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Tensile and Tearing Properties of Newly Developed Structural Denim Fabrics after Abrasion

Abstract

The aim of this study was to assess the tensile and tearing properties of newly developed structural denim fabrics after an abrasion load and to compare them with those of traditional denim fabric. The fabrics developed were designed as large and small structural pattern and traditional denim fabric. All the denim fabrics were first abraded, and later tensile and tearing tests were performed on them seperately. The tensile properties of the abraded large structural pattern denim fabrics were generally inferior to those of the small structural pattern and traditional denim fabric. When the abrasion cycles were increased, the tensile properties of all the denim fabrics generally decreased. The weft directional tearing strength of the small structural pattern denim fabric was significantly higher than that of the traditional and large structural pattern denim fabrics. When the abrasion cycles were increased, the tearing properties in the weft and warp of all the denim fabrics generally decreased.

Key words: *denim fabric, structural pattern, fabric abrasion, abraded fabric tensile strength, tearing strength, statistical test.*

Introduction

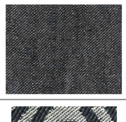
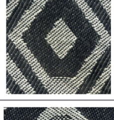
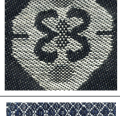
Denim fabrics are generally developed from cotton yarns for clothing. An extensive research work has been carried out on denim fabric behaviour affected by open-end and ring spun all-cotton yarns [1].

Dimensional changes in denim fabrics caused by washing treatments have also been studied [2]. The effects of using elastane fibres on the dimensional properties of denim fabrics have also been researched experimentally [3]. The mechanical and surface properties of knitted fabric have been examined after an abrasion load, in which it was found that the properties of the fabric depend on the in-plane direction. Moreover the mechanical and surface properties decreased as the abrasion cycles were increased [4]. Woven fabric with various weave types has been examined after an abrasion load, in which it was found that the abrasion resistance in long and few interlacements in the unit surface area of the woven fabric decreased [5]. Denim fabric produced from environmentally improved organic cotton has been studied to assess its tensile properties after repeated laundering and was compared to those of classical denim fabric. It was found that there was no significant difference between the tensile properties of both denim fabrics [6]. Another study on a denim garment was performed to identify the pilling resistance in processes such as pre-washing, enzyme treatment and stone washing. It was concluded that the pre-washed denim garment had more pilling than the enzyme treated and stone washed denim garment [7].

The surface smoothness of denim fabrics has been studied photographically, and the parameters acting on fabric surface homogeneity were determined [8]. For reliable investigations of the surface and mechanical properties of the fabrics, the data were analysed using a multivariate statistical analysis program [9].

This study aimed to assess the tensile and tearing properties of newly developed structural denim fabrics after an abrasion load and to compare them with traditional denim fabric. Furthermore, the tensile and tearing strengths of these fabrics were evaluated using such statistical

Table 1. *Specifications of the denim fabrics.*

Fabric type		Yarn count, tex		Yarn twist, t.p.m.		Density ends/cm		Weave type	Crimp, %		Weight, g/m²	Thickness, mm
		weft	warp	weft	warp	weft	warp		weft	warp		
TD		82	81	433 Z (ring)	477 Z (ring)	19.7	27.2	3/1 Z twill (traditional)	6	12	480	0.807
HD		84	74	469 Z (ring)	501 Z (ring)	13.5	26.5	hexagonal	6	12	280	0.919
OD		84	74	469 Z (ring)	501 Z (ring)	13.5	26.5	octagonal	6	12	280	0.877
PRD		66	66	531 Z (ring)	531 Z (ring)	25	27.5	parallel rhombus	6	12	385	0.924

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methods as ANOVA and the Student–Newman–Keuls (SNK) test [10 - 12].

Materials and methods

Fabric specifications

100% cotton yarns were used to develop new structural pattern denim fabrics. The cotton fibre properties were characterised by using Uster High Volume Instrument (HVI) systems. The cotton fibres were of a medium fineness (4.5 micronair) and averaged 29.5 mm in length. The fibres had a high tensile strength (29.6 g/tex) and elongation at break (8.2%). The yarn counts varied between 66 and 84 tex. The twist of the yarns was between 531 and 469 turns/m in the Z direction. The ring spinning system was used to produce carded cotton yarns. ***Table 1*** presents the specifications of the denim fabrics.

