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Investigation of Performance Properties of Denim Fabrics Containing Cotton/Sustans® Blend Rotor Yarn

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ABSTRACT

It is common to use open-end rotor yarn in the production of denim fabric, which is preferred by people of all ages and social status due to its durability and comfort. Recently, the demand for stretch denim fabrics that can take the body's shape due to the elastic fibers in its structure has been increasing. However, producing elastane-containing yarns in the rotor spinning system is not as practical as ring spinning. For this reason, this study aimed to use the staple Sustans® fibers with high elasticity in the rotor spinning system together with cotton fibers and reflect the good elasticity and elongation properties of Sustans® fibers to the rotor yarns and denim fabrics. In the study, the staple Sustans® fibers based on PTT (Polytrimethylene Terephthalate) were spun with cotton fibers in the rotor spinning system. Then denim fabrics were produced using these yarns in the weft. Later, strength (breaking and tear), dimensional stability (dimensional change after washing, fabric elasticity and growth), abrasion resistance and pilling tests were applied to the produced denim fabrics. Thus, the effects of using Sustans® fibers on the strength, dimensional stability, abrasion and pilling properties of denim fabrics were analyzed. As a result of the study, the dimensional change and growth values after washing were developed by using Sustans®. Although good dimensional stability was observed in the samples, the degree of elasticity was lower than expected. The use of Sustans® at rates of 50% and above improved the pilling values of the fabrics. In addition, it has been determined that the use of Sustans® in terms of abrasion resistance has a more positive effect at the end of long wear periods.

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1. INTRODUCTION

It is known that natural fibers are insufficient to meet the increasing demand, and this situation causes an increase in the consumption of synthetic fibers. Compared to natural fibers, it is predicted that the production of synthetic fibers will increase even more in the future. Recently released world fiber consumption data supported that the production of synthetic fibers will increase. The synthetic polymer industry is largely based on fossil fuels. The ability of petroleum-based plastics to survive in nature for many years brings environmental pollution and sustainability concerns. Some studies stated that 9 million tons of plastic waste reach oceans annually [1]. Regenerated fibers, in which relatively natural resources are used in their production, are not likely to be an alternative to synthetic fibers in terms of production amounts. The increase in synthetic fiber production is unavoidable due to factors such as production factors, costs, and fiber properties. In this case, it is essential to prefer sustainable resources in the polymer industry [2].

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The textile industry emits 1.2 billion tons of CO_2 equivalent of harmful gas per year. During the production processes of Sorona®, 30% less energy is consumed than Nylon 6 and 40% less than Nylon 6.6. Besides, 63% and 56% lower gas emitted than Nylon 6 and Nylon 6.6, respectively. 37% of the Sorona® polymer, introduced as an example of a more sustainable synthetic polymer by DuPont company, is produced from vegetable-based renewable natural resources such as corn. Therefore, it is shown as an example of more sustainable synthetic polymer production that causes lower greenhouse gas emissions [3, 4, 5, 6].

PTT forms the phthalates branch of aromatic polyesters together with Polyethylene Terephthalate and Polybutylene Terephthalate. PTT polymer is produced with the polycondensation reaction of pure terephthalic acid or dimethyl terephthalate with 1,3 propanediol (PDO). This polymer was firstly synthesized in 1941, and its commercialization was realized in 1990 by Shell Chemicals using the ethylene oxide hydroformylation method [4, 7, 8]. DuPont company produced its own PTT with the Sorona brand using PDO obtained by fermentation from corn starch [4]. PTT fibers have favorable properties such as good elasticity and dimensional stability, easy cleaning, easy dyeing, good color fastness, low static electricity, and soft-touch compared to most other fibers. Sustans® is the staple fiber produced by Haixing company using Sorona® polymer [9].

The denim fabric has become a popular cultural item in recent years. Because it is known in all societies and it is used in many areas such as upholstery, home textile products, and advertising products, especially in the production of clothes. Denim fabrics are expressed in the world with names such as "jeans", "blue-jeans", "jeans wear" and "sportswear".

Classic denim fabrics are produced from high twisted and strong cotton yarns. These fabrics are structurally dense, tough, and durable, and the yarns used in the warp are indigo dyed. However, with the effect of changing fashion trends and technological possibility, denim fabrics are produced in different ways, such as weft dyed denim fabrics or dyed with other processes. Synthetic fibers or cotton-synthetic blend yarns are frequently used in denim production [10, 11]. Increasing usage area changes the features expected from denim fabrics. For example, denim trousers are used frequently in different seasons and weather conditions.

Consequently; many properties such as strength, pilling, dimensional stability, abrasion resistance, and clothing comfort are expected to be good. For this reason, it is quite common to use fibers different from cotton and stretch yarns containing elastane in denim fabrics today. Elastic yarn requirement in denim fabrics is provided with multi-component core yarns. Core components except elastane are generally used to reduce the growth [12].

The literature review has shown a gap regarding the production of yarn and fabric from staple PTT fibers. Most of the studies on PTT fibers are related to polymer production, pure or bicomponent filament yarn production, and elasticity properties of these yarns [4, 7, 13, 14, 15, 16, 17, 18, 19]. Previous studies on the subject of research are as follows.

Zhao et al. investigated the factors affecting the return of fabrics produced from PTT filaments to their original shape after wrinkle. For this purpose, three different samples having different densities, including 8.3 tex PTT filament yarns, were produced. The researchers stated that the temperature had little effect on wrinkle recovery because of the fabric's tight structure and the filament crystallization rate [20].

Lou et al. studied the elasticity of woven fabrics containing PTT / PET bicomponent filament fibers. In the study, PET, PET/PTT-PET bicomponent, and PTT / PET bicomponent yarns were used as weft yarn in woven fabric. Researchers investigated the effects of fiber ratio, twist level, weft density, and weave type. It was noted that increasing PTT / PET fibers' ratio up to 66.7% increases elasticity property significantly; besides, increasing twist level prevented the curling in filaments, thereby considerably affecting the elasticity of fabrics [21].

Yan et al., examined swimwear fabrics, including Sorona-based fibers. The study stated that PET / Spandex and PA / Spandex yarns were mainly used in swimwear fabrics, but these yarns had defects such as easy deformation and short life. As an alternative to spandex-containing fabrics, swimwear fabrics were produced from PA / PTT / Spandex yarns and compared. According to research, the elasticity, elastic recovery, and plastic deformation properties of the new fabric structure were better than the commercialized fabrics. Besides, it had excellent explosion resistance and lower water absorbency [22].

Wang et al. investigated the elastic elongation properties of PTT / PET bicomponent fibers in their study. The study examined the effect of different nozzle structures and PTT/PET ratios on the elasticity properties. The curving degree of samples was predicted depending on the fiber cross-section and properties. As a result, they found that with the increase in PTT ratio in the existing structure, the elasticity feature also increased, but the nozzle types did not significantly affect elasticity. They also revealed a positive correlation between curving degree and elasticity [15].

