(REFEREED RESEARCH)

SKIN-FABRIC FRICTION AND OTHER PERFORMANCE CHARACTERISTICS OF SOCKS FABRICS PRODUCED FROM CELLULOSIC FIBERS

SELÜLOZİK LİFLERDEN ÜRETİLEN ÇORAPLARIN DERİ-KUMAŞ SÜRTÜNMESİ VE DİĞER PERFORMANS ÖZELLİKLERİ

Sibel KAPLAN, Ceren KARAMAN

Suleyman Demirel University, Textile Engineering Department, Isparta, Turkey.

Received: 12.01.2018 Accepted: 06.08.2018

ABSTRACT

Skin friction and some performance characteristics of single jersey fabrics produced from cotton (combed, carded and rotor) and regenerated cellulosic fiber (viscose, bamboo, modal, micromodal, Tencel®, Tencel LF® and some blends) yarns were investigated by surface friction, bursting strength, abrasion and pilling resistance tests. Daily or functional socks were the intended end use of the selected materials. According to the results, cotton, 48/52% cotton/modal and Tencel® fabrics have higher bursting strength. Pilling and abrasion resistances are the highest for also 48/52% cotton/modal fabric. For skin friction which is crucial for socks within shoes, rotor viscose, 48/52% cotton/modal and micromodal have smoother surfaces than modal and Tencel® for both kinetic and static friction coefficients. It means that these materials create less injuries on sweaty skin during an activity. It is thought that, results obtained for cotton and different regenerated cellulosic fabrics are valid also for all next-to-skin garments.

Keywords: Skin friction, socks, fiber type, cellulosic, pilling, abrasion, bursting strength.

ÖZET

Pamuk (penye, karde, rotor) ve rejenere selüloz liflerinden (viskon, bambu, modal, mikromodal, Tencel®, Tencel LF® ve bazı karışımlar) üretilen suprem kumaşların deriyle sürtünme ve bazı performans özellikleri sürtünme, patlama mukavemeti, aşınma ve boncuklanma direnci ölçümleriyle belirlenmiştir. Hammadde ve iplik parametreleri günlük veya fonksiyonel bir çorap göz önünde bulundurularak seçilmiştir. Elde edilen sonuçlara göre, en yüksek patlama mukavemeti pamuk, % 48/52 pamuk/modal ve Tencel® kumaşlarda elde edilmiştir. Boncuklanma ve aşınma dirençleri de % 48/52 pamuk/modal kumaşta en yüksek tespit edilmiştir. Ayakkabı içerisindeki çorap açısından hayati bir özellik olan deriyle sürtünme özellikleri incelendiğinde; rotor viskon, % 48/52 pamuk/modal ve mikromodal kumaşların statik ve kinetik sürtünme katsayılarının diğer hammaddelere göre düşük olduğu, dolayısıyla daha pürüzsüz kumaş yüzeyleri oluşturdukları tespit edilmiştir. Buradan, bu hammaddelerin herhangi bir aktivite sırasında terli deride daha az hasar oluşturacağı belirtilebilir. Bu çalışmayla pamuk ve farklı rejenere selüloz lifleri için elde edilen sonuçların deriyle temas halindeki diğer giysi grupları için de fikir verebileceği düşünülmektedir.

Anahtar Kelimeler: Deri sürtünmesi, çorap, lif tipi, selülozik, boncuklanma, aşınma, patlama mukavemeti.

1. INTRODUCTION

Besides thermal comfort, skin-fabric interactions are also important for foot health and comfort. As it is difficult to enable dryness within foot clothing system, deformations as a result of skin-fabric friction due to cyclic relative movements may result injuries, friction blisters which are more problematic for sports and diabetic people. The mechanoreceptors of the skin are very important in the assessment of comfort, because they relay information about fabric roughness and contact forces between skin and fabrics [1]. During walking or running, besides cyclic pressure, friction and shear forces acting on the skin under increased moisture and temperature levels within sports shoes are the main reasons of foot blisters [2]. Skin-fabric interactions are generally evaluated by subjective tests [1, 3-5] combined with fabric surface and skin analyses. There are several objective methods for fabric surface analysis. Friction coefficients between socks fabrics and synthetic

---

Corresponding Author: Sibel Kaplan, sibelkaplan@sdu.edu.tr

skin were measured using a Textile Friction Analyzer (TFA), and study results were correlated well to preferences of participants obtained by subjective tests [6]. Moreover, a widely used approach is the horizontal platform method, which involves pulling a weighted sled across a fabric adhered to a platform attached to the lower jaw of a tensile tester [1, 6]. Kenins [7] measured static and kinetic friction forces arise during skin contact of fabrics produced from different materials and possess different mechanical and chemical finishing treatments by using different normal forces on dry and wet skin (finger and forearm). He concluded that friction force is more related to wetness of the skin than material or finishing treatment of the fabric. Importance of skin wetness on skin-fabric relation was emphasized in another study [5]. Baussan et al. [2, 8] investigated friction characteristics of cotton athletic socks having different weaves by determining mechanical contacts between foot, sock and shoe during running. They developed a reciprocating linear tribometer to simulate friction contacts between skin and sport socks and created a model. Bogerd et al. [9] measured skin friction between the posterior surface of the calcaneus and a glass plate during wear trials conducted on military members. Van Amber [6] studied effects of fiber type (fine wool, mid-micron wool, acrylic), yarn type (high twist, low twist, single) and fabric structure (single jersey, half-terry, terry) on friction between sock fabrics and a synthetic skin using the horizontal platform method. The effect of weight of a hypothetical wearer and moisture content of the sock fabric were also investigated. Effect of fabric moisture content on friction characteristics were investigated in another study [10] by using FRICTORQ on cotton and cotton/elastane knitted fabrics. Studies about effects of socks on friction blisters on the feet suggest that, the establishment of a movement interface either within the sock itself or between the layers of a sock system will prevent skin injury. Reducing the friction force on skin surface depends upon the fiber composition of the sock, where synthetic fibers appear to work best [11].

