 11-18%) in denim fabrics produced from elastane core yarns (for both single-core and dual core yarns) as weft yarn. The shrinkage value in fabrics produced from cotton-elastane core yarns is higher than in fabrics produced from cotton/PET+elastane core yarns and dual-core yarns. When the results are analyzed statistically, it is seen that this difference is statistically significant ($p<0.05$).

Usable fabric width is one of the most important parameters for mass production of garments. When the widths of denim fabrics produced using the same weaving production parameters are examined, it is seen that the fabric width of the denim fabrics produced using 100% cotton (ring and OE-rotor) weft yarn is considerably higher than the denim fabrics produced using core (single and double) weft yarn (Figure 7) ($p=0.00$). This situation can be explained by the lower packing density and higher compressibility of core yarns [18]. When the shrinkage values after washing in denim fabric widths are examined, it is seen that the highest shrinkage value belongs to denim fabrics produced from single-core cotton-elastane yarns. The fabric width shrinkage values are in parallel with the dimensional stability values in the weft direction (R=0.99).

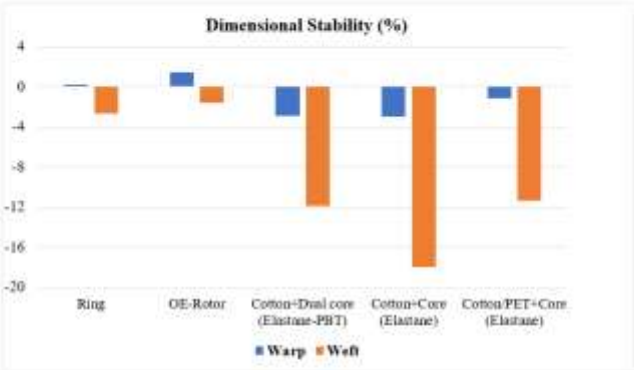

Figure 6. Dimensional stability of denim fabrics in warp and weft direction (%)

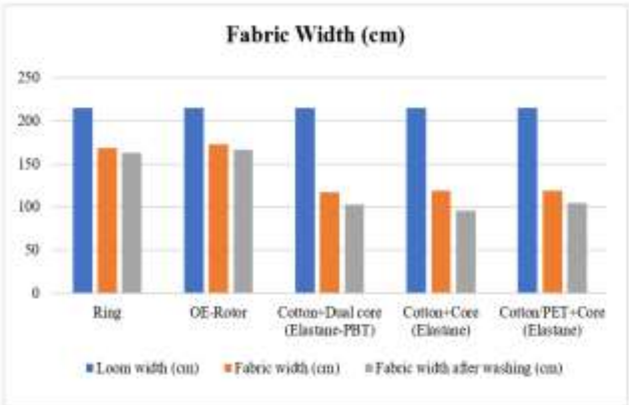

Figure 7. Denim fabric widths before and after washing

3.3 Tensile Strength and Breaking Elongation

The tensile strength (N) and breaking elongation (%) of denim fabrics produced using different weft yarns are shown in Figure 8. In warp direction, while the tensile strength values of denim fabrics containing elastane core yarn changes between approximately 675-795 N, breaking elongation values are 24-27%. In weft direction, the values for these fabrics are 245-345 N and 89-103%, respectively.

