(REFEREED RESEARCH)

THE STATISTICAL INVESTIGATION OF THE EFFECT OF HYDROPHILIC POLYURETHANE COATING ON VARIOUS PROPERTIES OF DENIM FABRIC

HİDROFİLİK POLİÜRETAN KAPLAMANIN DENİM KUMAŞIN ÇEŞİTLİ ÖZELLİKLERİ ÜZERİNE ETKİSİNİN İSTATİSTİKSEL İNCELENMESİ

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ABSTRACT

Coating is a textile finishing process to add various properties onto fabric along with change at the appearance and it found commercial interest in denim market for the last decade. Polyurethane (PU) polymer is one of the widely used coating materials for waterproofness and modified PU for breathable coatings have been developed but its effect on mechanical, performance and comfort properties has to be considered. This paper investigates the effect of PU coating on important mechanical, performance and comfort-related / breathability properties of denim fabric and evaluates the contribution of fabric and PU polymer weight at the final product.

Keywords: Polyurethane, coating, denim, mechanical properties, water resistance, water vapor permeability, wicking.

ÖZET

Kaplama, kumaşlara görünüm değişikliği ile birlikte çeşitli özellikler kazandırmak için yapılan bir bitim işlemidir ve son yıllarda denim pazarında ticari ilgi görmektedir. Poliüretan (PU) polimer, su geçirmezlik özellik kazandırmada en çok kullanılan kaplama maddelerinden birisidir ve nefes alabilir kaplamalar için modifiye PU geliştirilmiştir; bununla birlikte kaplamanın kumaşın mekanik, performans ve konfor özelliklerine etkileri göz önünde tutulmalıdır. Bu çalışmada, PU kaplamanın denim kumaşların önemli mekanik, performans ve nefes alabilirlik/konforla ilgili özelliklerine etkisi ile kumaş ve PU polimer gramajının nihai ürüne katkısı incelenmiştir.

Anahtar kelimeler: Poliüretan, kaplama, denim, mekanik özellikler, su geçirmezlik, su buharı geçirgenliği, kılcallık

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1. INTRODUCTION

Coating is used to impart new properties to textile fabrics like waterproofness flame retardant, antibacterial, UV resistance, abrasion resistance, creating a non-homogenous composite structure [1-6]. A coated fabric consists of a textile surface on to which the polymer is applied as a viscous liquid (Figure 1). The generally used coating polymers in textile applications can be listed as natural and synthetic rubber, polyvinylchloride (PVC), polyvinylidene chloride (PVDC), polyurethane (PU), polyethylene (PE), ethylene vinyl acetate (EVA), acrylic, silicone, polytetrafluoroethylene (PTFE), epoxy resin and polyester (PET). The coating of the textile fabric with those polymer emulsions can be conducted by several methods like blade coating, rotary screen coating, transfer coating, foam coating, calendar coating, spray coating and extrusion dye coating, depending upon the requirement of end product.

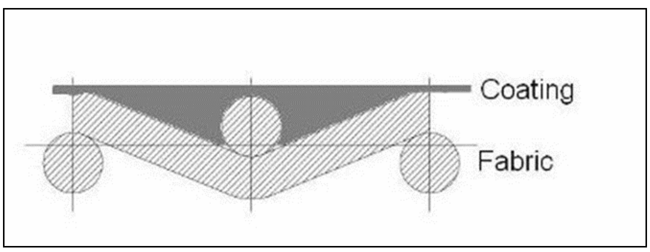


Figure 1. Schematic of a coated textile

Denim, which is characterized with certain physical properties, is a generally cotton fabric produced for work and sportswear for years thanks to superior abrasion and tear resistance than other fabric types like gabardine and poplin. The importance of this sector is easily accepted when considering approximately 3,5 billion meters annual worldwide manufacture.