There is a growing demand on comfortable and environmentally friendly materials for clothing. Cotton and regenerated cellulosic fibers are common materials used for next to skin garments such as socks, underwear and sports clothing. The reason of their increasing attention is the continuous improvement of their inherent qualities and introduction of new brands in the market like Tencel. Regenerated cellulosic fibers maintain their reputation for softness, strength and good appearance provided to apparel products [12]. Besides comfort, there are also studies in the literature investigating mechanical and performance characteristics of the cellulosic fibers in knitted fabric form. Structural and mechanical performances of knitted fabrics produced from viscose, modal and lyocell were investigated and found out that second and third generation cellulosic fibers have higher bursting strength values due to a higher degree of crystallinity and molecular orientation compared to bamboo and viscose rayon fibers [13-14] as expected. In a study about performances of socks produced from regenerated fibers [15], modal and viscose had similar bursting strength behaviors while strength of bamboo is lower. In other studies about mechanical performance characteristics or cellulosic knitted fabrics, pilling tendency of viscose fiber is found higher than other regenerated fibers [16]. Abrasion was found the highest for lyocell and the lowest for bamboo [17] and modal [14] while in another study, abrasion is maximum for micromodal [15].

The aim of this study is to investigate skin-fabric friction and some other performance characteristics of socks fabrics produced from cotton and regenerated cellulosic fibers by surface friction, bursting strength, pilling and abrasion resistance tests. Tenacity of the regenerated cellulosic fibers have been the main point during production processes but as far as we know, friction characteristics have not been investigated sufficiently. Moreover, relationships among fabric mechanical properties produced from cellulosic yarn were also studied.

2. MATERIAL AND METHODS

2.1. Material

Single jersey fabrics were produced from Ne 30 cellulosic yarns consisting of ring and OE-rotor yarns having identical twist coefficients (α_e = 3.59-3.96). Yarn evenness and tenacity parameters can be seen in Table 1. As can be seen, material group consists of cellulosic fibers; namely cotton, as a natural type, first, second and third generation regenerated cellulosic fibers and their blends. Cotton and viscose include both ring and OE-rotor spun forms. As it is known, viscose is the first generation regenerated cellulosic fiber and because of their mechanical insufficiency in wet form, modal and lyocell fibers were introduced as second and third generation cellulosic fibers. Besides higher wet strength and structural features between viscose and lyocell [18] modal fibers are twice as soft as cotton and are able to withstand repeated wash and dry cycles compared to cotton. Tencel® lyocell fibers are derived from sustainable wood sources and sustainably managed plantations which also enable formation of very long exclusive crystalline arrangement of its cellulose units which are extremely greatly oriented in the longitudinal axis of the fiber [12]. Tencel® fibers exhibit a circular cross section, smooth surface area giving fabrics a soft feel and ensuring comfort for sensitive skin. Both modal and Tencel absorb moisture more efficiently than cotton which is a property supporting body’s natural thermal regulating mechanism, keeping skin feeling pleasantly cool and dry [19]. An important feature of lyocell fibers is their propensity of fibrillation due to their high degree of polymer chain orientation and lack of lateral cohesion. Fibrillation is sometimes an advantage such as for creating 'peach skin' but it is not always a desirable property. Cross-linked versions of lyocell such as Tencel A100® and Tencel LF® (low fibrillation) were produced. Tencel LF® is more suitable for blending with cotton as a result of mercerization ability and closer dyeability to that of cotton [17]. Bamboo is also a regenerated cellulosic eco-friendly fiber which has some distinctive properties such as natural anti-bacterial performance and breathability [12].

2.2. Methods

Fabrics and socks were knitted by a Lonati/L462K machine having 3 ½“ diameter, 144 needles and a speed of 250 rpm. To investigate the performances of cellulosic fibers, undyed yarns were knitted without elastane. All fabrics were washed according to TS EN ISO 6330:2012 standard in a in a Wascator FOM71 CLS washing machine (James Heal and Co Ltd., Halifax, UK). All tests were conducted under standard atmospheric conditions (20 ± 2 °C, 65±2% RH).