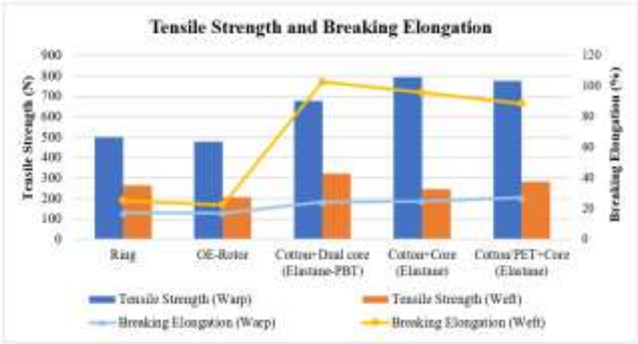

Figure 8. Tensile strength and breaking elongation of denim fabrics

When the tensile strength values of denim fabrics in the warp direction are examined, it is seen that fabrics containing elastane core weft yarn have higher values than fabrics containing both of 100% cotton ring and 100% cotton OE-rotor weft yarn. The reason of this situation is the increase of warp density in denim fabrics containing core yarn as seen in Table 5. When the strength and elongation values in the weft direction, which is the direction in which different weft yarns are used, are examined, it is seen that the differences are lower than in the warp direction. The fact that small differences between the tensile strength values in the weft direction can be explained by the loss of staple fibers in the yarn cross-section [18] and the lower differences between weft densities. It is seen that the highest tensile strength and breaking elongation values in the weft direction belong to denim fabrics produced using dual-core yarn, while the lowest values belong to denim fabrics produced using 100% cotton OE-rotor yarn. The second core in dual-core yarns supports the increase in strength. Tensile strength test results in the weft direction are parallel with yarn strength test results as seen in Table 2 [35]. In addition, fabric tensile strength test results are compatible with previous studies [17-18]. When the effect of using different weft yarns on tensile strength and breaking elongation is analyzed statistically, it is seen that it is statistically significant for both directions (weft and warp) ($p<0.05$). SNK test results have revealed that tensile strength values for warp and weft directions have been separated into five groups according to material in Table 6 and Table 7. When the SNK test results for breaking elongation are examined, it is seen that they have been divided into three groups for warp direction and they have been divided into three groups for weft direction (Table 8 and Table 9).

Table 6. SNK results for tensile strength values of denim fabrics (warp direction)

Material	*N*	1	2	3	4	5
OE-rotor	5	480.22				
Ring	5		499.76			
Cotton+Dual Core (Elastane-PBT)	5			676.22		
Cotton/PET+Core (Elastane)	5				774.18	
Cotton+Core (Elastane)	5					793.78
	Sig.	1.000	1.000	1.000	1.000	1.000

Table 7. SNK results for tensile strength values of denim fabrics (weft direction)

Material	*N*	1	2	3	4	5
OE-rotor	5	205.76				
Cotton+Core (Elastane)	5		244.36			
Ring	5			264.64		
Cotton/PET+Core (Elastane)	5				284.18	
Cotton+Dual Core (Elastane-PBT)	5					323.44
	Sig.	1.000	1.000	1.000	1.000	1.000

Table 8. SNK results for breaking elongation values of denim fabrics (warp direction)

Material	*N*	1	2	3
OE-rotor	5	17.16		
Ring	5	17.48		
Cotton+Dual Core (Elastane-PBT)	5		24.31	
Cotton+Core (Elastane)	5		24.89	
Cotton/PET+Core (Elastane)	5			27.28
	Sig.	0.517	0.246	1.000

Table 9. SNK results for breaking elongation values of denim fabrics (weft direction)

Material	*N*	1	2	3	4	5
OE-rotor	5	22.50				
Ring	5		25.32			
Cotton/PET+Core (Elastane)	5			88.61		
Cotton+Core (Elastane)	5				95.70	
Cotton+Dual Core (Elastane-PBT)	5					102.72
	Sig.	1.000	1.000	1.000	1.000	1.000

