(REFEREED RESEARCH)

ASSESSING THE EFFECT OF MEASUREMENT PARAMETERS ON SURFACE ROUGHNESS VALUES OF POLYESTER WOVEN FABRIC STRUCTURES

ÖLÇÜM PARAMETRELERİNİN POLİESTER DOKUMA KUMAŞLARIN YÜZEY PÜRÜZLÜLÜK DEĞERLERİ ÜZERİNDEKİ ETKİSİNİN ARAŞTIRILMASI

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ABSTRACT

This paper focused on the determination of the accurate measurement parameters of surface roughness of woven fabric structures. Surface roughness measurements were conducted on plain, twill and satin fabric samples woven with the same yarns in warp and weft directions with the same yarn densities in sub-groups. Roughness parameter of arithmetic average height (mean height) (Ra) was measured in the directions of warp, weft and diagonal (45o to the crossing axis of warp and weft) on front and back sides of fabric samples. It was concluded that surface roughness properties of woven fabrics changed considerably according to measurement parameters because of the anisotropic structure of fabric surfaces. Additional parameters which enable the characterization of surface roughness could be researched and determined with regard to fabric constructional parameters.

Keywords: Surface roughness, Roughness measurement parameters, Polyester woven fabric.

ÖZET

Bu makalede dokuma kumaş yapılarının yüzey pürüzlülüklerinin ölçümünde kullanılacak ölçüm parametrelerinin belirlenmesi amaçlanmıştır. Yüzey pürüzlülük ölçümleri bezayağı ve saten örgü yapılı (çözgü ve atkı iplik numaraları ve sıklıkları sabit tutularak) kumaşlar üzerinde yapılmıştır. Pürüzlülük parametresi olarak aritmetik ortalama yükseklik (Ra) değerleri kumaşların ön ve arka yüzeylerinden çözgü, atkı ve diyagonal (çözgü ve atkı iplik kesişimlerine 45o'lik açı ile) yönlerde alınmıştır. Sonuç olarak dokuma kumaşların yüzey pürüzlülük özelliklerinin kumaşların anizotropik yapılarından dolayı farklı ölçüm parametrelerine göre değişim gösterdiği görülmüştür. Dokuma kumaşların yüzey pürüzlülüklerinin değerlendirilmesi için yeni parametrelerin araştırılması ve değerlendirilmesi çalışmalarının kumaş konstrüksiyon özelliklerine göre yapılması gerekmektedir.

Anahtar Kelimeler: Yüzey pürüzlülüğü, Pürüzlülük ölçüm parametreleri, Poliester dokuma kumaş.

1. INTRODUCTION

Roughness is a measure of the texture of a surface. A surface can never be perfectly smooth and will always have two components of surface texture; namely roughness and waviness. They may vary from fine to coarse according to the production process used. Roughness is quantified by the vertical deviations of a real surface from its ideal form. If these deviations are large, the surface is rough; if they are small the surface is smooth. Roughness is typically considered to be the high frequency, short wavelength component of a measured surface. Roughness plays an important role in determining how a real object will interact with its environment. Rough surfaces usually wear more quickly and have higher friction coefficients than smooth surfaces (1, 2). Fabrics that yield more peaks and lower amplitude pulses are judged smoother than those with fewer peaks and higher amplitudes. Generally, there are two kinds

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of irregularities–systematic variation arising from uniform fabric structures such as cord or ribs, and random variation caused by uneven threads or thread spacing (3). The geometrical roughness measurement is a part of the global objective measurements of fabrics, which include the full set of the micromechanical parameters of fabric (4). The geometrical roughness signals only the upper and lower limits of thickness variation of fabric (5). Surface data obtained using optical methods and subjected to signal processing techniques have been used for the identification of fabric structures (6, 7).

The surface of the textile fabrics is not absolutely flat and smooth. Textile fabrics are rarely balanced in terms of appearance of warp and weft on their surface. Very often, even in the case of plain weave fabrics, there is a domination of one group of threads. They appear more intense on the surface resulting in hiding the other group of threads. This introduces a certain difficulty in obtaining structural information from surface roughness data (5).