Table 1. Yarn properties of the fabrics

Fabric Code	Material	CVm (%)	IPI Imperfections (Thin+Thick+Neps)	Hairiness (H)	Tenacity (cN/tex)	Breaking Elongation (%)	Work of Rupture (cN.cm)
1	100% Combed cotton	12.26	332.6	4.62	18.99	5.74	577.0
2	100% Carded cotton	14.76	1086.0	5.14	17.96	5.11	493.1
5	100% OE.-Rotor viscose	13.52	678.0	4.05	13.90	12.48	1109.0
6	100% Bamboo	12.21	205.8	5.66	18.05	14.81	1668.0
7	70%/30% Bamboo/ Cotton	13.00	354.0	5.68	13.14	8.24	746.6
8	100% Modal	11.67	104.2	6.46	27.39	11.03	1770.0
9	48%/52% Cotton/Modal	11.45	146.2	6.07	16.53	5.55	551.8
10	100% Micromodal	11.49	81.4	6.07	27.39	10.83	1715.0
11	100% Tencel®	11.38 [0.44]	180.0	6.89	25.39	8.24	1255.0
12	100 % Tencel LF®	11.65	280.0	7.09	25.29	8.10	1237.0

*: Yarn properties belonging to 100% OE-rotor cotton (3) and 100% viscose (4) yarns could not be tested because of sample shortage

Yarn evenness and breaking strength characteristics were tested by Uster Tester 4-S and Uster Tensojet devices in turn. Weight values of the fabrics were determined according to TS 251 and thickness values were measured according to TS 7128 EN ISO 5084 with 5 g/cm^2 pressure. Bursting strength tests were carried out according to ISO 13938-2. Bursting strength (Pa) and elongation occur while bursting (bursting distance) were measured. Pilling and abrasion resistance (weight losses of the samples were recorded for 20.000 revolutions) tests were conducted according to TS EN ISO 12947-2 and TS EN ISO 12945-2 standards respectively by a Martindale Pilling and Abrasion Tester (James H. Heal & Co Ltd., USA).

Friction coefficients of the sock fabrics were calculated by friction force measurements conducted according to ASTM D 1894 by a Lloyd LR5K plus (Lloyd Instruments, Inc., USA) tensile strength tester. Static and kinetic friction forces were obtained for both course and wale directions as a result of movement of a sled (6x7 cm) on a platform covered with the socks fabric inner side up with a speed of 25 mm/min. Sled was covered with a membrane simulating artificial skin and a normal force of 4.72 g/cm^2 was applied during tests. The coefficient of friction μ is defined as the ratio between the frictional force F and the applied normal load N: $\mu = F/N$ [1, 6, 20-21].

SPSS 21.0 Statistics Software (SPSS Inc. USA) was used for Analysis of variance (ANOVA) test. Duncan and Student Newman Keuls (SNK) tests were used to examine significant differences among measured parameters of the cellulosic socks. A value of p 0.05 indicated statistical significance. Correlation analysis was conducted to determine relationships among physical and mechanical parameters.

3. RESULTS & DISCUSSIONS

As can be seen in Table 2, weight values of the single jersey fabrics ranged between 140-175 g/m^2 and thickness values ranged between 0.70-1.10 mm. Both properties have significant differences according to statistical analyses. Significant changes were marked with letters on Table 2; different letters showing statistical significance. It is thought that weight and thickness differences may be sourced from fiber density and rigidity variations of the fibers. Cotton fabrics have significantly higher thickness values than regenerated cellulosic fabrics. Bamboo (6), modal (8), micromodal (10) and Tencel® (11) have identical and the lowest thickness values.

Fabric mechanical properties are compiled in Table 3. Significant changes were marked with letters on Table 3.

According to bursting strength results, combed cotton fabric (1) has significantly ($p<0.05$) higher bursting strength values than the other fabrics (Figure 1). Carded cotton (2), cotton/modal blend (9), Tencel® (11) and Tencel LF® (12) fabrics having statistically identical performances come after. Fabrics produced from viscose ring and rotor (4 and 5) and bamboo ring (6) yarns have statistically identical and the lowest bursting strength values, which is a result in harmony with preceding studies [13, 15]. Bursting strength values did not have the same tendency with yarn breaking strength values that, while combed cotton (1), carded cotton (2) and cotton modal blend (9) yarns have lower breaking strength values (Table 1) than modal and Tencel, they have identical bursting strength values with Tencel fabrics (11 and 12). This result does not confirm a preceding study result [22] that reported significant relationships between yarn and fabric strength values. We can conclude that transfer of strength from yarn to fabric is better for cotton which may be related to its rougher structure resisting multi-directional deformation of bursting. When yarn spinning techniques are considered, while rotor and ring spininng techniques did not created significant changes for viscose fabric (4 and 5), it created significant differences for cotton and rotor yarn fabric (3) had lower bursting strength values than combed and carded cotton yarn fabrics (1 and 2).

Modal and viscose fabrics have identical strength values in a preceding study [15] but in this study, strength values can be ranked according to the generation of the regenerated cellulosic materials; Tencel fabrics (11 and 12) having the maximum values followed by modal and micromodal (they have identical performances),bamboo and viscose have the minimum bursting strength values. Cotton increased bursting strength values when blended with bamboo (7) and modal (9) as expected.

