TEKSTİL VE KONFEKSİYON

Vol: 33, No: 1
DOI: 10.32710/tekstilvekonfeksiyon. 982224

Investigation of the Friction Coefficients and Surface Roughness Properties of Denim Fabrics after Abrasion

Gizem Kara[1] 0000-0001-5202-8863
Mine Akgün[2] 0000-0002-6415-7782

[1] Almaxtex Tekstil Sanayi ve Ticaret A.Ş., Bursa, Türkiye
[2] Bursa Uludağ University, Engineering Faculty, Department of Textile Engineering, Bursa, Türkiye

Corresponding Author: Mine Akgün, akgunm@uludag.edu.tr

ABSTRACT

The abrasion behavior of denim fabrics could be affected by fabric surface properties (surface friction coefficient and roughness) depending on fabric structural parameters. This work aimed to investigated the friction coefficients and surface roughness properties of denim fabrics woven with different structural parameters after abrasion. In general, while the abrasion process reduced the fabric friction coefficients during the initial abrasion cycles, the surface's friction coefficient increased as the number of abrasion cycles increased. However, due to the increased abrasion cycles, there was a steady decline in the roughness values of the fabric surfaces. Denim fabrics were woven with a 3/1 twill weave pattern. When the effect of the fabric structural parameters on fabric friction coefficient and roughness values were evaluated, the yarn count (Nm), yarn density, and fabric cover factor showed negative correlation coefficients. In contrast, the thickness, unit weight, and bulk density of fabric showed positive correlation coefficients.

ARTICLE HISTORY

Received: 17.08.2021
Accepted: 20.09.2022

KEYWORDS

Denim fabric, friction coefficient, surface roughness, structural properties

1. INTRODUCTION

Denim fabrics are conventionally woven with a 3/1 twill weave structure using 100% cotton yarns. While indigo-dyed cotton yarns are used in the warp yarns that make up the fabric structure, the weft yarns consist of undyed cotton yarns. As a result of denim fabrics woven with dyed warp yarns and undyed weft yarns using warp-faced twill weave structure, fabrics' front and back surfaces appear in different colors [1]. In addition, denim fabrics are woven in 2/2 twill or plain weave structures [2, 3]. Denim structures can be produced with yarns containing polyester, polyamide, and elastane to have ergonomically designed and the desired performance properties. [3, 4].

Surface roughness plays an important role in fabric handling properties. Fabric surfaces are not exactly smooth; they have geometric roughness at specific intervals according to their structural properties. Periodic variations of the fabric surface resulted from the regular crossings of the yarns in the weave structure. Each of the yarns intersecting with each other causes geometric roughness. The large repeating units in the structure form rough textures, while the smaller ones form fine textures. [5, 6].

The friction force is the force that resists moving relatively to each other between two materials' opposing surfaces. Frictional properties of fabrics are essential for determining roughness degree, smoothness, or other tactile properties. Moreover, fabric friction property is necessary for determining fabric features such as abrasion and wear. Fabric structures with a low friction coefficient are generally smooth. These fabric structures indicate little frictional resistance to movement applied to their surface. Some studies assume that fabric's low friction coefficient is less affected by the mechanical effects resulting of low abrasion [7-11].

To cite this article: Kara G, Akgun M. 2023. Investigation of the friction coefficients and surface roughness properties of denim fabrics after abrasion. *Tekstil ve Konfeksiyon* 33(1), 27-36.

Friction properties of fabrics vary according to fiber content variations, yarn properties, fabric structure, and finishing processes [12]. In polyester blends made with cotton and viscose fibers, it was found that the friction force increased as the cellulose ratio increased in the blend [9]. Due to the variation of fabric surfaces, the friction resistance of fabrics is not always linearly proportional. A study on the effect of weave structure on the friction coefficient of cotton fabric surfaces found that the highest friction coefficient values were obtained in plain fabrics, and the lowest friction coefficient values were obtained in twill fabrics. Regarding the effect of weave structure on the friction coefficient of plain, twill, and satin weaves, it was concluded that the open contact area was the essential factor in fabric's frictional characteristics. [13-15]. Structurally, the yarn crowns and fiber ends that are formed as a result of the yarn intersections on the fabric surface affect the fabric smoothness [16] and friction properties [17-20].

The balance of the fabric surface depends on the position of warp and weft yarns. In determining the surface characteristics of the fabric, yarn crimp values are significant, as well as the yarn densities and yarn counts. Yarn crimps are influenced by the yarn count, yarn density, and weave structure. If the crimp values of the warp and weft yarns are close to each other, the fabric appearance is more or less stable. When the yarn crimp values are quite different, an irregular fabric surface is formed where one of the yarn systems is dominant [5]. In the study carried out by Ukponmwan [21], it was observed that the systematic increase in yarn settlings changed the yarn crimps (surface boundaries) and thus the fabric smoothness, provided that the yarn counts were constant [18, 20]. When the yarn settlements are systematically increased in woven fabric constructions, for example, the friction resistance against movement on the fabric surface systematically increases in the case of an increase in weft yarn density. As a result, it was obtained that the friction on the weft-faced surface is greater than the friction on the warp-faced surface. This result is due to the "knuckle effect" [11] as a result of the high level of crimps in the warp yarns, although there is a reduction in the spacing between the weft yarns due to the increase in the weft density [17-20]. Although a systematic increase in fabric structures (such as the number of yarns in cm) increases frictional resistance, it makes the fabric surface smoother. This result is due to the tightening of the yarn settlements and the reduction of the peak heights of the yarns during yarn intersections. As the yarn thickness increases (yarn diameter increases), the friction resistance and surface roughness increase too. This result is due to the increase in the mechanical intersection heights of the yarn crowns [22, 23].

