Chapter

# A Research on Polyamide6.6/ Polyurethane Blends in Finishing Process Which Are Used for Sportswear

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## Abstract

In this work, softeners obtained from various companies were applied to the polyamide6.6/polyurethane fabrics which are used in sportswear industry using impregnation and exhaustion methods; water vapor permeability were determined for humidity control, air permeability and capillarity tests of these fabrics were studied. In addition, the wool hydrolysate obtained from the waste wool was also applied to these fabrics by using exhaustion method and the fabric properties were compared. In order to investigate the washing resistance of the process, experiments were performed with 1% and 3% potassium aluminum sulfate $KAl(SO_4)_2$ and aluminum sulfate $Al_2(SO_4)$ under the same conditions. The chemical and morphological surface properties of the fabrics were examined by using X-ray photoelectron spectroscopy (XPS). It was observed that the capillarity, water vapor and air permeability, and handle values of fabrics treated with wool hydrolysate were better and more resistant to consecutive washings than the fabrics treated with commercial recipes. Furthermore, this process did not have a side effect on the color difference and whiteness values of the fabrics treated with wool hydrolysate. Thus, an example of sustainable, economical and environmental study was done.

**Keywords:** polyamide6.6/polyurethane, capillarity, wool hydrolysate, water vapor permeability, handle, sustainable, sportswear industry

## 1. Introduction

Sports activities have become a hobby and lifestyle for many people, since the importance of healthy life is known and the quality of life has increased. In addition, sports activities have become a necessity for today's people who want to get away from excessive work and overwhelming business of urban life. For this reason, the interest in sportswear has also increased. Not only professional athletes but also individuals who do sports are accustomed to wearing sportswear making the clothing a functional necessity.

Sportswear is regarded as an area open to development, high potential and high added value in the textile industry. The global sports apparel market grew up to 181 billion U.S. dollars in 2019, and compared with the previous year, it has increased more than seven billion U.S. dollars. It is estimated that it will continue to grow and reach approximately 208 billion U.S. dollars in 2025 [1, 2]. With the development of

technical textiles, it is possible to have comfort during the highly intense sports activity and under different climate conditions. Knowing the humidity (water vapor permeability) and air permeability values of the clothing are two most important parameters in the measurement of comfort parameters as well as touching. Therefore, the measurement of how humid is a textile material is of great importance as well. For such measurement of humidity not only traditional testing methods but also recently developed sensors with different techniques – such as inkjet printing, carbon nanotubes, coating technology, stamp transfer, electrospinning and dip coating-can be used [3, 4]. Humidity control is widely carried out in many sectors dominating the daily life, such as agriculture, chemistry, food, health, pharmacy and automation.

The hydrophilicity of natural fibers such as cotton provides superiority during sports activities. Since drying duration is too long, it reduces comfort and may cause various complications and discomforts [5, 6]. Otherwise, the traditional filaments such as polyester and polyamide are hydrophobic and are prone to dry rapidly and give a feeling of dryness. Synthetic yarn or blended yarn are used to increase the comfort property of the fabric [7, 8]. The water vapor and air permeability values of the garment depend on fiber, yarn species [9–11], surface structure [10–12], and finishing treatment [13–16]. A special finishing process is performed to increase hydrophilicity values of the fabric with synthetic fibers such as polyamide and polyester. Textile chemistry manufacturers produce different hydrophilicity enhancers and textile dyehouses use these products. Although these chemicals are suitable for eco-textile and environmental standards, they are produced with chemical materials and processes. Hence, they may give harm to the nature and the user during production and consumption. They are also expensive and have some drawbacks such as staining and yellowing/color change problems [16]. In this regard, the attempts for sustainable and clean production continue.

Raw wool, which is not efficient for textile production, is an important source for biopolymer. Recycling of this easily accessible protein source and the production of keratin are important sources for biocirculation and biocompatible material production. It has been used in cosmetics, recycable composites, transportation, medical membranes, agriculture and coating industry in recent years. The wool obtained from sheep breed in Turkey is generally suitable for being used in products such as the blankets, rugs and carpet [17]. The gradual decrease in the carpet sector in Turkey has reduced the use of this wool and the material has only been waiting in warehouses [18]. The active wool can cause global warming due to methane gas which can be soluble in nature. As a result, the utilization/recovery of the wool waiting in the warehouse [19] has great importance, both in terms of obtaining materials which have superior properties and low cost, optimum utilization of resources and environmental protection [20]. The obtaining methods of keratin are reduction, oxidation, alkali and enzymatic hydrolysis [21–23]. Alkali, oxidation and reducing chemicals used break into disulfide and peptide bonds which are the basic structure of wool at high temperature and time, and wool solution is obtained. Studies using wool hydrolysate have been done to obtain fiber and nanofiber and to increase the performance of dyeing and starch material in textile industry.

The aim of this study is to obtain the hydrolysate from wool fibers, which were left in the carpet industry but now waiting in the warehouse as waste with the decrease in production, and the hydrolysate obtained was used instead of commercial finishing bath of the polyamide6.6/polyurethane fabrics which are used in sportswear industry in Turkey. Capillarity, water vapor and air permeability and handle and yellowing/color change values of the fabrics treated with wool hydrolysate were compared with the ones which were treated with commercial products [24]. Thus, a new production method has been introduced for the finishing of polyamide6.6/polyurethane blend, which are widely used in the market.

## 2. Experimental section

### 2.1 Fabrics

The fabrics made of 80/20 polyamide 6.6/polyurethane blend were used. The weights of both fabrics were 170 g/m$^2$ (150 den PA 6.6/30 den PU) and 190 g/m$^2$ (100 den PA6.6/30 den PU) and ready to dye. Fabric thicknesses were 0.48 mm and 0.66 mm respectively. The fabrics were knitted on a double comb bar (laying-in) Rachel warp knitting machine. While first laying-in bar (Gb1) were knitting the tuh pattern 1–0/2–3//with full draft, in the second bar (Gb2), tricot pattern 1–2/1–0// was being knitted with full draft.