Table 2. Physical properties of the cellulosic fabrics

Fabric Code	*Material*	*Weight (g/m^2)* [S.D.]	*Thickness (mm)* [S.D.]	*Fabric Density (g/cm$^{3)}$)*	*Pilling Resistance*
1	100% Combed cotton	165.9^{bc} [2.68]	1.05^{b} [0.02]	0.16	2-3
2	100% Carded cotton	175.48^{a} [7.91]	1.10^{a} [0.03]	0.15	2-3
3	100% OE.-Rotor cotton	161.08^{bc} [6.26]	1.02^{c} [0.01]	0.16	2-3
4	100% Viscose	147.95^{de} [4.28]	0.82^{e} [0.02]	0.19	2-3
5	100% OE.-Rotor viscose	175.74^{a} [4.08]	0.81^{ef} [0.04]	0.22	1-2
6	100% Bamboo	155.68^{d} [2.41]	0.79^{fg} [0.03]	0.20	3-4
7	70%/30% Bamboo/Cotton	168.08^{ab} [3.21]	0.88^{d} [0.04]	0.19	3-4
8	100% Modal	147.38^{de} [7.17]	0.74^{g} [0.02]	0.23	2-3
9	48%/52% Cotton/Modal	153.66^{d} [3.79]	0.90^{d} [0.03]	0.18	4-5
10	100% Micromodal	135.96^{f} [4.10]	0.70^{g} [0.02]	0.21	2-3
11	100% Tencel ®	142.90^{ef} [1.89]	0.79^{fg} [0.04]	0.18	1-2
12	100% Tencel LF®	140.00^{ef} [2.88]	0.83^{e} [0.05]	0.19	1-2

Letters on values show statistical significance of the results ($p < 0.05$), same letters having identical properties.

Table 3. Mechanical properties of the cellulosic fabrics

Fabric Code	Material	Bursting Strength (kPa) [S.D.]*	Bursting Distance (mm) [S.D.]*	Weight Loss (%) [S.D.]*	Friction Coefficients [S.D.]*			
					Wale Direction [S.D.]*		Course Diection [S.S.]*	
					μ_k	μ_s	μ_k	μ_s
1	100% Combed cotton	288.52^{a} [25.55]	43.66^{a} [0.68]	5.31^{bc} [0.55]	0.29^{bcd} [0.02]	0.44^{a} [0.06]	0.23 [0.03]	0.36^{bcd} [0.02]
2	100% Carded cotton	264.84^{b} [18.18]	43.04^{a} [1.28]	5.34^{bc} [1.14]	0.32^{bc} [0.01]	0.46^{a} [0.07]	0.19 [0.04]	0.35^{ef} [0.03]
3	100% OE.-Rotor cotton	193.2^{d} [12.52]	42.72^{a} [1.48]	6.67^{abc} [1.49]	0.26^{cde} [0.05]	0.37^{a} [0.04]	0.26 [0.05]	0.37^{abcd} [0.04]
4	100% Viscose	151.6^{e} [15.82]	37.18^{b} [0.52]	8.14^{a} [1.36]	0.21^{ef} [0.01]	0.35^{a} [0.04]	0.21 [0.02]	0.32^{cd} [0.04]
5	100% OE.-Rotor viscose	150.66^{e} [8.59]	38.08^{b} [1.02]	5.33^{bc} [0.76]	0.21^{ef} [0.00]	0.30^{a} [0.04]	0.10 [0.007]	0.20^{f} [0.03]
6	100% Bamboo	162.84^{e} [10.85]	34.56^{c} [1.02]	3.91^{c} [0.67]	0.39^{a} [0.05]	0.37^{a} [0.24]	0.31 [0.13]	0.45^{ab} [0.11]
7	70%/30% Bamboo/Cotton	190.9^{d} [21.04]	38.64^{b} [1.00]	3.76^{c} [0.52]	0.25^{de} [0.02]	0.36^{a} [0.02]	0.31 [0.03]	0.44^{abc} [0.03]
8	100% Modal	219.16^{c} [19.84]	31.64^{d} [1.02]	4.32^{c} [2.01]	0.34^{b} [0.04]	0.35^{a} [0.20]	0.30 [0.02]	0.43^{abc} [0.02]
9	48%/52% Cotton/Modal	261.16^{b} [26.24]	37.56^{b} [1.07]	1.54^{d} [1.31]	0.28^{bcd} [0.02]	0.40^{a} [0.09]	0.19 [0.02]	0.31^{ef} [0.04]
10	100% Micromodal	195.78^{d} [1.90]	28.56^{e} [1.17]	4.07^{c} [0.95]	0.18^{f} [0.04]	0.32^{a} [0.05]	0.21 [0.02]	0.35^{cd} [0.04]
11	100% Tencel ®	265.28^{b} [15.72]	34.48^{c} [1.65]	3.98^{c} [1.31]	0.32^{bcd} [0.005]	0.50^{a} [0.06]	0.35 [0.06]	0.48^{a} [0.09]
12	100% Tencel LF®	244.13^{b} [5.85]	34.05^{c} [1.39]	5.01^{bc} [2.01]	0.32^{bcd} [0.005]	0.51^{a} [0.03]	0.24 [0.04]	0.42^{bcd} [0.07]

Letters on values show statistical significance of the results ($p < 0.05$), same letters having identical properties.

