SURFACE PROFILE AND FRICTIONAL PROPERTIES OF DENIM FABRICS

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ABSTRACT

Several parameters might contribute to the tactile comfort of a fabric in a different way and rate, therefore which parameter would stand out will be mostly determined by fabric type and end use. In this study, the effect of weaving parameters and three different washing processes on surface characteristics of denim fabrics was investigated. Accordingly, several surface profile parameters and fabric-to-skin friction coefficients of 24 custom production and 15 commercial denim fabrics were determined by objective measurements, meanwhile fabric surfaces were investigated by photomicrographs.

Key Words: Denim fabrics, surface profile parameters, frictional properties

1. INTRODUCTION

The surface properties of various materials have an important role and been investigated in many fields including textiles. Considering the fact that there are numerous test methods, it is essential to select a proper method to obtain accurate and significant results when determining the surface characteristics of a particular material. Researchers suggested various test methods to investigate the surface properties of textiles such as smoothness-roughness, frictional behavior, surface texture, prickle propensity and so on.[1-9] The relations between findings of suggested objective measurements and sensory evaluation results were also established in several tactile comfort studies.[6-12]

The aim of this study is to investigate the effect of weaving parameters and washing processes on surface characteristics of denim fabrics. For this purpose; surface profile parameters and fabric-to-skin friction coefficients of 39 denim fabrics were determined. The fabric surfaces were visually examined by photomicrographs as well.

2. MATERIAL AND METHOD

2.1 Material

The investigated denim fabrics were divided into six categories; set A, B, C, D, E and F. Fabrics in set A are raw denim fabrics with 3/1 Z warp dominant twill weave pattern. Fabrics in set B have plain weave pattern and lower warp settings. Set C includes fabrics which were subjected to stone washing1. The fabrics in set D were supplied from a local manufacturer. Set E and set F include the modified versions of fabrics in set D, with enzyme washing and stone washing2 respectively. Yarn properties and production parameters of fabrics are presented in Table 1 and Table 2. All washing processes have rinsing, washing, softening and drying steps consecutively. Enzyme amount, stone size, the ratio of stone per fabric and duration of stone washing1 are lower than stone washing2 (Table 3). Parameters of enzyme washing are identical with stone washing2, except the absence of pumice stones.

Table 1. Properties of fabrics in sets A, B and C

Fabric code	Weave pattern	Material (%)		Yarn count (tex)	Setting (/cm)	Mass per unit area (g/m^2)	Treatments	
		warp	*weft*	*warp, weft*	*warp x weft*		*finishing*	*washing*
A1	3/1 Twill	CO[a]	CO[a]	30, 20	47 x 21	206	-	-
A2	3/1 Twill	CO[a]	PES[a]	30, 20	47 x 21	212	-	-
A3	3/1 Twill	CO[a]	67/33 PES/CV[a]	30, 20	47 x 21	210	-	-
A4	3/1 Twill	CO[a]	50/50 PES/CV[a]	30, 20	47 x 21	211	-	-
A5	3/1 Twill	CO[a]	CV[a]	30, 20	47 x 21	208	-	-
A6	3/1 Twill	CO[a]	85/15 CV/WA[a]	30, 20	47 x 21	207	-	-
A7	3/1 Twill	CO[a]	85/15 CV/WO[a]	30, 20	47 x 21	211	-	-
A8	3/1 Twill	CO[a]	85/15 CV/SE[a]	30, 20	47 x 21	205	-	-
B1	Plain	CO[a]	CO[a]	30, 20	38 x 21	152	-	-
B2	Plain	CO[a]	PES[a]	30, 20	38 x 21	162	-	-
B3	Plain	CO[a]	67/33 PES/CV[a]	30, 20	38 x 21	157	-	-
B4	Plain	CO[a]	50/50 PES/CV[a]	30, 20	38 x 21	157	-	-
B5	Plain	CO[a]	CV[a]	30, 20	38 x 21	156	-	-
B6	Plain	CO[a]	85/15 CV/WA[a]	30, 20	38 x 21	154	-	-
B7	Plain	CO[a]	85/15 CV/WO[a]	30, 20	38 x 21	154	-	-
B8	Plain	CO[a]	85/15 CV/SE[a]	30, 20	38 x 21	152	-	-
C1	3/1 Twill	CO[a]	CO[a]	30, 20	47 x 21	240	-	St1
C2	3/1 Twill	CO[a]	PES[a]	30, 20	47 x 21	241	-	St1
C3	3/1 Twill	CO[a]	67/33 PES/CV[a]	30, 20	47 x 21	246	-	St1
C4	3/1 Twill	CO[a]	50/50 PES/CV[a]	30, 20	47 x 21	248	-	St1
C5	3/1 Twill	CO[a]	CV[a]	30, 20	47 x 21	240	-	St1
C6	3/1 Twill	CO[a]	85/15 CV/WA[a]	30, 20	47 x 21	242	-	St1
C7	3/1 Twill	CO[a]	85/15 CV/WO[a]	30, 20	47 x 21	242	-	St1
C8	3/1 Twill	CO[a]	85/15 CV/SE[a]	30, 20	47 x 21	239	-	St1