### 2.2 Auxiliaries

- Arristan HPC T (hydrophility enhancer agent, polyester copolymer, non-ionic, CHT) [25].
- Tubingal SHE (Hydrophile silicone softener, functional polisiloxane, mild cationic, CHT/Bezama) [26].
- Hydroperm LPU liq c (Hidrophility enhancer agent, thermoreactive polyurethane resin, non-ionic, Archroma) [27].
- Siligen SIH liq (Hydrophile silicone softener, modified silicone, Archroma) [28].
- Potassium aluminum sulfate ($KAl(SO_4)_2$, Sigma-Aldrich)
- Aluminum sulfate ($Al_2(SO_4)$ Merck)
- The hydrolysate wool solution: The solution was obtained by alkali hydrolysis by using wool fibers which have 28 micron fineness and 40–60 mm length [21]. Average particle size was detected 211.91 millimicron with Mastersize 2000 in Merlab/ODTU.

### 2.3 Methods

Recipe for impregnation method

- 50 g/lt Arristan HPC T or Hydroperm LPU liq
- 20 g/lt Tubingal SHE or Siligen SIH, pH 5–5.5 ($CH_3COOH$),
- The fabric was padded with impregnated liquid and then they were squeezed at pick up 70% and were dried in Mathis CH-8156, 110°C for 3 min.

Recipe for exhaustion method

- % 3.5 Arristan HPC T or Hydroperm LPU liq
- %1.4 Tubingal SHE or Siligen SIH liq, pH value: 5–5.5 ($CH_3COOH$) at liquid ratio of 10:1 in Ataç Lab-Dye HT 10 for 30 min, at 40°C.

Samples were treated by using both impregnation and exhaustion methods in the same conditions in which only wool solution was used instead of chemicals. In order to ensure the washing resistance of the process, additions of 1% and 3% KAl $(SO_4)_2$ and $Al_2(SO4)$ were worked under the same conditions.

Dye uptake experiments were carried out in an Atac LAB-DYE HT machine at liquor ratio of 10: 1 as shown in **Figure 1**.

Recipe 1

- 0.12% Nylosan Red N-2RBL (CI Acid Red 336)
- 0.14% Nylosan Blue N-BLN (CI Acid Blue 350)
- 0.55% Optilan Golden Yelow MF-RL (CI Acid Orange 67)

pH value: 5–5.5 ($CH_3COOH$).

Recipe 2

- 0.17% Nylosan Red N-2RBL (CI Acid Red 336)
- 0.006% Nylosan Blue N-BLN (CI Acid Blue 350)
- 0.50% Optilan Golden Yelow MF-RL (CI Acid Orange 67)

pH value: 5–5.5 ($CH_3COOH$).

After dyeing, the samples were bathed at 50°C for 10 minutes with a non-ionic detergent (Fluidol W 100, Pulcra Chemicals) and rinsed with cold water.

### 2.4 Measurements and characterizations

All the physical measurements following the process were carried out after conditioning the fabrics for 24 hours under the standard atmosphere conditions

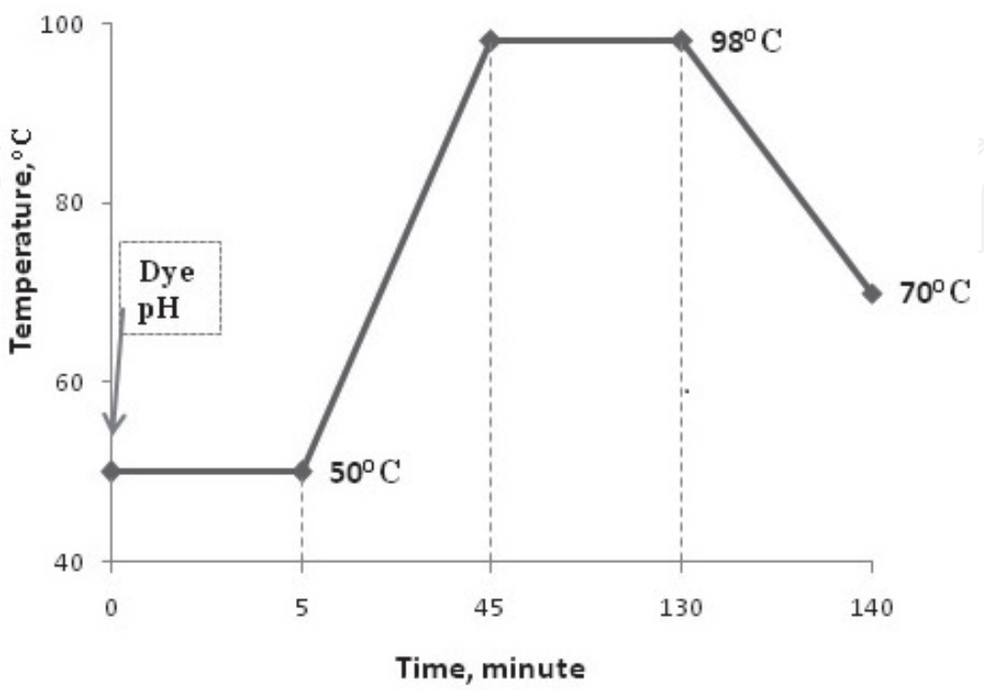


**Figure 1.**
*Dyeing graph.*

(20°C ± 2) temperature, % 65 ± 2). The capillarity of the fabrics was evaluated with the capillarity test method according to DIN 53924, water vapor permeability was measured according to ASTM E96-B and air permeability of the fabrics was measured by the Textest FX 3300 model Air Permeability Tester according to ASTM D737–04.