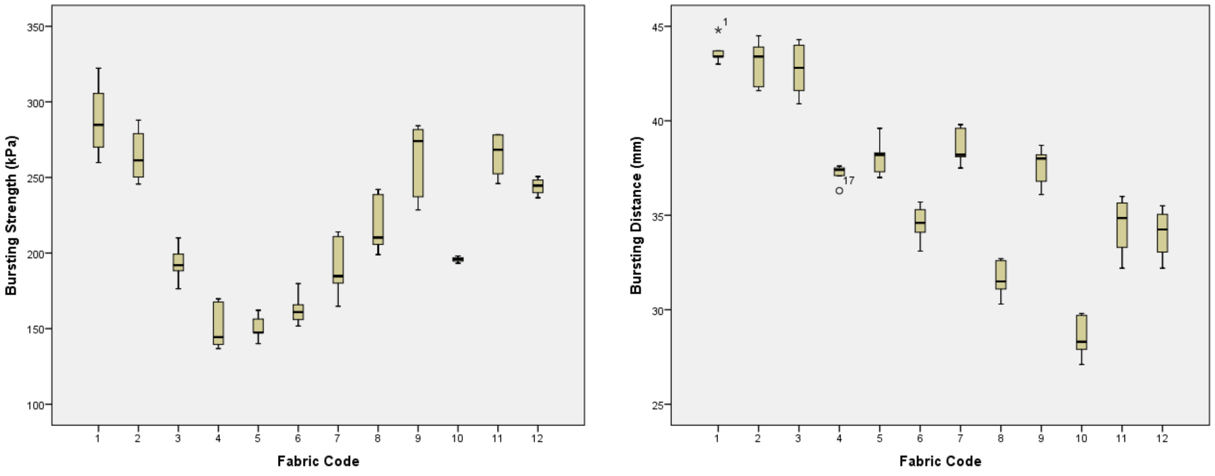


Figure 1. Bursting strength and distance values of cellulosic fabrics *1: 100% Combed cotton, 2: 100% Carded cotton, 3 100% OE.-Rotor cotton, 4: 100% Viscose, 5: 100% OE.-Rotor viscose, 6: 100% Bamboo, 7: 70/30% Bamboo/Cotton, 8: 100% Modal, 9: 48/52% Cotton/Modal, 10: 100% Micromodal, 11: 100% Tencel ®, 12: 100% Tencel LF®*

Bursting distance values showing the elongation of the fabrics while deformation are the maximum for cotton fabrics (1, 2 and 3) and minimum for micromodal fabric (10) as can be seen in Figure 1. Yarn spining technique does not have any influence on elongation values of fabrics for both cotton and viscose. Modal fabric (8) is significantly more eleastic than micromodal fabric. Tencel® (11 and 12) and bamboo (6) fabrics have identical and moderate performances. Viscose (4 and 5), cotton blends of bamboo (7) and modal (9) have statistically identical performances and cotton content increased their elongation values. Fabric bursting distance values do not show a similar trend with yarn breaking elongation values that while cotton yarns have the minimum elongation values (Table 1), their bursting distances are the maximum in fabric form. Higher elongation values of viscose and bamboo yarns which comes from their inherent structures [13] did not create significant differences in fabric form.

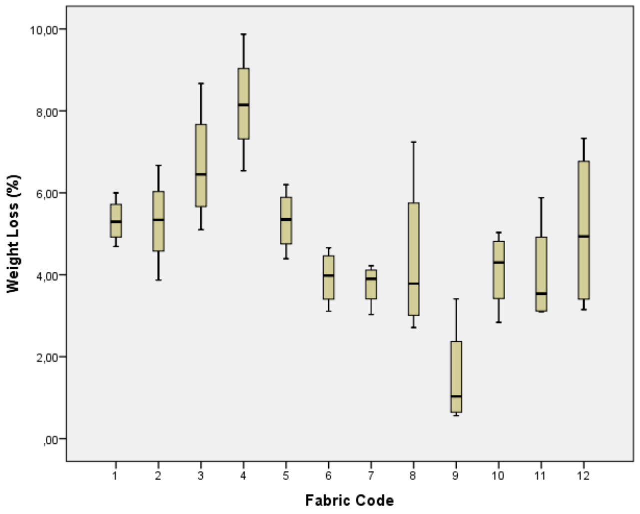
Pilling resistance evaluation results are given in Table 2. Minimum pilling tendency (4-5) was obtained for 48%/52% cotton/modal fabric (9). 100% bamboo (6) and 70%/30% cotton/bamboo fabric (7) had also acceptable pilling performances (3-4). OE-rotor viscose (5) and Tencel® fabrics (11 and 12) had the worst pilling resistance performances that they were evaluated with 1-2 in EMPA scale. Lower pilling resistance of Tencel® can be explained by the fibrillation occuring as a result of mechanical abrasion in wet condition. Standard washing and drying applied before tests might have manipulated pill formation. Moreover, fuzz was mainly generated by dry mechanical abrasion applied during pilling test [23]. Although Tencel LF® includes cross links within the structure to prevent fibrillation [24], its pilling resistance is not superior than standard Tencel® fabric (11). Performances of other fabrics are between the mentioned ones (3-4). The worst performance of viscose (5) was confirmed by preceding studies [16, 22].