A factor which has an important role in the configuration of surface characteristics of fabric is the crimp of yarns. If the crimp values of weft and warp yarns are close to each other, the fabric produced is more or less balanced in terms of appearance. If the values of the crimp are far from each other, the result is an unbalanced surface with one dominating direction in surface structure of fabric. The real structure of fabrics differs from the ideal one, mainly because of flattening of yarns cross-sections. The flattened yarns lead to a compressed profile of fabric, and to minimized amplitude of the variation of surface level (5). Schematic presentation of the thread spacing of warp and weft yarns in plain weave pattern was presented in Figure 1.

Also, studies related with polyester woven fabrics revealed that fabric constructional parameters such as fineness of filaments and yarn, weft density, type of weave and also cover and balance properties of fabrics, affect the texture and also surface roughness of fabrics. Results showed that fabrics with smooth surface properties could be produced by using higher yarn density, by finer filament yarns, by decreased yarn float lengths, by increased fabric cover and by improved fabric balance (8 - 10).

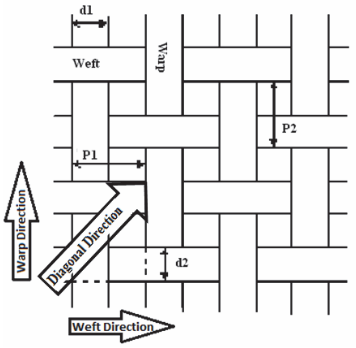

Figure. 1. Schematic presentation of the thread spacing of individual warp (P_1) and weft (P_2) yarns (d_1: warp diameter; d_2: weft diameter).

2. MATERIALS AND METHODS

Surface roughness experiments were performed on plain, twill and satin patterned polyester woven fabrics which composed of textured polyester warp and weft yarns with semi-dull fibers of round cross sectional shapes. Fabric samples were woven under controlled mill conditions in order to obtain the exact constructional properties. After weaving, samples were pre-treated (washed with a non-ionic agent (2 g/L) at 60°C for 30 minutes and later stentered without applying any tension at 180°C for 60 seconds) under mill conditions and prepared for roughness measurements in the laboratory. The constructional parameters of the samples were given in Table 1.

Surface roughness of the samples was measured by a Surfcom 130A roughness tester (Figure 2) and surface roughness values were recorded according to ISO 4287-1997 (13). The essential properties of surface roughness tester were given in Table 2. Different measurement parameters of roughness such as measurement direction (warp direction, weft direction and diagonal direction (45^o to the crossing axis of warp and weft), evaluation length (10 mm and 50 mm), measurement speed (0,15 mm/s and 1,5 mm/s) at both front and back sides of fabric were considered to assess the fabric surface roughness.

Table 1. Constructional parameters of fabric samples.

Fabric Code	Fabric Weave	Yarn Count [denier/filament]		Yarn Density [thread/cm]		Yarn Crimp [%]		Thread Spacing of Individual Warp and Weft Yarns [cm]		Cover Factor*		
		Warp	Weft	Warp	Weft	Warp	Weft	Warp (P_1)	Weft (P_2)	Warp (K_1)	Weft (K_2)	Fabric (K_f)
F1	Plain	70/35	135/35	65	17	14,90	4,95	0,01538	0,05882	18,92	6,87	21,15
F2	Plain	70/35	135/35	65	23	17,75	5,75	0,01538	0,04348	18,92	9,30	21,93
F3	Twill (2/1)	70/35	135/35	65	17	13,45	4,35	0,01756	0,08058	18,92	6,87	21,15
F4	Twill (2/1)	70/35	135/35	65	23	14,50	5,20	0,01756	0,05756	18,92	9,30	21,93
F5	Satin (5/1)	70/35	135/35	65	17	9,55	4,55	0,02410	0,14584	18,92	6,87	21,15
F6	Satin (5/1)	70/35	135/35	65	23	11,40	4,95	0,02410	0,09980	18,92	9,30	21,93

*Cover factors were calculated according to Refs. (11, 12).

Table 2. The properties of surface roughness tester.

Measuring Range	X-axis (horizontal)	50mm
	Z-axis (vertical)	800μm (Measuring range/resolution: 800μm/10nm, 80μm/1nm, 8μm/0,1nm)
Detector Properties	Tip radius: 2μm, Material: Diamond, Measuring Force: 0.75 mN	

Figure 2. Surface Roughess Tester (Surfcom 130 A).

