TEKSTİL VE KONFEKSİYON

VOL: 33, NO. 2
DOI: 10.32710/tekstilvekonfeksiyon.1065250

Improving the Water Repellency of Polyester Filament Yarn and Fabrics

Beysim Garip [1] 0000-0002-2236-9701
Ayten Nur Yüksel Yılmaz [1,2] 0000-0003-4206-6051
Seda Ünal [3] 0000-0002-7024-2684
Ayşe Çelik Bedeloğlu [1] 0000-0003-2960-5188

[1]Bursa Technical University, Faculty of Engineering and Natural Sciences, Department of Polymer Materials Engineering,Bursa, Türkiye
[2]Bursa Technical University, Faculty of Engineering and Natural Sciences, Department of Mechanical Engineering, Bursa, Türkiye
[3]Polyteks Tekstil Sanayi Araştırma ve Eğitim A.Ş. Ar-Ge Merkezi, Bursa, Türkiye

ABSTRACT

Water-repellent finishing is one of the most applied finishing processes by using materials that prevent the wetting of textile products and the passage of water drops. Fluorinated compounds are widely used in conventional methods applied for the development of water repellency, but the threats posed by these to humans and the environment have led to new searches for water repellency. Giving the water-repellent effect by reinforcing the masterbatch during fiber production can provide longer-lasting, homogeneously dispersed and environmentally friendly products. This reason, in this study, filament yarns containing fluorine-free water-repellent additives in three different weight percentages and fabrics coated with a water-repellent finishing without fluorine were produced. Then, the performance properties of the yarns were analyzed and water repellency, tensile and air permeability tests of the fabrics were performed. As coating repetition increased, the water repellency of the fabrics improved and air permeability decreased by approximately 80%.

ARTICLE HISTORY

Received: 10.02.2022
Accepted: 01.11.2022

KEYWORDS

Water repellency, polyester filament yarn, hydrophobic masterbatch, fluorine free

1. INTRODUCTION

Water-repellent finishing is defined as the application performed by using various finishing materials to ensure that no water droplets remain on the fabric surface, or in other words, to prevent the fabric from getting wet. This finishing process creates a hydrophobic and porous thin film on the fabric surface and allows water vapor to pass through the fabric surface [1,2]. The angle of contact between a drop of water and fabric surface determines the water drop's tendency to spread out over the surface. Water repellency is crucial in many areas of the textile industry. Water-repellent treatments are carried out by depositing hydrophilic substances on the surface of fabric by methods such as mechanical treatment, chemical treatment and coating. The efficiency of the process depends on the type and quality of the yarns, the type of weaving and production method, and so on [3].

Today, various studies are carried out to achieve hydrophobic properties to textile materials. While water repellent additives containing fluorinated compounds are commonly used in these studies, the negative effects of fluorinated compounds on the environment and human health bring about the search for new materials. Fluorine-free water repellents are one of these materials [4]. If we look at the studies using fluorine-containing and non-fluorine water-repellent additives: in a patent study conducted in 2015, the fluorine content of the water-repellent chemical and dispersant used for the masterbatch-fed apparatus was in the range of 0.5-30% and 0.01-6%,

To cite this article: Garip B, Yüksel Yılmaz AN, Ünal S, Çelik Bedeloğlu A. 2023. Improving the Water Repellency of Polyester Filament Yarn and Fabrics. *Tekstil ve Konfeksiyon* 33(2), 161-168.

respectively [5]. The effects of different types of water repellent additives (fluorocarbon-based, chromstearylclorur-based and 3XDRY smart water repellent) on the water repellent performance of different type textile fabrics (cotton/polyester) were investigated and it was stated that the best water repellence performance was obtained with fluorocarbon-containing repellent. Also, increasing the repellent concentration made the fabrics more repellent [3]. Weft density and filament fineness are other parameters that improve the water repellency performance of fabrics [6]. Similarly, 3 different water-repellent chemicals (silicone, C8 fluorocarbon and C6 fluorocarbon) were applied to polyester fabric and the effects of these chemicals on the handle and sewability properties of the fabrics were investigated. The fabrics treated with 8-carbon fluorocarbon chemical (C8) showed the best water repellency and decreasing the chain length in fluorocarbon compounds reduced the water repellency performance [7]. Studies in the literature show that the C8 fluorocarbon-based chemicals can provide excellent water repellency, but they also releases toxic perfluorooctane sulfonate (PFOS) and perfluorooctanoic acid (PFOA) [8,9]. Furthermore, they are carcinogenic, harm children's immune systems, and reduce female fertility [10,11]. In order to get rid of these harmful effects, studies have been carried out on e environment friendly and durable repellent compounds that can be an alternative to C8-based fluorocarbons. In a thesis study, fluoro-free water repellent finishings were applied to evaluate the characteristics of silica films on polyester fabric. It was stated that the obtained silica films can provide water-repellent properties without the need for fluorine-containing chemicals [12]. In another study, the application of water repellency with the foam application technique and its effect on denim fabric properties were examined. It was stated that dendrimers, known as branched polymers, could be used instead of fluorocarbon water-repellent chemicals containing 6 and 8 carbons in the textile industry [4]. The effect on knitted fabrics was investigated by using water-repellent finishing chemicals with and without fluorocarbon, and as a result, it was stated that the type and concentration of water-repellent chemicals were very important parameters to obtain water repellent fabrics with the desired properties. It was also shown that the most effective water repellency was in fluorocarbon and dendrimer structures [13]. In the literature, there are studies in which fluorocarbon-containing and non-fluorocarbon-containing water-repellent finishes are used to increase the water-repellent property of textile materials. However, in these studies, while the repellents were generally applied to the surface of textile with the coating method, there were no studies in which water-repellents were added to the yarns. The aim of this study is to obtain yarns and fabrics reinforced with water-repellent additives that do not contain fluorine, and then to examine the performance of the yarns and to investigate the mechanical, water-repellent and air permeability properties of the fabrics.