CO: cotton, CV: viscose, PES: polyester, SE: silk, WA: angora, WO: wool, [a]: ring spun carded yarn, St1: stone washing1.

2.2 Method

Mass per unit area of fabrics was measured according to ASTM D3776/D3776M-09a**.** The fabric thickness (T) was measured using James Heal R&B Cloth Thickness Tester under 5 gf/cm^2 pressure and the compressed thickness (T') was measured under 50 gf/cm^2 pressure. The compressibility (CA) was calculated using Equation 1.

$$\mathbf{CA} = \frac{\mathbf{T} - \mathbf{T'}}{\mathbf{T}} \times \mathbf{100}\ (\%) \qquad (1)$$

Surface profile parameters in warp and weft directions were determined by Mitutoyo SJ 301 surface roughness tester (Figure 1a).[7,13] The surface profile was recorded by a 10 μm diameter stylus, with a traversing speed of 0.50 mm/s and a measuring force of 4 mN. The evaluation length was 12.5 mm. Several profile parameters such as; arithmetical mean deviation of the assessed profile (Ra), root mean square deviation from the assessed profile (Rq), maximum profile peak height (Rp), root mean square slope of the assessed profile (PΔq) and

material ratio of the profile (Rmrd) were determined by the vertical stylus of the device.[14]. It must be noted that the measuring range of Mitutoyo SJ301 is -200 μm to +150 μm. Therefore, further examination of the fabric surface was carried out by photomicrographs.

Table 2. Properties of fabrics in sets D, E and F

Fabric code	Weave pattern	Material (%)		Yarn count (tex)	Setting (/cm)	Mass per unit area (g/m^2)	Treatments	
		warp	*weft*	*warp, weft*	*warp x weft*		*finishing*	*washing*
D1	Plain	CO[bc]	LI[a]	20, 42	32 x 21	189	1,3,4,5	-
D2	Plain	CO[a]	CO[a]	30, 30	28 x 21	179	1,3,4,5	-
D3	2/1 Twill	CO[ac]	CO[ac]	30, 30	39 x 22	202	1,2,3,4,5	-
D4	2/1 Twill	CO[a]	CO[a]	26, 25	45 x 27	201	1,2,3,4,5	-
D5	3/1 Twill	CO[ac]	82/18 CO/PES[dc]	30, 30	36 x 24	197	3,4,5	-
E1	Plain	CO[bc]	LI[a]	20, 42	32 x 21	189	1,3,4,5	Enz
E2	Plain	CO[a]	CO[a]	30, 30	28 x 21	161	1,3,4,5	Enz
E3	2/1 Twill	CO[ac]	CO[ac]	30, 30	39 x 22	200	1,2,3,4,5	Enz
E4	2/1 Twill	CO[a]	CO[a]	26, 25	45 x 27	198	1,2,3,4,5	Enz
E5	3/1 Twill	CO[ac]	82/18 CO/PES[dc]	30, 30	36 x 24	200	3,4,5	Enz
F1	Plain	CO[bc]	LI[a]	20, 42	32 x 21	193	1,3,4,5	St2
F2	Plain	CO[a]	CO[a]	30, 30	28 x 21	169	1,3,4,5	St2
F3	2/1 Twill	CO[ac]	CO[ac]	30, 30	39 x 22	206	1,2,3,4,5	St2
F4	2/1 Twill	CO[a]	CO[a]	26, 25	45 x 27	202	1,2,3,4,5	St2
F5	3/1 Twill	CO[ac]	82/18 CO/PES[dc]	30, 30	36 x 24	209	3,4,5	St2