TD (traditional denim) and PRD (parallel rhombus denim) fabrics were produced using a rapier weaving machine with a dobby (Dornier, Germany). An air-jet weaving machine (Picanol Omni Plus, Belgium) was used to produce HD (hexagonal denim) and OD (octagonal denim) fabrics. The TD fabric was 3/1 Z twill denim fabric, whereas the HD, OD and PRD fabrics were newly developed. The HD and OD fabrics had large structural patterns, whereas the PRD fabric had a small structural pattern.

Abrasion test

Abrasion tests of the denim fabrics were performed using the Martindale abrasion test method. A Nu-Martindale Abrasion Tester (James H. Heal, UK) was used to evaluate the abrasion behaviour of the developed denim fabrics in compliance with the TS EN ISO 12947-2 standard. Standard wool fabric was used for abrading, and the fabrics were abraded under a pressure of 12 kPa (795 ± 7 g). The experiment was repeated three times. A developed metal token was used for the conical attachment of the sample holder, as seen in ***Figure 1***. The diameter of the aluminum token developed was 28 mm, and its thickness - 2 mm. A fabric sample, polyurethane foam and the metal token were put into the sample holder, respectively. The excess parts of the fabric samples were folded, and the body of the sample holder was closed.

An abrasion test was performed after 15.000, 20.000 and 25.000 abrasion cycles. Tensile and tearing tests were carried out before abrasion and after each abrasion cycle.

Tensile test

A tensile strength test of all the fabrics in the warp and weft directions was performed on an Instron 4411 tester (Instron Inc., U.S.A) according to TS EN ISO 13934-1. The tensile testing speed was 100 mm/min. The test dimensions were determined considering the abrasion test fixture, given in ***Figure 2***.

After the abrasion test, the sample's dimensions were reduced to 28 × 160 mm by simply pulling out undamaged yarns from the edge of the sample in order to apply the tension load to only the abraded region of the sample.

Tearing test

Tear strength tests of all the fabrics in warp and weft courses were performed on an Instron 4411 tester (Instron Inc., U.S.A) according to TS EN ISO 13937-2, in which the tear strength testing speed was 100 mm/min and the tensile testing speed - 100 mm/min. The test dimensions were determined considering the abrasion test fixture, given in ***Figure 3***.

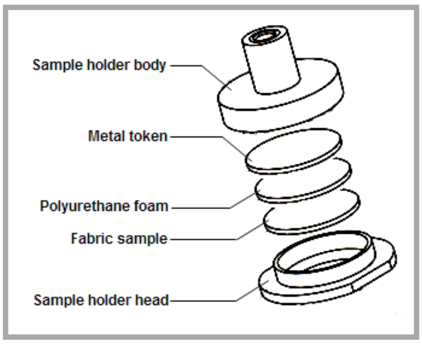

Figure 1. *Sample preparation diagram for the abrasion test.*

Optical microscope

After all the fabrics were tested, they were examined by optical microscope (Olympus SZ61-TR). ***Figure 4*** shows optical microscope views of the denim fabrics before and after the abrasion cycles.

Statistical analyses

In this study, four different abrasion cycles were applied to the four different denim fabrics. The values measured were tested for significant differences using two-way replicated analysis of variance (ANOVA), and the means were compared by Student–Newman–Keuls (SNK) tests at a level of 0.05 in the SPSS V.13.0 statistical package. In the interpretation of SNK results, abbreviations a, b, c and d represent factor levels, that the factor levels marked by the same letter are not different from each other at a 95% significant level. If the p-values are smaller than 0.05, they are considered to be significant.

Results and discussions

Tensile and tearing results

The breaking load versus breaking elongations for all the denim fabrics in the weft and warp directions were plotted