There are studies investigating the effects of abrasion on various mechanical performance properties of fabrics [24, 25]. In a study examining the effects of abrasion on tensile and tear strength properties of newly developed structural denim fabrics [24], it was stated that the tensile strength properties of abraded large structural pattern denim fabrics were generally lower compared to small structural pattern and conventional denim fabrics. In addition, it was stated that the tensile and tear strength properties of all denim fabrics generally decreased as the abrasion cycles were increased [24].

In a study investigating the effects of abrasion on the strength, elasticity, and recovery properties of stretch-denim fabrics stated that the comfort related to body movement and the shape retention properties of the stretch-denim fabrics were affected by abrasion. In addition, it was stated that the fabric structure with a higher level of elastane content resulted in a more significant loss of shape-retention properties due to abrasion [25].

Due to wearing, using, washing, and cleaning, abrasion damage occurs on the fabric structures. In addition to causing a loss of performance durability, such as strength in fabric structures, abrasion also affects properties such as fabric appearance, wearing comfort, and comfort durability [25].

The extent to which abrasion affects the friction coefficients and fabric surface roughness of denim fabrics in terms of appearance and wearing comfort, especially in denim structures with a high usage lifetime in terms of durability, should be considered as a design parameter. For this purpose, it was investigated to what extent the fabric structural parameters and abrasion cycles affect the tribological properties of denim fabric structures, such as friction coefficients and fabric surface roughness.

This study aimed to investigate the effect of surface roughness and friction coefficient values of denim fabrics woven with different structural properties on abrasion behaviors. Fabrics were abraded at different abrasion cycles. The friction coefficients and surface roughness values of the fabrics after each abrasion cycle were tested. The effects of abrasion cycles on the friction coefficients and roughness values of the fabric surfaces were evaluated depending on the fabric structural parameters. From the results, the effects of fabric structural parameters on abrasion, which should be taken into consideration in determining the structural parameters suitable for fabric usage performance in denim fabric designs, were analyzed.

2. MATERIAL AND METHOD

2.1 Material

The denim fabrics used in the experimental study were woven with 100 % cotton open-end indigo dyed warp yarns and with undyed open-end weft yarns containing 97 % cotton - 3% elastane. Fabrics were woven with a 3/1 twill weave structure. The structural properties of denim fabrics are given in Table 1.

Table 1. Fabric structural properties

Fabric Code	Yarn Count [Nm]		Yarn Density [thread/cm]		Yarn Crimp [%]		Cover Factor			Fabric Thickness [mm]	Fabric Unit Weight [g/m^2]	Fabric Bulk Density [g/cm^3]
	Warp	Weft	Warp	Weft	Warp	Weft	Warp [K_{wa}]	Weft [K_{we}]	Fabric [K_f]			
F1	14	12	26	18	18	19	22.93	17.15	26.04	0.78	423.5	0.54
F2	14	17	30	20	17	30	26.46	16.01	27.34	0.73	412.1	0.56
F3	14	18	29	20	15	28	25.58	15.56	26.92	0.75	411.5	0.55
F4	14	18	31	19	20	18	27.34	14.78	27.69	0.76	388.6	0.51
F5	20	25	39	22	10	40	28.78	14.52	28.38	0.68	342.0	0.50
F6	22	33	37	22	10	40	26.03	12.64	26.92	0.55	284.0	0.52

2.2 Method

Measurement of thickness and unit weight of the fabric

The thickness and unit weight of fabrics were measured according to ASTM D1777-96 (2007) [26] and ASTM D3776 (2011) [27], respectively.

Calculation of fabric bulk density

Fabric bulk density (*FBD*) was calculated according to Equation (1) [28, 29]:

$$FBD\ (g/cm^3) = \text{Fabric unit weight}\ (g/cm^2)\ /\ \text{Fabric thickness}\ (cm) \quad (1)$$

Calculation of fabric cover factor

Warp cover factor (K_{wa}) and weft cover factor (K_{we}) were calculated to Equations (2) and (3) [30]:

$$K_{wa} = \frac{3{,}3\ x\ n_1}{\sqrt{Nm_1}} \quad (2)$$

$$K_{we} = \frac{3{,}3\ x\ n_2}{\sqrt{Nm_2}} \quad (3)$$

where, n_1 and n_2 are warp and weft yarn density (thread/cm); Nm_1 and Nm_2 are warp and weft yarn count in Nm (metric count; length in meters of 1 g of yarn), respectively.

Calculation of fabric cover factor (K_f) is presented by Equation (4) [30-32]:

$$K_f = K_{wa} + K_{we} - \frac{K_{wa}\ x\ K_{we}}{28} \quad (4)$$

where '*f*' stands for fabric, '*wa*' stands for warp, and '*we*' stands for weft.

Abrasion test

The abrasion tests of the fabrics were carried out under the load of 12 kPa, in the Nu-Martindale abrasion test device, by the standard of ASTM D 4966 [33], and four different abrasion cycles (2500, 5000, 10000, and 50000) were applied. Since denim fabrics were generally designed as structures with long-term use resistance and, simultaneously, considering the properties such as the high fabric unit weight of the denim samples used in the experimental study, it was aimed to obtain a higher abrasion effect. Therefore, the fabric samples were tested under a 12 kPa abrasive load.

However, to obtain a measurement length of at least 50 mm for roughness and friction, the locations of standard abrasive wool fabric and denim fabric samples were changed in the test device. Standard abrasive wool fabric was used on the upper face (the face with 38 mm diameter) of the motion plate, while denim fabric under test was mounted on the stable plate (the face with 140 mm diameter). Surface friction and roughness values were measured after each abrasion cycle, and the same fabric samples were used in the continuing abrasion cycles.