Denim fabrics are subjected to coating to give new appearance, create new market and performance with an increasing interest in the last decade. When considering the coating of garment fabrics like denim, breathability of the product is also essential along with performance and aesthetic properties. Breathability of the fabric is the ability of clothing to allow the transmission of water vapor by diffusion and breathable garments help to provide the wearer with a greater level of comfort in many situations [7,8]. There is no doubt that waterproof fabrics which are also breathable would find premium choice for consumers with a wide range including active sports or casual wearers. There are several ways of achieving fabric with waterproof breathable properties starting with densely woven %100 cotton fabrics to the novel method to enhance breathability of coated fabrics while remaining the waterproof property via micro-cracking in relevant solvent bath [9]. But when micro-porous PTFE membrane had huge commercial success in this area, several manufacturers developed breathable coatings based on modified polyurethane. In this case, PU is chemically modified by introducing ionic or nonionic hydrophilic segments which make the final polymer water or solvent soluble [10]. There are now commercially available modified PU coating polymers serving the coated fabric market.

This paper deals with important mechanical, performance and comfort-related / breathability properties of denim fabric before and after coating with hydrophilic PU to assess the effect of fabric and PU polymer weight at the final product.

2. MATERIAL AND METHOD

%100 cotton, slasher-dyed denim fabric samples (3/1 Z twill) were supplied from Gap Güneydoğu Tekstil A.Ş. (Malatya / Turkey) in ready–to-finish conditions and they were coded according to their differing sett values. The commercially available hydrophilic PU polymer was supplied from Rudolf-Duraner (Bursa / Turkey) and the coating was applied in industry environment by rotary screen coating with the following recipe: PU at two different concentrations (200 g/kg or 300 g/kg), 20 g/kg polyisocyanate crosslinker, 12 g/kg thickener and 5 g/kg polysiloxane based defoamer. The coated fabrics were then cured at 150 ^{0}C at the stenter. The basic properties of the samples are given in Table 1.

The denim fabric samples were then subjected to tensile strength and elongation, abrasion resistance and tearing strength (mechanical properties), water resistance, contact angle analysis (performance properties), air permeability, water vapor permeability and vertical wicking (comfort-related / breathability properties) measurements for the assessment of hydrophilic PU coating on the mentioned properties of denim fabric. All the measurements were completed in the controlled laboratory environment at about 24^{0}C and 55% RH and repeated three times. The average of three measurements was taken for each parameter.

The results were also statistically analyzed by completely randomized two-way analysis of variance (ANOVA) at %5 significance level to find out the contribution of denim fabric and PU polymer weights along with which fabric property was affected at most after coating. The results were evaluated based on the F-ratio and the probability of the F-ratio; the lower the probability of the F-ratio or the higher the F-ratio, the stronger the contribution of the variation which is denim fabric sett or PU coating weight here. The Student-Newman-Keuls (SNK) range test was also used to decide if the PU coating weight had statistically significant effect on measured properties of the samples; the coating levels (no coating, 200 g/kg and 300 g/kg coating) were marked in accordance with the mean levels and any levels marked by the same letter showed that they were not significantly different.

Table 2 shows the relevant international standard used for the measurements; in additional, the vertical wicking characteristics of fabrics were determined in both warp and weft directions as described by Wong [11]. For the measurements, a 2.5 x 20 cm (1” x 8”) long fabric strip was hanged and immersed in a vertical direction into the distilled water. The depth of fabric immersion in the reservoir was 10 mm and the height of soaking (mm) along the fabric was determined at 2, 5, 10, 15, 20, 25 and 30 minutes after the immersion. The contact angle analyses of the samples for the drops of distilled water were determined by image analysis of the droplet on the sample which is captured by camera mounted on the automated contact angle measurement instrument (KSV CAM 100 Contact Angle Meter)

Table 1. Constructional properties of the denim fabrics

Fabric Code	Sett (thread / cm) (warp x weft)	Weight (g/m²)	Thickness (mm)	PU coating (gr/kg)
G1	34 x 22	321	0,55	no coating
G1PU1		342	0,62	200
G1PU2		348	0,60	300
G2	32 x 16	314	0,59	no coating
G2PU1		327	0,67	200
G2PU2		329	0,65	300