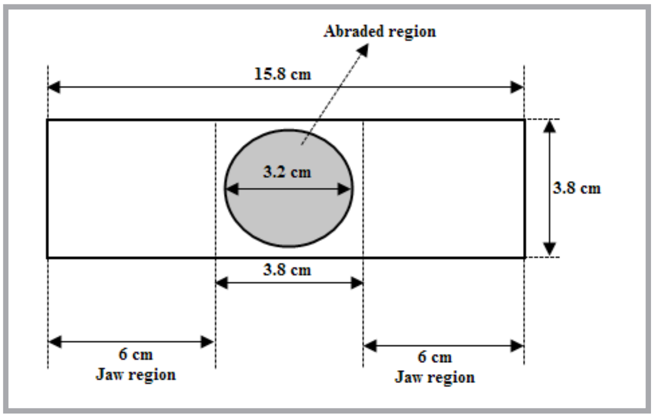

Figure 2. *Dimensions of the tensile test specimen.*

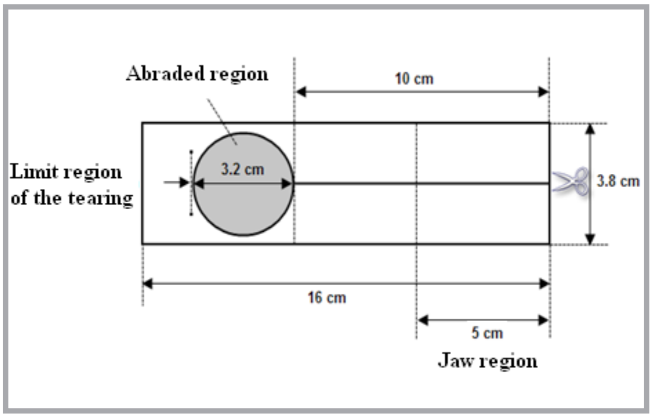

Figure 3. *Dimensions of the tear test specimen.*

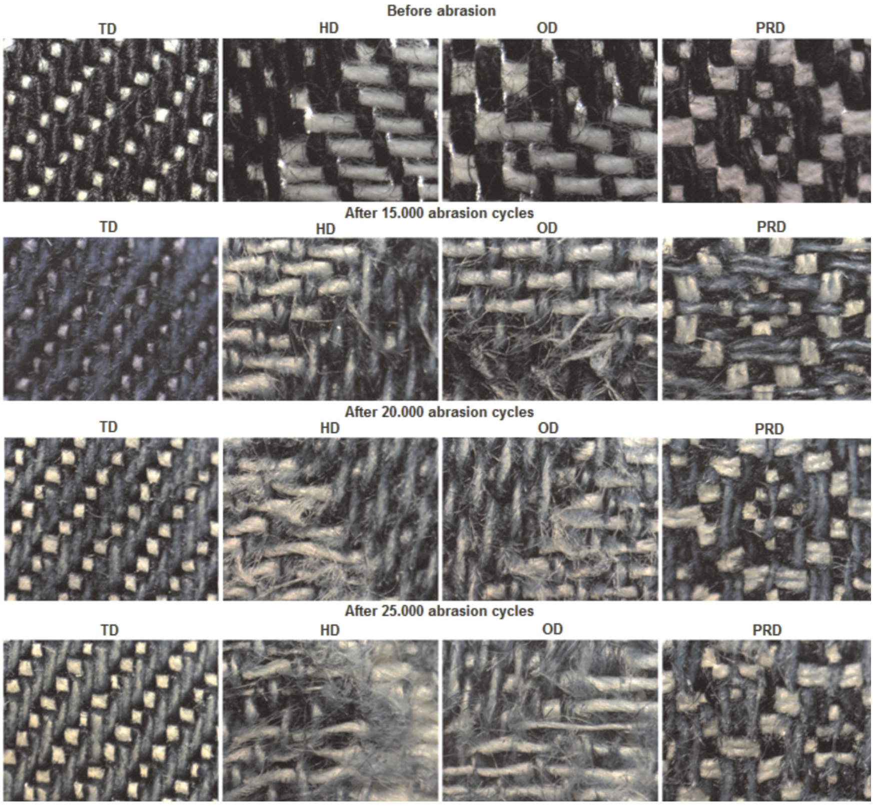

Figure 4. *Optical microscope views of the denim fabric samples before and after abrasion cycles at a magnification of 15×.*

Table 2. *ANOVA table for the breaking load in the weft and the warp direction.*

Direction	Source	SS	dF	MS	F	P	
Weft	Fabric Type (F)	1726497.5	3	575499.2	3443.5	0.000	significant
	Abrasion Cycle (A)	534338.5	3	178112.8	1065.7	0.000	significant
	F×A	128884.2	9	14320.5	85.7	0.000	significant
	Error	5348.0	32	167.1			
	Total	12425644.1	48				
Warp	Fabric Type (F)	68460.0	3	22820.0	29.7	0.000	significant
	Abrasion Cycle (A)	3371233.8	3	1123744.6	1462.6	0.000	significant
	F×A	75685.7	9	8409.5	10.9	0.000	significant
	Error	24585.4	32	768.3			
	Total	9413194.4	48				

and are given in ***Figures 5*** and ***6***, respectively.