Zhao et al., investigated the use of PTT / PET bi-component fibers instead of PU / PA to produce seamless knitted garments. As a result, they have shown that PTT / PET bicomponent fibers exhibit high elongation and elastic recovery. The researchers stated that the use of PTT / PET yarns provided more controlled and efficient knitting. Besides, the dimensional stability and anti-wrinkle properties of fabrics produced from PTT / PET bicomponent yarns were better than PU / PA [23].

Jin et al., examined the breaking elongation, elasticity, wrinkle recovery, pilling resistance, water absorption, and air permeability of Sorona/Cotton blended seamless knitted fabrics. As a result of the research, it was emphasized that an increase in Sorona fiber ratio improved the elongation, elasticity, crease recovery and pilling resistance properties of knitted samples [24].

Jianbo et al. Investigated the functional properties of fabrics knitted with modal / cashmere / Sustans® fiber blended spun yarn with antibacterial properties. As a result of the research, it was noted that the fabrics produced had positive antibacterial properties, as well as good pilling resistance and warm keeping properties [25].

Özkan et al. aimed to spin Sustans® fibers together with cotton in an open-end (OE) rotor spinning system. In this way, it is desired to transfer the favorable properties of Sustans® fibers such as good elasticity, good dimensional stability, low static electrification, and soft hand to the staple yarn structure. Researchers successfully produced OE yarns using Sustans®/Cotton blends in the open-end rotor system and were stated the 50/50% blend ratio as the optimum value for the process [9].
Recently, the demand for stretch denim fabrics, containing elastic yarns, that can stretch and take the body shape easily has been increasing. The open-end spinning technique is a highly productive method, and OE yarns are frequently used in denim fabric production. For this reason, this study aimed to spin the Sustans® fibers with high elasticity in the rotor spinning system together with cotton and thus reflect the good elasticity and elongation properties of Sustans® fibers to the rotor yarns and denim fabrics. With this study, it is also aimed to contribute to the lack of literature on yarn and fabric production with staple PTT fibers. In this context, the effects of the positive properties of PTT fibers such as elasticity and dimensional stability on yarn and fabric structure when these fibers are in staple form were investigated. In the study, the staple Sustans® fibers based on PTT (Polytrimethylene Terephthalate) were spun with cotton in the rotor spinning system. Then denim fabric was produced using these yarns in the weft. Breaking strength and elongation, tear strength, dimensional stability (dimensional change after washing, fabric elasticity and growth), abrasion resistance and pilling tests were applied to the produced denim fabrics. According to the results, the effects of Sustans® fibers in weft on the properties of denim fabrics were analyzed statistically and compared.

2. MATERIAL AND METHOD

2.1. Material

In this study, Sustans® fibers and American cotton were used as raw materials. Cotton fiber properties were determined with the Uster HVI Spectrum (High Volume Instrument). The average measurement results of cotton fiber provided from nine different bales. The Sorona® polymer-based Sustans® fibres supplied by Chinese Haixing Material Technology Company. The fineness and length data of Sustans® fibers were obtained from the manufacturer. The strength and elongation tests were carried out using a 2.5 N capacity load cell, 10 mm jaw distance and 50 mm / min speed by Instron 5564 universal tensile tester. Tests results represented as the average of 20 tests. Cotton and Sustans® fiber properties are given in Table 1 [9].

Table 1. Cotton and Sustans® fiber properties

Properties	Results	
	Mean	%CV
Sustans® (SU)		
Linear Density (dtex)	2.00	-
Length (mm)	38.00	-
Mean Breaking Strength (cN/tex)	31.80	1.65
Mean Breaking Elongation (%)	35.73	24.96
Cotton (CO)		
Spinning Consistency Index)	136.00	6.69
Fiber Fineness (Micronaire)	4.01	5.08
Maturity	0.87	1.63
Length (mm)	29.26	1.87
Uniformity (%)	82.28	1.70
Short Fiber Index (shorter than 12.7 mm) (%)	8.20	6.57
Strength (cN/tex)	30.87	4.70
Elongation (%)	7.27	3.51
Moisture (%)	7.30	3.99
Reflectance Degree	76.16	1.46
Yellowness Degree (+b)	7.37	8.00
Color Grade (C Grade)	41-1	-
Trash Count	40.22	32.08

Table 2. Yarn production stages and machines

Production Stages	Machine Brand-Model-Year		Process Output
Bale Opener-Mixer	Rieter B 34 - 1989		Blended fiber
Fine Opener-Cleaner	Rieter B 5/5 ERM - 1989		Homogeneous blend
Carding	Trützschler DK 760 - 1995		Sliver - Ne 0.13
Drawing	Rieter RSB D50 - 2017		Sliver - Ne 0.11
Drawing	Rieter RSB 51 - 1991		Sliver - Ne 0.11
Open-End Rotor Spinning	Saurer Schlafhorst Autocoro 9- 2017		Yarn - Ne 8,25 (71.60 tex)
	Rotor Type / Diameter	T 640 BD/40 mm	
	Navel Type	K 4-A	
	Torquestop Type	30-0G (Green)	
	Opening Roller Type	B 174DN	
	Twist Coefficient (αe)	4,5	
	Rotor speed (rev / min)	60.000	
	Opener (rev / min)	7000	

2.2. Method

In the research, Cotton / Sustans® blend yarns and 100% cotton yarn were produced with the same production parameters. In blended yarns, the cotton ratios were 70%, 60%, 50%, 40% and 30%, respectively. The number of the produced yarns was set to Ne 8.25 (71.6 tex).

The first fiber blend was obtained by feeding fiber bales in pieces to the bale opener. The following steps were carried in the yarn production process; bale opening, blending, opening-cleaning, carding, the first passage of drawing, the second passage of drawing and spinning. In the production, the homogeneity of blending was increased in the fine opener and cleaner machine. The carded slivers in the mentioned blending ratios were passed through two passage drawing processes. The obtained slivers were spun to yarn in an open-end rotor spinning frame. Four bobbins of yarn were produced for each blending ratio. Yarn production stages, used machines and spinning parameters are indicated in Table 2 [9].

Yarn breaking strength and elongation tests were performed in Uster Tensorapid 3 V7.0 device according to the ISO 2062: 2009 standard. In the measurements, ten tests were applied to four bobbins from each blending ratio. Denim fabrics were produced by the Dornier AWSE 4 / E D model air-jet weaving machine. Ne 8.25 rotor warp yarns, which are rope dyed in the classical denim production style, are used in the fabrics. Weaving was carried out sequentially on the same machine with 10 m lengths of warps. Weaving production parameters are listed in Table 3.