Surface roughness measurements were conducted on ready to dye white polyester fabric samples at single fabric fold. Fabric sample was mounted on a glass sheet (surface roughness value of glass sheet; R_a: 0,023 at 50 mm evaluation length and at 1,5 mm/s measurement speed), the sample was fastened from one side and the other side was left free so that the measurement was performed on relaxed state without causing further tension. Ten roughness measurements were made on each direction with the selected measurement parameters.

For the characterization of fabric surface roughness, the arithmetical average height (mean height) (R_a) was used (Eq. 1). R_a is defined as the average absolute deviation of the roughness irregularities from the mean line over one sampling length. R_a parameter is the most universally used roughness parameter, especially for general quality control. This parameter is easy to define and it gives good general description of height variations (14).

$$R_a = \frac{1}{n}\sum_{i=1}^{n}|Z_i| \qquad \text{(Eq. 1)}$$

where absolute values of the profile variations $Z_1, Z_2, \ldots, +Z_n$ from the mean line in the evaluation length and n is the number of profile variation.

Statistical analysis of roughness values was performed according to analysis of variance (ANOVA). Statistical analysis was performed for each fabric sample taking evaluation length, measurement speed and fabric side as the factors. SNK test was chosen because significant differences between three sample means had been revealed by analysis of variance (ANOVA). SNK (Student-Newman-Keuls Test) results of the experimental procedure were presented in Table 3.

3. RESULTS AND DISCUSSION

Roughness measurement results (R_a) in warp, weft and diagonal directions according to evaluation length, measurement speed and side of fabric were presented in Figure 3 for plain, in Figure 4 for twill and in Figure 5 for satin patterned structure.

For the parameters of surface roughness, evaluation length and measurement speed are important in discussion of the results. Surfaces of woven structures, together with the most textile structures, are anisotropic and they exhibit different properties when measurements are conducted in different directions and sides.

Surfaces of woven structures have different material- and structure-based properties in different measurement and assessment directions, i.e. warp, weft and diagonal. Most of the mechanical properties of woven structures change according to warp, weft and diagonal directions because of the multi-directional properties of these structures. As the yarns which constitute the fabric structure form a network of crossings among themselves, and as the properties of yarns that affect the mechanical properties of woven structures depend on the location of yarns in the network of the fabric bulk, always the same results of mechanical properties could not be obtained in measurement directions. Surface roughness of textile woven structures is prone to show very distinct properties in different measurement directions because of the claims given above.

The evaluation lengths (10 mm and 50 mm) used in the experimental part were chosen as the shortest and longest evaluation lengths which could be tested by the surface roughness tester. Also the measurement speeds (0,15 mm/s and 1,5 mm/s) were chosen as the slowest and the fastest speeds of the roughness tester. Measurement speed of 3 mm/s was also tested but regular stylus movement could not be obtained and roughness results could not be recorded.

Surface roughness measurements in warp, weft and diagonal directions showed different properties according to evaluation lengths (10 mm and 50 mm), to measurement speeds (0,15 mm/s and 1,5 mm/s) and to the side of fabrics (front and back) on which the measurements were conducted.

R_a values of plain fabric samples in the measurement directions of warp, weft and diagonal were presented in Figure 3 for two different weft yarn densities (F1 and F2). R_a values of F1 were higher than the values of F2. R_a values in warp and diagonal directions decreased when evaluation lengths were increased from 10 mm to 50 mm in F1. However R_a values in weft direction increased when evaluation lengths were increased. Roughness values in warp and weft directions increased when measurement speeds were increased from 0.15 mm/ s to 1.5 mm/s. R_a values in diagonal direction changed regularly with measurement speeds and lengths on the front side of F1 while they showed slight changes on the back side.