Friction coefficient test

The ratio of friction force (F) to normal force (N) between two surfaces is defined as the friction coefficient (μ=F/N). Static friction coefficient (μs) is the ratio between the maximum value of the friction force and the normal force, and kinetic (dynamic) friction coefficient (μk) is the ratio between the friction force and the normal force in motion. In general, the static friction coefficient is higher than the kinetic friction coefficient for the same material. According to the adhesion theory, when the friction behavior of two surfaces is investigated microscopically, contact is occurred on touching roughs between two surfaces when a force is applied to two surfaces that touch each other. Strong asperities must be eliminated to overcome the object's frictional force and slip from the surface. The smaller the actual contact area (the sum of the asperities), the less load required for the slip to occur, and the friction coefficient will decrease accordingly [7].

The static (μs) and kinetic (μk) friction coefficients used to evaluate the friction characteristics of the fabrics were measured according to ASTM D1894 [34] standard on a Labthink Param MXD-02 friction coefficient test device (Figure 1). Static and kinetic friction coefficients of the denim samples were measured by fabric-to-fabric (i.e., denim fabric-to-abrasive wool fabric) friction by using standard abrasive wool fabric (ASTM D 4966) [33]. The denim fabric sample under test was mounted on the sled (mass of sled: 200 g), and the standard abrasive wool fabric was mounted on the moving plate (the test speed: 150 mm/min; the measurement length: 150 mm) of the coefficient tester. Friction measurements of fabric samples were made in warp and weft directions, three measurements were recorded in each fabric direction, and mean values were calculated.

Figure 1. Friction coefficient tester (Labthink Param MXD-02)

Surface roughness test

Surface roughness values of denim samples were measured by a roughness tester (Accretech Surfcom 130A) (Figure 2). Surface roughness values were recorded according to ISO 4287-1997 standard [35]. The measurement was performed in a steady-state without causing any further tension on the sample. Three roughness measurements were made in each direction (warp and weft) with the selected measurement parameters of 50 mm evaluation length (0.8 mm cut-off value) and 1.5 mm/s measurement speed. Three measurements were recorded in each fabric direction, and mean values were calculated.

Figure 2. Surface roughness tester (Surfcom 130 A)

The arithmetic average height (*Ra*) parameter was measured to characterize the surface roughness properties of denim fabrics. Arithmetical average height is defined as the average absolute deviation of the roughness irregularities from the mean line in the evaluation length [36].

Correlation coefficient analysis

The effects of fabric structural parameters (yarn count, yarn density, yarn crimp, yarn cover factor, fabric thickness, fabric unit weight, fabric bulk density, and fabric cover factor) on fabric friction coefficient and surface roughness to abrasion were investigated by correlation analysis. The correlation coefficients (r-value) higher than 0.3 were considered related but with a weak relationship, and the correlation coefficients higher than 0.6 were considered to have moderate to strong relationship levels [37,38]. The correlation coefficient analysis results (r-value) are given in Tables 2 - 4.

Microscopic Analysis

Optical microscopic photographs of original (non-abraded) and 50000 cycles fabric samples, taken under a microscope coupled to a digital camera, were presented (15 times magnified) to observe the fabric surface appearance after the abrasion process according to the different constructional parameters.

3. RESULTS AND DISCUSSION

3.1 Friction coefficients of fabrics

In Figures 3 and 4, the changes in the friction coefficients of denim fabrics in warp and weft directions depending on the abrasion cycles were presented. In Fig. 3, it was observed that as the number of abrasion cycles increases, the μs values of surface increase in the overall fabrics except for the F1 fabric. This increase appeared to occur in an almost linear form due to abrasion in F5 and F6. When the structural properties of F5 and F6 fabrics were examined (Table 1), it was observed that they have low fabric unit weight, low fabric thickness, and low fabric bulk density values. Also, in the F5 and F6 fabrics, the weft crimp values were significantly higher than that of the other fabric structures. Unlike other fabrics, the μs values of the F1 fabric, which had the highest fabric unit weight, decreased as the number of abrasion cycles increased, and it increased after 10000 abrasion cycles. When the changes in the μk values of the warp direction were examined, it was found that generally, in all fabrics (except for F3 fabric), there was a decrease in the μk with the increasing number of abrasion cycles, and a significant increase occurred after about 10000 abrasion cycles.

When the warp direction friction behaviors of the fabrics in Fig.3 were examined, it could be observed that the tendencies of abrasion-related changes in the μs and μk were different from each other. It was observed that the deformation, which occurred on the surface (such as the fiber ends pulled out of the yarn structure in the fabric surface) of the fabric after the abrasion, increased the μs values (which occurs because of the resistant effect between the two surfaces during the start of the first movement) of the fabric surface, while it decreased the μk values obtained after the process started. It was seen that the decrease in the μk values might occur by the deformation of the twill diagonals due to the abrasion effect. And also, the fiber ends that were pulled through the yarn to the fabric surface after abrasion would decrease the μk, as they filled the gaps between twill diagonals within the fabric structure.

When the weft direction friction behaviors of the fabrics in Fig.4 were examined, it was observed that the μs and μk values decreased as the number of abrasion cycles increased at 10000 abrasion cycles. However, they increased after almost 10000 abrasion cycles. It was found that the diagonal peaks originating from the 3/1 twill weave structure forming the denim fabrics deformed due to the abrasion, and the friction coefficients decreased in the initial abrasion cycles. However, due to the continued abrasion process, it was found that the fiber piles and deformation on the fabric surface could have caused the increased friction coefficient between the two friction surfaces.

Correlation analysis between the fabric structural properties and friction coefficients was presented in Tables 2 and 3 depending on the different abrasion cycles in warp and weft directions.