CO: cotton, LI: flax, PES: polyester, [a]: ring spun carded yarn, [ac]: ring spun combed yarn, [bc]: compact spun combed yarn and [dc]: core spun combed yarn, Enz: Enzyme washing, St2: stone washing2, 1: singeing, 2: indigo coating, 3: scouring, 4: softening and 5: sanforization.

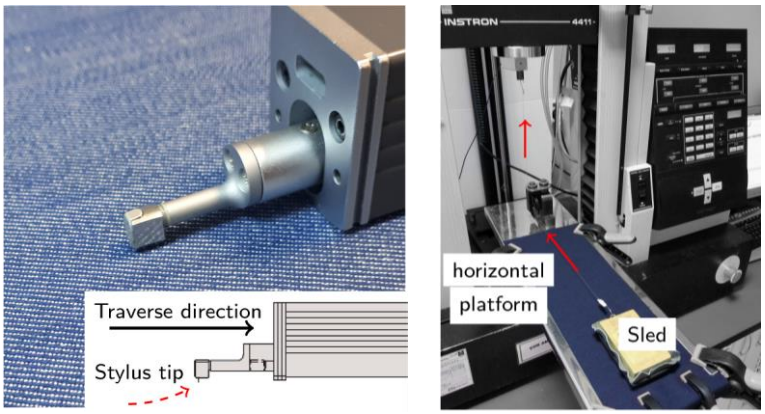
Table 3. Washing treatments

		Stone washing1	Stone washing2	Enzyme washing
Rinsing	Temperature	40°C	40°C	40°C
	Duration	5 min	5 min	5 min
Washing	Temperature	40°C	40°C	40°C
	Enzyme	1 g/L	2 g/L	2 g/L
	Stone size	1-2	2-4	-
	Stone ratio	1/2	1/12	-
	Duration	5 min	10 min	10 min
Softening	Temperature	40°C	40°C	40°C
	Softener[1]	5 g/L	5 g/L	5 g/L
	Softener[2]	10 g/L	-	-
	Duration	5 min	5 min	5 min
Drying	Temperature	70°C	70°C	70°C
	Duration	45 min	45 min	45 min

[1]: Mikro silicon ELAM RP CONC., [2]: Hidrophil micro silicon Evo Soft HST.

Fabric-to-skin friction was measured by Instron 4411 Universal Tensile Tester, a friction device including a horizontal platform and a sled covered with leather (Figure 1b).[1,13] Friction forces (F_s and F_k) in were recorded and fabric-to-skin friction coefficients (μ_s and μ_k) were calculated using Equation 2 (N=1.2 g/cm^3).

$$\mu = {}^{F}/_{N} \quad (2)$$



(a) **(b)**

Figure 1. Surface measurements; (a) test probe of Mitutoyo SJ-301 Surface Roughness Tester, and (b) Instron 4411 Universal Tensile Tester combined with a friction device

3. RESULTS AND DISCUSSION

The effect of weaving parameters was investigated by comparing the fabrics in set B with set A. It was observed that the denim fabrics in set B exhibited significantly lower Ra (24 to 38%), Rq (22 to 36%) and Rp (6 to 16%) values. Friction coefficients were considerably lower as well (4 to 11%). However, it must be stated that some desirable properties for a better tactile comfort such as compressibility, thickness and mass per unit area were lower for these fabrics. The different characteristics of roughness profiles of twill and plain weave fabrics' surfaces can be seen in Figure 2.