Weight loss values after 20.000 cycles of abrasion test are compiled in Figure 2. According to the statistical analysis results, minimum weight loss was observed for 48%/52% cotton/modal fabric (9). Viscose ring yarn fabric (4) lost the highest amount of fiber during abrasion. Fibres with high elongation, elastic recovery and work of rupture have a good ability to withstand repeated distortion; hence a good abrasion resistance [25]. For viscose, fiber cross section and lower fiber strength might have caused high material loss. Abrasion resistances of other fabrics are statistically identical. Effect of yarn spinning technique on abrasion resistance seems insignificant for cotton but fabric produced from ring yarn was abraded more for viscose fabric. This result may be sourced from wrapper fibers on rotor yarn surface increasing abrasion resistance. Tencel LF® yarn fabric (12) having crosslinks within its structure for decreasing fibrillation, hence abrasion did not create significant enhancement when compared with standard Tencel® yarn fabric (11). In a preceding study [17], abrasion resistance of standart Tencel® fabric was the highest and better than bamboo but they had identical performances in this study.

Friction coefficients of the cellulosic fabrics in wale direction can be seen in Figure 3. Differences among static friction coefficients are not statistically significant for wales direction ($p > 0.05$). This result does not confirm a preceding study [6] result stating that the most important effect of fiber was on the static frictional force. According to kinetic friction coefficients, bamboo fabric (6) had the highest value, meaning the roughest surface. Viscose (4 and 5) and micromodal (10) yarn fabrics are the ones having the smoothest surfaces among all cellulosic fabrics. From this result, it can be concluded that fiber cross section do not have an influence on surface friction characteristics. Micromodal yarn fabric (10) have a smoother surface than modal yarn fabric (8) and this result may be attributed to lower diameter decreasing surface roughness and lower bending rigidity of the fibers. Among cotton fabrics, rotor yarn fabric (3) and combed yarn fabric (1) have significantly smoother surfaces than carded yarn fabric (2) and all cotton fabrics have rougher surfaces than viscose fabrics because of their higher fiber bending rigidities. The performances of cotton yarn fabrics are similar with second and third generation regenerated cellulosic fibers having greater degree of crystallinity. Yarn spinning technology does not have an influence on friction characteristics for viscose fabrics (4 and 5). Modal yarn fabric (8) and 48%/52%

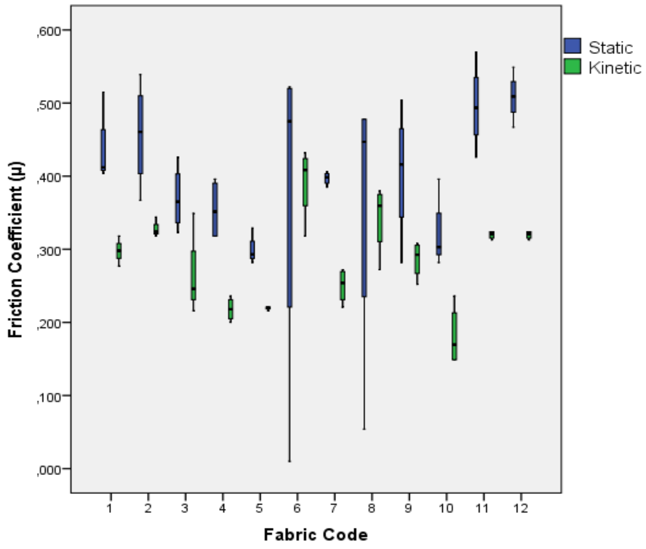
cotton/modal yarn fabric (9) have significantly rougher surfaces when compared with viscose fabrics (4 and 5) but they have identical performances with Tencel® yarn fabrics (11 and 12) for kinetic friction coefficients in wale direction.

Static and kinetic friction coefficients calculated for course direction both have statistical significances among fabrics ($p<0.05$). According to static friction coefficient results, viscose rotor yarn fabric (5) had significantly smoother surface than the other fabrics (Figure 4). Bamboo (6), its blend with cotton (7), modal (8) and Tencel® (11, 12) yarn fabrics have significantly rougher surfaces than the other fabrics. Performances of modal and Tencel are in harmony with the results in wale direction and can be explained with the higher crystallinity of the fibers and fibrils if exist enabling higher bending rigidity. Cotton yarn fabrics produced by different spinning techniques have statistically identical performances but rotor yarn fabric has smoother surface than ring yarn fabric (4) in course direction. Kinetic coefficients in course direction have a similar trend that viscose has the smoothest surface followed by modal and Tencel® fabrics. Different from results in wale direction, cotton yarn fabrics (1, 2 and 3) and cotton/modal blend (9) have similar performances with modal. Micromodal and modal yarn fabrics have similar performances for both static and kinetic friction coefficients. Tencel LF® yarn has a smoother surface than standard Tencel® for kinetic coefficent which was not the case for other coefficients. No relationship was found between yarn hairiness and surface friction characteristics.