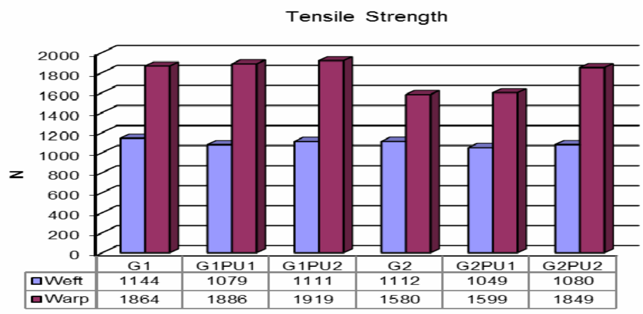
Table 2. The standards and the assessments used for the measurements

Measured property	Relevant standard	Unit	Assessment
Air permeability	ASTM D737-75	$l/m^2/sec$	Air flow rate through 20 cm^2 of sample under 100 Pa air pressure
Water vapor permeability	BS 3424 - 26	$g/m^2/day$	Weight of water vapor passed through unit area of sample in 24 hours
Water resistance	EN ISO 811-1981	mbar	Maximum water column pressure which sample can resist penetration
Tensile strength	EN ISO 1421	N	Amount of stress at complete rupture of sample under loading rate of 300 mm/min
Tensile elongation	EN ISO 1421	%	Percent elongation of sample until complete rupture
Abrasion resistance	ASTM D 4966	%	Percent amount of weight loss of sample after 20000 abrading cycle under 12kPa load
Tearing strength	EN ISO 13937-2	N	Amount of stress at complete tearing of sample

3. RESULTS AND DISCUSSIONS

3.1.Mechanical Properties

Tensile strength and elongation values of the samples are given in Figure 2a and 2b respectively. The results showed that PU coating increased tensile strength especially in the warp direction and also increase at elongation at break. Since the coated samples continued to carry higher load at higher strain level, it clearly indicated the increased toughness after coating; the higher the PU weight, the more the increase at tensile properties. The ANOVA result for tensile properties showed that the contribution of coating was stronger than the denim sett, meanwhile the SNK rankings revealed that coating weight was only important at breaking elongation in warp direction. The statistical assessments for tensile properties are given in Table 3 and 4.



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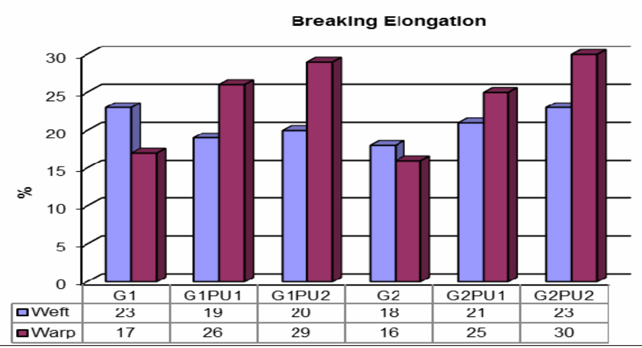


(b)

Figure 2. a) Tensile strength **b)** Breaking elongation of the samples

The PU coating reduced the tearing strength of the samples as given in Figure 3. This indicated that the coating penetrated the denim structure well to hold the yarns together, which would also cause to increase at tensile properties, and avoided the individual yarn rupture. Since some findings in the literature pointed increase at tearing after coating [12], these results would be contributed the chemical nature of the coating polymer. The ANOVA results (Table 5 and 6) showed that both coating and denim fabric structure had significant effect on determining the tearing strength after coating; the contribution of the denim stronger was stronger and the interaction of the variations was non-significant which also pointed the strong effect of those two variables. The coating weight was a statistically important parameter on tearing strength, thus 200g/kg and 300 g/kg coatings were marked separately.