2. MATERIAL AND METHOD

2.1 Material

The properties of INDORAMA SEMI-DULL polyester chips used to produce partially oriented polyester yarns (POY) and textured yarns are given in Table 1. The water-repellent chemical was produced by the company RUDOLF-DURANER. This additive is a cationic chemical consisting of a mixture of super-branched linear polymers

Table 1. Properties of polyester chips.

Viscosity	0.640 Dl/g
Carboxyl end groups	23.4 mmol/kg
Deg (diethylene glycol) amount	1.20 %
Polymer density	1.18 g/cm^3
Melting temperature	260 ^{o}C
Glassing temperature	60-80 ^{o}C

2.2 Method

In this study, yarns containing 3, 5 and 8% water repellent additives were produced by melt spinning method using polyester chips conditioned under operating conditions. 8 different yarns were produced that included 4 types of POY (P0, P3, P5, P8) and 4 types of textured yarns (T0, T3, T5, T8). Produced POY yarns were indicated by the letter P and textured yarns by the letter T, while the numbers next to these letters indicated the percentage of additives used (for example, P3; POY yarn with 3% water repellent additive). The yarns were produced in the production line of POLYTEKS company. Table 2 shows the production parameters.

Table 2. Production parameters of 167/36 water repellent polyester yarn (POY).

Chips type	Chips Semi Dull
Oil type	% Spin Finish
Shooting speed	3100-3300 m/dk
Jet pressure	4.2 bar
Extruder temperature	285 °C
Drying temperature	165 °C
Crystallization temperature	175 °C
Additive type	Clariant NBA0025612
Contribution rates	3%, 5%, 8%
Cooling air temperature	20 °C
Cooling air speed	0.58 m/sn

First of all, POY production was conducted and the tests and analyzes of the yarns were carried out. Then, these yarns were textured in the texturing room of POLYTEKS company and drawn-textured yarn (DTY) was obtained.

The texturing process was carried out on the Barmag FK V type false-twist texturing machine according to the production parameters given in Table 3.

Table 3. Production parameters of 167/36 water repellent textured yarn (DTY).

Machine no	7
Winding speed	550 m/min
Draw	1.72
W3/W4/W5/W6	-4.0/-5.2/31/1.90
T1	180 °C
Pressure	3.5 bar
Jet	P203 insert
Disc type	1-6-1 6 mm PU S
Oil age	0.6 rpm
Coil kilogram	1 kg

In order to examine the effect of the water-repellent additive on the fabric properties, woven fabrics were produced from both pure DTY yarns and DTY yarns containing 3 different ratio of water-repellent additives (3, 5 and 8). By using DTY yarns in warp and weft, fabrics with a warp density of 34 cm and a weft density of 28 cm in 1/1 plain weave were produced in DIVLIT DESEN TASARIM company. These fabrics are shown as K0, K3, K5, K8 (K3: woven fabric from DTY yarn with 3% water-repellent additive). These fabrics were coated with a fluorine-free water-repellent finishing chemical (RUDOLF DURANER) by using dip-coating method. A solution containing 60% finishing chemical (40% pure water) and 0.5 mL/L acetic acid was prepared, and fabrics cut in appropriate sizes were dipped in this solution. Wet pick-up of the fabrics was about 80% and the pH values of solutions were between 4.5-5. The dipping process was repeated 1, 3 and 5 times to increase the amount of coating. In each cycle, the fabrics were kept in the coating solution for 30 seconds and then dried at 150 °C for 3 minutes in an oven. According to the amount of coating (1, 3 and 5), this process was repeated respectively.