In Tables 2 and 3, it could be seen that there was a negative correlation between yarn count and fabric friction coefficient values. This result showed that as the yarn count increased (in Nm), in other words, as the yarn fineness increased, the friction coefficient values decreased. When the effects of the yarn densities on the fabric friction coefficients were examined, the correlation between them was found to be negative. This result showed that as the yarn densities increased, the friction coefficients of the denim fabrics decreased.

When the effects of yarn crimps in the fabric structure on the friction coefficient of the fabric surface were examined, it was seen that the crimp effect of the yarns created a negative correlation in the weft direction while creating a positive correlation in the warp direction. This result showed that; as the crimps on the warp yarn increased, the values of the friction coefficients in the warp direction also increased; on the other hand, as the crimps on the weft yarn increased, the values of the friction coefficients in the weft direction decreased. This effect of the yarn crimps on the fabric friction coefficient values was because of their having a warp-dominant surface due to the 3/1 twill weave structure of the denim fabrics used in this study, and the increase in the friction coefficient in the warp direction with the rise in the amount of the crimps on the warp yarns, which were dominant on the fabric surface.

In Tables 2 and 3, it was observed that there was a negative correlation between the warp cover factor and the fabric friction coefficient in the warp direction. At the same time, there was a positive correlation between the weft cover factor and the fabric friction coefficient in the weft direction. Here, as the warp cover factor increased, the warp direction friction coefficient decreased. This result showed that as the warp direction cover factors of the warp-faced fabric surfaces (3/1 twill) increased, the friction coefficients of these surfaces would decrease. When the cover factor values of the weft yarns increased, their weft direction friction coefficient would also increase. This result was thought to be due to the fact that factors that increase the cover factor of the weft yarn system (such as increased weft density or increased thickness of the weft yarn) caused an increase in the distance between the diagonals formed by the twill structure on the warp faced fabric. Thus, the increase in the distance between the diagonals originating from the twill structure on the fabric surface also increases the friction coefficients in the weft direction. In denim structures, it was observed that the warp yarn cover factors' having higher values gave favorable results in reducing the friction coefficient in the warp direction. It could be also stated that keeping the weft yarn cover factor at low levels might be appropriate to reduce the friction coefficient in the weft direction. However, it was observed that negative correlation coefficients were obtained in both warp and weft directions between the fabric cover factor values and fabric friction coefficients.

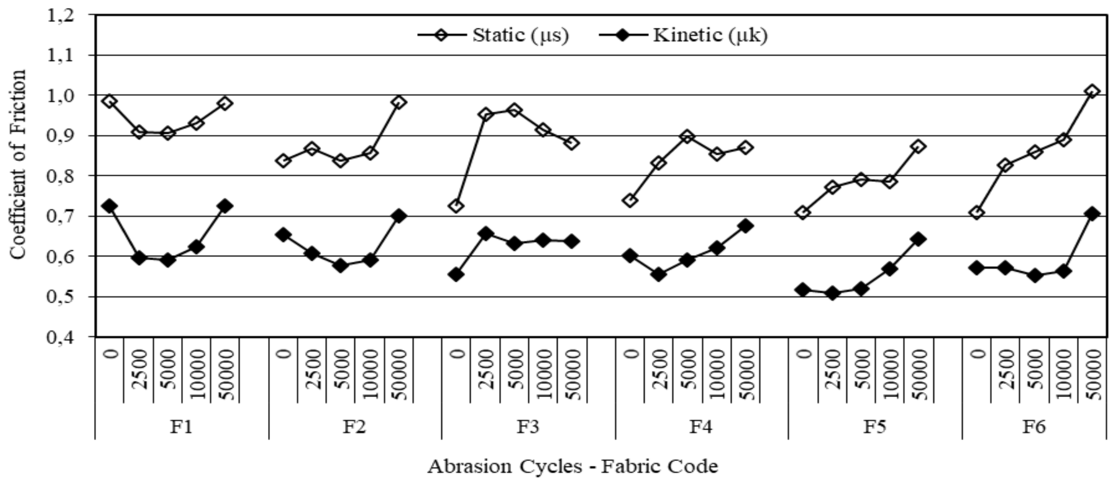

Figure 3. Change of fabric friction coefficient values in the warp direction

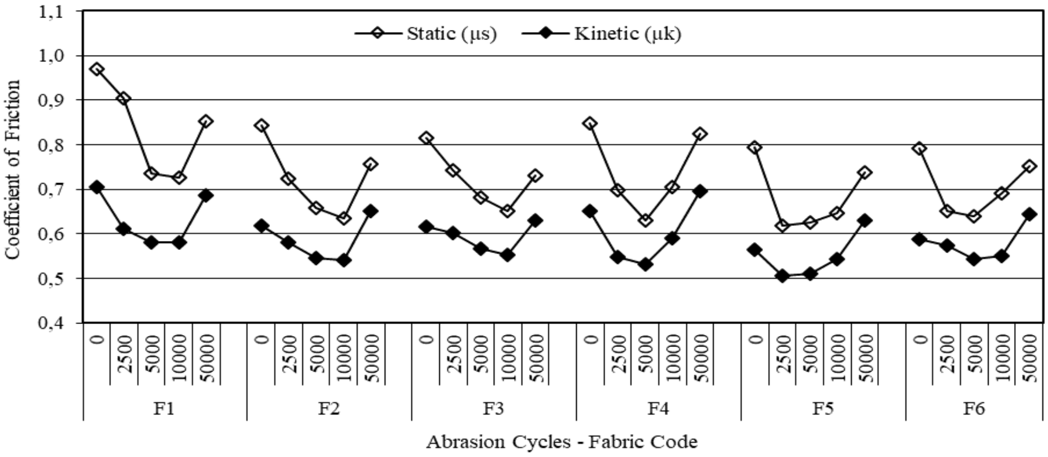

Figure 4. Change of fabric friction coefficient values in the weft direction

Table 2. Correlation coefficients between the fabric structural properties and friction coefficients in the warp direction