The results of the ANOVA for the breaking load of the denim fabrics in the weft and warp directions are summarised in ***Tables 2***, respectively. According to the ANOVA results, the fabric type and abrasion cycle factors are statistically significant for the breaking loads of denim fabrics in the weft and warp directions. The effects of the interaction between the fabric type and abrasion cycle factors are also found to be statistically significant for the breaking load of denim fabrics in the weft and warp directions.

As seen in ***Figures 5*** and ***6***, there are significant differences in the weft directional tensile strength before and after abrading fabrics HD and OD. This is because the irregular and long floating yarn interlacement between the weft and warp on the fabric surface is severely damaged under the abrasion load. The differences in the weft directional tensile strength before and after abrading fabrics PRD and TD are relatively small, which may be due to the short floating interlacement between the warp and weft on the fabric surface as well as to the fact that a less weft fibre volume fraction is subjected to the abrasive load. On the other hand, there are significant differences in the warp directional tensile strength before and after the abrasion of all the denim fabrics, which may be due to the warp yarns appearing frequently on the surface of all the denim fabrics, resulting in more warp yarns being damaged under the abrasion load. This can be clearly seen in ***Figure 4***.

The results of the ANOVA for the breaking elongation of the denim fabrics in the weft and warp directions are summarised in ***Tables 3*** (see page 58), respectively. Similar to the ANOVA results for the breaking load, the fabric type and abrasion cycle have a statistically significant effect on the breaking elongations of the fabrics in both the weft and warp directions.

The weft directional tensile elongation of fabrics HD and OD is low compared to that of fabrics TD and PRD, which is due to the irregular and long floating interlacement in the fabric structure of HD and OD, unlike the regular interlacements of fabrics TD and PRD as 3/1 twill, which results in high tensile elongation. Similar results are observed for the warp directional tensile elongation behaviour of the denim fabrics developed. On the other hand, the warp directional tensile elongation of all the denim fabrics is higher than their weft directional tensile elongation, which is because the warp crimp ratio is higher than the weft crimp ratio.

It is also understood that increasing the abrasion cycles raises the amount of damage in all the denim fabrics, which causes a deterioration in the tensile behavior of all the denim fabrics developed. Moreover the form of abrasive damage is generally found to be fibre breakages and fibre entanglement.

The results of the ANOVA for the tearing load of the denim fabrics in the weft and warp directions are summarised in ***Tables 4*** (see page 58), respectively. Fabric type and abrasion cycle factors are statistically significant for the tearing loads of denim fabrics in the weft and warp directions. The effects of the interaction between the fabric type and abrasion cycle are also found to be statistically significant.

Although the results for the warp and weft directional tearing strength of fabrics HD and OD show similarity in general, the warp directional tearing strength is slightly higher than that of the weft, the reason being that fabrics HD and OD have higher warp densities than weft densities. Furthermore the highest tearing strength is obtained for fabric PRD, followed by fabric TD, whose warp and weft densities are higher than those of fabrics HD and OD. On the other hand, an increase in abrasion cycles causes an