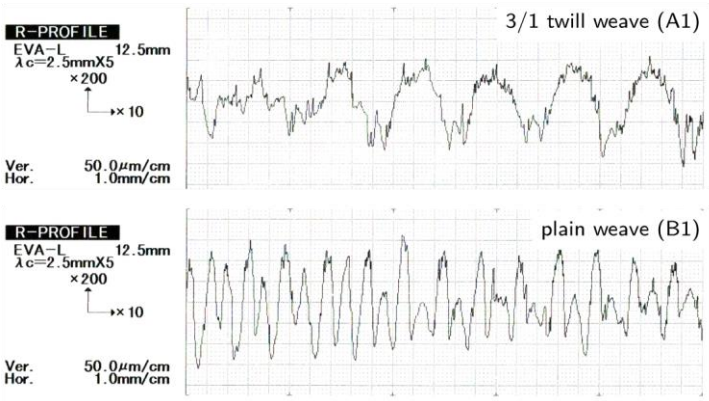


Figure 2. Roughness profiles of 100% cotton 3/1 twill raw denim fabric A1 and 100% cotton plain weave raw denim fabric B1 recorded in warp direction

Fabrics in set C, which were subjected to stone washing treatment, have higher roughness profile values; Ra (37 to 58%), Rq (37 to 58%), Rp (32 to 55%), RΔq (23 to 42%) and lower surface friction coefficients; μ_s (7 to 12%), μ_k (5 to 10%). These findings indicate that the number of protruding fibers from the fabric surface increased after stone washing, causing a higher surface roughness. As a consequence, this hairiness on the surface leads to lower friction coefficients and hence a better tactile comfort. Custom production denim fabrics which were subjected to stone washing, exhibit lower Rmrd (profile material ratio) values but a higher mass per unit area and thickness (Figure 3).

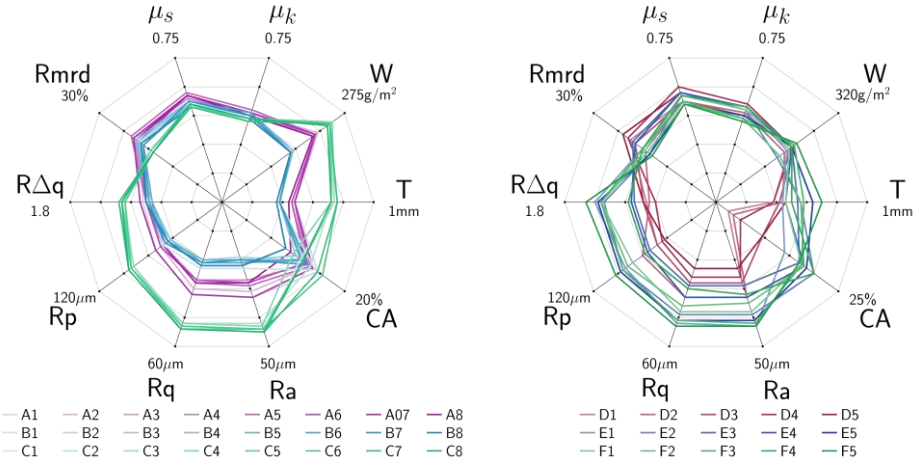


Figure 3. Mass per unit area (W), thickness (T), compressibility (CA), arithmetical mean deviation of the profile (Ra), root mean square deviation from the profile (Rq), maximum profile peak height (Rp), root mean square slope of the profile (PΔq), material ratio (Rmrd), static fabric-to-skin friction coefficient (μ_s) and kinetic fabric-to-skin friction coefficient (μ_k) of denim fabrics