3.4 Tearing Strength

The tearing strength values of elastane core denim fabrics are equal to approximately 45 N in warp direction for all fabrics, while it changes between 26-42 N in weft direction (Figure 9). Performing statistical analysis for the tearing strength values of the denim fabrics showed that differences are not statistically significant for warp direction but statistically significant for weft direction in which different yarns were used. When pairwise comparisons are made in the weft direction, it is seen that there is no significant difference between the tearing strength values of denim fabrics produced using single core weft yarn (cotton+elastane and cotton/PET+elastane) ($p>0.05$). Tearing strength values in weft direction of denim fabrics produced from dual-core yarns are higher than single-core (cotton+elastane and cotton/PET+elastane) fabrics because the second core supports the yarn breaking strength, and this difference is statistically significant ($p<0.05$). SNK results for the tearing strength of fabrics (for warp and weft direction) are seen in Table 10 and Table 11. For warp direction, tearing strength of fabrics have been divided into two groups. It was determined that fabrics produced from ring and OE-rotor weft yarrns are in the same group, while fabrics containing elastane yarns are in the other group. For weft direction, tearing strength of fabrics have been seperated into four groups. It was determined that fabrics produced from both single-core yarns are in the same group and that each of other fabrics are in different groups for weft direction.

Table 10. SNK results for tearing strength values of denim fabrics (warp direction)

Material	*N*	1	2
Ring	5	41.60	
OE-rotor	5	41.60	
Cotton/PET+Core (Elastane)	5		44.80
Cotton+Core (Elastane)	5		44.80
Cotton+Dual Core (Elastane-PBT)	5		44.80
	Sig.	1.000	1.000

Table 11. SNK results for tearing strength values of denim fabrics (weft direction)

Material	*N*	1	2	3	4
OE-rotor	5	15.99			
Cotton/PET+Core (Elastane)	5		25.60		
Cotton+Core (Elastane)	5		25.60		
Ring	5			32.00	
Cotton+Dual Core (Elastane-PBT)	5				41.59
	Sig.	1.000	1.000	1.000	1.000

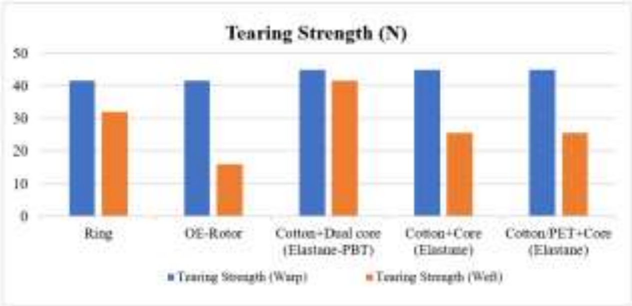

Figure 9. Tearing strength of denim fabrics

3.5 Bursting Strength

Bursting strength (kPa) and height at burst (mm) values of denim fabrics are given in Figure 10. From Figure 10, it is seen that the bursting strength values of all fabrics produced using core (single and dual) yarn are different and higher than fabrics produced from 100% cotton yarn (ring and OE-rotor). The effect of weft yarn type on bursting strength is also statistically significant ($p<0.05$). SNK test results for bursting strength and height at burst are given in Table 12 and Table 13, respectively. SNK test results have revealed that bursting strength values have been separated into three groups. It was determined that denim fabrics produced from ring and open-end rotor weft yarns are in one group, cotton+elastane and cotton+dual-core yarns are in the other group and cotton/PET+elastane yarn is in the last group. The highest bursting strength values belong to the fabrics produced from single-core cotton/PET+elastane weft yarns, and the highest bursting height values belong to the fabrics produced from dual-core weft yarns which have the highest elongation values in the tensile strength test as seen in Figure 8. The reason why the bursting strength test results are not completely parallel with the breaking strength test results is that force is applied to the fabric in both directions in bursting strength tests. For this reason, both weft and warp yarns contribute greatly to the results in bursting strength tests. According to the tensile strength test results, the fabric with the highest total of weft and warp breaking strength is the fabric produced from cotton/PET+elastane single-core weft yarns, and similarly, this fabric has the highest bursting strength value. When the correlation between the total tensile strength (weft+warp) values and bursting strength values is examined, it is seen that the correlation coefficient is statistically significant ($R=0.85$).