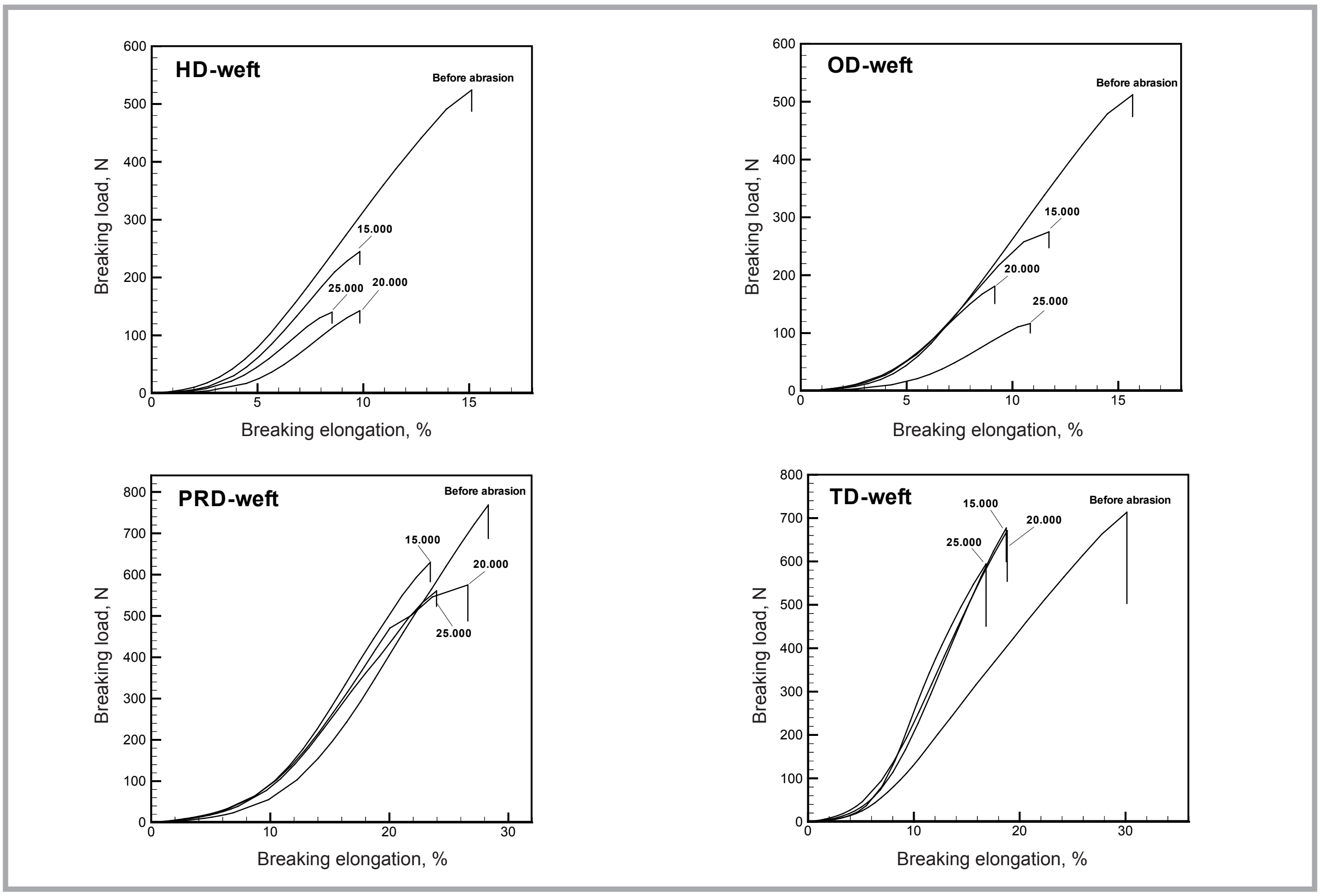

Figure 5. *Tensile load-elongation graphs of the denim fabrics in the weft direction.*