The laundry was done by using a front-loading Wascator machine (Electrolux FOM) with 2.0 kg loads consisting of processed samples and 100% PES ballast fabrics. All the washing cycles were performed according to BS EN ISO 26330 Standard (5A program). This laundering process was repeated 5 times in accordance with supplier's recommendation (Archroma and CHT). The samples were dried with dry flat in laboratory condition for 24 hours. The chemical and morphological surface properties of the fabrics were examined by using X-ray photoelectron spectroscopy (XPS). The samples were determined in terms of surface smoothness with XPS K-Alpha Surface Analysis with monochromatic Al Kα irradiation. The relative amounts of various bound atoms were determined through C1s, O 1 s, N1s, Si2p, Ca2p, S2p. Working condition is shown in **Table 1**.

The handle of the samples were carried out according to two different methods under the standard atmospheric conditions (20 °C ± 2) temperature, % 65 ± 2). Ten healthy women were selected as the participant group aged between 35 and 65 consisting of professionals including academic lecturers at Department of Textile Engineering, Suleyman Demirel University, academic lecturers at Textile, Apparel, Footwear and Leather Department of Technical High School at Isparta University of Applied Sciences and Dyehouse Manager of Isparta Mensucat Corporation.

Samples were examined on 10 subjects with 3 repetition in terms of thinnes/thickness, softness/stiffness, smoothness/roughness and total handle values [29]. Moreover, another subjective evaluation was to have carried out examination in terms of softness/coolness/dampness sensation. The scale used is as shown in **Table 2**.

The degree of whiteness and yellowness indices of the samples were assessed by the CIE value and ASTM E 313 respectively, using Macbetch Coloreye 7000A. Color differences were indicated as ΔE, which was computed by Eq. (1):

$$\Delta E = \left[(\Delta L)^2 + (\Delta a)^2 + (\Delta b)^2\right]^{1/2} \quad (1)$$

In the CIELAB color space, L is the lightness; a is the red/green axis, b is the yellow/blue axis, c is the chroma and h is the hue, ΔE is the color difference between the reference and the sample.

| **Parameter** | |
|---|---|
| Total acquisition time | 3 mins 24.2 secs |
| Number of scans | 15 |
| Source gun type | Al K Alpha |
| Spot size | 400 μm |
| Lens mode | Standard |
| Analyzer mode | CAE: Pass Energy 150.0 eV |
| Energy step size | 1.000 eV |
| Number of energy steps | 1361 |

**Table 1.**
*Working conditions used in XPS analysis.*

| Attribute | Rating scale | | | Time (s) |
|---|---|---|---|---|
| **Thinness/thickness** | **1 Thinnest** | **5 medium** | **10 thickest** | **15** |
| Softness/stiffness | 1 softest | 5 medium | 10 stiffest | 20 |
| Smoothness/roughness | 1 smoothest | 5 medium | 10 roughest | 15 |
| Total handle value | 1 Not proper | 5 medium | 10 Most proper | 20 |
| Softness/coolness/dampness | 1 Not proper | 3 medium | 5 Most proper | 60 |

**Table 2.**
*The scale used for subjective handle.*

## 3. Results and discussion

### 3.1 The finishing process using impregnation and exhaustion methods

In **Table 3** the obtained capillarity, air permeability and water vapor permeability values of the sample values are given. These values are compared with those of fabrics non-treated.

As given in **Table 3**, the capillarity, air permeability and water vapor permeability values of the samples having two different weights are similar to each other when treated with both softener combinations by using impregnation method.

As seen in the values from **Table 3**, the capillarity values of both fabrics increase significantly after finishing process. Capillarity is essentially stated by the surface energy of the structure. In a textile structure, the surface energy is largely determined by the chemical structure of the exposed surface of the fiber. Hydrophilic fibers have a high surface energy; therefore, these fiber take up humidity quickly than hydrophobic fiber. Hydrophobic fibers conversely possess low surface energy and resist to humidity. Hydrophilic finishing can be used as enhancer in surface energy between face and back of the fabric to improve its ability to wick [30]. The greatest increase is observed in fabrics treated with only hydrophilicity enhancer for both fabrics. However, the lowest capillarity, water vapor and air permeability values are obtained with silicone softener for both fabrics. It is known that the capillarity of the fabric decreases by the treatment with amino silicon due to its hydrophobic character of silicone softener. The pores are also covered by the placement of the silicone on the fabric. This process also causes to reduction in water vapor and air permeability values of them. Recently, hydrophilic effective softening agents can be produced by modifying the fatty acid long chain in the silicone structure. Therefore, the decrease in **Table 3** values is not at an excessive amount. According to the results of **Table 3**, the water vapor and air permeability values of the fabrics are improved together with the capillarity values. The process of humidity transport in hydrophobic textile material take place in wicking, spreading and evaporation [31, 32]. The fabric evaporation and water vapor values become better as the rate of wicking increases.

Capillarity values obtained by applying wool hydrolysate to both fabrics by using impregnation method and then drying were obtained under the same conditions, and since the values were quite low, they are not given in **Table 3**. This indicates that the hydrolysate cannot be attached to the polyamide6.6/polyurethane blend fabrics. The capillarity, air permeability and water vapor permeability values

| | | Capillarity (sec) | | | Air permeability ($l/m^2/s$) | Water vapor permeability ($g/24\ s/m^2$) |
|---|---|---|---|---|---|---|
| | | **10** | **30** | **60** | | |
| Fabric without treatment | Fabric I | 11 | 25 | 39 | 870 | 521 |
| | Fabric II | 14 | 33 | 49 | 820 | 507 |
| Arristan HPC T/Tubingal SHE | Fabric I | 27 | 47 | 67 | 970 | 634 |
| | Fabric II | 33 | 52 | 66 | 920 | 628 |
| Arristan HPC T | Fabric I | 34 | 54 | 68 | 945 | 643 |
| | Fabric II | 24 | 44 | 61 | 900 | 631 |
| Tubingal SHE | Fabric I | 33 | 52 | 65 | 890 | 633 |
| | Fabric II | 23 | 50 | 63 | 920 | 623 |
| Hydroperm LPU liq c/Siligen SIH liq | Fabric I | 32 | 51 | 62 | 1010 | 650 |
| | Fabric II | 31 | 51 | 60 | 990 | 640 |
| Hydroperm LPU liq c | Fabric I | 35 | 52 | 62 | 985 | 655 |
| | Fabric II | 34 | 53 | 62 | 950 | 648 |
| Siligen SIH liq | Fabric I | 20 | 42 | 61 | 930 | 630 |
| | Fabric II | 18 | 34 | 54 | 905 | 620 |

**Table 3.**
*Capillarity, water vapor and air permeability values of samples by using impregnation method.*

of the samples with two different weights by using exhaustion method are shown in **Table 4**.