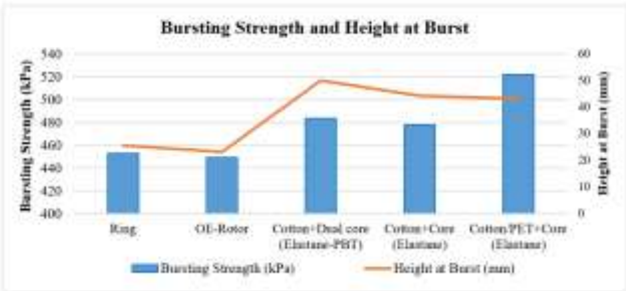

Figure 10. Bursting strength and height at burst of denim fabrics

Table 12. SNK results for bursting strength values of denim fabrics

Material	*N*	1	2	3
OE-rotor	5	448.96		
Ring	5	452.92		
Cotton+Core (Elastane)	5		478.20	
Cotton+Dual Core (Elastane-PBT)	5		483.74	
Cotton/PET+Core (Elastane)	5			522.02
Sig.		0.702	0.594	1.000

Table 13. SNK results for height at burst values of denim fabrics

Material	*N*	1	2	3	4
OE-rotor	5	23.06			
Ring	5		25.62		
Cotton/PET+Core (Elastane)	5			43.12	
Cotton+Core (Elastane)	5			44.28	
Cotton+Dual Core (Elastane-PBT)	5				49.96
	Sig.	1.000	1.000	0.177	1.000

3.6 Elasticity and Growth

Elasticity is one of the most desired performance properties for denim fabrics containing elastane. In elasticity tests, elasticity (stretch) value shows the elongation (%) that occurs in the fabric under the load, and growth (%) value shows the permanent elongation that occurs in the fabric after the applied load is removed at the end of the determined time. Figure 11 and Figure 12 give the elasticity (%) and growth (%) values obtained in tests performed according to ASTM D3107-07 and BS EN 14704-1 standards. When the elasticity values are examined, it is seen that the highest values for both methods belong to the fabrics produced from cotton+elastane single-core weft yarns, while the lowest values belong to the fabrics produced from cotton/PET+elastane single core weft yarns. While the elasticity values of denim fabrics containing core weft yarn vary between 62% and 84% according to ASTM D 3107-07 standard, these values vary between 43% and 54% according to BS EN 14704-1 standard. This difference between elasticity values is due to the method differences. While the load (1.36 kg=13.34 N) applied to the fabric for 30 minutes according to ASTM D 3107-07 standard, the load (6 N/cm= 30 N) is applied to the fabric in 5 cycles according to the BS EN 14704-1 standard, and therefore the exposure time of the fabric to the applied load is also reduced. It is thought that this situation causes the lower elasticity results obtained in the BS EN 14704-1 test method. The elasticity values obtained by both methods show that the denim fabrics used in the study provide the movement elasticity (power stretch) [1,36]. When the growth (%) values are examined, it is seen that parallel results are obtained for both methods, as in the elasticity results. For both methods and all time periods (1 min, 30 min, 2 hours), the highest growth values belong to the denim fabric with the highest elasticity values, and the lowest permanent elongation values belong to the denim fabric with the lowest elasticity values. The difference between elasticity and growth values of core denim fabrics is statistically significant ($p<0.05$). SNK test results for elasticity and growth values according to ASTM D3107-07 and BS EN 14704-1 standards are given in Table 14-Table 19. According to SNK test results for elasticity and growth values for ASTM D 3107-07 standard, each fabric takes place in different groups (Table 14-Table 16). SNK results for elasticity and growth (30 min) according to BS EN 14704-1 standard have been divided into two groups (Table 17 and Table 19). It was determined that denim fabrics produced from cotton+elastane and cotton+dual-core weft yarns are in the same group, while denim fabric with single core cotton/PET+elastane weft yarns is in the other group. Within the scope of the study, elastic recovery values for 30 minutes were also calculated using elastic elongation and permanent elongation values. For both methods, it is seen that the elastic recovery values of the core denim fabrics are in the range of 90%-92% and there is no statistically significant difference between the elastic recovery values for the denim fabrics examined in the study ($p>0.05$). The results of elasticity, growth and elastic recovery are compatible with previous studies [5,37].