The most significant change in commercial fabrics after stone washing is the 84 to 570% increase in fabrics' compressibility. It was observed that fabrics have higher roughness profile values; Ra (7 to 92%), Rq (8 to 88%), Rp (20 to 94%), RΔq (41 to 79%) and thickness (19 to 52%) and lower material ratios (3 to 10%) after stone washing. Similarly, fabrics have higher compressibility (80 to 490%), roughness profile values; Ra (6 to 83%), Rq (6 to 81%), Rp (10 to 84%), RΔq (14 to 74%) and thickness (13 to 40%) and lower material ratios (6.5 to 28%) after enzyme washing. Therefore, no major change in friction coefficients of commercial denim fabrics was established after enzyme washing or stone washing (Figure 3). Visual examinations showed that fabric D2 has honeydew problem (particle sizes up to 1700 μm) (Figure 4). The diameter of honeydew particles was reduced to 1100 μm and 840 μm by enzyme washing and stone washing respectively.

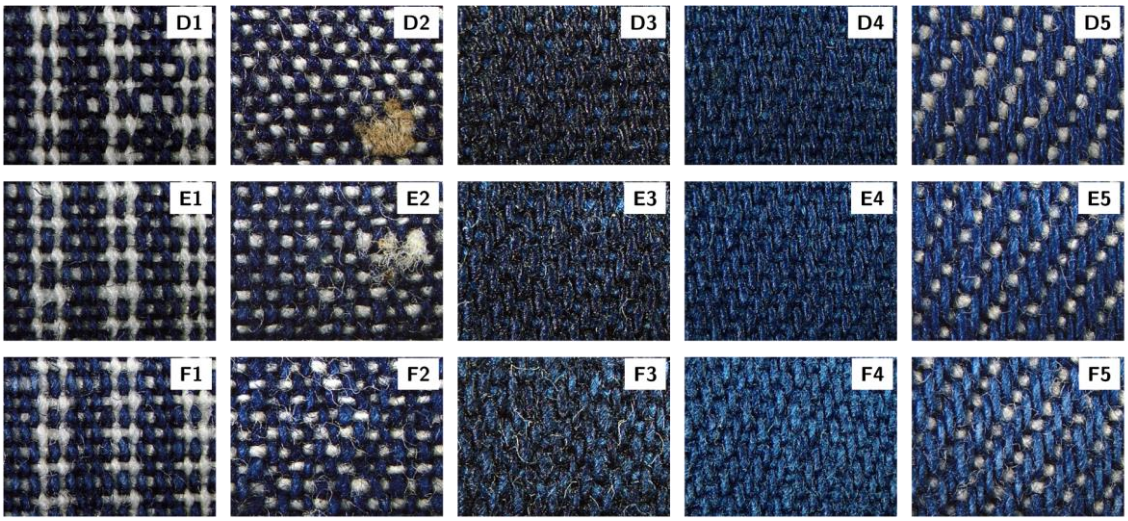


Figure 4. Photomicrographs of fabrics in set D, set E and set F

4. CONCLUSION

The findings showed that it is possible to improve denim fabrics' surface characteristics by applying different washing treatments or by simply changing the weaving parameters. It was

observed that the suggested washing treatment was quite effective on surface roughness, mass per unit area and thickness values of custom production raw denim fabrics, yet the change in compressibility was not significant. On the other hand, washing treatments were quite effective on compressibility, thickness and roughness of commercial denim fabrics, which were formerly subjected to a series of finishing treatments, but no major change in friction coefficients or mass per unit area was recorded for these fabrics. Findings of the study also proved that using alternative weaving parameters might lead to a significant change in surface roughness, friction coefficients, compressibility, thickness and mass per unit area.

5. REFERENCES

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