Table 3. Weaving production parameters

Parameters	Values
Comb number	68/4
Comb width	175 cm
Total number of warps	4760 pcs
Machine speed	520 rpm
Warp density	27 pcs / cm
Weft density	17 pcs / cm
Weave type	Twill - 3/1 Z
The raw material of warp yarn	%100 Cotton
Warp yarn number	Ne 8.25 (71.60 tex)
Warp yarn type	OE rotor

Burning, washing, pre-drying and sanforizing processes were applied to the woven fabrics as finishing processes. These processes have been implemented in a single machine line, which is a combination of different machine parts and provides continuous operation. Besides, all fabrics were treated as one piece under the same conditions. The burning process was applied in the Osthoff brand machine with 90 ° burner angle, 30 mm burner distance, 9 bar burner pressure and 35 m / min processing speed. Acetic acid was used as an acidity regulator to provide a pH range of 5-5.5 in the washing process. Then, the fabrics were pre-dried by passing through drums at 110 °C. Finally, sanforizing is applied with the felt-blanket system at 35 m / min speed.

Breaking strength and elongation (ISO 13934-1: 2013), tear strength (ISO 13937-1: 2000), dimensional change after washing (ISO 3759: 2011, ISO 6330: 2012), elasticity and growth (ASTM D 3107-07: 2015) tests were applied to fabric samples. Elasticity and growth tests were only applied in the direction of the fabric showing elastic properties. Elasticity and growth tests were conducted to fabrics both in finished form and after washing at 60ºC. The dimensional change after the washing was tested at 40 °C and 60 °C separately. Washings at 40°C and 60°C were carried out according to Table B.1 4N and 6N methods of the related standard. Fabric production parameters are kept constant in all blending ratios. Density (EN 1049-2:1993), weight (ISO 3801:1977), and finished product width (EN 1773: 1996) tests were also performed to determine the effect of different weft yarn types on these properties.

Both the abrasion resistance and pilling tests were performed on the James H. Heal brand and Nu-Martindale model abrasion and pilling tester. The tests were applied on the reverse side of the fabrics because the produced Cotton/Sustans® blend yarns were used in the weft of the fabrics and the weft density was higher on the reverse side of the fabrics. Abrasion resistance tests were applied on the basis of ISO 12947-3: 1998 standard method. The fabrics were abraded up to 25000 cycles using 9 kPa pressure and woolen abrasion fabric. The loss of mass was determined by weighing at every 5000 cycles. Pilling tests were applied according to the ISO 12945-2: 2000 standard method. The test samples were evaluated at the end of 125, 250, 500, 1000, 2000, 5000 and 7000 cycles according to the EMPA SN 198525 W3 standard photograph series. VeriVide brand pilling evaluation cabinet was used for visual evaluation. For both methods, 3 samples from each fabric type were tested. Test results of all samples for pilling tests are indicated. In terms of abrasion resistance, the average of 3 samples belonging to each fabric type is reflected in the results.

Pilling test results are evaluated by visual scale and are not numerical data. Therefore, statistical analysis was not applied for the pilling test results, the results of all test samples were stated and interpreted. Considering that the use of Sustans® will affect the fabric stiffness and also the fabric stiffness will affect the abrasion resistance, the circular stiffness test was also performed on the fabrics according to the ASTM D 4032-94: 2001 standard.

In statistical analysis, firstly, Kolmogorov-Smirnov (K-S) normality analysis was applied. The relationship between Sustans® ratio and fabric properties was examined with Pearson correlation analysis for the normally distributed data, and Spearman correlation analysis was used for the other data sets. According to the correlation analysis, the level of significant relationships between fiber blend ratio and data sets was defined according to the power of the coefficients [26]. Analysis of variance (ANOVA) was applied to the normally distributed data, and the Kruskal Wallis test [27, 28] was used for the other data sets.

3. RESULTS AND DISCUSSION

According to the Kolmogorov-Smirnov (K-S) test, the data except for the density, warp tear strength of the fabrics, and the growth after washing at 60ºC showed normal distribution. Since all the growth test results in the finished state are 0.4%, statistical analysis could not be done. The correlation analysis results between Sustans® ratio and fabric properties are given in Table 4.

ANOVA test results of normally distributed data are given in Table 5, and Kruskal Wallis test results of data that do not show normal distribution are given in Table 6.

3.1. Finished Fabric Width, Weight and Densities

It is seen in Tables 5 and 6 that the weft yarn blending ratio has a statistically significant effect on the weight, width and warp density of finished fabric ($p < 0.05$). However, there was no significant effect of blending ratio on weft density. The width of 100% cotton fabric is greater than the width of all fabrics containing Sustans®, and it differs statistically from them (Figure 1). Fabrics containing 40%, 50% and 60% Sustans® yarns formed a separate group from fabrics containing 30% and 70% Sustans® yarns. Fabrics containing 40%, 50% and 60% Sustans® yarns have the lowest finished widths. Besides, these three fabrics had the highest warp density values (Figure 1). As a result, while there was no difference between weft densities according to blending ratio, a weak correlation and statistically significant effect was found between warp densities and Sustans® ratio. A statistically significant decrease in the width of the finished fabric was observed with the use of sustans fibers in the weft. The reduction in fabric width has increased the warp density. Parallel to the increase in warp density, an increase was observed in fabric weight (Figure 2).

Table 4. Results of correlation test between Sustans® ratio and fabric properties

Fabric Properties	Correlation Coefficient	Significance Value (p)
Pearson Correlation Results		
Weight	0.408*	**0.025**
Finished Width	-0.843**	**0.000**
Tensile Strength (Weft Direction)	-0.009	0.967
Tensile Strength (Warp Direction)	0.348	0.096
Elongation at Break (Weft Direction)	0.982**	**0.000**
Elongation at Break (Warp Direction)	-0.065	0.763
Tear Strength (Weft Direction)	0.085	0.695
Dimensional Change (Weft Direction-40ºC)	-0.948**	**0.000**
Dimensional Change(Weft Direction-60ºC)	-0.802**	**0.000**
Dimensional Change (Warp Direction-40ºC)	0.549*	**0.018**
Dimensional Change (Warp Direction-60ºC)	0.326	0.187
Elasticity (Finished)	-0.651**	**0.003**
Elasticity (60ºC)	-0.873**	**0.000**
Circular Stiffness	0,215	0,314
Abrasion-5000 Cycle	-0,062	0,805
Abrasion-10000 Cycle	-0,202	0,421
Abrasion-15000 Cycle	-0,343	0,164
Abrasion-20000 Cycle	-0,436	0,070
Abrasion-25000 Cycle	**-0,469***	**0,050**
Spearman Correlation Results		
Weft Density	0.054	0.775
Warp Density	0.323	0.081
Tear Strength (Warp Direction)	0.622**	**0.001**
Growth (60ºC)	-0.469*	**0.049**