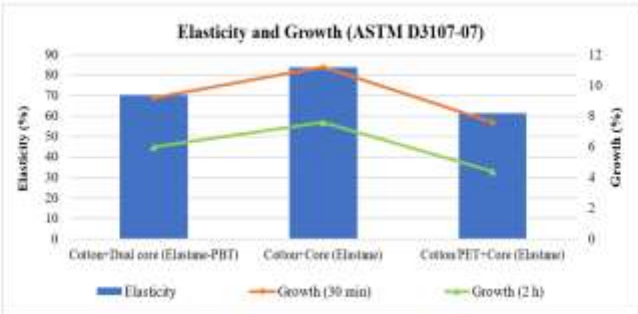

Figure 11. Elasticity (%) and growth (%) values in weft direction of denim fabrics (ASTM D3107-07)

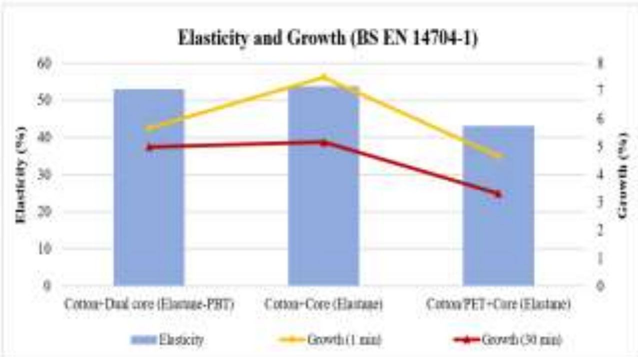

Figure 12. Elasticity (%) and growth (%) values in weft direction of denim fabrics (BS EN 14704-1)

Table 14. SNK results for elasticity values of denim fabrics (ASTM D3107-07)

Material	*N*	1	2	3
Cotton/PET+Core (Elastane)	5	61.60		
Cotton+Dual Core (Elastane-PBT)	5		70.40	
Cotton+Core (Elastane)	5			84.00
Sig.		1.000	1.000	1.000

Table 15. SNK results for 30 min. growth values of denim fabrics (ASTM D3107-07)

Material	*N*	1	2	3
Cotton/PET+Core (Elastane)	5	7.60		
Cotton+Dual Core (Elastane-PBT)	5		9.20	
Cotton+Core (Elastane)	5			11.20
Sig.		1.000	1.000	1.000

Table 16. SNK results for 2 hours growth values of denim fabrics (ASTM D3107-07)

Material	*N*	1	2	3
Cotton/PET+Core (Elastane)	5	4.40		
Cotton+Dual Core (Elastane-PBT)	5		6.00	
Cotton+Core (Elastane)	5			7.60
Sig.		1.000	1.000	1.000

Table 17. SNK results for elasticity values of denim fabrics (BS EN 14704-1)

Material	*N*	1	2
Cotton/PET+Core (Elastane)	5	43.03	
Cotton+Dual Core (Elastane-PBT)	5		52.74
Cotton+Core (Elastane)	5		53.63
Sig.		1.000	0.560

Table 18. SNK results for 1 min. growth values of denim fabrics (BS EN 14704-1)

Material	*N*	1	2	3
Cotton/PET+Core (Elastane)	5	4.68		
Cotton+Dual Core (Elastane-PBT)	5		5.67	
Cotton+Core (Elastane)	5			7.50
Sig.		1.000	1.000	1.000

Table 19. SNK results for 30 min. growth values of denim fabrics (BS EN 14704-1)

Material	*N*	1	2
Cotton/PET+Core (Elastane)	5	3.33	
Cotton+Dual Core (Elastane-PBT)	5		5.00
Cotton+Core (Elastane)	5		5.17
Sig.		1.000	0.682