Coefficient of Friction	Abrasion Cycle	Warp Yarn Count	Warp Yarn Density	Warp Yarn Crimp	Warp Cover Factor	Fabric Thickness	Fabric Unit Weight	Fabric Bulk Density	Fabric Cover Factor
	0	-0.53	-0.73	0.54	-0.78	0.54	0.62	0.54	-0.69
	2500	-0.65	-0.85	0.56	-0.78	0.41	0.58	0.75	-0.80
μs	5000	-0.75	-0.91	0.64	-0.81	0.42	0.61	0.61	-0.60
	10000	-0.77	-0.95	0.66	-0.84	0.67	0.77	0.67	-0.80
	50000	0.21	-0.13	-0.11	-0.55	-0.41	-0.20	0.41	-0.61
	0	-0.57	-0.77	0.67	-0.78	0.48	0.58	0.57	-0.72
	2500	-0.58	-0.72	0.66	-0.62	0.63	0.55	0.83	-0.66
μk	5000	-0.79	-0.66	0.67	-0.62	0.76	0.71	0.63	-0.62
	10000	-0.75	-0.95	0.79	-0.86	0.59	0.70	0.65	-0.82
	50000	-0.05	-0.35	0.29	-0.63	-0.09	0.02	0.29	-0.64

Table 3. Correlation coefficients between the fabric structural properties and friction coefficients in the weft direction

Coefficient of Friction	Abrasion Cycle	Weft Yarn Count	Weft Yarn Density	Weft Yarn Crimp	Weft Cover Factor	Fabric Thickness	Fabric Unit Weight	Fabric Bulk Density	Fabric Cover Factor
	0	-0.77	-0.87	-0.75	0.79	0.63	0.64	0.58	-0.69
	2500	-0.64	-0.75	-0.60	0.76	0.57	0.56	0.65	-0.48
μs	5000	-0.58	-0.66	-0.49	0.68	0.41	0.54	0.61	-0.93
	10000	-0.22	-0.61	-0.63	0.52	0.43	0.48	0.69	-0.67
	50000	-0.57	-0.81	-0.81	0.48	0.50	0.40	-0.01	-0.47
	0	-0.78	-0.96	-0.90	0.72	0.67	0.67	0.39	-0.72
	2500	-0.45	-0.69	-0.70	0.60	0.30	0.47	0.67	-0.80
μk	5000	-0.53	-0.66	-0.53	0.56	0.37	0.53	0.68	-0.96
	10000	-0.50	-0.81	-0.87	0.31	0.45	0.40	0.63	-0.57
	50000	-0.51	-0.77	-0.83	0.35	0.46	0.36	-0.03	-0.33

In Tables 2 and 3, it was observed that there was a positive correlation between the fabric thickness and the fabric friction coefficient in the warp and weft directions. In other words, the fabric friction coefficients increased as the fabric thickness increased. Because the diagonal peak heights would also increase as the fabric thickness increase in the twill fabric structures, the difference in height between the peak and the valley points of the fabric surface increased the friction coefficient between the two surfaces. Similar to fabric thickness, fabric unit weight and fabric bulk density was found to be positively correlated with the friction coefficients in the warp and weft directions. The friction coefficient of the fabric surfaces increased together with the increase in the fabric unit weight and fabric bulk density.

In Tables 2 and 3, it was observed that the correlation between fabric structural properties and the friction coefficients of the fabrics was remarkable up to 50000 abrasion cycles. Especially, it was observed that the fabric structural properties did not significantly affect the fabric friction coefficients in warp direction at 50000 abrasion cycles. It was seen that the correlation coefficients between the structural parameters and the friction coefficients were low in warp direction at 50000 abrasion cycles. This result was because the warp-faced denim fabric surfaces were subjected to abrasion.

3.2 Surface roughness of fabrics

In Fig.5, the changes in arithmetic average roughness values (*Ra*) of denim fabrics depending on the abrasion were presented. It was observed that when the abrasion cycle increased, the roughness values in the warp and weft direction of the fabrics decreased. In Fig.5, it was also shown that the roughness values in the weft direction of the fabrics were higher than the roughness values in the warp direction. This result could be due to the 3/1 twill weave structure of the denim fabrics. During the roughness measurement in the warp direction, the stylus probe of the roughness measurement device moves on the warp yarn floating since it carries out the measurement on a warp yarn dominant surface. During the measurement of roughness in the weft direction, while the stylus probe of the instrument moves in the direction of the weft, it carries out its movements in the cross direction on each of the three floating yarn crowns of the warp yarn dominant surface. Therefore, since the measurement device moved in the weft direction and passed over each of the warp yarns one by one, it was considered that the indentation-protrusion zones between the yarns increased the roughness of the surface.

Regression equations and R^2 values of the changes in surface roughness of fabric samples after abrasion cycles were given in Figure 5. In Fig. 5, when the slopes of the changes in the surface roughness values that vary depending on the abrasion were examined, it was observed that the change in the warp direction roughness values was greater than in the weft direction. This result was because of the high deformation of the abraded warp yarn surface at the fabric surface where the warp yarns dominate due to the 3/1 twill structure. Experimental results showed that surface roughness values of denim fabrics decreased as abrasion cycles increased.