When the **Tables 3** and **4** are compared, the capillarity test results of the samples processed with Hydroperm LPU liq c/Siligen SIH liq in both fabric 1 and fabric 2 using exhaustion method are higher. This can be attributed to the harmony of the ionic character due to the fact that both chemicals are non-ionic.

An important point in the **Tables 3** and **4** is that the fabrics which have same knitting structures (fabric 1 and 2) but with different weights and fineness of the yarn are different. While fabric 1 was 170 $g/m^2$ (150 den PA6.6/30 den PU), fabric 2 190 $g/m^2$ was (100 den PA6.6/30 den PU). This shows that capillarity depends on the diameter of the yarn forming the surface. In textile structures, the spaces between fibers effectively form capillarities. Therefore, the narrower are the spaces between these fibers, the greater is the ability of the textile to absorb moisture. The construction of fabric that forms narrow capillarity has vital importance to pick up moisture quickly [11, 12, 33].

As stated in **Table 4**, only wool hydrolysate was applied to fabrics as a softener bath at 40°C and 50°C. The capillarity, water vapor and air permeability values obtained are observed to increase with the application at 50°C. Raising the temperature from 40–50°C improves the fixation of the wool hydrolysate to the fabric. The softening process of polyamide6.6 fabric is carried out at 40–50°C. Since glass transition temperature of polyamide6.6 is 60–80°C [34, 35], processing at 60°C and above may cause the previously dyed fabric to flow into the softening bath.

In order to increase the fixation of wool hydrolysate to the polyamide6.6/polyurethane fabric, aluminum sulfate, potassium aluminum sulfate which are used as mordant in wool dyeing were added in an amount of 1% and 3% in the finishing bath at 50°C. According to the **Table 4** results, potassium aluminum sulfate at the amount of 1% gives the highest results for capillarity. This can be attributed to the

| | | | Capillarity (sec) | | | Air permeability ($l/m^2/s$) | Water vapor permeability ($g/24\ s/m^2$) |
|---|---|---|---|---|---|---|---|
| | | | 10 | 30 | 60 | | |
| Fabric without treatment | | Fabric I | 11 | 25 | 39 | 850 | 521 |
| | | Fabric II | 14 | 33 | 49 | 820 | 507 |
| Arristan HPC T/Tubingal SHE | 40°C | Fabric I | 25 | 38 | 50 | 1100 | 630 |
| | | Fabric II | 21 | 38 | 45 | 1050 | 630 |
| | 50 °C | Fabric I | 36 | 49 | 61 | 1100 | 643 |
| | | Fabric II | 32 | 48 | 57 | 1020 | 625 |
| Arristan HPC T | 50 °C | Fabric I | 33 | 43 | 65 | 1050 | 643 |
| | | Fabric II | 28 | 53 | 59 | 975 | 625 |
| Tubingal SHE | 50 °C | Fabric I | 28 | 45 | 48 | 990 | 620 |
| | | Fabric II | 22 | 35 | 35 | 900 | 616 |
| Hydroperm LPU liq c/Siligen SIH liq | 40°C | Fabric I | 21 | 46 | 58 | 1100 | 640 |
| | | Fabric II | 20 | 34 | 52 | 1060 | 632 |
| | 50 °C | Fabric I | 35 | 46 | 64 | 1120 | 651 |
| | | Fabric II | 21 | 39 | 55 | 1105 | 632 |
| Hydroperm LPU liq c | 50 °C | Fabric I | 41 | 60 | 72 | 1050 | 655 |
| | | Fabric II | 28 | 51 | 66 | 1000 | 648 |
| Siligen SIH liq | 50 °C | Fabric I | 16 | 31 | 45 | 990 | 635 |
| | | Fabric II | 13 | 23 | 30 | 980 | 626 |
| Wool hydrolyzate | 40°C | Fabric I | 16 | 32 | 46 | 950 | 551 |
| | | Fabric II | 15 | 27 | 35 | 925 | 550 |
| | 50 °C | Fabric I | 17 | 30 | 39 | 980 | 560 |
| | | Fabric II | 13 | 25 | 33 | 955 | 552 |
| $Al_2(SO_4)$/wool hydrolyzate | 1% | Fabric I | 13 | 28 | 55 | 1085 | 642 |
| | | Fabric II | 19 | 39 | 53 | 1015 | 640 |
| | 3% | Fabric I | 30 | 50 | 67 | 1120 | 650 |
| | | Fabric II | 35 | 50 | 65 | 1100 | 653 |
| $KAl(SO_4)_2$/wool hydrolyzate | 1% | Fabric I | 25 | 50 | 70 | 1175 | 671 |
| | | Fabric II | 34 | 55 | 70 | 1150 | 670 |
| | 3% | Fabric I | 34 | 53 | 70 | 1200 | 673 |
| | | Fabric II | 37 | 53 | 69 | 1150 | 677 |

**Table 4.**
*Capillarity, water vapor and air permeability values of samples by using exhaustion method.*

fact that potassium aluminum sulfate is pure and has high water solubility [36], molecular weight and high chelating property. Hence, it can bond wool hydrolysate to polyamide6.6 surface [37]. The fabrics processed have given approximately the same capillarity results shown in **Table 4**. This can be attributed to richness of wool hydrolysate rich in hydrophilic groups [38, 39] and better bonds to polyamide6.6 fabrics.