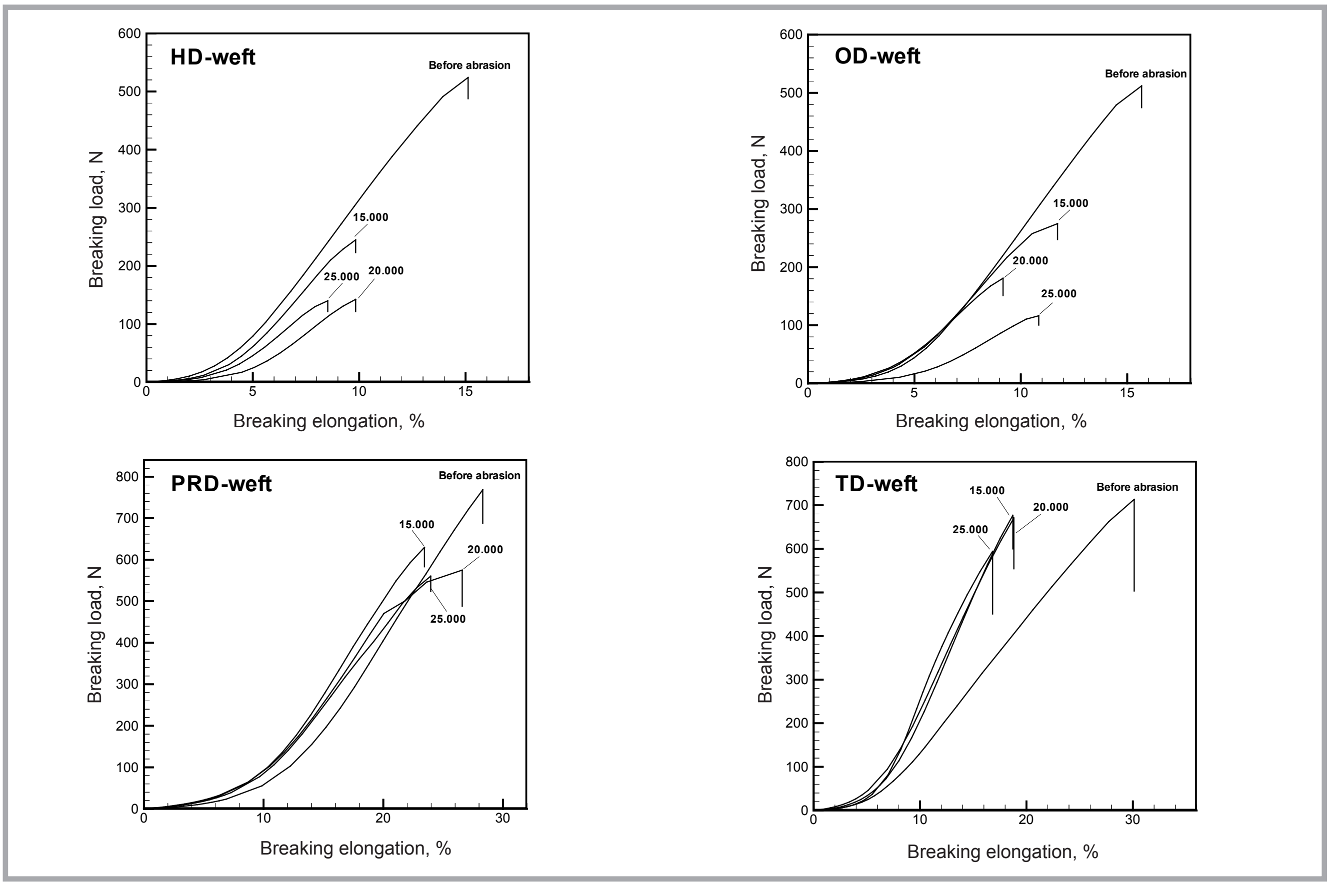

Figure 6. *Tensile load-elongation graphs of the denim fabrics in the warp direction.*

Table 3. *ANOVA table for the breaking elongation in the weft and the warp direction.*

Direction	Source	SS	dF	MS	F	P	
Weft	Fabric Type (F)	1801.423	3	600.474	183.328	0.000	significant
	Abrasion Cycle (A)	408.094	3	136.031	41.531	0.000	significant
	F × A	99.818	9	11.091	3.386	0.005	significant
	Error	104.813	32	3.275			
	Total	17490.887	48				
Warp	Fabric Type (F)	1731.614	3	577.205	16.299	0.000	significant
	Abrasion Cycle (A)	1750.845	3	583.615	16.481	0.000	significant
	F × A	787.786	9	87.532	2.472	0.029	significant
	Error	1133.198	32	35.412			
	Total	24239.112	48				

Table 4. *ANOVA table for the tearing load in the weft and the warp direction.*

Direction	Source	SS	dF	MS	F	P	
Weft	Fabric Type (F)	18617.216	3	6205.739	842.417	0.000	significant
	Abrasion Cycle (A)	15424.736	3	5141.579	697.959	0.000	significant
	F × A	6658.025	9	739.781	100.424	0.000	significant
	Error	235.731	32	7.367			
	Total	180127.652	48				
Warp	Fabric Type (F)	3300.145	3	1100.048	33.314	0.000	significant
	Abrasion Cycle (A)	31912.244	3	10637.415	322.149	0.000	significant
	F × A	1943.471	9	215.941	6.540	0.000	significant
	Error	1056.644	32	33.020			
	Total	169894.363	48				

Table 5. *Effects of fabric type and abrasion cycles on the breaking load and breaking elongation of the denim fabrics in the weft and warp directions, obtained from the Student-Newman-Keuls Test.*

Parameters		Breaking load, N		Breaking elongation, %	
		Weft	Warp	Weft	Warp
Fabric type	TD	659.67 d	415.12 b	21.78 b	25.09 b
	HD	261.84 a	326.37 a	11.49 a	13.89 a
	OD	273.66 b	331.28 a	12.01 a	13.75 a
	PRD	633.35 c	326.42 a	25.60 c	26.49 b
Abrasion cycle	0	628.89 d	798.45 d	22.69 b	30.12 b
	15.000	454.22 c	288.30 c	16.32 a	17.61 a
	20.000	392.20 b	177.77 b	16.62 a	16.68 a
	25.000	353.21 a	134.67 a	15.25 a	14.82 a

rise in the amount of damage to all the fabrics developed. Therefore, the tearing strengths of all the fabrics are reduced after abrasion.