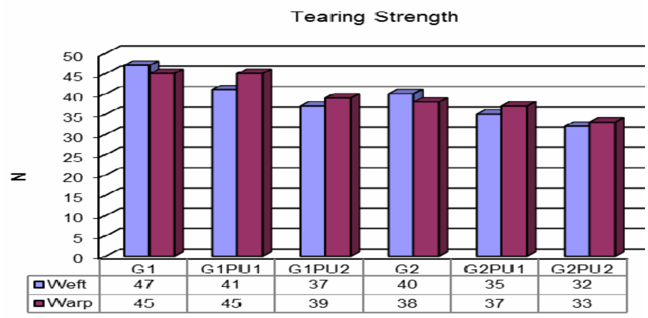


Figure 3. Tearing strength of the samples

Figure 4 shows the percentage amount of weight loss of the samples after abrading as an assessment of abrasion resistance. Denim samples exhibited mass loss values lower than %5, and the PU coating with higher weight reduced it to lower than %1,5. For the denim sample with lower fabric sett; enhancement at abrasion resistance was over %53. The ANOVA results clearly showed that the contribution of coating was highly significant in abrasion resistance and the coating weight was not important in determining abrasion resistance after coating. The statistical analysis for abrasion resistance is given in Table 7 and 8.

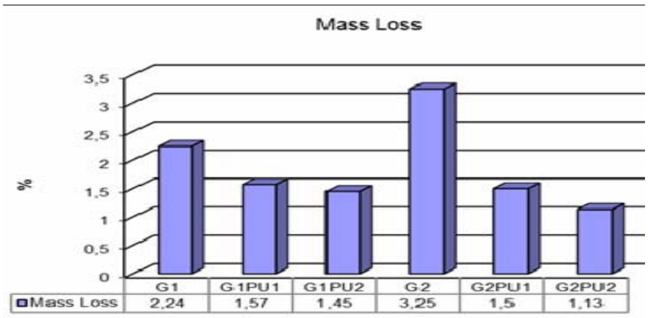


Figure 4. Abrasion resistance of the samples

Table 3. The ANOVA table for tensile properties

Source	Tensile Strength			
	Weft Direction		Warp Direction	
	F-ratio	Probability (F-ratio)	F-ratio	Probability (F-ratio)
Coating	3,059	0,844	15,698	0,002
Denim	1,512	0,139	1,787	0,209
Coating x Denim (Interaction)	0,017	0,983	5,765	0,465
Source	Breaking Elongation			
	Weft Direction		Warp Direction	
	F-ratio	Probability (F-ratio)	F-ratio	Probability (F-ratio)
Coating	3,050	0,063	266,125	0,000
Denim	1,020	0,101	0,500	0,493
Coating x Denim (Interaction)	28,500	0,000	2,003	0,178

Table 4. The SNK rankings for the effect of PU coating on tensile properties

Coating	Tensile Strength		Breaking Elongation	
	Weft	Warp	Weft	Warp
no coating	a	a	A	c
200 g/kg	a	a	A	b
300 g/kg	a	a	A	a

Table 5. The ANOVA table for tearing strength

Source	Tearing Strength			
	Weft Direction		Warp Direction	
	F-ratio	Probability (F-ratio)	F-ratio	Probability (F-ratio)
Coating	123,500	0,000	55,500	0,000
Denim	162,000	0,000	220,500	0,000
Coating x Denim (Interaction)	1,500	0,262	1,500	0,262

Table 6. The SNK rankings for the effect of PU coating on tearing strength

Coating	Tearing Strength	
	Weft	Warp
no coating	a	a
200 g/kg	b	a
300 g/kg	c	b

Table 7. The ANOVA table for abrasion resistance

Source	Abrasion Resistance	
	F-ratio	Probability (F-ratio)
Coating	112,926	0,000
Denim	1,634	0,225
Coating x Denim (Interaction)	30,339	0,000