| | | | Capillarity (sn) | | | Air permeability ($l/m^2/s$) | Water vapor permeability ($g/24\ s/m^2$) |
|---|---|---|---|---|---|---|---|
| | | | 10 | 30 | 60 | | |
| Fabric without treatment | | Fabric I | 11 | 25 | 39 | 850 | 521 |
| | | Fabric II | 14 | 33 | 49 | 820 | 507 |
| Hydroperm LPU liq c/Siligen SIH liq | 50 °C | Fabric I | 16 | 26 | 35 | 970 | 555 |
| | | Fabric II | 7 | 13 | 19 | 950 | 533 |
| $KAl(SO_4)_2$/Wool Hydrolyzate | 50 °C | Fabric I | 31 | 46 | 60 | 1070 | 640 |
| | | Fabric II | 16 | 26 | 42 | 1040 | 632 |

**Table 5.**
*Capillarity, water vapor and air permeability values of samples by using exhaustion method after 5 consecutive washing.*

The samples were compared in respect of capillarity, water vapor and air permeability of samples treated with the wool hydrolysate containing 1% potassium aluminum sulphate and with commercial recipe (Hydroperm LPU liq c and Siligen SIH liq) after 5 consecutive washing. As it is seen in **Table 5**, the values of the fabric treated with wool hydrolysate are rather higher than commercial chemicals in terms of capillarity, water vapor and air permeability values.

### 3.2 XPS analyses

XPS analysis of the 170 g/m2 fabrics one of which was applied commercial recipe and the other was applied wool hydrolysate containing 1% potassium aluminum sulphate before and after 5 consecutive washing steps are shown in **Figures 2**–**5** and **Table 6**.