SNK test results

According to the SNK test results of the breaking load and elongation, presented in ***Table 5***, the weft directional breaking load of fabric TD is significantly higher than that of fabrics HD and OD, while the breaking load of fabric PRD is close to that of fabric TD. However, the warp directional breaking load of fabrics HD, OD and PRD are close to each other and are not statistically different, while fabric TD has the highest breaking load, which is statistically different. The breaking load of denim fabrics has a tendency to decrease with an increase in the number of abrasion cycles in both the weft and warp directions. The breaking loads of denim fabrics dramatically decrease at 25.000 abrasion cycles, particularly in the warp direction. The breaking loads of fabrics TD and PRD at 25.000 abrasion cycles decrease by 17.7 - 27.15% and 83.85 - 81.46% in the weft and warp directions, respectively. At 25.000 abrasion cycles fabrics HD and OD show a decrease in the breaking load of 73.2 - 75.01% and 89.04 - 77.52% in weft and warp directions, respectively. Consequently, it can be stated that the SNK test explains the actual experimental test results, as seen in ***Figures** 7* and ***8***.

The weft and warp directional breaking elongations of fabrics HD and OD are close to each other, and they are not statistically different. On the other hand, fabrics TD and PRD show a similar breaking elongation, particularly in the warp direction, which is not statistically different. Before abrasion, denim fabrics have a high breaking elongation in both the weft and warp directions. Abrasion cycles of 15.000, 20.000 and 25.000 have no statistically different effect on the breaking elongation of denim fabrics for both the weft and warp directions. It can be interpreted that all abraded denim fabrics, regardless of their structural patterns, show low tensile elongation, which can also be seen from the measurement data in ***Figures** 7*.

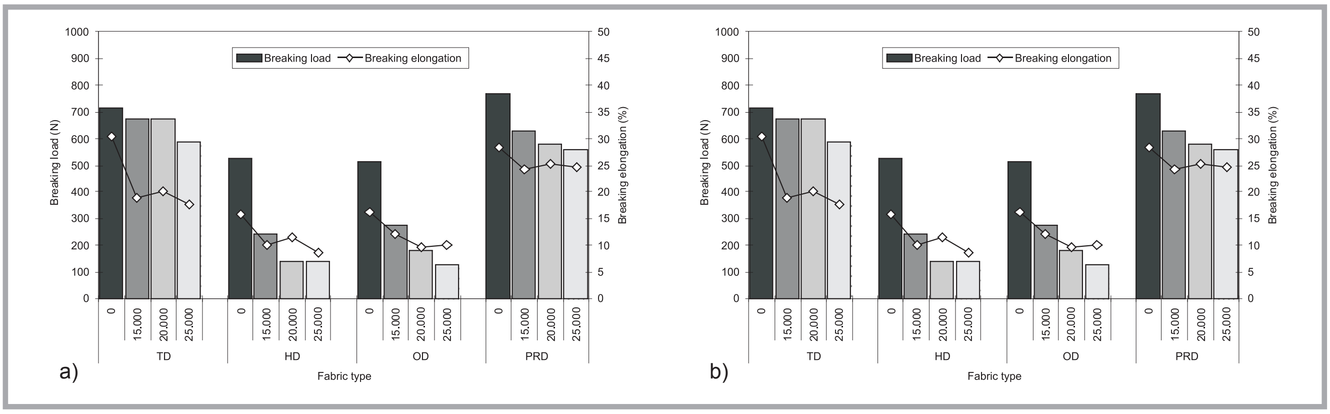

Figure 7. *Breaking load and breaking elongations of the denim fabrics in the weft (a) and the warp (b) direction.*

Table 6. Effects of fabric type and abrasion cycles on the tearing load of the denim fabrics in the weft and warp directions, obtained from the Student-Newman-Keuls Test.