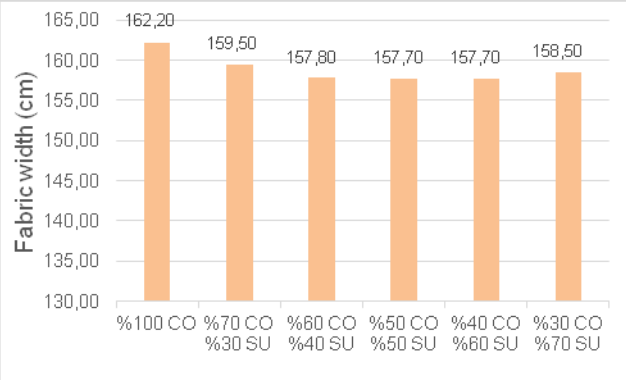
* Correlation is significant at 0.05 level. ** Correlation is significant at 0.01 level.

Table 5. ANOVA test results

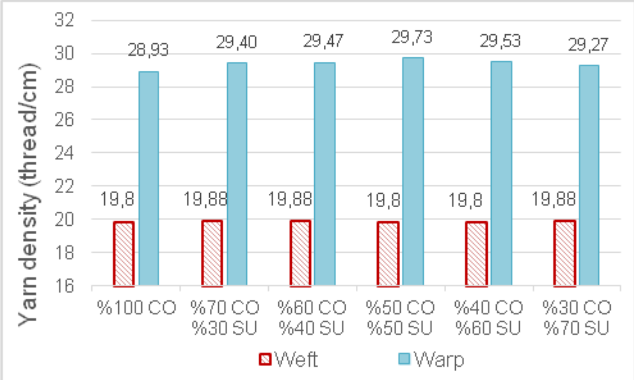
Fabric Properties	Sum of Squares	Degree of Freedom	Mean Squares	F Value	Significance Value (p)
Weight	396.87	29	43.21	5.74	**0.001**
Finished Width	77.19	29	15.40	1885.50	**0.000**
Breaking Strength Weft Direction	41975.03	29	5565.24	9.44	**0.000**
Breaking Strength Warp Direction	57051.89	29	4975.54	3.71	**0.012**
Breaking Elongation Weft Direction	251.89	29	49.58	299.45	**0.000**
Breaking Elongation Warp Direction	16.71	29	2.38	11.85	**0.000**
Tear Strength Weft Direction	27.98	29	0.78	0.78	0.575
Dimensional Change- Weft Direction (40º C)	9.53	17	1.81	43.32	**0.000**
Dimensional Change Weft Direction (60 º C)	6.72	17	1.00	6.90	**0.003**
Dimensional Change Warp Direction (40º C)	4.91	17	0.70	6.05	**0.005**
Dimensional Change Warp Direction (60º C)	3.22	17	0.47	6.72	**0.003**
Elasticity Finished	2.10	17	0.33	9.40	**0.001**
Elasticity (60ºC)	3.16	17	0.50	9.47	**0.001**
Circular Stiffness	5402479	29	449843.71	3.42	**0.018**
Abrasion-5000 Cycle	0.97	17	0.05	0.88	0.522
Abrasion-10000 Cycle	1.20	17	0.04	0.43	0.821
Abrasion-15000 Cycle	1.86	17	0.06	0.42	0.827
Abrasion-20000 Cycle	3.06	17	0.13	0.64	0.671
Abrasion-25000 Cycle	5.51	17	0.26	0.76	0.595

Table 6. Kruskal Wallis test results

Fiber Blending Ratio	Weft Density		Warp Density		Warp direction tear strength		Growth (60°C)	
	Mean Rank	Sig. Value (p)	Mean Rank	Sig. Value (p)	Mean Rank	Sig. Value (p)	Mean Rank	Sig. Value (p)
%100 CO	12.50	0.572	4.70	**0.001**	14.30	**0.001**	13.50	0.299
%70 CO %30 SU	18.10		14.90		7.50		10.50	
%60 CO %40 SU	18.10		17.30		6.40		7.50	
%50 CO %50 SU	13.10		25.60		18.40		10.50	
%40 CO %60 SU	13.10		19.70		18.40		7.50	
%30 CO %70 SU	18.10		10.80		28.00		7.50	



(a)



(b)

Figure 1. a) Fabric width - blend ratio graph b) Yarn density - blend ratio graphs

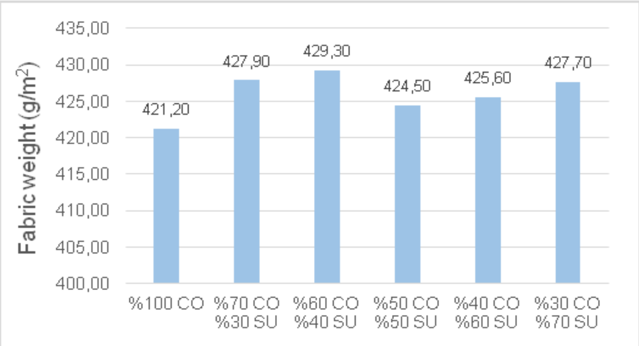
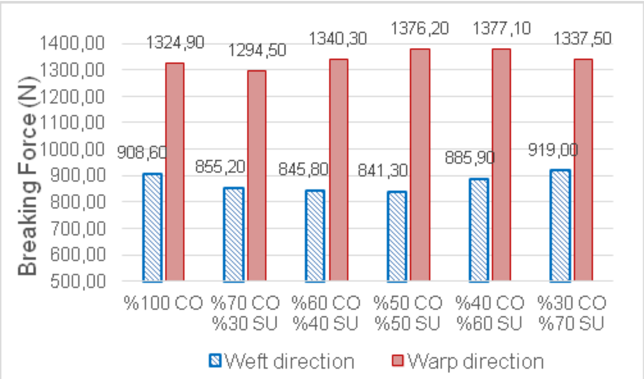


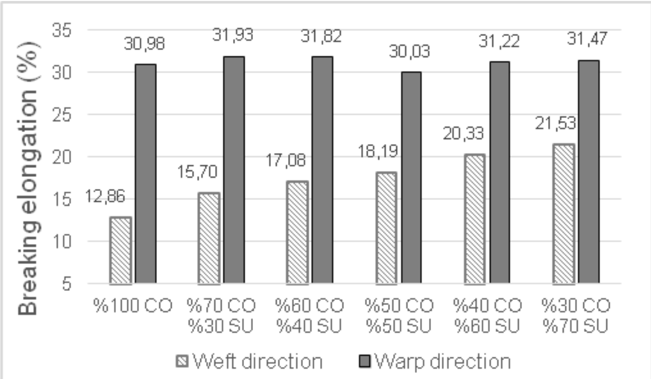
Figure 2. Fabric weight - blend ratio graph

3.2. Fabric Tensile Strength and Elongation

As a result of the ANOVA test (Table 5), it was seen that the blending ratio had a statistically significant effect on the tensile strength and elongation in both directions ($p < 0.05$). The average of the fabric test results is given in Figure 3, and the strength-elongation graphs of the weft yarns are shown in Figure 4 [9]. Although the fabrics have the same warp yarns, it has been determined that the differences in warp strength and elongation are related to the warp density. Similar trends are seen in warp density and warp direction strength graphs.