Yarn Tests: Linear densities, strength properties, crimp, shrinkage and unevenness properties of POY and DTY yarns were measured. Yarn density was determined in accordance with TS 244 ISO 2060 standard [14]. First, the yarn was cut to a length of 50 m and passed through the guide. Then, a bow was made by wrapping 100 turns from the bobbin, one of which was set to be 1 meter. The bow was weighed on a precision scale and the result was multiplied by 100 to calculate the density of the yarn. The measurement was repeated 3 times for each yarn and the average was taken. The tensile tests of the yarns were carried out in the Statimat test device according to the DIN EN ISO 2062 standard [15]. In POY yarns, the distance between the jaws, test speed and pre-stress was 200 mm, 1500 mm/min, 0.05 g/dtex, respectively. In DTY yarns, the distance between the jaws was 500 mm and the test speed was adjusted so that the break time of the yarn was 20 sn. The crimp values of DTY yarns were measured according to the DIN 53840-T1 [16] standard by using Texturmat test device. The yarns were brought into a hank form and kept in the oven at 120 °C for 10 min. The shrinkage measurements of the yarn samples were conducted according to the DIN 53866-1:1979 standard [17]. The yarns were brought into a hank form. After the hank was placed in the magazine apparatus, 2 cN/tex force was applied to the end of each yarn hank and the first yarn length was measured. Then, it was kept in an oven at 190 °C for 5 minutes, and the final yarn length was measured by removing it from the oven and applying 2 cN/tex force again. The boiling shrinkage value was found by subtracting the measured length after the boiling shrinkage from the first length and dividing it by the initial length. The unevenness measurements of the yarns were made in accordance with the ISO 16549:2004 [18] standard by applying a test speed of 50 m/min in the USTER device.

Fabric Tests: Water repellency, tensile test and air permeability tests were applied to woven fabrics and coated fabrics obtained from polyester yarns containing water-repellent finish. The water repellency test was carried out according to the TS EN ISO 4920 standard on fabrics containing 3 different percentages of finish (3%, 5%, 8%) and fabrics with three different coating numbers (1, 3 and 5 times). First, the specimens were cut in dimensions of 180*180 mm and were placed in the sample holder. Then, 250 ml of distilled water with a temperature of about 22 ˚C was discharged from the funnel and the time required for the water to drain completely was kept by the chronometer. The degree of wetting in the sample was evaluated using a photographic scale. Also, red dyestuff was added to the pure water in order to better evaluate the results. Tensile test was applied to the fabrics in both weft and warp directions in accordance with TS EN ISO 13934-1 standard [19]. The samples were cut in 300*60 mm dimensions and the yarns were removed and the sample width was adjusted to be 50 mm. The distance between the jaws was 200 mm and the test was carried out with a tensile speed of 100 mm/min. For each sample set, 5 replicate tests were performed and averaged. Air permeability test was performed on the fabrics according to the test standard TS 391 EN ISO 9237 using the DEVOTRANS brand test device [20]. Air flow values were recorded 1 minute after the test was started. Samples were taken from different parts of the fabric and test repeated 3 times and the average was taken. In order to analyze the chemical structure, Fourier-transform infrared (FT-IR) spectra of the water repellents coated fabrics were recorded on a Thermo Scientific Nicolet i550 spectrometer between 4000 and 400 cm^{-1} wavelengths. Finally, the distribution of the additives was examined by taking SEM images of the fabrics produced from yarns containing finishing.

3. RESULTS AND DISCUSSION

3.1 Yarn Test Results

Table 4 shows the linear density, tenacity, boiling shrinkage, unevenneess and elongation at break responses of POY yarns. A slight decrease was observed in POY yarn strength values with the increase of water-repellent additive ratio. PO and P3 showed a tenacity of 2.1 cN/dtex, while P5 and P8 showed 2 cN/dtex. It was observed that increasing the amount of water-repellent additive did not cause a change in the boiling shrinkage property of POY yarns. However, with the increase in the amount of additives, an increase was observed in the unevenness values of the POY yarns. P0 and P8 showed the unevenness values of 1.42% and 1.88%, respectively.