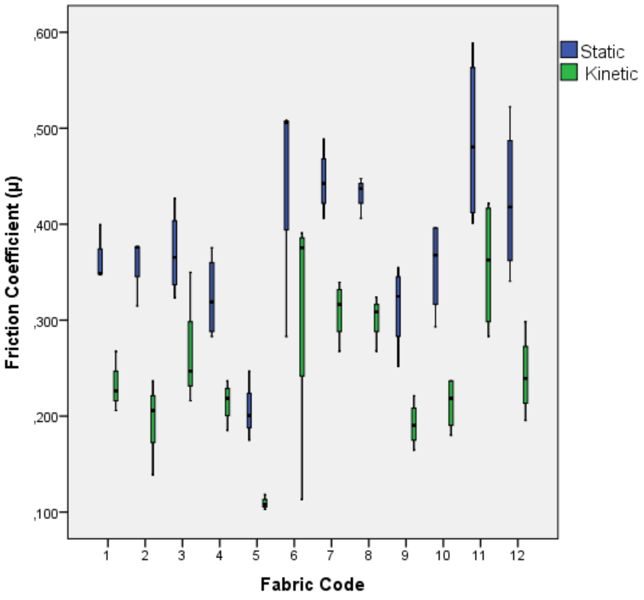
1: 100% Combed cotton
2: 100% Carded cotton
3 100% OE.-Rotor cotton
4: 100% Viscose
5: 100% OE.-Rotor viscose
6: 100% Bamboo
7: 70/30% Bamboo/Cotton
8: 100% Modal
9: 48/52% Cotton/Modal
10: 100% Micromodal
11: 100% Tencel ®
12: 100% Tencel LF®

Figure 2. Boxplot diagram of weight loss values as a result of abrasion



1: 100% Combed cotton
2: 100% Carded cotton
3 100% OE.-Rotor cotton
4: 100% Viscose
5: 100% OE.-Rotor viscose
6: 100% Bamboo
7: 70/30% Bamboo/Cotton
8: 100% Modal
9: 48/52% Cotton/Modal
10: 100% Micromodal
11: 100% Tencel ®
12: 100% Tencel LF®

Figure 3. Friction coefficients in wale direction



1: 100% Combed cotton
2: 100% Carded cotton
3 100% OE.-Rotor cotton
4: 100% Viscose
5: 100% OE.-Rotor viscose
6: 100% Bamboo
7: 70/30% Bamboo/Cotton
8: 100% Modal
9: 48/52% Cotton/Modal
10: 100% Micromodal
11: 100% Tencel ®
12: 100% Tencel LF®

Figure 4. Friction coefficients in course direction

Significant relationships obtained for yarn and fabric characteristics are summarised in Table 3. Thickness, weight and bursting strength are significantly correlated with each other as expected. Fabric weight is correlated with friction coefficients in course direction; as the fabric becomes heavier and denser, its surface friction decreases, meaning a smoother surface. Weight values are also negatively correlated with yarn breaking elongation, which may be related to the density of the yarn and fiber. It is though that, as the crystalline region of the fiber decreases, yarn becomes more elastic and weight of the fabric decreases. It is interesting to note that bursting strength is negatively correlated with yarn elongation and work of rupture. Higher energy needed for yarn rupture did not contribute the multi-directional deformation of fabric during bursting. Friction coefficients in course and wale directions are correlated with each other and it was observed that differentiation capacity of friction coefficients in course direction is better as they bring forth differences among fabrics more. Thickness has negative relationships with yarn hairiness and yarn strength parameters (elongation and work of rupture). This result may be attributed to higher twist values causing denser yarn structure, higher strength and lower fabric thickness values.

CONCLUSIONS

Skin-fabric friction and other performance characteristics of some socks fabrics produced from cotton and regenerated cellulosic fibers were investigated by surface friction, bursting strength, pilling and abrasion resistance tests. According to the results, cotton and its blend with modal had better performances for bursting strength and cotton/modal had better performances for pilling and abrasion resistances. Besides these performance characteristics, skin-fabric friction is lower for viscose among cellulosic fibers, enabling smoother surface for next to skin garments. Relationships among fabric mechanical and surface parameters were also investigated and significant relationships were observed between fabric weight and friction coefficients which may be valuable for producers. Moreover, fabric bursting strength is correlated with not yarn strength but work of rupture. Friction tests on course direction may be suggested for further studies as they show differences among fabrics better than the results on wale direction. Summing up, cotton/modal blend, having minimum to moderate friction coefficients, good strength, pilling and abrasion resistances can be suggested for daily or functional socks as a material. It is thought that, results obtained for cellulosic fibers may give an idea for all clothing types.

Table 3. Correlation coefficients among yarn and fabric characteristics

	Weight	**Bursting Strength**	**KFC*** (Course)**	**SFC*** (Course)**	**SFC*** (Wale)**	**Thickness**
Thickness	0.748**	0.519*	-0.667**	-0.518*		
KFC* (Course)	-0.716**					
SFC* (Course)	-0.663**					
KFC (Wale)			0.485*	0.509*	0.761**	
Yarn Hairiness	-0.642**					-0.511*
Yarn Break. Elong	-0.705**	-0.665**	0.622**			-0.782**
Work of Rupt.(Yarn)	-0.861**	-0.484*	0.754**	0.636**		-0.854**

*: Correlation is significant at the 0.05 level
**: Correlation is significant at the 0.01 level
***: KFC: Kinetic friction coefficient, SFC: is significant at the 0.05 level