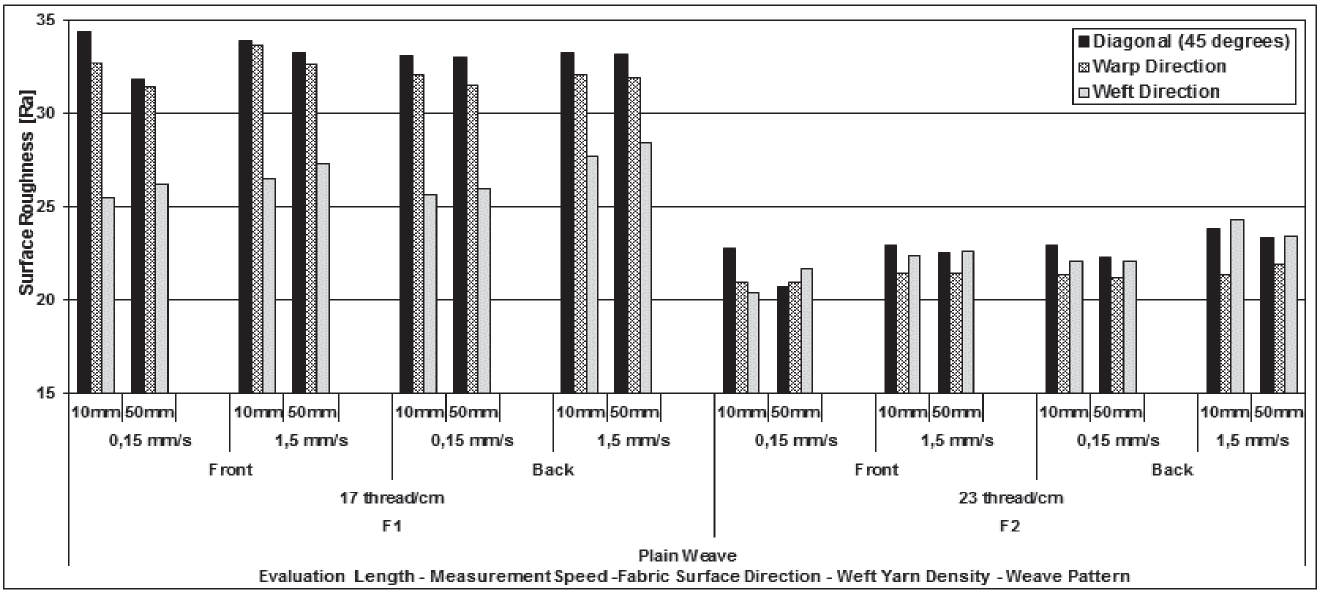

Figure 3. Surface roughness values of plain fabrics in three directions according to different measurement parameters.

When F2 fabric was considered, it was observed that R_a values were almost the half ones of the values obtained in F1. Roughness values in warp and weft directions increased very slightly when evaluation length and measurement speed were increased. But the only exception for R_a values in weft direction was the measurement results of 10 mm and 50 mm at 1.5 mm/s measurement speed. Roughness values in diagonal direction decreased slightly when evaluation length was increased but they increased slightly when measurement speed was increased.

An overall consideration of roughness values of F1 and F2 in Figure 3 showed that R_a values were closely related with weft yarn densities and they decreased considerably when weft density increased. Roughness values were higher in F1 probably due to longer thread spacing of weft yarns when compared to the weft thread spacing of F2 (Table 1). Longer thread spacing resulted in deep valleys so that roughness values increased. Effect of longer thread spacing on weft yarns was measured in warp direction because the measuring stylus travels along the warp threads while measuring the gaps between weft yarns which are due to thread spacing. For that reason Ra values in warp and diagonal directions were much higher than the R_a values in weft direction of F1. In F2, the higher weft yarn density with lower thread spacing minimised the differences between R_a values in the three measurement directions.