(a)



(b)

Figure 3. a) Fabric breaking strength graph b) Fabric breaking elongation graph

As shown in Figure 4-a, with the use of Sustans®, there has been a slight decrease in yarn breaking strength values compared to 100% cotton yarn. This situation is explained by the inability of Sustans® fibers to be sufficiently incorporated into the yarn structure in blended yarns. Although the strengths of the used cotton and Sustans® fibers are very close to each other, as the Sustans® ratio increases (60% and 70% Sustans® ratios) in the blended yarns, fiber clumps (Figure 5) has formed inside the rotor and spinning has become difficult [9]. The trend seen in yarn strength values is also reflected in the weft direction tensile strength of the fabrics.

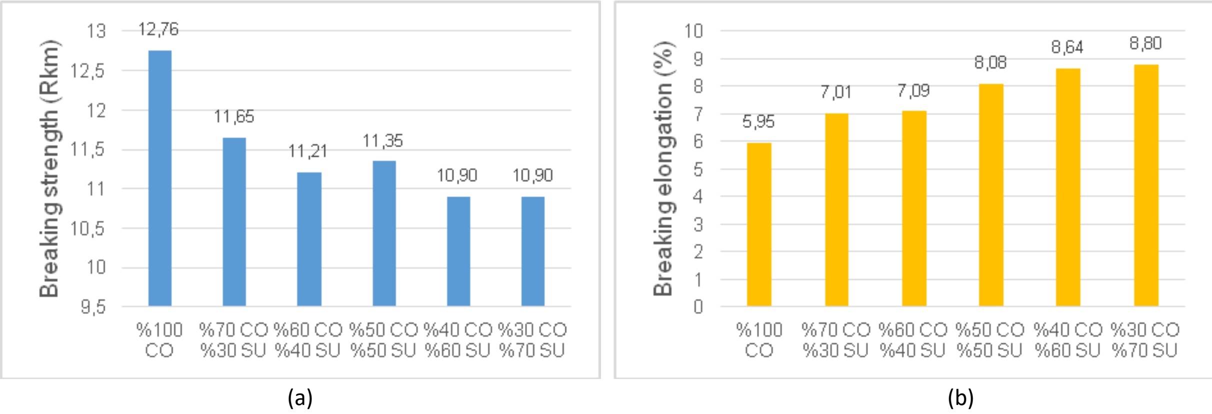


Figure 4. a) Yarn breaking strength graph b) Yarn breaking elongation graph

Figure 5. Fiber clumps inside the rotor for 60% and 70% Sustans® ratios [9]

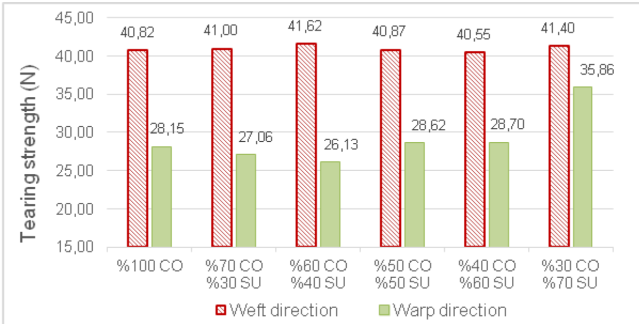


Figure 6. Tearing strength at the weft and warp direction

Since the elongation value of the Sustans® fibers is 35.73% and is five times higher than the cotton fibers with 7.27%, the yarn elongation values have increased with the use of Sustans® (Figure 4-b). A similar trend was observed in fabric breaking elongation at weft direction (Figure 3-b). According to the Pearson correlation test, a statistically significant and very high positive correlation was found between the blending ratio and breaking elongation at the weft direction (Table 4). Since the warp threads of all fabrics are the same, the warp direction elongation values are close to each other (Figure 3-b). There was no statistically significant linear correlation between blending ratio and fabric breaking elongation at the warp direction (Table 4).

3.3. Fabric Tear Strength

In the tearing tests, the tearing behaviour of the weft yarns is determined in the warp direction. For this reason, warp tear strength values are essential for the research. The average test results are given in Figure 6 graphically.

Correlation analysis showed a statistically significant ($p < 0.01$) and moderately positive correlation in the warp direction, but there is no statistically significant relationship between the Sustans® ratio and fabric tear strength in the weft direction. According to the ANOVA test (Table 5), there was no statistically significant effect of blending ratios on tear strength in weft direction ($p > 0.05$). The variation graph of tear strength is consistent with the ANOVA results. It is an expected result because the warp threads of the fabrics are the same. The Kruskal Wallis test (Table 6) showed that the blending ratios have a statistically significant effect on the warp direction tearing values ($p < 0.05$).

It can be said that the use of Sustans® has not improved the tear strength of the warp direction up to 50% blending ratio. Above this ratio, Sustans® supports the tear strength of fabrics in warp direction. In the tear strength test, the yarns are forced to break sequentially. Therefore, the most critical factor in test results is yarn strength. However, the yarn under the effect of force is supported by following yarns at the yarns' level of adhesion. It was also observed that yarns, including 60% and 70% Sustans® exhibit the lowest strengths. The fabrics produced from these yarns showed the highest warp tearing strength values. This indicates that the yarns which include a high percentage of Sustans® fiber have higher adhesion and the ability to move together within the fabric.

3.4. Dimensional Change after Washing

Washing processes are conducted at two different temperatures, which are frequently used in domestic washing, to examine dimensional change behaviour. All dimensional changes occurred as minus shrinkage. Test results are given graphically in Figure 7. When the dimensional change graph is examined, as the general trend at both temperatures, decreasing shrinkage was observed as the Sustans® ratio increased. Correlation analysis results also support the trend in the graph (Table 4). The Pearson correlation test exhibited very high and high levels of significant negative correlation among the blending ratio with 40ºC and 60ºC weft direction washing data. According to results, a significant and moderately positive relationship between the Sustans® ratio and the 40ºC warp direction washing data were determined. On the other hand, there was no statistically significant relationship between warp direction 60ºC washing data and blending ratio. The ANOVA test (Table 5) showed that the blending ratios have a statistically significant effect on all washing types ($p < 0.05$).