Table 5 shows the test results of DTY yarns. With the increase in the water-repellent additive ratio, no significant change was observed on tenacity of DTY yarns. When the textured yarn test results given in Table 5 are examined, no significant change was observed on the textured yarn strength with the increase in the water repellency additive ratio. Boiling shrinkage increased with increasing water-repellent additive ratio. While the lowest boiling shrinkage value was observed in the T0 (8.3%), the highest boiling shrinkage value was observed in the T8 (9.8%). The crimp shortening, crimp modulus, crimp stability values decreased with the increase in the amount of water-repellent. The average crimp shortening, crimp modulus, and crimp stability of T8 were 17%, 11%, and 63.5%, respectively. In addition, the lowest elongation was seen in T0 with 22.8%, while the highest elongation was observed in T8 with 25.5%. DTY yarns showed higher tenacity than POY yarns because they were exposed to draw during production. Sedighi et al. were produced at different weight percentages (0.4, 1, 2 and 4%) silica aerojel reinforced polyester yarns. Similar to the results obtained in this study, the aerogel particle reinforcement to the yarns did not cause a significant change in their mechanical properties [21].

3.2 Fabric Test Results

Repellent finishes provide water repellency by reducing the free energy on the fiber surface. If the interaction between a fiber and a drop of liquid dropped on the fiber is greater than the internal cohesive interactions in the liquid, the liquid spreads on the fiber surface. Conversely, if this interaction is less than the adhesive interaction in the liquid, the droplet will not spread on the fiber surface. The surfaces on which the liquids can not spread on the fiber are also called low energy surfaces. So, water repellency is achieved when the surface tension is lower than the surface tension of the liquid that is repelled [22-24].The water-repellency spray test results of woven fabrics and coated fabrics obtained from polyester yarns containing water-repellent finish were made according to the table of evaluation specified in the AATCC 22 spray test standard [25]. The evaluation given in this standard "0" indicates the worst result and "100 (ISO-5)" indicates the best result.

Table 4. Test results of POY yarns.

Specimen code	Linear density (dtex)	Tenacity (cN/dtex)		Boiling shrinkage (%)	Unevenness (%)	Elongation at break (%)	
	Avg.	Avg.	%CV	Avg.	Avg.	Avg.	%CV
P0	287.1	2.1	2.2	64.1	1.42	129.8	2.9
P3	286.1	2.1	1.9	64.7	1.74	130.4	2.2
P5	285.1	2	2.1	64	1.84	130.5	2.5
P8	285.1	2	2.7	64.1	1.88	127.8	2.8

Table 5. Test results of DTY yarns.

Specimen code	Linear density (dtex)	Tenacity (cN/dtex)		Boiling shrinkage (%)	Crimp shortening EK (%)	Crimp modulus KK (%)	Crimp stability KB (%)	Elongation at break (%)		Oil ratio (%)
	Ort	Ort	%CV	Ort	Ort	Ort	Ort	Ort	%CV	Ort
T0	181.5	3.3	2.1	8.3	24.25	15.12	74.62	22.8	4	2.44
T3	177.2	3.5	2	8.8	20.5	13	67.5	23.8	3.6	2.55
T5	177.8	3.5	2	9.6	18.5	12	65	24.8	4	2.65
T8	176.2	3.5	2	9.8	17	11	63.5	25.5	4	2.55

Spray test results of K0, K3, K5 and K8 coded fabrics are given in Table 6. It was observed that the non-finished fabrics did not show water-repellent, was completely wet, and corresponds to "0" on the photographic scale (Figure 1-

a). A small amount of water droplets were seen on the surface of the fabric samples, which were treated once with a finishing coating (Figure 1-b). This corresponds to 90 (ISO-4) at scale. Wetting wasn't observed in the fabric samples that were applied 3 and 5 times finishing coating. This corresponds to 100 (ISO-5) on the photographic scale (Figure 1-c, d). It was observed that increasing concentrations of water-repellent additives in fabrics produced by applying water-repellent additives to yarns did not improve the water-repellent properties of the fabrics. However, as the amount of coating (1,3 and 5 times) increased with the water-repellent finishing of the fabrics, the water-repellent properties increased and 100 (ISO-5) was reached after the 5th coating.

Table 6. Water-repellency spray test results of fabrics.

Specimen code	AATCC Spray Rating			
	Uncoated	1 time	3 times	5 times
K0	0	90	100	100
K3	0	90	100	100
K5	0	90	100	100
K8	0	90	100	100

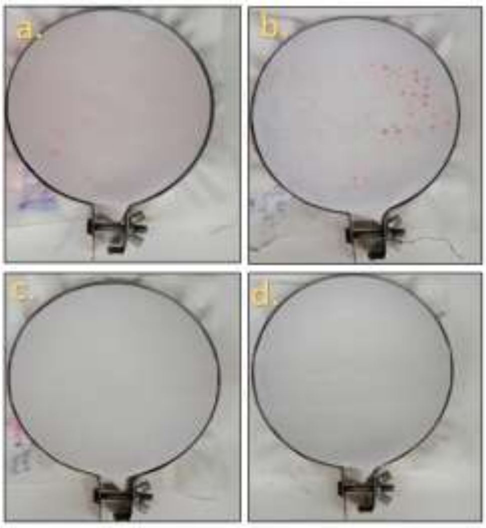

Figure 1. Images of K5 fabric specimen after water-repellent test (a: uncoated, b:1 times, c:3 times and d: 5 times)