3.4 Elasticity and Hysteresis under Low Stress

Elasticity (mm/N), stiffness (mm), hysteresis (J) and plasticity (µm) values of denim fabrics containing elastane under low stress are given in Table 20. When Table 20 is examined, it is seen that the elasticity and stiffness values of denim fabrics containing different core yarn constructions in the weft direction are quite close to each other and the lowest values belong to the fabrics produced from cotton+elastane single-core yarns. For these parameters, the differences between fabrics are not statistically significant ($p>0.05$). When the hysteresis and plasticity values are examined, it is seen that the highest values belong to the fabrics produced from cotton+elastane single-core yarns and the differences between the fabrics are statistically significant ($p<0.05$). This means that fabric produced from cotton+elastane single-core yarns consumes more energy when returning to original size, that is, its recovery ability is less. It is thought that the higher growth values of the fabrics produced from cotton+elastane single-core yarns in the tests performed with standard test methods (ASTM D 3107-07 and BS EN 14704-1) support this result.

Table 20. Elasticity parameters measured under low stress

Sample code	Elasticity (E) (mm/N)			Stiffness (D) (mm)			Hysteresis (H) (J)			Plasticity (P) (µm)		
	Face	Back	**Mean**	Face	Back	**Mean**	Face	Back	**Mean**	Face	Back	**Mean**
Cotton+Dual Core (Elastane-PBT)	1.88	1.86	**1.87**	1.88	1.95	**1.92**	42.7	48.1	**45.40**	-60.8	-86.6	**-73.7**
Cotton+Core (Elastane)	1.80	1.82	**1.81**	1.86	1.91	**1.89**	50.7	56.6	**53.65**	-72.0	-91.0	**-81.5**
Cotton/PET+ Core (Elastane)	1.85	1.87	**1.86**	1.89	1.94	**1.92**	45.2	52.3	**48.75**	-59.8	-84.2	**-72.0**

4. CONCLUSION

Strength and elasticity properties are the most important performance parameters expected from denim fabrics. This study investigated the effect of different weft yarns (ring, OE-rotor, single-core and dual-core) on elasticity and strength properties of denim fabrics. In this context, the strength properties of denim fabrics were analyzed by breaking, tearing and bursting strength tests, and their elasticity properties were analyzed using the two most widely used test methods (ASTM D3107-07 and BS EN 14704-1) and under low stress. In addition, the effect of using different weft yarn structures on the structural and dimensional properties of fabrics was also evaluated. The main results of the study can be summarized as follows: The use of elastane core yarn in the weft direction has significantly increased the density in this direction and fabric unit weight. It was remarkable that 16%-26% fabric unit weight increased for single-core and dual-core weft yarn structure, in parallel with previous studies. It was seen that the dimensional change (shrinkage) in the weft direction is quite high (between 11-18%) in denim fabrics produced from single-core and dual core yarns. When the results were analyzed in terms of tensile strength and elongation, it was seen that the highest values in the weft direction belong to denim fabrics produced using dual-core yarn, while the lowest values belong to denim fabrics produced using 100% cotton OE-rotor yarn. For the tearing strength, it was seen that there was no statistically significant difference for warp direction which has the same yarn construction for all fabrics, but there was a statistically significant difference in weft direction in which different yarn structures are used. The tearing strength values in weft direction of the denim fabrics produced from dual-core yarns were higher than the fabrics produced from single-core yarns, as in the tensile strength test results, due to the second core support the breaking strength. Bursting strength results, like other strength test results, show that fabrics with elastane core yarn structure have quite different behavior compared to other fabrics (cotton ring and cotton OE-rotor). On the other hand, bursting strength test results were not completely parallel with other strength test results. The reason for this is that the fabric is under the effect of multi-directional forces in the bursting strength test. Therefore, both weft and warp yarns contribute simultaneously to the bursting strength of fabrics. When the elasticity values are examined, for ASTM D 3107-07 standard: 62%-84%, and for BS EN 14704-1 standard: 43%-54%. This difference is due to the difference between test methods. For both methods, it is seen that the elastic recovery values of denim fabrics are: 90%-92%. The elasticity results show that the denim fabrics produced from single and dual-core yarns used in the study have power stretch, and thus provide movement elasticity and comfort.