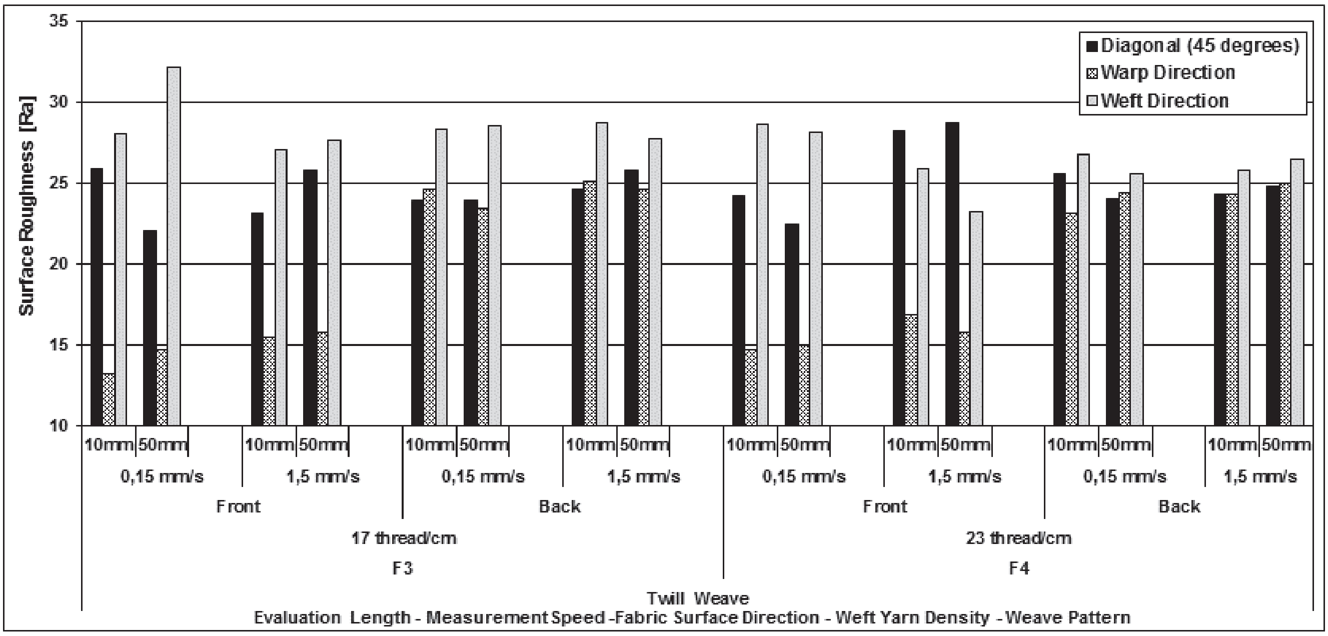

Figure 4. Surface roughness values of twill fabrics in three directions according to different measurement parameters.

R_a values of twill fabric samples in the measurement directions of warp, weft and diagonal were presented in Figure 4 for two different weft yarn densities (F3 and F4). The distribution and character of the roughness values were completely different from the roughness values of plain fabric samples which were presented in Figure 3. In both F3 and F4, R_a values in warp direction changed considerably according to measurement speeds and fabric sides (front and back) on which the measurements were conducted. Roughness values in warp direction were apparently higher on back sides of F3 and F4 when compared to the front sides. Also R_a values in warp direction increased as evaluation length and measurement speed were increased both on front and back sides of fabrics F3 and F4. However, there were two exceptions which did not showed the same character mentioned above but the differences between the values were considerably small. Almost all the highest roughness values in twill samples were obtained in weft direction of fabrics F3 and F4. Distribution of R_a values changed considerably according to evaluation lengths and measurement speeds in both fabrics. When F3 sample was considered, R_a values in weft direction slightly increased when evaluation length was increased but they slightly decreased when measurement speed was increased. R_a values in diagonal direction showed considerable differences according to evaluation length and measurement speed both in F3 and F4. Roughness values in diagonal direction decreased when evaluation length was increased at 0.15 mm/s measurement speed. An opposite behaviour was obtained when measurements were conducted at 1.5 mm/s.

An overall consideration of roughness values of F3 and F4 in Figure 4 showed that the regularity of fabric surfaces affected roughness results which were obtained on front and back sides. Although R_a values in warp direction showed considerable differences when measurements were conducted on either sides, R_a values in weft and diagonal directions were usually consistent on both sides. R_a values of F3 and F4 fabric samples showed slight differences according to weft yarn densities. However, R_a values of F1 and F2 fabric (Figure 1) samples differed according to weft yarn densities and they did not show distinct differences according to the side of fabric sample on which the roughness measurement was conducted.

R_a values of satin fabric samples in the measurement directions of warp, weft and diagonal were presented in Figure 5 for two different weft yarn densities (F5 and F6). Roughness values in the three measurement directions changed considerably to weft yarn density in both fabric samples. The highest roughness values in the three directions were obtained in F5 sample among all the fabric samples (F1-F6). This was probably due to high number of deep valleys on fabric surface because of longer weft and warp spacing on fabric surface. R_a values in warp direction decreased when measurement speed was increased from 0.15 mm/s to 1.5 mm/s. Roughness values measured on front side of F5 in three directions were higher than the values measured on back side of F5. But this behaviour was not observed in F6. Roughness values in warp and diagonal directions measured on front side of F6 were smaller than the values measured on back side. This was probably due to shorter weft thread spacing of F6. Roughness measurements made on F5 and F6 differed from each other especially when measurements were conducted on front and back sides of the fabric samples although the two samples had satin weave pattern. R_a values in weft direction increased when evaluation length and measurement speed was increased on both sides of F5. But R_a values in weft direction decreased when evaluation length was increased on both sides of F6. However, R_a values in weft direction showed almost no changes when measurement speed was increased for the same evaluation length.