Table 7 shows the air permeability test results of the fabrics. While increasing the amount of additives (3, 5 and 8) in the yarn did not affect the air permeability, it was observed that the air permeability of the fabrics decreased as the number of coatings increased by applying the water-repellent finishing surface to the fabrics (1, 3 and 5). In the literature studies, it has been seen that the most important factors affecting the air permeability of fabrics are the linear density of the yarns, the weaving type of the fabrics (plain, satin, twill etc.), dyeing or coating of the fabrics [26-30].

Table 7. Air permeability test results of fabrics.

Specimen code	Uncoated (m/s)	1 time (m/s)	3 times (m/s)	5 times (m/s)
K0	0.0555	0.0475	0.0203	0.0174
K3	0.0560	0.0498	0.0262	0.0180
K5	0.0562	0.0446	0.0226	0.0110
K8	0.0580	0.0491	0.0162	0.0120

SEM images of fabrics containing different water repellent percentages are given in Figure 2. When the SEM pictures were examined, it was observed that the water-repellent particles in the cross-section increased as the additive ratio increased. It is also seen that the water-repellent chemical applied to the fabric is homogeneously coated around the fibers. While it is seen that the surface of the fibers in the K3 coded sample is smooth and the cross section is round, a rougher surface is observed on the K5 and K8 fabrics with the increase in the additive ratio used in the yarns. Similar surface morphology was seen in articles [31] and [32].

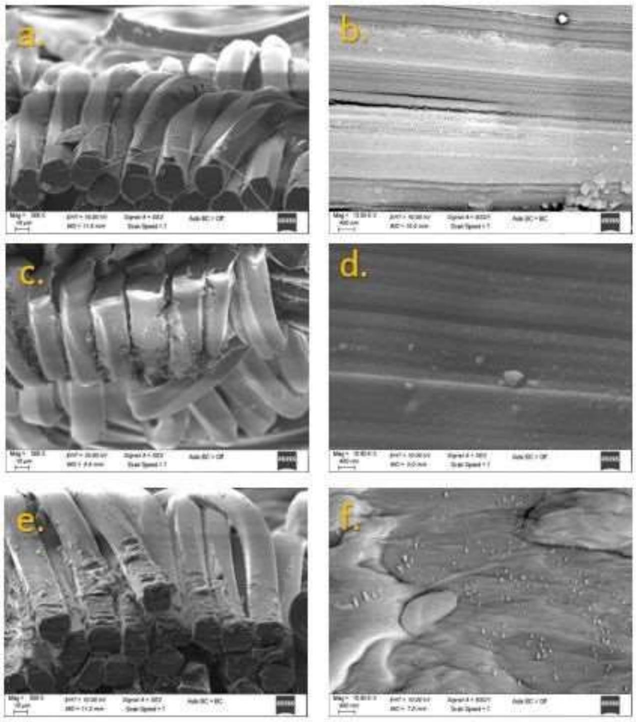

Figure 2. SEM images of fabric samples; a-b: K3, c-d: K5, e-f: K8.

The infrared spectrum of the K5 (uncoated, 1 times, 3 times and 5 times) coded samples are shown in Figure 3. The bonds seen in the range of 2800–3000 cm^{-1} are attributed to the stretching vibrations of the C-H groups such as CH_3 and CH_2 [33]. Fabric coated with water repellent additives shows the stretching vibrations of C-H groups have approximately the similar absorption bands. It was observed that these band intensities also increased with the increase of water repellent additives in the fibers. It was determined that increasing the C-H bonds were proportional to the water repellent capacity. It is thought that alkyl groups reduce the effect of hydrogen bonding between water molecules and the fabric surface, thus increase the water repellency of the fabric. The band resulting from the stretching vibrations of the C=O group was observed at 1712.66 cm^{-1}[34]. The increase in the intensity of C-H groups with the increase in the amount of coating used in the fabrics decreases the intensity of the C=O group in parallel. Similar spectra results were also seen in K0, K3 and K8 coded samples.

For each coated and uncoated fabric specimens set (K0, K3, K5 and K8) at least five tensile tests were conducted in both the weft and warp directions, the results were averaged, and the max.tensile load and elongationat break values are listed in the Table 8. While the yarns used in the production of the K0 coded fabric do not contain water repellent finishing additives, the yarns used in the production of the K8 coded fabric contain a water repellent additive at the rate of 8% by weight. Accordingly, increasing the additive ratio of the yarns caused a decrease in the tensile strength of the fabrics. In order to increase understanding, it is given as a column chart in Figure 4. While the water repellent coating process applied to the fabrics with 1, 3 and 5 repetitions didnt have much effect on the maximum force and elongation values of the fabrics, it was seen that the fabrics endured higher forces in the warp direction compared to the weft direction.