Parameters		Tearing load, N	
		Weft	Warp
Fabric type	TD	44.92 c	42.36 a
	HD	40.15 a	52.92 b
	OD	42.50 b	49.07 b
	PRD	87.84 d	65.16 c
Abrasion cycle	0	82.78 d	93.95 d
	15.000	53.07 c	49.44 c
	20.000	44.84 b	42.44 b
	25.000	34.71 a	23.68 a

SNK test results of the tearing load are presented in ***Table 6***. Different fabric types have statistically different effects on the weft directional tearing load. The weft directional tearing load of fabric PRD is significantly higher in comparison with fabrics TD, HD and OD. The warp directional tearing loads of fabrics HD and OD are not statistically different from each other.

The weft and warp directional tearing loads of all the denim fabrics have a tendency to decrease with an increasing number of abrasion cycles. Abrasion cycles have statistically different effects on the tearing loads of all the denim fabrics according to the SNK results. Therefore, the directional tearing strength of all the fabrics after abrasion is reduced. The SNK test accurately explains the tearing strength behaviour of all the initial and abraded denim fabrics, which can be compared to the measurement data in ***Figure 8***. The tearing loads of fabrics TD and PRD at 25.000 abrasion cycles decrease by 14.05 - 30.95% and 64.81 - 60.85% in the weft and warp directions, respectively. At 25.000 abrasion cycles Fabrics HD and OD show a decrease in the tearing load of 87.95 - 84.15% and 85.95 - 85.02% in the weft and warp directions, respectively.

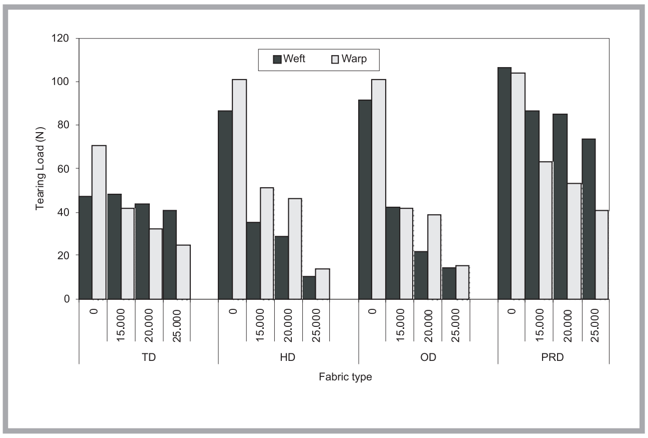

***Figure 8.** Tearing loads of the denim fabrics in the weft and warp directions.*

Conclusions

Denim fabrics with large and small structural patterns were developed, and their tensile and tear strength were investigated after an abrasion load and compared to those of traditional denim fabric. The data generated from the study were analysed by using such statistical methods as ANOVA and the SNK test.

The fabrics developed were classified as large (HD, OD) and small (PRD) structural pattern, and traditional denim fabric (TD). The warp densities of the denim fabrics designed were almost the same, but the weft densities of fabrics HD and OD were almost half as those of fabrics TD and PRD. Moreover, fabrics HD and OD were lighter than TD and PRD.

From the SNK test, the weft directional tensile strength properties of the abraded large (HD and OD) structural pattern denim fabrics were low compared to those of the small (PRD) structural pattern and traditional denim fabrics (TD), whereas the warp directional tensile strength properties of the abraded large (OD and HD) and small (PRD) structural pattern denim fabrics were inferior to those of traditional denim fabric (TD). The weft and warp directional tensile elongations of the abraded large (OD and HD) structural pattern denim fabrics were lower than those of the small (PRD) structural pattern and traditional denim fabrics (TD). It was also found that the warp directional tensile elongation of all the denim fabrics is generally higher than their weft directional tensile elongation. This is because all the denim fabrics have higher warp crimp ratios than those of the weft. On the other hand, when the abrasion cycles were increased, the tensile properties of all the denim fabrics generally decreased. The weft directional tearing strength of fabric PRD is significantly higher than that of fabrics TD, HD and OD. The warp directional tearing strengths of fabrics HD and OD are similar to each other. On the other hand, when the number of abrasion cycles was increased, the tearing strengths of all the denim fabrics in both the weft and warp directions generally decreased.

The results from the SNK test were compared with the values measured, and it can be concluded that almost all the values from SNK are accurately evaluated and can be used in this study as a viable and reliable tool.

Acknowledgments

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