REFERENCES

1. Kurban NS, Babaarslan O. 2019. Literature review on the properties of super stretch denim fabrics. *Journal of Textiles and Engineer* 26(113), 104-115.
2. İTKİB. 2012.Türkiye'nin denim kumaş ve konfeksiyon dış ticareti üzerine istatistiki bilgiler 2011 ve Dünya denim pantolon pazarına bakış. İTKİB Genel Sekreterliği AR-GE ve Mevzuat Şubesi.
3. Paul R. 2015, Denim and jeans: an overview. In P.R. Editor (Ed.), *Denim: Manufacture, Finishing and Applications.* United Kingdom: Woodhead Publishing, 1-11.
4. Lawrence CA. 2003. *Fundamentals of Spun Yarn Technology*. New York: CRC Presss LLC.
5. Chen T. 2011. Compound yarns. In R. H. G. Editor (Ed.), *Specialist Yarn and Fabric Structures: Developments and applications.* United Kingdom: Woodhead Publishing, 1-20.
6. Gowda RVM. Advances in yarn spinning and texturizing. In R. A. and A.D. Editors (Ed.), *Technical textile yarns: Industrial and Medical Applications.* United Kingdom: Woodhead Publishing, 56-90.
7. Mezarcioz S, Oğulata RT, Nergis A. 2020. Investigation of elasticity and growth properties of denim fabrics woven with core and siro spun yarn. Tekstil ve Konfeksiyon 30(4), 312-320.
8. Shaw VP, Mukhopadhyay A. 2021. Impact of abrasion on strength, elasticity and elastic recovery properties of stretch-denim fabric. *International Journal of Clothing Science and Technology*, online published.
9. Sarıoğlu E, Babaarslan O. 2017. A comparative strength analysis of denim fabrics made from core-spun yarns containing textured microfilaments. *Journal of Engineered Fibers and Fabrics* 12(1), 22-32.
10. Sarıoğlu, E, Babaarslan O. 2019. Porosity and air permeability relationship of denim fabrics produced using core-spun yarns with different filament finenesses for filling. *Journal of Engineered Fibers and Fabrics* 14, 1-8.
11. Özdil, N. 2008. Stretch and bagging properties of denim fabrics containing different rates of elastane. *Fibres & Textiles in Eastern Europe* 16(1) 66, 63-67.
12. El-Ghezal S, Babay A, Dhouib S, Cheikhrouhou M. 2009. Study of the impact of elastane's ratio and finishing process on the mechanical properties of stretch denim. *The Journal of the Textile Institute* 100(3), 245-253.
13. Sinha SK, Bansal P, Maity S. 2017. Tensile and elastic performance of cotton/lycra core spun denim yarn. *Journal of the Institution of Engineers (India): Series E* 98(1), 71-78.
14. Daşan Y, Babaarslan O. 2020. Stretch and physical properties of weft stretch denim fabrics containing elastane and filament yarn. *Journal of Textile Science & Fashion Technology* 4(4), 1-10.
15. Ertaş OG, Zervent Ünal B, Çelik N. 2016. Analyzing the effect of the elastane-containing dual-core weft yarn density on the denim fabric performance properties. *The Journal of The Textile Institute* 107(1), 116-126.
16. Yildirim N, Akgül E, Türksoy HG. 2021. Selection of dual-core yarn production parameters for denim fabric by using MULTIMOORA method. *The Journal of The Textile Institute* 1-9, online published.-web sitesi adresi/DOI yok
17. Bedez Ute T. 2019. Analysis of mechanical and dimensional properties of the denim fabrics produced with double-core and core-spun weft yarns with different weft densities. *The Journal of the Textile Institute* 110(2), 179-185.
18. Erbil Y, Babaarslan O, Islam M R, Sirlibaş S. 2021. Performance of core & dual-core cotton yarn structures on denim fabrics. *Journal of Natural Fibers* 1-14, online published. web sitesi adresi/DOI yok
19. Sarıoğlu E. 2019, June. the effect of core-spun yarn type and layout of these yarns in the fabric on stiffness properties of denims. In Ö.Ç.