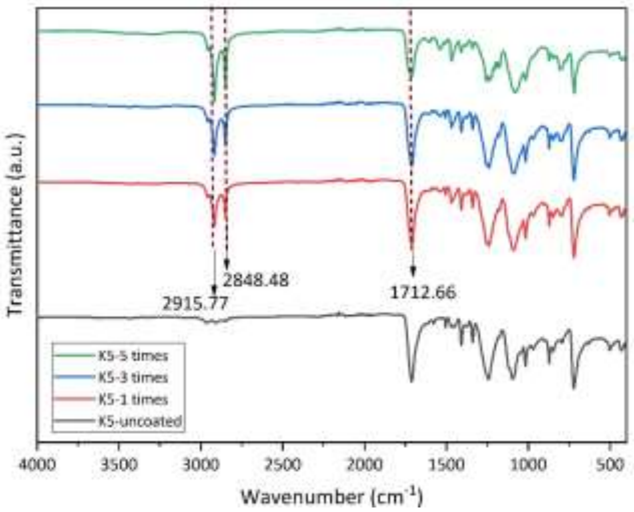

Figure 3. FTIR spectra of K5 fabric specimen (uncoated, 1 times, 3 times and 5 times)

Table 8. Tensile test results of uncoated and coated fabrics in weft and warp directions.

Specimen code		Warp Max. load (N)	Warp Elongation at break (%)	Weft Max. load (N)	Weft Elongation at break (%)
K0	***Uncoated***	964.66 ± 8.68	33.71 ± 0.75	787.80 ± 26.20	21.86 ± 1.38
	1 time	964.17 ± 7.45	39.37 ± 0.46	757.21 ± 25.45	24.24 ± 6.46
	3 times	908.83 ± 60.44	35.07 ± 4.04	832.54 ± 10.66	27.22 ± 0.57
	5 times	847.45 ± 48.45	33.31 ± 2.95	795.45 ± 15.60	29.80 ± 1.42
K3	***Uncoated***	959.17 ± 9.25	36.04 ± 0.40	679.91 ± 15.00	35.02 ± 2.12
	1 time	988.44 ± 9.47	41.24 ± 1.82	753.22 ± 36.60	26.69 ± 0.67
	3 times	795.59 ± 32.84	30.25 ± 2.49	800.06 ± 24.70	28.41 ± 1.94
	5 times	857.65 ± 92.88	35.83 ± 5.02	816.36 ± 13.36	28.48 ± 1.29
K5	***Uncoated***	946.29 ± 30.93	35.02 ± 0.60	569.46 ± 33.80	19.69 ± 0.03
	1 time	924.48 ± 16.23	39.13 ± 4.20	679.06 ± 35.29	23.38 ± 2.76
	3 times	937.89 ± 14.51	38.69 ± 1.23	694.79 ± 26.36	24.01 ± 1.10
	5 times	864.57 ± 38.85	38.34 ± 3.22	738.67 ± 22.46	25.55 ± 1.29
K8	***Uncoated***	878.60 ± 24.16	30.94 ± 1.93	525.79 ± 11.40	20.64 ± 0.40
	1 time	894.93 ± 52.95	37.87 ± 2.30	575.22 ± 8.68	24.26 ± 1.85
	3 times	913.23 ± 13.47	39.43 ± 0.75	641.54 ± 21.99	27.07 ± 1.30
	5 times	766.49 ± 23.23	32.26 ± 0.76	515.45 ± 31.21	27.17 ± 1.04

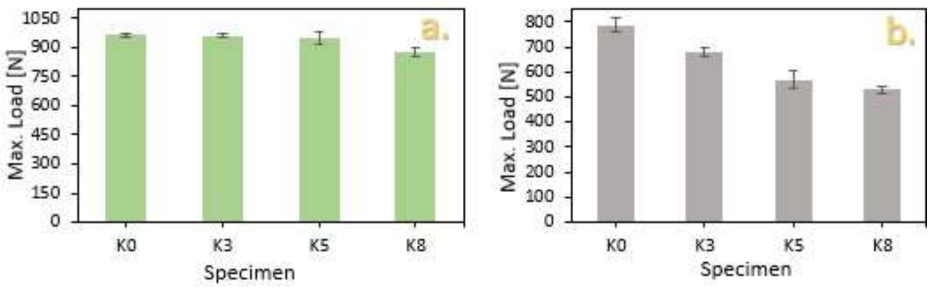

Figure 4. Tensile test results of uncoated fabrics (a) in warp and (b) weft directions.