A negative and high-level linear relationship was found between weft direction shrinkage and yarn elongation values with the correlation coefficients -0.815 for 40ºC and -0.702 for 60 ºC. Besides, there was an increase in shrinkage after 60ºC washing compared to 40ºC. This situation is expected because the washing done at 60ºC caused the fabric structure to be relaxed more than 40ºC. Because the tensions within the fabric relaxed during washing cause shrinkage, and some strains can loosen at higher temperatures.

In Figure 7, shrinkage at 60ºC increased compared to 40ºC, similar to the weft direction. Dimensional variations in warp direction generally tend to increase slightly with an increase of the Sustans® ratio, and this trend is not as evident as in the weft direction. Correlation analyzes also support this weak trend. Besides, considering that the fabrics have the same warp yarns, it is concluded that the Sustans® ratios do not have a significant effect on the warp direction shrinkage.

3.5. Elasticity and Growth

Tests were applied only in the weft direction, as there was only elasticity expectation in weft direction. However, the tests were conducted separately to the finished samples, and samples washed at 60ºC**.** Correlation test showed that (Table 4) the moderate and high level negative correlations among blending ratio with finished product elasticity and post-washing elasticity data ($p < 0.01$). A weak level of significant negative correlation ($p < 0.05$) was found between the growth after washing and the blending ratio. According to the ANOVA test results (Table 5), it was determined that the blending ratio had a statistically significant effect on the elasticity of samples ($p < 0.05$).

In Figure 8, it is seen that the finished fabrics containing weft yarns, which include 60% and 70% Sustans®, had lower elasticity compared to other samples. In the elasticity data of washed fabrics, elasticity values decrease with increasing Sustans® ratio. Graphic trends in terms of elasticity are consistent with correlation analysis.

The Kruskal Wallis test showed that the blending ratio had no statistically significant effect ($p = 0.299$) on the growth data after washing. The graph of growth changes and correlation analysis also did not indicate a strong relationship. Elasticity values of washed fabrics have increased compared to finished samples. Compared to 100% cotton fabric, some improvement was observed in the growth values of the fabrics containing Sustans® after washing.

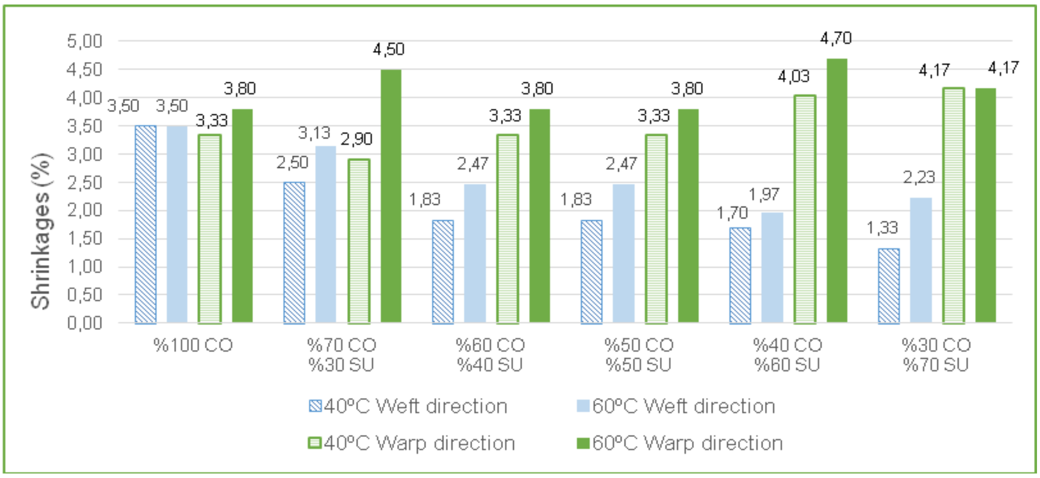


Figure 7. Dimensional change graphs

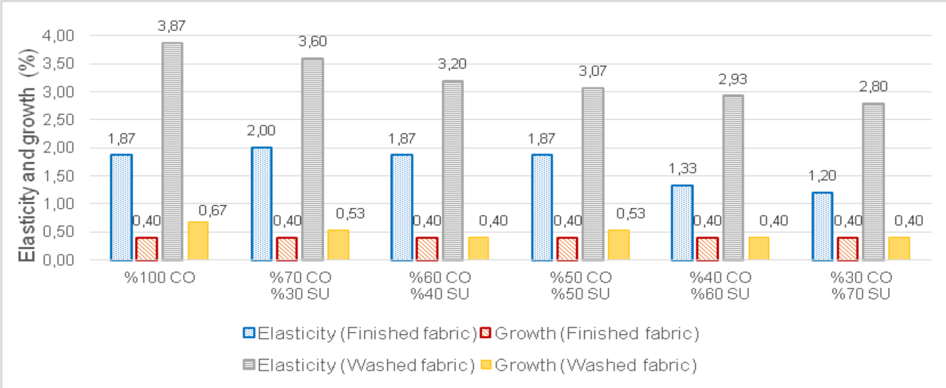


Figure 8. Elasticity and growth graphs

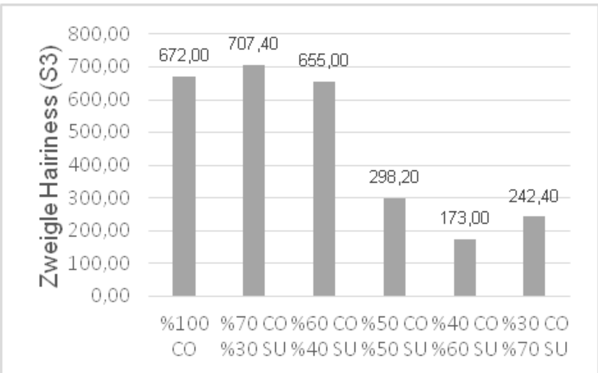
As a result, it was determined that the finished fabrics elasticity values were not affected by the use of Sustans® up to 60%; the Sustans® ratios above 60% negatively affect the elasticity. Moreover, the elasticity values after washing decreased with the increase of the Sustans® ratio. Besides, it was determined that the after washing elasticity values increased compared to the finished fabrics. It has been concluded that 60ºC washing provides more relaxing in the finished fabric than 40ºC, the fabric recover a little more. As a result, the potential elongation capability becomes a little more active. It has been evaluated that the dimensional changes after 60ºC washing are greater than 40ºC, which confirms this claim. More shrinkage is observed in washing at higher temperatures, which provides more elongation in the elasticity test. Thus, the elasticity and the growth values increase.