Editor (Ed.) Proceedings of the 5th International Conference on Engineering and Natural Science (408-413), Prague, Czech Republic.

20. Bedez Ute, T, Kadoglu, H. 2019. The effect of single and dual-core yarns produced with different core materials on the elasticity and recovery properties of denim fabrics. *Textile & Leather Review* 2(4), 174-182.
21. Sabry M, Bakry M. 2017. The Effect of Different Weft Yarn Production Technique on the Pilling Property of Jeans Fabrics. *International Design Journal* 7(3), 161-169.
22. Türksoy HG, Yıldırım N, Ertek Avcı M. 2021. Comparative evaluation of some comfort properties of denim fabrics including dual-core yarns containing wool and elastane yarn. *The Journal of the Textile Institute* 1-8, online published. web sitesi adresi /DOI yok
23. Baykuş D, Oğulata, RT. 2019. Effects of using core weft yarn on elasticity and residual extension properties of denim fabrics. *Journal of Textiles and Engineer*, 26(116), 372-380.
24. TS EN 12127. Textiles- Fabrics- Determination of mass per unit area using small samples. Turkish Standards Organization, Turkey, 1999.
25. TS 250 EN 1049-2. Textiles-Woven fabrics-Construction-Methods of analysis-part 2 determination of number of threads per unit length. Turkish Standards Organization, Turkey, 1996.
26. TS 7128 EN ISO 5084. Textiles-Determination of thickness of textiles and textile products. Turkish Standards Organization, Turkey, 1998.
27. TS EN ISO 3759. Textiles - Preparation, marking and measuring of fabric specimens and garments in tests for determination of dimensional change. Turkish Standards Organization, Turkey, 2012.
28. TS EN ISO 13934-1. Textiles- Tensile properties of fabrics- Part 1: Determination of maximum force and elongation at maximum force using the strip method. Turkish Standards Organization, Turkey, 2013.
29. TS EN ISO 13937-2. Textiles- Tear properties of fabrics- Part 2: Determination of tear force of trouser- shaped test specimens (Single tear method). Turkish Standards Organization, Turkey, 2002.
30. TS EN ISO 13938-1. Textiles - Bursting properties of fabrics - Part 1: Hydraulic method for determination of bursting strength and bursting distension. Turkish Standards Organization, Turkey, 1999.
31. ASTM D3107-07. Standard test methods for stretch properties of fabrics woven from stretch yarns. American Society for Testing and Materials, USA, 2019.
32. BS EN 14704-1. Determination of the elasticity of fabrics - Part 1: Strip tests. British Standards Institution, United Kingdom, 2006.
33. Emtec. 2022. Tissue Softness Analyzer User Manual. Germany: Emtec Electronic GmbH.
34. Erbil Y, Islam R, Babaarslan O, Sırlıbaş S. 2020. Effect of structural changes on the cotton composite yarn properties. *Journal of Natural Fibers*, 1-9, online published. web sitesi adresi /DOIyok
35. Balci Kilic G. 2018. Analysing the physical and mechanical properties of core-spun yarns, *Annals of the University of Oradea Fascicle of Textiles*, *Leatherwork* 19(2), 13-18.
36. Wang X, Liu X, Hurren C. 2008. Physical and mechanical testing of textiles. In J. H. Editor (Ed.) *Fabric Testing.* United Kingdom: Woodhead Publishing, 90-124.
37. Babaarslan O, Sarioğlu E, Çelik Hİ, Artek Avci M. Denim Fabrics Woven with Dual Core-Spun Yarns. In M. K. S. Editor (Ed.) *Engineered Fabrics.* United Kingdom: IntechOpen