4. CONCLUSION

In this study, filament yarns containing fluorine-free hydrophobic additives in different weight percentages (3, 5 and 8) and fabrics coated with a water-repellent finish without fluorine (1, 3 and 5 times) were produced. Plain woven fabrics were weaved from these yarns. The water repellency properties of polyester fabrics was not be improved at the desired level with the addition of fluorine-free additives. SEM analysis results and water repellency spray tests were evaluated together, and it was seen that there was water-repellent additive in the fibers, but fabrics was not show an effective water repellency performance. It is thought that the reason why the fabrics produced with these yarns containing water-repellent additives do not show water-repellent properties is the low percentage of additives in the yarns.

When the performance of the fabrics produced by coating 1, 3 and 5 times water-repellent finishing was examined, it was observed that the water repellent property of the fabrics improved with the increase in the number of coatings. No wetting and water droplets were seen on the fabric surfaces that were coated 3 and 5 times. In addition, the air permeability of the fabrics decreased as the number of coatings increased.

In future studies, it is aimed to improve the water-repellency properties of fabrics by increasing additives used in filament yarns or by using different types of water-repellent additives. When more effective and successful results are obtained with non-fluorine water repellents, it may be an economically and ecologically good alternative to fluorinated compounds.

ACKNOWLEDGMENTS

This work was supported by TUBITAK 2209-B Undergraduate Research Projects Support Program for Industry with project application number 1139B411900908. The authors wish to thank POLYTEKS Tekstil Sanayi Araştırma ve Eğitim A.Ş (Bursa/Turkey) staff and R&D managers for their support during the conduct of this study. The authors thank to RUDOLF DURANER (Bursa/Turkey).

REFERENCES

1. Çoban S. 1999, Genel tekstil terbiyesi ve bitim işlemleri. Ege Üniversitesi.
2. Oğultürk G. 2008. Dokuma kumaşlarda su iticilik ve buruşmazlik özelliklerinin tek adimda iyileştirilmesi (Master’s thesis). Available from https://polen.itu.edu.tr/bitstream/11527/4584/1/8449.pdf.
3. Ozcan G. 2007. Performance evaluation of water repellent finishes on woven fabric properties. *Textile Research Journal*, 77, 265- 270.
4. Akman İ. 2018. Köpük aplikasyon tekniği ile su iticilik apresi uygulanmasi ve denim kumaş performansina etkisinin incelenmesi (Master’s thesis). Available from https://tez.yok.gov.tr/UlusalTezMerkezi/tezDetay.jsp?id=R41vKpgXx0Tji0DXU_eQtA&no=7TexQSOVz0KfvhtlVpYa0Q
5. Lin SC, Yan K, Hsu CT, Chang TC, Chen CC. 2015. Apparatus of fabrication water-repellent fabric united states patent application publication. 2015/0202816A1. US
6. Akinci CF. 2017. Mikrofilament inceliğinin ve atkı sıklığının su iticilik bitim işlemi görmüş bezayağı ve panama kumaşların performans özelliklerine etkilerinin araştırılması (Master’s thesis). Available from https://tez.yok.gov.tr/UlusalTezMerkezi/tezSorguSonucYeni.jsp
7. Eryaman, Y. 2016. Spor teknik tekstillerine uygulanan su iticilik bitim işleminin kumaş tutum özellikleri ve dikilebilirliliği üzerindeki etkilerinin araştırılması (Master’s thesis). Available from https://tez.yok.gov.tr/UlusalTezMerkezi/tezSorguSonucYeni.jsp
8. Mazzon G, Zahid M, Heredia-Guerrero JA, et al. 2019. Hydrophobic treatment of woven cotton fabrics with polyurethane modified aminosilicone emulsions. *Applied Surface Science*, 490, 331-342.
9. Sharif R, Mohsin M, Ramzan N, et al. 2022. Synthesis and application of fluorine-free environment-friendly stearic acid-based oil and water repellent for cotton fabric. *Journal of Natural Fibers*, 19, 1632-1647.
10. Sunderland EM, Hu XC, Dassuncao C, et al. 2019. A review of the pathways of human exposure to poly-and perfluoroalkyl substances (PFASs) and present understanding of health effects. *Journal of Exposure Science & Environmental Epidemiology*, 29, 131-147.
11. Grandjean P, Andersen EW, Budtz-Jørgensen E, et al. 2012. Serum vaccine antibody concentrations in children exposed to perfluorinated compounds. *Jama*, 307, 391-397.
12. Colleoni C, Esposito F, Guido E, Migani V, Trovato V, Rosace G. 2017. Ceramic coatings for water-repellent textiles. *In IOP Conference Series: Materials Science and Engineering*, 254(12).
13. Chowdhury PK, Chowdhury S, Hosain AM, Al Mamun AA, Alahi N, Rahman S. 2018. Comparative enactment of fluorocarbon-free and fluorocarbon-based water repellent finishes on cotton single jersey fabrics. *International Journal of Current Engineering and Technology*, 8, 1-7.
14. TS 244 EN ISO 2060. 1999. Tekstil-iplikler-doğrusal yoğunluk (birim uzunluk basına kütle) tayini- çile metodu. Türk Standartları Enstitüsü, Ankara.
15. DIN EN ISO 2062. 2009. Textiles-Yarns from packages-determination of single-end breaking force and elongation at break using constant rate of extension (CRE) tester, International Organization for Standardization and European Committee for Standardization, London.
16. DIN 53840-1. 1983. Determination of parameters for the crimp of textured filament yarns; filament yarns with a linear density exceeding 500 dtex.
17. DIN 53866. 1979. Testing of textiles; shrinkage of single and plied yarns, determination of shrinkage in water.
18. ISO 16549. 2004. Textiles unevenness of textile strands capacitance method. International Organization for Standardization, Switzerland.
19. TS EN ISO 13934-1. 2002. Textiles – tensile properties of fabrics – Part 1: Determination of maximum force and elongation at maximum force using the strip method.p.14.
20. TS 391 EN ISO 9237. 1999. Textiles-determination of the permeability of fabrics to air. Turkish Standards Institution, Ankara.
21. Sedighi S, Khoddami A, Izadan H, Alsharif MA, Naeimirad M. 2022. The influence of silica aerogels on physical, mechanical, and morphological properties of melt-spun POY and DTY polyester yarns. *Polymer Testing*, 107628.