When elasticity and growth data are analyzed together, the low growth and elasticity values indicate that the fabrics exhibited low elongation during the tests. However, it was seen that the breaking elongation values increase as the Sustans® ratio increases both in yarn and fabric. The critical detail at this point is that, in accordance with standard methods, the breaking elongation values of the fabrics were obtained at the force level of 850-900 N, and elasticity values at the force level of approximately 23 N. In other words, as the Sustans® ratio increases, the elongation values increase, but this increase can manifest itself at much higher levels than the stresses that may occur in daily use and applied elasticity tests.

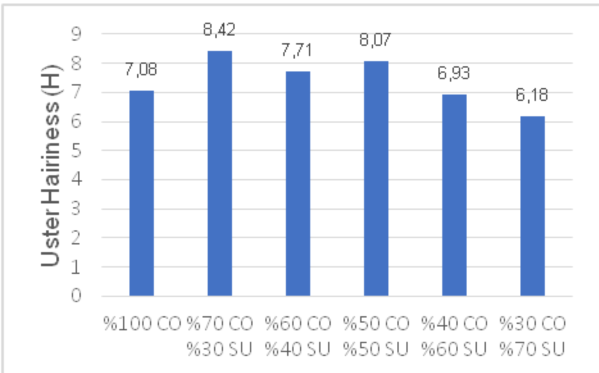
Sustans® fibers must be opened and longitudinally settled in the yarn structure during the spinning process to benefit sufficiently from the elasticity and dimensional stability properties. It was concluded that the airflow, centrifugal force, etc., parameters in the rotor were not adequate to open Sustans® fibers longitudinally; therefore, the elasticity property of Sustans® fibers could not be adequately transferred to the yarn and fabric structure. However, while a slight decrease was observed in the elasticity value of the fabrics with a 50 % Sustans® determined in the previous study as the optimum blending ratio [9], there was some improvement in the growth after washing.

3.6. Pilling

Pilling and abrasion behavior of fabrics are affected by many factors such as fiber type, yarn and fabric properties. However, in the study, all factors except weft yarn fiber mixing ratios were kept constant. For this reason, fabric pilling and abrasion behaviors were investigated by considering the results of weft yarn hairiness and fabric stiffness. For this purpose, the graphics of weft yarn hairiness data evaluated in the previous study are given in Figure 9 [9].



(a)



(b)

Figure 9. a) Zweigle S3 hairiness graph; b) Uster H hairiness graph

In terms of hairiness data S3, yarns with a Sustans® ratio of 50% and above and yarns with a Sustans® ratio of less than 50% were separated into two different groups. These two groups did not show significant differences within themselves. It was stated that the use of Sustans® had a statistically significant effect on the hairiness values of Uster H and Zweigle S3. The use of Sustans® at rates of 50% and above significantly reduced the S3 hairiness values. A statistically significant and highly negative linear relationship (Pearson correlation coefficient -0.791) was observed between the sustans ratio and S3 hairiness value. A statistically significant linear relationship was not found between the Uster H hairiness values and the Sustans® ratio [9].

The similar or different behavior of yarns in terms of H and S3 hairiness is highly affected by the amount of fibers shorter than 3 mm or not [29]. Considering that unwanted hairs in yarns consist of fibers of 3 mm and longer [30], yarns containing 50% and more Sustans® are more advantageous compared to other yarns [9].

Circular stiffness tests were applied to determine the possible effects of weft yarns containing Sustans® in different mixing ratios on the resistance of fabrics to bending. The graphic reflecting the average test results obtained is given in Figure 10.

According to the ANOVA test result given in Table 5, the Sustans® ratio has a statistically significant effect on fabric stiffness ($p < 0.05$). With the use of Sustans® fibers, which are known to have a soft touch, the fabric stiffness values have decreased, in other words, the softness of the fabrics has increased. On the other hand, Pearson correlation analysis showed that there was no statistically significant linear relationship between Sustans® ratio and stiffness test results (Table 4). The fabric with 50% Sustans® ratio became the softest fabric with the lowest stiffness value. As in most of the other tests applied to yarns and fabrics, 50% Sustans® ratio is the mixing ratio at which the trend reversed [2, 9].

Fabric pilling values are given in Table 7. According to the test results, it was observed that all fabrics reached the highest pilling level 2000 cycles. It was determined that the pilling levels of all fabrics decreased at 5000 cycles and the reduction continued at 7000 cycles in some of them.

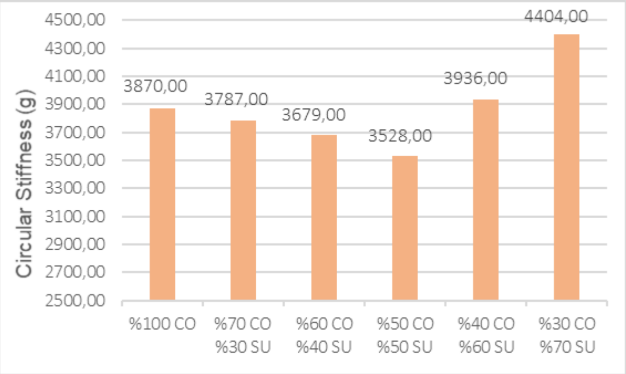


Figure 10. Circular Stiffness graph

Table 7. Pilling test results

Weft Yarn Blend Ratio	Sample Number	Pilling Cycles 125	500	1000	2000	5000	7000
%100 CO	1	4	3/4	3/4	3	3	3/4
	2	4	4	3/4	3/4	3/4	4
	3	4	4	3/4	3	3/4	4
%70 CO - %30 SU	1	4	4	3/4	3	3/4	3/4
	2	4	3/4	3	3	3/4	3/4
	3	4	3/4	3	3	3/4	3/4
%60 CO - %40 SU	1	4	4	3/4	3	3/4	3/4
	2	4	3/4	3	3	3/4	3/4
	3	4	3/4	3	3	3/4	3/4
%50 CO - %50 SU	1	4	4	3/4	3/4	3/4	3/4
	2	4	4	3/4	3/4	3/4	4
	3	4	3/4	3/4	3	3/4	4
%40 CO - %60 SU	1	4/5	4	4	3/4	4	4
	2	4	4	4	3/4	4	4
	3	4	4	3/4	3/4	4	4
%30 CO - %70 SU	1	4	3/4	3/4	3/4	3/4	4
	2	4	4	3/4	3/4	4	4
	3	4	4	4	3/4	4	4

The worst results were seen at 30% and 40% Sustans® ratio with 3 degrees of pilling at 2000 cycles. Even though a sample of 100% cotton fabric was better than these two fabrics with a level of 3/4, when the 3 pilling degree of the other two samples were evaluated, it was determined that three fabrics formed a group. Although a sample of the fabric containing 50% Sustans® had a half point worse result with 3 degree of pilling than those containing 60% and 70% the three fabrics formed a separate batch at 2000 cycles. It was determined that these results match the S3 hairiness data of the yarns. All three samples of 50% Sustans® fabric were pilled at the level of 3/4 at 5000 cycles. In other words, 30%, 40% and 50% Sustans® fabrics showed the same amount of pilling at 5000 cycle. However, it was grouped with 60% and 70% Sustans® fabrics again in 7000 cycles. In other words, in 50% Sustans® fabric, the reduction in pilling after the worst level was slower than 60% and 70% Sustans® fabrics. In addition, the pilling degree of 100% cotton fabric at the end of 500 and 7000 cycles is closer to 50% and above Sustans® fabrics. As a result, the use of Sustans® at rates of 50% and above improved the pilling values by half a point for most of the pilling process. However, there was no significant difference in pilling according to the change in Sustans® ratio among the groups formed.