Table 8. The SNK rankings for the effect of PU coating on abrasion resistance

Coating	Mass loss after 20000 abrading cycle
no coating	a
200 g/kg	b
300 g/kg	b

3.2. Performance Properties

The PU coating showed significant effect on water resistance of denim samples as given in Figure 5. The increase at measured water column pressure without penetration on the denim samples was %30 and %47 with higher PU coating weight. Since high sett weave and close-packed textile structure like denim help to achieve higher level of repellency, the highest water resistance performance were achieved at coated denim fabrics with higher weight (G1) and fabric weight had significant contribution. On the other hand, the statistical analysis pointed that PU coating weight was not important in determining water resistance after coating, like as for abrasion resistance (Table 9 and 10).

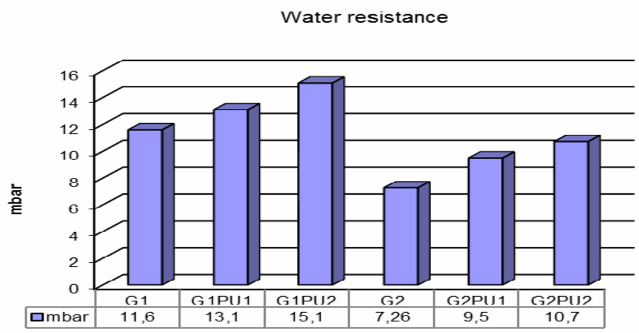


Figure 5. Water resistance of the samples

Denim samples exhibited quite high contact angle values against water (> 90^0) prior to coating (Figure 6) and decrease at contact angle during contact time (from 0 to 10 seconds) as seen in Table 11. The PU coating gave increased and steady-state contact angle values and the statistical analysis when performed for the contact angle measurements after 10 seconds revealed the significant effect of both coating and denim weight with highly strong contribution of the coating (Table 12 and 13). The higher PU coating resulted with significantly different higher contact angle (better water repellency performance).

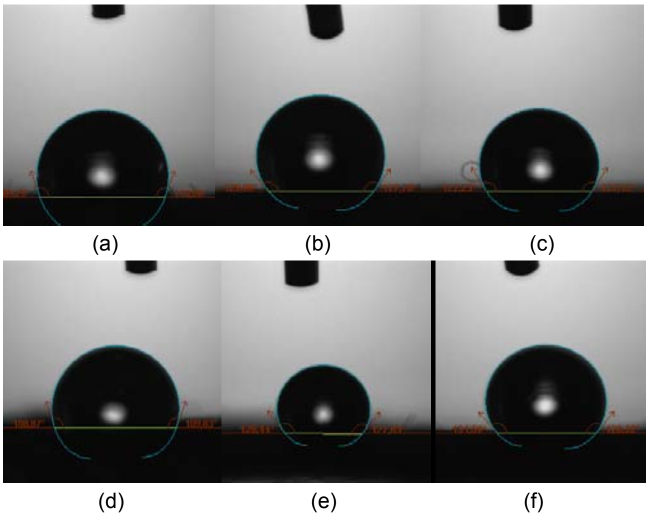


Figure 6. Contact angle images of the sample a) G1 b) G1PU1 c) G1PU2 d) G2 e) G2PU1 f) G2PU2 after 10 contact seconds

Table 9. The ANOVA table for water resistance

Source	Water Resistance	
	F-ratio	Probability (F-ratio)
Coating	10,284	0,002
Denim	26,300	0,002
Coating x Denim (Interaction)	0,905	0,430

Table 10. The SNK rankings for the effect of PU coating on water resistance

Coating	Water column pressure
no coating	b
200 g/kg	a
300 g/kg	a

Table 11. Contact angle values of denim samples

Fabric Code	Contact angle after 0 seconds	Contact angle after 5 seconds	Contact angle after 10 seconds
G1	114^0	113^0	109^0
G1PU1	123^0	122^0	122^0
G1PU2	128^0	128^0	128^0
G2	118^0	112^0	109^0
G2PU1	128^0	127^0	128^0
G2PU2	130^0	130^0	130^0