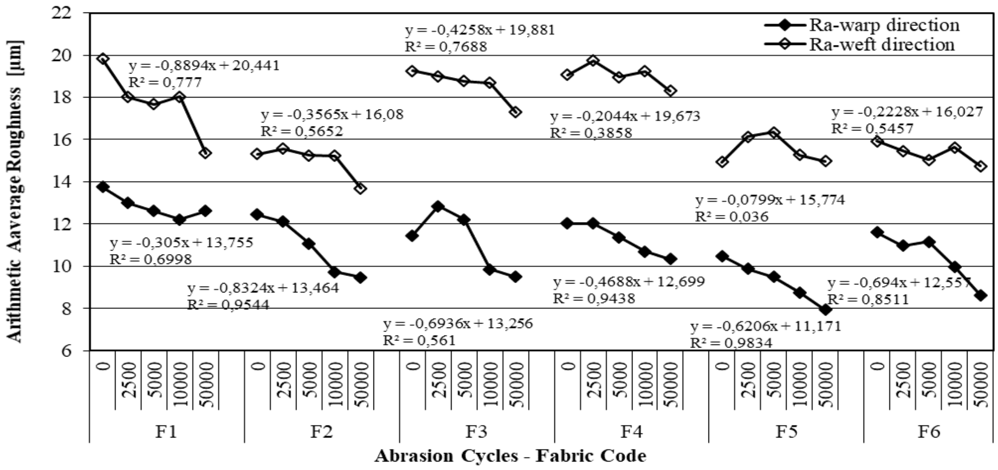

Figure 5. Change of fabric surface roughness values in warp and weft direction

Table 4. Correlation coefficients between the fabric structural properties and surface roughness

Surface Roughness	Abrasion Cycle	Yarn Count	Yarn Density	Yarn Crimp	Warp Cover Factor	Fabric Thickness	Fabric Unit Weight	Fabric Bulk Density	Fabric Cover Factor
Warp Direction	0	-0.32	-0.61	0.46	-0.81	0.34	0.30	0.65	-0.77
	2500	-0.84	-0.97	0.76	-0.78	0.66	0.78	0.72	-0.75
	5000	-0.61	-0.87	0.59	-0.89	0.44	0.55	0.57	-0.90
	10000	-0.45	-0.71	0.61	-0.83	0.42	0.41	0.49	-0.79
	50000	-0.69	-0.87	0.77	-0.82	0.66	0.68	0.43	-0.74
	Abrasion Cycle	Yarn Count	Yarn Density	Yarn Crimp	Weft Cover Factor	Fabric Thickness	Fabric Unit Weight	Fabric Bulk Density	Fabric Cover Factor
Weft Direction	0	-0.58	-0.72	0.73	-0.64	0.60	0.51	0.06	-0.59
	2500	-0.64	-0.55	0.69	-0.20	0.68	0.54	-0.06	-0.15
	5000	-0.62	-0.52	0.59	-0.17	0.71	0.56	-0.05	-0.11
	10000	-0.64	-0.63	0.66	-0.36	0.62	0.53	0.06	-0.34
	50000	-0.42	-0.31	0.35	-0.01	0.41	0.30	-0.09	-0.02

In Table 4, the correlation between the yarn properties constituting the denim fabrics and the surface roughness (*Ra*) depending on different abrasion cycles was presented. It was observed that there was a negative correlation between the yarn counts and the roughness values of the fabric surface. As the yarn count was increased (in Nm), in other words, as the yarn became finer, the roughness values of the fabric surface decreased. When the correlation between yarn densities and fabric surface roughness was examined, it would be seen that there was a negative correlation between the yarn densities and the surface roughness values of the fabrics. As the yarn densities forming the fabric increased, the roughness values of the fabric surface decreased. A positive correlation was observed between the yarn crimps in the fabric structure and the roughness values of the fabrics, and the surface roughness increased as the yarn crimp increased.

The literature stated that the fabric surface roughness decreased with increasing yarn density. This result could be due to the positioning of the yarns within the fabric structure. An increase in yarn density decreased the gaps between the yarn peaks, decreasing surface roughness [39-41].

In Table 4, when the values of cover factor and the roughness values in warp and weft directions of fabrics were examined, a negative correlation was observed between them. This result indicates that when the cover factors were increased, the roughness values of the fabric surface would be reduced. Also it was seen that the correlation coefficients between cover factor and roughness values in the warp direction were higher than in the weft direction. This could be result the fabrics where the warp yarns dominate, due to the 3/1 twill structure. In general, it was observed that there was a positive correlation between the fabric thickness, fabric unit weight, fabric bulk density, and fabric surface roughness values. When the thickness, unit weight, and bulk density values of fabrics were increased, the surface roughness values of the fabrics were increased.

Digital photographs of all fabric samples (F1 – F6) were presented in Figure 6 to consider the abrasion effect on the fabric surface appearance.

4. CONCLUSION

This study investigated the abrasion behaviors of denim fabrics woven with different structural parameters and the relation between surface friction coefficients and surface roughness values of fabrics depending on these parameters. While the abrasion process reduced the friction coefficients of the fabrics during the initial abrasion cycles, the surface's friction coefficient increased as the number of abrasion cycles increased. The changes occurring in the friction coefficient due to abrasion showed different tendencies for the warp and weft directions of the fabrics. However, due to the increased number of abrasion cycles, there was a steady decline in the roughness values of the fabric surfaces.

Denim fabrics were woven with a 3/1 twill weave pattern. When the effect of the fabric structural parameters on fabric friction coefficient and roughness values were evaluated, the yarn count (Nm), yarn density, and fabric cover factor showed negative correlation coefficients. In contrast, the thickness, unit weight, and bulk density of fabric showed positive correlation coefficients.

Results showed that the highest friction coefficient and roughness values were in fabrics woven with thick yarn and low yarn density values. And also the maximum variation on the fabric surface in terms of friction coefficient and roughness due to abrasion was in these types of fabrics. However, even though the non-abraded states of the fabrics woven with fine yarn and high density values have low roughness and friction coefficients, it was determined that the variations in surface roughness and friction coefficients of these structures were high with increasing abrasion cycles.

The extent to which abrasion affects the friction coefficients and fabric surface roughness of denim fabrics in terms of appearance and wearing comfort, especially in denim structures with a high usage lifetime in terms of durability, should be considered as a design parameter.