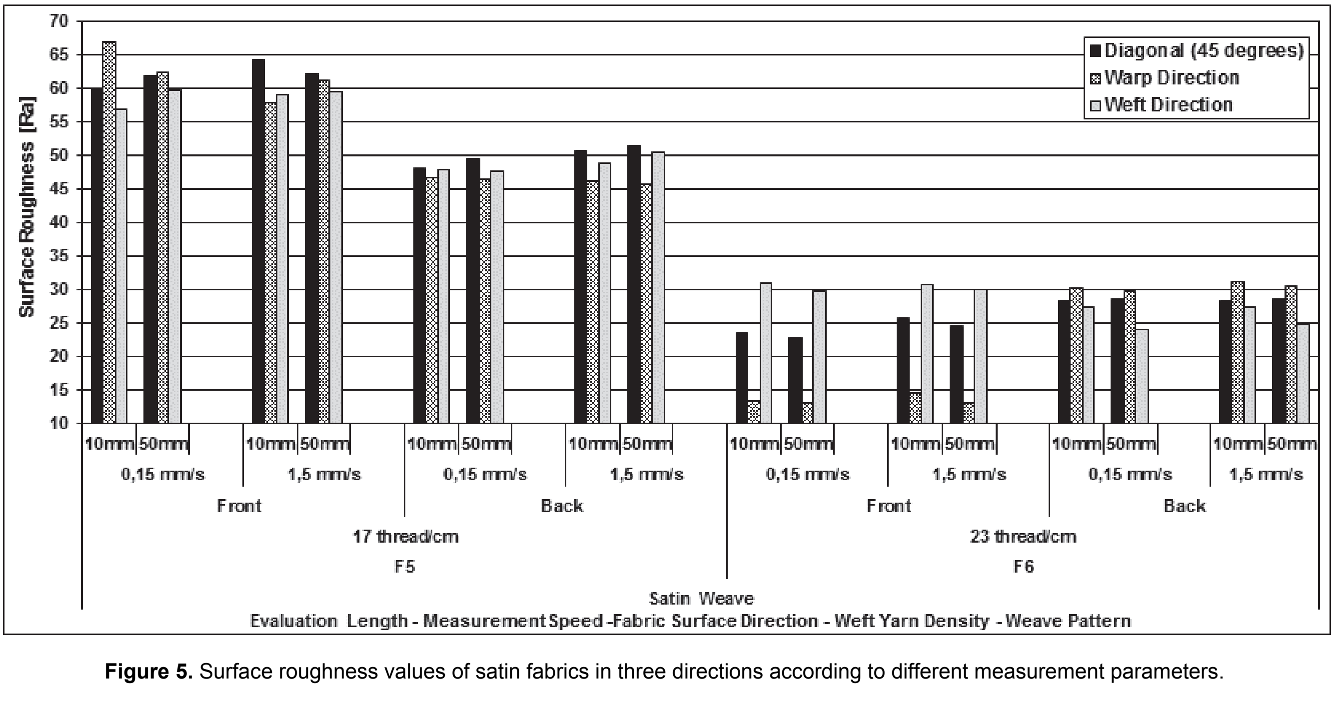

Figure 5. Surface roughness values of satin fabrics in three directions according to different measurement parameters.

The great differences between the R_a values of F5 and F6 were probably due to the differences between weft yarn spacing of the two fabric samples. The highest weft yarn thread spacing among all the fabric samples were obtained in F5 (Table 1) and also the highest roughness values in the three measurement directions were obtained in F5.