Table 12. The ANOVA table for water resistance

Source	Contact angle	
	F-ratio	Probability (F-ratio)
Coating	91,539	0,000
Denim	6,685	0,024
Coating x Denim (Interaction)	1,859	0,198

Table 13. The SNK rankings for the effect of PU coating on water resistance

Coating	Contact angle
no coating	a
200 g/kg	b
300 g/kg	c

3.3. Comfort-Related Properties

The water vapor can be transferred though the yarn and openings of the fabric, therefore water vapor permeability of textile fabric is highly related with inter-yarn pores, weight, thickness and fiber type. It is well-known that any clothing material with high water vapor permeability allows the wearer to take the advantage of its ability to provide cooling due to mainly evaporation and sweat production. The measurements showed that water vapor permeability of denim fabrics was reduced after PU coating up to %5 at higher PU weight as seen in Figure 7. However, the statistical analysis showed that water vapor permeability of fabrics before and after coating was not significantly different, a result of hydrophilic nature of the coating (Table 14 and 15)

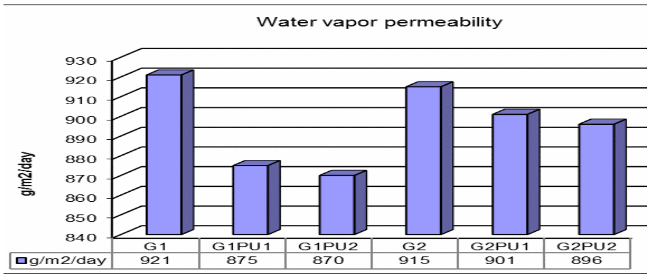


Figure 7. Water vapor permeability of the samples

Air permeability of the samples were reduced dramatically after coating due to closed porosity and openness of fabrics as seen in Figure 8. The contribution of the coating on air permeability of denim fabrics was found rather strong through statistical analysis; and the PU weight was non-significant in determining the air permeability of denim samples after coating, as given in Table 16 and 17.

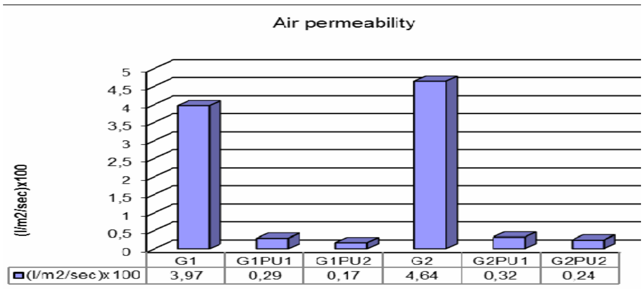
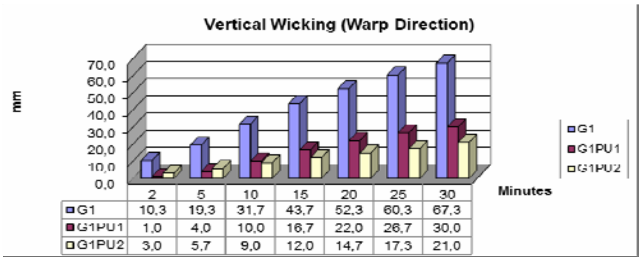


Figure 8. Air permeability of the samples

Vertical wicking measurements of the samples in warp and weft directions are given in Figure 9a-d. The results revealed that coating reduced wicking ability of denim samples in both directions. When ANOVA was performed for the height of soaking along the fabric after 30 minutes (Table 18 and 19), the statistical analysis based on mean values showed that higher PU weight resulted with lower wicking ability but the difference between coating weights was non-significant. Also, the contribution of coating was much higher than that of denim sett.