3.7. Abrasion Resistance

The change of abrasion resistance test results is given in Figure 11. Statistical analyzes were applied to make a comparison between fabrics according to the mass losses occurring at the end of each abrasion period, and no comparison was made between different abrasion periods.

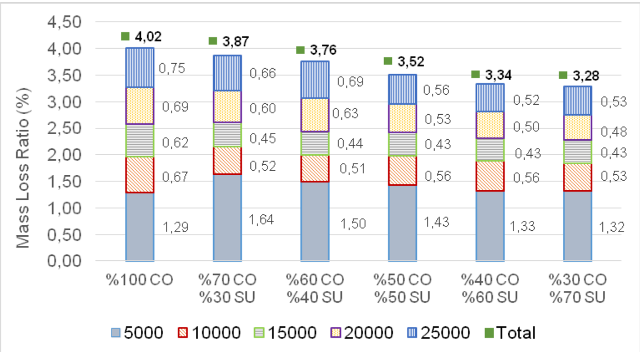


Figure 11. Abrasion resistance graph

According to the results of Kolmogorov-Smirnov normality analysis, all data sets showed normal distribution. As a result of the Pearson correlation test (Table 4), a statistically significant and weakly negative linear relationship at the level of 0.05 was found only in the data of 25000 cycles. According to ANOVA test results (Table 5), there was no statistically significant effect of blend ratios on abrasion resistance ($p > 0.05$).

Although there is no clear trend among the mass losses occurring in the cycle ranges, as a result, the increase in the Sustans® ratio had positive effect on the abrasion resistance. The mass loss of 100% cotton fabric is the lowest at the end of the first 5000 cycles. However, more mass loss was observed than any of the fabrics containing Sustans® in all of the subsequent 5000 cycle periods. As a result, the 100% cotton fabric has abraded more than any other fabric after 25000 cycles. When the graphical view of the first 5000 cycle results is examined, it is determined that the graph show a similar trend to the yarn H hairiness values. In the abrasion test, the highest mass losses are usually seen at the beginning of the test. The reason for the high mass losses at the beginning is the rapid removal of the fibers on the fabric surface, which is caused by the yarn hairiness. This explains the similarity of the graphic image at the end of the first 5000 cycles to the H hairiness graph.

However, 100% cotton yarn is much hairier than the yarns including 60% and 70% Sustans® in terms of Uster H and S3 hairiness values. In fact, according to the mass loss data at the end of the first 5000 cycles, 100% cotton fabric is more durable than all fabrics. In this case, it was concluded that fiber melting and pilling observed on the yarn surfaces containing Sustans® are also effective [9]. It was evaluated that these beads rapidly moved away from the fabric surface at the begining of the abrasion resistance test and increased mass loss in the first 5000 cycles of fabrics containing Sustans®. As a result, although the hairiness of yarns containing 60% and 70% Sustans® was lower than 100% cotton yarn, the mass loss of fabrics containing these yarns in the first 5000 cycles was higher than 100% cotton fabric due to the fiber beads. It has been determined that fabrics produced with less hairy yarns have higher abrasion and pilling resistance, and this result is consistent with previous studies [31].

As raw materials, polyester, polyamide, polypropylene fibers are high, wool, cotton fibers are medium; viscose and acetate fibers have low abrasion resistance [32]. Therefore, the abrasion resistance of Sustans® fibers, which form the phthalates branch of aromatic polyesters together with Poly (ethylene Terephthalate) (PET) and Poly (butylene Terephthalate) (PBT), is higher than cotton fibers. For this reason, the abrasion resistance of the fabrics containing Sustans® was higher.

4. CONCLUSION

In this study, Sustans® fibers, produced from renewable natural resources, bio-based, sustainable, having good elasticity and dimensional stability, were used in rotor spinning system. Although there is a slight decrease in the weft and warp tensile strength of denim fabrics, including these yarns in the weft, these values have provided the required limit values according to the TS 2791 "Textile - Cotton Denim Fabric" standard. On the other hand, a statistically significant and very high positive correlation was found between weft breaking elongation and Sustans® ratio.

The use of 50% or more Sustans® has increased the tear strength of fabrics compared to 100% Cotton fabric. Study results showed that the use of Sustans® has improved the dimensional stability of the denim fabrics against washings.

The elasticity of Sustans® fibers has not been adequately transferred to the yarn and fabric structure. The reason for this result was evaluated that Sustans® fibers could not be opened enough longitudinally during spinning. However, it was observed that the use of Sustans® slightly improved the permanent elongation values.

When the results are evaluated in general, the use of Sustans® 50% and above in the weft yarn improved the pilling values of the fabrics. S3 hairiness values of the yarns affected the fabric pilling especially at 2000 cycles. However, due to the reduction of hairiness on the fabric surface as a result of processes such as finishing, it has been determined that this effect is limited according to the difference between the amount of hairiness.

In general, it has been observed that the use of Sustans® has a positive effect on abrasion resistance and the abrasion resistance increases as the Sustans® ratio increases. However, it has been determined that the positive effect is limited until about 10.000 abrasion cycles especially at low Sustans® rates. Within the scope of the study, it has been determined that the use of Sustans® has a more positive effect at the end of long abrasion periods and this positive effect can create an advantage for denim fabrics that are used frequently and for a relatively long time.

In the previous study, 50/50% Sustans®/Cotton was specified as the optimum blending ratio for the yarns [9]. In terms of fabric properties measured in this study, denim fabrics, containing 50% Sustans® in the weft, were also evaluated as the having optimum blend yarns. However, it should not be ignored that the yarns containing Sustans® are only weft in the fabrics. If also 50/50% Sustans®/Cotton yarns are used in the warp direction, it is most likely that some advantages, obtained in the weft direction, will be seen in the warp direction. In addition, improvement in pilling and abrasion resistance properties may also occur.

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