REFERENCES

1. Bertaux, E., Derler, S., Rossi, R. M., Zeng, X., Koehl, L. And Ventenat, V., 2010, “Textile, Physiological and Sensorial Parameters in Sock Comfort”, Textile Research Journal, Vol: 80 (17), pp: 1803-1810.
2. Baussan, E., Bueno, M. A., Rossi, R. M. and Derler, S., 2010, Experiments and modelling of skin-knitted fabric friction“, Wear, Vol: *268*(9),pp:1103-1110.
3. Gwosdow, A.R., Stevens, J.C., Berglund, L.G. and Stolwijk, J. A. J., 1986, “Skin Friction and Fabric Sensations in Neutral and Warm Environments”, Textile Research Journal, Vol: 56 (9), pp: 574-580.
4. Herring, K.M. and Richie Jr, D.H., 1990, “Friction blisters and sock fiber composition. A double-blind study”, Journal of the American Podiatric Medical Association, Vol: 80 (2), pp: 63-71.
5. Tasron, D. N., Thurston, T. J., & Carré, M. J. 2015, Frictional behaviour of running sock textiles against plantar skin“, Procedia Engineering, Vol: 112, pp: 110-115.
6. Van Amber, R. R., Lowe, B. J., Niven, B. E., Laing, R. M., Wilson, C. A., & Collie, S., 2015. “The Effect of Fiber Type, Yarn Structure and Fabric Structure on the Frictional Characteristics of Sock Fabrics”, Textile Research Journal, Vol: *85*(2), pp: 115-127.
7. Kenins, P., 1994, “Influence of Fiber Type and Moisture on Measured Fabric-to-Skin Friction”, Textile Research Journal, Vol: 64(12), pp: 722-728.
8. Baussan, E., Bueno, M. A., Rossi, R. M., & Derler, S. 2013, “Analysis of current running sock structures with regard to blister prevention“, Textile Research Journal, Vol:*83*(8), pp: 836-848.
9. Bogerd, C.P., Rechsteiner, I., Wüst, B., Rossi, R.M. and Brühwiler, P.A.,B.C. and Brühwiler, P.A., 2011, “The Effect of Two Sock Fabrics on Physiological Parameters Associated with Blister Incidence: A Laboratory Study“, Annual Occupational Hygiene, Vol: 55 (5), pp: 510-518.
10. Hes, L., Oglakcioğlu, N., Marmarali, A., Özdil, N., & Lima, M. 2008, “The Effect Of Moisture On Friction Coefficient Of Elastic Knitted Fabrics“, Journal of Textile & Apparel/Tekstil ve Konfeksiyon, Vol: *18*(3), pp: 206-210.
11. Werd, M. B., & Knight, E. L. 2010, “Athletic footwear and orthoses in sports medicine” P. R. Langer (Ed.), Springer, New York, pp: 98.
12. Badr, A. A., Hassanin, A., Moursey, M., 2016, “Influence of Tencel/cotton blends on knitted fabric performance”, Alexandria Engineering Journal, Vol: *55*(3), pp: 2439-2447.
13. Erdumlu, N. and Ozipek, B., 2008, “Investigation of Regenerated Bamboo Fibre and Yarn Characteristics”, Fibres & Textiles in Eastern Europe, Vol: 16, No: 4 (69), pp: 43-47.
14. Dirgar, E., 2017, The Performance Properties of the Fabrics Produced From Cupro and Some Other Regenerated Cellulose Fibers., Vol: 27(2), pp: 139-144.
15. Cimilli, S.,, 2007, “Modelling Of Heat Transfer Behaviors Of Socks Made From New Fibers Using Finite Element Method”, Unpublished master’s thesis, 124 p., Istanbul Technical University, Istanbul.
16. Kayseri, G. O., Bozdogan, F., and Hes, L., 2010, “Performance properties of regenerated cellulose fibers”, Tekstil ve Konfeksiyon, Vol: 20(3), pp: 208-212.
17. Dündar, E., 2008, “Performance Comparison of Knitted Fabrics Produced from Different Cellulosic Yarns”, Unpublished master’s thesis, 76p., Istanbul Technical University, Istanbul.
18. Mather, R. R., & Wardman, R. H., 2015, “The chemistry of textile fibres”. Royal Society of Chemistry, Second Edition, Cambridge, UK, pp: 133-134.
19. https://tencel.com/general
20. Okur A., 2002, “A Study on the Frictional Properties of Plain-knitted Cotton Fabrics”, Textile Asia, Vol: 33(8), pp: 32–34.
21. Kaplan, S. and Okur, A., 2009, “Determination of Coolness and Dampness Sensations Created by Fabrics by Forearm Test and Fabric Measurements”, Journal of Sensory Studies, Vol: 24(4), pp: 479-497.
22. Avcı, H., 2007, “Comfort Properties of Socks Produced from New Generation Fibers”, Unpublished master’s thesis, 75p., Istanbul Technical University, Istanbul.
23. Periyasamy, A. P., Khanum, R., 2012, “Effect of fibrillation on pilling tendency of Lyocell fiber”, https://www.textiletoday.com.bd/effect-of-fibrillation-on-pilling-tendency-of-lyocell-fiber/.
24. Ozbagcı, Ö., 2008, “Physical and Dimensional Properties of Some Single Jersey Fabrics Produced From Cotton and Some Regenerated Fibers”, unpublished master’s thesis, 160p., Dokuz Eylul University, Izmir, Turkey.
25. Özdil, N., Kayseri, G. Ö., Mengüç, G. S., 2012, “Analysis of abrasion characteristics in textiles“, in Abrasion resistance of materials, InTech, pp: 123.