22. Sayed U, Dabhi P. 2014. Finishing of textiles with fluorocarbons. *Waterproof and water repellent textiles and clothing*: Elsevier. p. 139-52.
23. Holmes, D., Horrocks, A., Anand, S. (Eds.), 2000. Handbook of Technical Textiles. Woodhead Publishing Ltd, Cambridge p. 461.
24. Kissa, E., Lewin, M., Sello, S., 1984. Handbook of Fiber Science and Technology. *Chemical Processing of Fibers and Fabrics*, Part B Functional Finishes, vol. 2. New York.
25. AATCC 22. 2010. Water repellency: Spray test, AATCC Technical Manual. Amer. Assoc. text. chem. colo Research Triangle Park, N.C., USA.
26. Cay A, Vassiliadis S, Rangoussi M, Tarakçıoğlu I. 2007. Prediction of the air permeability of woven fabrics using neural networks. *International Journal of Clothing Science and Technology*,19(1), 18-35.
27. Selli F, Turhan Y. 2017. Investigation of air permeability and moisture management properties of the commercial single jersey and rib knitted fabrics. *Textile and Apparel*, 27(1), 27-31.
28. Oğulata RT, Mavruz S. 2010. Investigation of porosity and air permeability values of plain knitted fabrics. *Fibres & Textiles in Eastern Eur*ope, 18(5), 71-75
29. Havlová M. 2020. Air permeability, water vapour permeability and selected structural parameters of woven fabrics. *Fibres and Textiles*, 27(1), 8-12.
30. Garip B, Yüksel Yilmaz AN, Necati E, Bedeloğlu A. 2021. Farklı punta sayılarının poliester kumaş özellikleri üzerindeki etkilerinin incelenmesi. *Konya Mühendislik Bilimleri Dergisi*, 9(1), 25-35.
31. Jiang C, Liu W, Yang M, Liu C, He S, Xie Y, et al. 2018. Facile fabrication of robust fluorine-free self-cleaning cotton textiles with superhydrophobicity, photocatalytic activity, and UV durability. *Colloids and Surfaces A: Physicochemical and Engineering Aspects*, 559, 235-242.
32. Liu Q, Zhou Y, Shen Y, Li Y, Guo H, Deng B, et al. 2019. Morphology, Structure, and Properties of Conductive Polylactide Fibers Prepared Using Polyvinyl Acetate and Multiwalled Carbon Nanotubes. *Coatings*, 9(10), 651.
33. Chukwu M, Madueke C, Ekebafe L. 2019. Effects of Snail Shell as Filler on the Mechanical Properties of Terephthalic Unsaturated Polyester Resin. *Niger Res J Chem Sci*., 6, 21-32.
34. Bhattacharya S, Chaudhari S. 2014. Study on structural, mechanical and functional properties of polyester silica nanocomposite fabric. *International Journal of Pure and Applied Sciences and Technology*, 21(1), 43.