SNK (Student-Newman-Keuls Test) results according to analysis of variance (ANOVA) results of the experimental procedure were presented in Table 3. Statistical analysis was performed for each fabric sample taking evaluation length, measurement speed and fabric side as the factors. SNK results showed that it was difficult to express the exact effect of any experimental parameter on any fabric constructional property. SNK results of experimental parameters showed small clusters according the weave patterns. All the p-values which were obtained in ANOVA analysis had the 0.00 value which pointed that all the factors and their cross effects were important in the interpretation of the results.

Roughness results of the fabric samples (F1-F6) presented in Figures 3-5 revealed the anisotropic structure of textile fabrics from the viewpoint of surface characteristics. R_a values changed mainly with the changes in thread spacing which were due to the weft yarn density differences among different weave patterns. R_a values did not change considerably between front and back sides of plain samples (F1 and F2) but they changed considerably between front and back sides of twill (F3 and F4) and satin (F5 and F6) samples.

Although plain, twill and satin fabric samples had the same cover factor (woven from the same count yarns at the same yarn densities) values of R_a parameter of satin sample were higher than that of the two samples at different measuring parameters. The difference between the thread spacing of the three patterns could have caused this result. The yarn spacing of satin sample was much higher than plain and twill ones (Table 1). This could have caused long deep valleys which increased R_a. Generally, it could be stated that shorter thread spacing caused height variations to decrease and as a result R_a values decreased.

Table 3. SNK results of the ANOVA analysis

Fabric Code	Factors	Treatment	Rank of Surface Roughness Values*		
			Warp Direction	Weft Direction	Diagonal Direction
F1	Measurement Speed	1 (0,15 mm/s)	2	2	2
		2 (1,5 mm/s)	1	1	1
	Evaluation Length	1 (10 mm)	1	2	1
		2 (50 mm)	2	1	2
	Fabric Surface Direction	1 (Front)	1	2	1
		2 (Back)	2	1	2
F2	Measurement Speed	1 (0,15 mm/s)	2	2	2
		2 (1,5 mm/s)	1	1	1
	Evaluation Length	1 (10 mm)	2	2	2
		2 (50 mm)	1	1	1
	Fabric Surface Direction	1 (Front)	2	2	2
		2 (Back)	1	1	1
F3	Measurement Speed	1 (0,15 mm/s)	2	1	2
		2 (1,5 mm/s)	1	2	1
	Evaluation Length	1 (10 mm)	2	2	1
		2 (50 mm)	1	1	2
	Fabric Surface Direction	1 (Front)	2	1	2
		2 (Back)	1	2	1
F4	Measurement Speed	1 (0,15 mm/s)	2	1	2
		2 (1,5 mm/s)	1	2	1
	Evaluation Length	1 (10 mm)	2	1	1
		2 (50 mm)	1	2	2
	Fabric Surface Direction	1 (Front)	2	1	1
		2 (Back)	1	2	2
F5	Measurement Speed	1 (0,15 mm/s)	1	2	2
		2 (1,5 mm/s)	2	1	1
	Evaluation Length	1 (10 mm)	1	2	2
		2 (50 mm)	2	1	1
	Fabric Surface Direction	1 (Front)	1	1	1
		2 (Back)	2	2	2
F6	Measurement Speed	1 (0,15 mm/s)	2	2	2
		2 (1,5 mm/s)	1	1	1
	Evaluation Length	1 (10 mm)	1	1	1
		2 (50 mm)	2	2	2
	Fabric Surface Direction	1 (Front)	2	1	2
		2 (Back)	1	2	1

*The rank was given from the highest to value the lowest one.

The surface roughness results obtained in this research revealed that surface characteristics of woven patterns related with roughness must be researched by considering the constructional properties of fabric samples in a more detailed manner. Although R_a parameter gives information about the amplitude properties of surfaces, further roughness properties of woven surfaces could be researched by the consideration of other roughness parameters.

4. CONCLUSION

Surface roughness properties of woven fabrics were characterized by arithmetic average height (mean height) (R_a). The measurements were performed on fabric samples in warp, weft and diagonal directions. Surface roughness values changed considerably with weft yarn density, evaluation lengths and measurement speeds. Surface roughness of the front and back sides of plain, twill and satin patterns changed in different ways according to the weave pattern. Surface roughness values showed different characters in the three directions of measurement for the three patterns. The anisotropic structure of fabric surfaces caused discordant roughness values to be obtained. Further surface roughness parameters for the characterization of fabric surfaces could be researched.

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