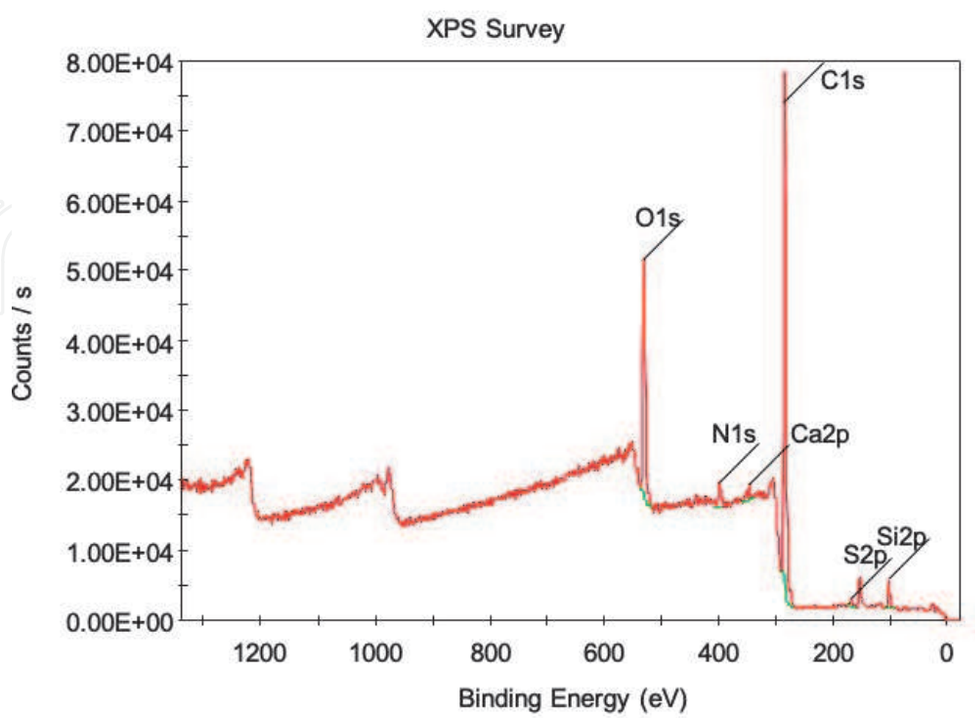


**Figure 2.**
*The XPS analysis of fabric treated with the wool hydrolysate containing 1% $KAl(SO_4)_2$ before washing.*

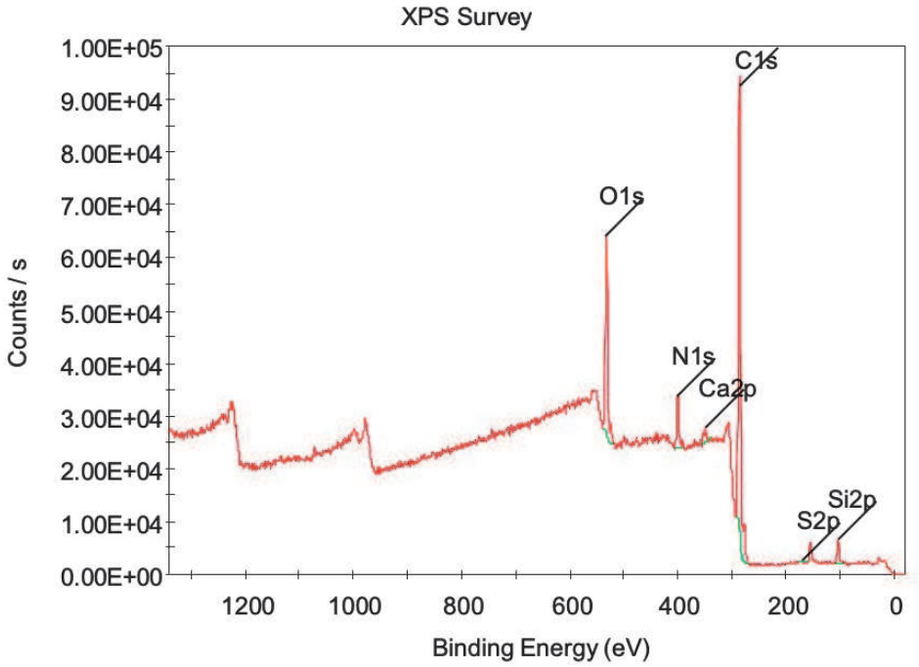


**Figure 3.**
*The XPS analysis of wool hydrolysate after washing.*

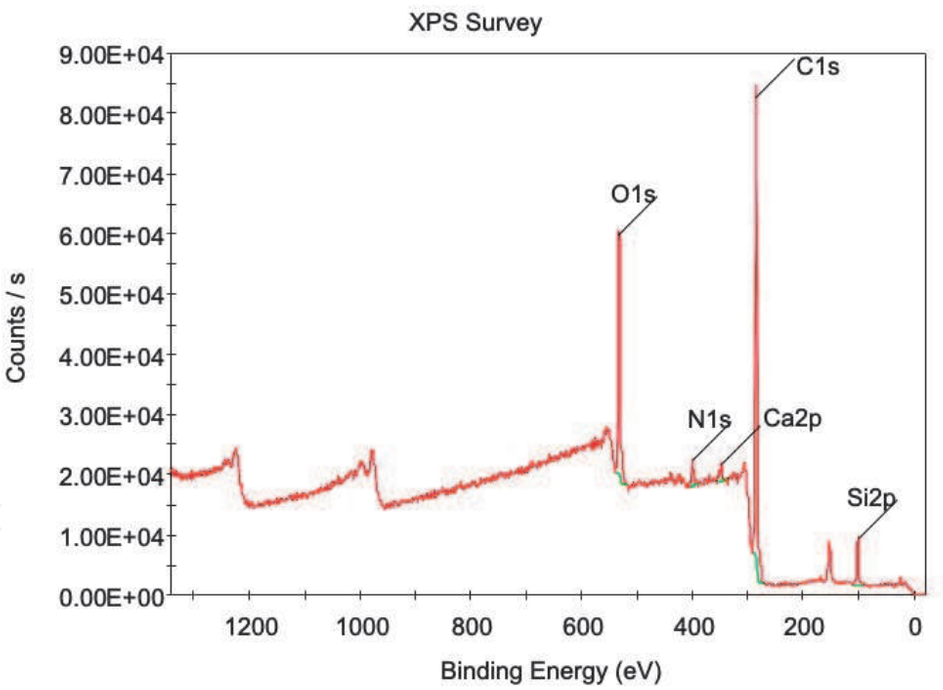


**Figure 4.**
*The XPS analysis of the fabric treated with commercial recipe before washing.*

In **Table 6** and **Figures 2** and **3**, XPS analyses of the fabric 170 g/m$^2$ treated with wool hydrolysate before and after 5 consecutive washing are observed. The carbon, oxygen and nitrogen atoms which are seen at the **Table 5** belong to polyamide6.6 structure. It is estimated that calcium comes from washing water bonded with amide onto the polyamide [40]. Although the process is made of demineralized water, it involves impurity and the amount of the calcium (Ca) increases after washing for all samples. Silicone (Si) is bonded to surface active agents based on dimethyl siloxane. This silicone comes from the silicone-based fats used in the

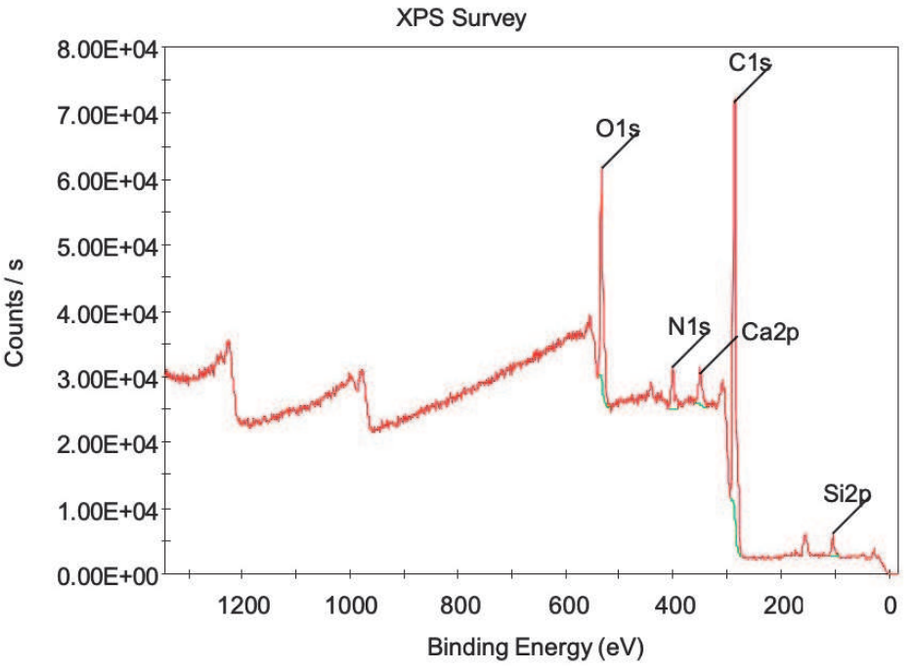


**Figure 5.**
*The XPS analysis of the fabric treated with commercial recipe after washing.*

polyurethane (PU) production [41, 42] and decreases with washing. Silicone has decreased from 8.96 to 7.74. The amount of sulfur (S) decreases with washing. It has fallen from %1.5 to %0.26 by getting away with wool hydrolysate.

**Table 6** and **Figures 4** and **5** are the XPS analysis of the fabric 170 g/m$^2$ before and after washing according to the recipe at 50°C containing hyrophility enhancer and silicone (Hidroperm LPU liq.c and Siligen SIH liq). The difference from the analyses, they do not contain sulfur. Because this sulfur is situated in the structure of wool hydrolysate. This process was made of polyurethane resin and polysiloxane. Accordance with **Table 6** values, silicone has rised up at both two fabrics. This situation is the result of treating with micro silicone based polisiloxane. But the extremely decreasing of the amount of Si after 5 consecutive washing, indicates that the processing is not permanent and this explains that the capillarity and water vapor permeability values are lower than the samples treated with wool hydrolysate. Silicone plays a significant role in the bounding of hydrophility enhancer agent to the fabric. Silicone can provide permanent effect with bounding hydroxyl group in fabric [32, 43].