Due to the fact that the abrasion effect on the fabric surface could be measured precisely and objectively with the friction coefficient and surface roughness measurements; it could be envisaged that the friction coefficient and surface roughness parameters might be the parameters to be considered in the stages of determining the appropriate structural parameters in the fabric design process and determining various performance properties in the production and usage process.

Acknowledgement

This study is a part of the MSc thesis titled “Investigation of Relations between Constructional Parameters and Some Surface Properties in Denim Fabrics Woven with Different Fiber Contents” by Gizem Kara.

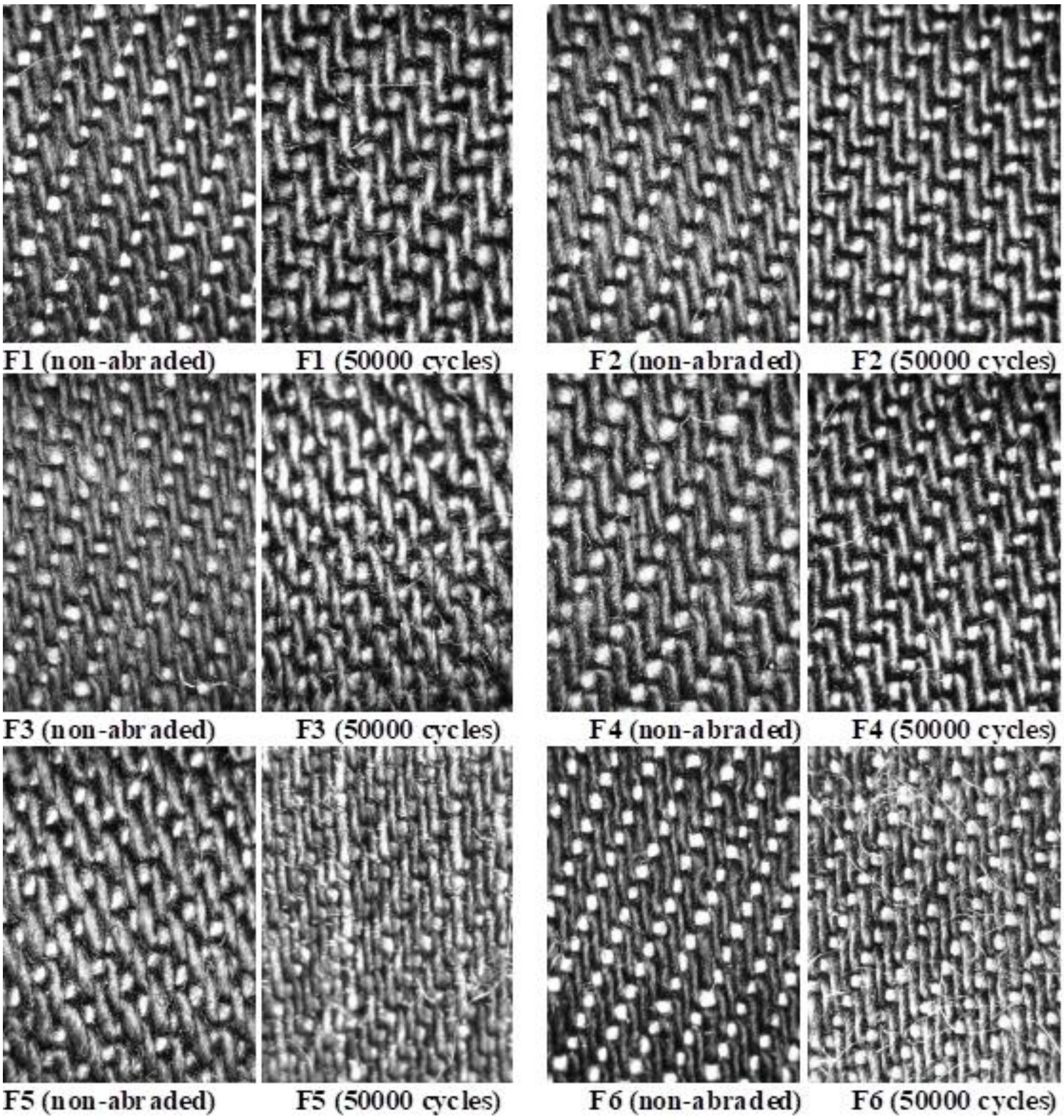

Figure 6. Digital photographs of all fabric samples

REFERENCES

1. Korkmaz İB. 2009. Denim kumaş imalatı ve üzerine uygulanan işlemler (Master's thesis). Haliç Üniversitesi, Sosyal Bölümler Enstitüsü, Tekstil ve Moda Tasarımı Anasanat Dalı, Tekstil ve Moda Tasarımı Programı, İstanbul, p. 108.
2. Çakır N. 2010. Kot pantolon üretiminde bitim işlemlerinin ve farklı denim kumaşların fit üzerine etkileri (Master's thesis). Pamukkale Üniversitesi, Fen Bilimleri Enstitüsü, Tekstil Mühendisliği Anabilim Dalı, Denizli, p. 99.
3. Tarhan M. 2005. Eskitme yöntemlerinin denim mamullerin performans özelliklerine etkisi (Master's thesis). Dokuz Eylül Üniversitesi, Fen Bilimleri Enstitüsü, Tekstil Mühendisliği Ana Bilim Dalı, İzmir, p. 120.
4. Toksöz M, Mezarcıöz S. 2013. Application of special washing processes to denim fabrics. *Çukurova University Journal of the Faculty of Engineering and Architecture* 28(2), 141-147.
5. Vassiliadis SG, Provatidis CG. 2004. Structural characterization of textile fabrics using surface roughness data. *International Journal of Clothing Science and Technology* 16(5), 445-457.
6. Xin JH, Lam CC. 2005. Investigation of texture effect on visual colour difference evaluation. *Color Research and Application* 30(5), 341-347.
7. Balcı G, Sülar V. 2009. Yarn friction properties: Importance and test methods. *Tekstil ve Mühendis* 16(74), 6-15.
8. Budinski KG. 2007. Guide to friction, wear and erosion testing. ASTM Stock Number: MNL56, ASTM International, 95.
9. Das A, Kothari VK, Vandana N. 2005. A study on frictional characteristics of woven fabrics. *AUTEX Research Journal* 5(3), 133-140.
10. Ajayi JO. 1992a. Fabric smoothness. friction and handle. *Textile Research Journal* 62(1), 52-59.
11. Ajayi JO. 1992b. Effects of fabric structure on frictional properties. *Textile Research Journal* 62(2), 87-93.
12. Hearle JWS, Husain AKMM. 1971. Studies in needled fabrics. Part VIII: The effect of friction on the processing and properties of needle-bonded fabrics. *The Journal of The Textile Institute* 62, 83-107.