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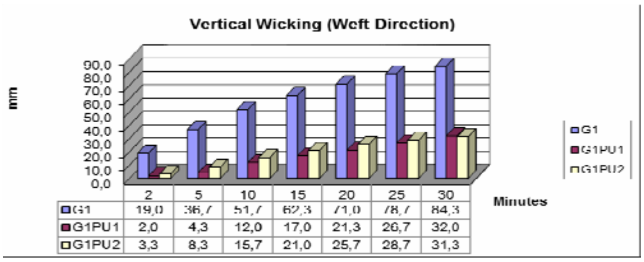

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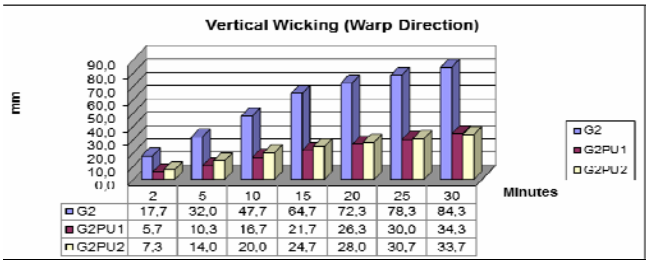

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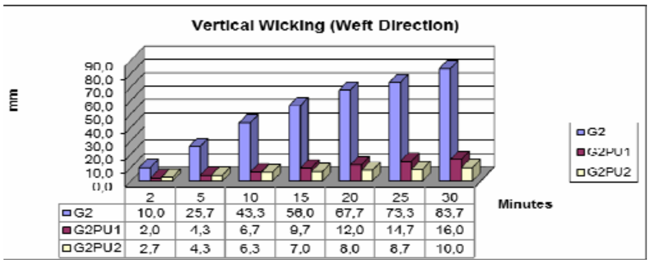

(d)

Figure 9 a-d. Wicking ability of the samples

Table 14. The ANOVA table for water vapor permeability

Source	Water Vapor Permeability	
	F-ratio	Probability (F-ratio)
Coating	0,449	0,648
Denim	0,227	0,642
Coating x Denim (Interaction)	0,102	0,903

Table 15. The SNK rankings for the effect of PU coating on water resistance

Coating	Water Vapor Permeability
no coating	a
200 g/kg	a
300 g/kg	a

Table 16. The ANOVA table for air permeability

Source	Air Permeability	
	F-ratio	Probability (F-ratio)
Coating	104,532	0,000
Denim	2,455	0,644
Coating x Denim (Interaction)	78,775	0,023

Table 17. The SNK rankings for the effect of PU coating on water resistance

Coating	Air Permeability
no coating	a
200 g/kg	b
300 g/kg	b

Table 18. The ANOVA table for wicking

Source	Distance travelled by water in warp direction		Distance travelled by water in weft direction	
	F-ratio	Probability (F-ratio)	F-ratio	Probability
Coating	644,131	0,000	173,220	0,000
Denim	61,014	0,000	23,379	0,004
Coating x Denim (Interaction)	14,531	0,006	0,122	2,514

Table 19. The SNK rankings for the effect of PU coating on water resistance

Coating	Wicking in warp direction	Wicking in weft direction
no coating	a	A
200 g/kg	b	B
300 g/kg	b	B

CONCLUSION

Hydrophilic polyurethane (PU) coating became more popular in the last decade to achieve breathable water resistance textile fabrics with enhanced appearance and it also found interest in denim market. This study investigates the effect of commercially available hydrophilic PU coating on mechanical, performance and comfort related properties of denim samples in detail by relevant measurements and statistical analysis. For this purpose, denim samples with two sett values were coated at two PU weight. The results showed that the contribution of coating was particularly strong on tensile strength, breaking elongation, abrasion resistance, water vapor permeability, air permeability, wicking ability and contact angle value of denim samples, but the change of PU weight was significant only at breaking elongation, tearing strength and contact angle. On the other hand, fabric weight represented stronger contribution on determining tearing strength and water resistance properties after coating. The findings helped us to find out which coating parameter (PU weight or fabric weight) should take primary consideration to evaluate various properties after the treatment.

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