### 3.3 The effect of the process on handle

One of the most important parameters to determine the effectiveness of a textile finishing is handle of fabric. The sensations of fabric such as softness, smoothness and drape created on the consumer can play a primary role in the preference of textiles.

So as to make subjective determination of fabric handles – as it is shown in measurement and characterization section, two different methods were used and the results are shown in **Tables 7** and **8**. The fabrics used have different weight, thickness and yarn count as it is mentioned in materials section. Furthermore, handle values of Fabric 1 were examined after 5 consecutive washing following 2 different softening process. As it is seen in **Table 7** values, while no increase were detected in thinness sensations of the fabrics treated with commercial finishing agents (Hyroperm LPU liq c/Siligen SIH liq), thickness sensation were detected in

The elemental properties of 170 g/m$^2$ fabric treated with wool hydrolyzate

| *Name* | *Peak BE* | *FWHM eV* | *Area (P) CPS.eV* | *Weight%* | *Q* |
|---|---|---|---|---|---|
| C1s | 284.96 | 3.36 | 290336.09 | 64.73 | 1 |
| O1s | 531.34 | 3.98 | 162004.01 | 19.89 | 1 |
| Si2p | 102.63 | 2.15 | 17248.82 | 8.96 | 1 |
| N1s | 399.61 | 4.05 | 17646.15 | 2.96 | 1 |
| Ca2p | 347.92 | 4.16 | 15059.93 | 1.96 | 1 |
| S2p | 168.90 | 3.03 | 5098.65 | 1.50 | 1 |

The elemental properties of the fabric weight 170 g/m$^2$ treated with wool hydrolyzate after 5 consecutive washing

| *Name* | *Peak BE* | *FWHM eV* | *Area (P) CPS.eV* | *Weight%* | *Q* |
|---|---|---|---|---|---|
| C1s | 285.17 | 3.94 | 424943.11 | 68.37 | 1 |
| O1s | 531.31 | 4.24 | 194006.24 | 17.19 | 1 |
| N1s | 399.49 | 3.73 | 41320.20 | 4.99 | 1 |
| Si2p | 102.69 | 3.85 | 20666.95 | 7.74 | 1 |
| Ca2p | 347.58 | 6.36 | 15367.73 | 1.44 | 1 |
| S2p | 168.43 | 4.90 | 1207.10 | 0.26 | 1 |

The elemental properties of the fabric 170 g/m$^2$ treated with commercial recipe

| *Name* | *Peak BE* | *FWHM eV* | *Area(P) CPS.eV* | *Weight %* | *Q* |
|---|---|---|---|---|---|
| C1s | 284.94 | 3.40 | 315966.69 | 61.93 | 1 |
| O1s | 531.74 | 3.73 | 184086.70 | 19.88 | 1 |
| Si2p | 102.21 | 3.34 | 29328.08 | 13.39 | 1 |
| N1s | 399.16 | 3.32 | 19843.50 | 2.92 | 1 |
| Ca2p | 347.29 | 3.27 | 16516.76 | 1.88 | 1 |

The elemental properties of the fabric 170 g/m$^2$ treated with commercial recipe after 5 consecutive washing

| *Name* | *Peak BE* | *FWHM eV* | *Area (P) CPS.eV* | *Weight %* | *Q* |
|---|---|---|---|---|---|
| C1s | 285.80 | 5.51 | 422461.96 | 65.55 | 1 |
| O1s | 532.23 | 5.38 | 218497.26 | 18.68 | 1 |
| N1s | 400.16 | 5.34 | 39566.58 | 4.61 | 1 |
| Si2p | 103.29 | 5.25 | 19263.55 | 6.96 | 1 |
| Ca2p | 349.21 | 7.83 | 46517.72 | 4.21 | 1 |

**Table 6.**
*XPS analyses of fabrics.*

the fabrics treated with wool hydrolysate containing 1% potassium aluminum sulphate ($KAl(SO_4)_2$. This can be explained with the fact that the average particle size of the hydrolysate wool solution is much bigger than commercial finishing agents as it is mentioned auxialiries section. When the softness/stiffness and smoothness/ roughness values were evamined, it was determined that the fabrics treated with

| | | Fabric | Hyroperm LPU liq c/Siligen SIH liq | $KAl(SO_4)_2$/ wool hydrolysate | Hyroperm LPU liq c/Siligen SIH liq after 5 consecutive washing | $KAl(SO_4)_2$/wool hydrolysate after 5 consecutive washing |
|---|---|---|---|---|---|---|
| Thinness/ thickness | Fabric I | 3.41 | 2.85 | 3.75 | 3.83 | 3.08 |
| | Fabric II | 4.58 | 4.75 | 5.23 | | |
| Softness/ stiffness | Fabric I | 3.41 | 2.92 | 3.58 | 2.58 | 3.66 |
| | Fabric II | 4.33 | 4 | 2.16 | | |
| Smoothness/ roughness | Fabric I | 3.41 | 3.17 | 4.25 | 2.91 | 3 |
| | Fabric II | 4.33 | 4.16 | 2.92 | | |
| Total handle value | Fabric I | 5.66 | 8.58 | 7.41 | 7 | 7.16 |
| | Fabric II | 6.41 | 6.5 | 7.16 | | |

**Table 7.**
*Subjective evaluation of fabrics in terms of thinness/thickness, softness/stiffness, smoothness/roughness and total handle.*

| | Softness | Coolness | Dampness |
|---|---|---|---|
| Fabric I | 3.5 | 3.41 | 3.16 |
| Fabric II | 2.66 | 3.66 | 4.08 |
| Hyroperm LPU liq c/Siligen SIH liq | | | |
| Fabric I | 4.21 | 3.42 | 3.5 |
| Fabric I after 5 consecutive washing | 4.08 | 3.75 | 3.83 |
| Fabric II | 3.66 | 3.25 | 3.33 |
| $KAl(SO_4)_2$/wool hydrolysate | | | |
| Fabric I | 4.17 | 4.25 | 4.08 |
| Fabric I after 5 consecutive washing | 4 | 4.25 | 4 |
| Fabric II | 4.08 | 4.42 | 4 |

**Table 8.**
*Subjective evaluation of fabrics in terms of softness, coolness, dampness.*

commercial finishing agents showed a bit higher sensation values. However, total handle values of fabrics processed with two different processes are similar as it is shown in **Table 7**.