13. Sülar V, Öner E, Okur A. 2013. Roughness and frictional properties of cotton and polyester woven fabrics. *Indian Journal of Fibre & Textile Research* 38, 349-356.

14. Wilson D. 1963. A study of fabric-on-fabric dynamic friction. *Journal of the Textile Institute Transactions* 54(4), T143-T155.

15. Ohsawa M, Namiki S. 1979. Anisotropy of static friction of plain-woven filament fabrics. *Journal of the Textile Machinery Society of Japan* 32, T40.

16. Stockbridge HCW, Kenchington KWL, Corkindale KG, Greenlands J. 1957. The subjective assessment of the roughness of fabrics. *Journal of the Textile Institute Transactions* 48(1), T26-T34.

17. Thornedike GH, Varley L. 1961. Measurement of the coefficient of friction between samples of the same *cloth. Journal of the Textile Institute Proceedings* 52(6), 255-271.

18. Ohsawa M, Namiki S, Kodaka H. 1969. Relationship between fabric balance and surface friction of plain woven fabrics. *Journal of the Textile Machinery Society of Japan* 15, 98-105.

19. Thomas TR. 1999. Rough surfaces (2nd ed.), Imperial College Press, London.

20. Zurek W, Jankowiak D, Frydrych I. 1985. Surface frictional resistance of fabrics woven from filament yarns. *Textile Research Journal* 55(2), 113-121.

21. Ukponmwan JO. 1987. Appraisal of woven fabric quality. *Textile Research Journal* 57(5), 283-298.

22. Ajayi JO, Elder HM. 1997. Effects of surface geometry on fabric friction. *JTEVA* 25, 182-188.

23. Militký J. 2005. Fabric roughness characterization. Technical University of Liberec. Czech Republic, ITSAPT Summer School, September, http://centrum.tul.cz/centrum/itsapt/Summer2005/files/militky_3.pdf - (07.07.2009)

24. Bilisik K, Yolacan G. 2011. Tensile and tearing properties of newly developed structural denim fabrics after abrasion. *Fibres & Textiles in Eastern Europe* 19(5), 54-59.

25. Shaw VP, Mukhopadhyay A. 2022. Impact of abrasion on strength, elasticity and elastic recovery properties of stretch-denim fabric. *International Journal of Clothing Science and Technology* 34(2), 241-261.

26. ASTM D1777-96. 2007. Test method for thickness of textile materials.

27. ASTM D3776. 2011. Standard test methods for mass per unit area (weight) of fabric.

28. Hsieh YL. 1995. Liquid transport in fabric structures. *Textile Research Journal* 65(5), 299-307.

29. Hsieh YL, Cram LA. 1998. Enzymatic hydrolysis to improve wetting and absorbency of polyester fabrics. *Textile Research Journal* 68(5), 311-319.

30. Peirce FT. 1937. The geometry of cloth structure. *The Journal of The Textile Institute Transactions* 28(3), T45–T96.

31. Seyam AM. 2002. The structural design of woven fabrics: theory and practice. *The Textile Institute, Textile Progress* 31, 11-19.

32. Hearle JWS, Grosberg P, Backer S. 1969. Structural mechanics of fibers, yarns and fabrics. Wiley-Interscience, New York, USA.

33. ASTM D 4966-12. 2012. Standard test method for abrasion resistance of textile fabrics.

34. ASTM D1894-14. 2014. Standard test method for static and kinetic coefficients of friction of plastic film and sheeting.

35. ISO 4287-1997. 2005. Geometrical product specification (GPS) - Surface texture: profile method – terms, definitions and surface texture parameters.

36. Gadelmawla ES, Koura MM, Maksoud TMA, Elewa IM, Soliman HH. 2002. Roughness parameters, *Journal of Materials Processing Technology* 123(1), 133–145.

37. Mansor A, Ghani SA, Yahya MF. 2016. Knitted fabric parameters in relation to comfort properties. *American Journal of Materials Science* 6(6), 147-151.

38. Mukaka MM. 2012. A guide to appropriate use of correlation coefficient in medical research. *Malawi Medical Journal* 24(3), 69-71.

39. Akgun M, Becerir B, Alpay HR. 2012. The effect of fabric constructional parameters on percentage reflectance and surface roughness of polyester fabrics. *Textile Research Journal* 82(7), 700–707.

40. Akgun M. 2014. Assessment of the surface roughness of cotton fabrics through different yarn and fabric structural properties. *Fibers and Polymers* 15, 405–413.

41. Akgun M. 2015. Assessment of the effect of fabric constructional parameters on surface roughness of wool fabrics. *The Journal of The Textile Institute* 106(8), 845–852.