In **Table 8**, handle values of samples were examined in terms of softness, coolness and dampness sensations. According to the **Table 8** values, all the fabrics treated with wool hydrolysate containing 1% potassium aluminum sulphate ($KAl(SO_4)_2$ show a considerable increase in coolness and dampness sensation values. This is true for all the fabrics processed with 5 consecutive washing. This is related to fabric's giving more coolness and dampnesss sensation by diffusing more dampness to the structure of the hydrolysate wool solution processed fabric with hydrophilic groups. This continues also after 5 consecutive washing stages.

According to the results above, the coolness and dampness sensations that the fabric gives depend on, to a great extent, the surface capillarity and water vapor permeability values. These results are in correlation with literature [44, 45]. This

can be explained as the higher capillarity and water vapor transmission values cause humidity transfer which enables the fabric to have a greater evaporation capacity, and hence to have a more comfortable feeling.

### 3.4 The effect of the process on whiteness and color values of fabrics

Textiles are treated with a wide variety of complex chemicals in accordance with their end use. In addition to the production phase, softeners are the most well-known for their use in household and commercial cleaning. The basis of these softeners can be natural substances, such as modified animal fat, vegetable oil and wax, or hydrocarbon wax and silicon based synthetic materials. Due to the chemical nature of most softeners, they tend to turn yellow and change color with factors such as high temperature, prolonged storage, and their formulation [46]. In addition, due to its oily adhesive structure and application conditions (amount of use and pH), the increase in the amount taken causes the surface to turn yellow. The high free amine value of the cationic softener causes color change due to air oxidation during drying phase. The azo yellow and azoxy yellow resulting from the oxidation of the amino radical with the effect of heat and air cause the fabric to turn yellow [47]. Today, cationic softeners with ester quate structure that do not contain free amines can be preferred in colors not to cause yellowing.

The measurement of whiteness and yellowing index of the fabrics treated were done and shown in **Table 9**. According to the results of the **Table 9**, the values of the fabrics are slightly different.

In order to determine the color difference problem that softeners create in colored textile materials, the color difference value of the fabric treated with two different recipe were determined and given in **Tables 10** and **11**. According to the results of the **Tables 10** and **11**, the color difference of the fabrics treated with wool hydrolysate is similar.

Depending on the findings shown **Tables 9–11** yellowing/color change problems do not occur in the fabrics treated with commercial softener combination (Hydroperm LPU liq/Siligen SIH liq, thermoreactive polyurethane resin/modified hydrophile silicone softener) and wool hydrolysate prepared by diluting at a high rate (10 g/15 L).

| | L | a | b | c | h° | WI-CIE/ Tint | YI-E313 | |
|---|---|---|---|---|---|---|---|---|
| Fabric without treatment | 91.67 | −0.86 | −0.62 | 1.06 | 215.94 | 82.85/1.69 | −1.93 | 1.69 |
| | ΔL | Δa | Δb | Δc | Δh | | YI-ASTM E313 | ΔE |
| Wool hydrolyzate $KAl(SO_4)_2$ before washing | −0.58 D | 0.27 R | −0.35 B | 0.08 B | 0.44 B | 83.68/1.38 | −2.44 | 0.66 |
| Wool hydrolyzate $KAl(SO_4)_2$ after washing | −2.52 D | 0.32 R | −0.19 B | −0.09 D | 0.36 B | 78.49/1.25 | −2.11 | 1.02 |
| Hydroperm LPU liq c/Siligen SIH liq before washing | −3.72 D | 0.22 R | −0.10 B | −0.09 D | 0.22 B | 75.44/1.41 | −2.03 | 1.34 |
| Hydroperm LPU liq c/Siligen SIH liq after washing | −1.59 D | 0.28 R | −0.19 B | −0.06 D | 0.33 B | 80.58/1.31 | −2.13 | 0.74 |

**Table 9.**
*Whiteness and yellowing index of the fabrics.*

| **Fabric without treatment** | **L** | **a** | **b** | **c** | **h°** | |
|---|---|---|---|---|---|---|
| | **32.34** | **−2.03** | **6.25** | **6.57** | **108.03** | |
| | ΔL | Δa | Δb | Δc | Δh | ΔE |
| Hydroperm LPU liq c/Siligen SIH liq | 0.36 L | 0.00 | 0.43 B | −0.41 D | 0.14 G | 0.48 |
| Wool Hydrolyzate $KAl(SO_4)_2$ | 0.48 L | −0.20 G | −0.24 B | −0.16 D | 0.27 G | 0.47 |

**Table 10.**
*Color measurement of fabrics (recipe 1).*

| **Fabric without treatment** | **L** | **a** | **b** | **c** | **h°** | |
|---|---|---|---|---|---|---|
| | **53.98** | **56.69** | **43.38** | **71.38** | **37.42** | |
| | ΔL | Δa | Δb | Δc | Δh | ΔE |
| Wool hydrolyzate $KAl(SO_4)_2$ | −1.21 D | −0.56 G | −0.30 B | −0.63 D | 0.10 Y | 0.58 |
| Hydroperm LPU liq c/Siligen SIH liq | −1.25 D | −0.65 G | −0.12 B | −0.59 D | 0.29 Y | 0.62 |

**Table 11.**
*Color measurement of fabrics (recipe 2).*

## 4. Conclusion

In this study, hydrophilicity enhancer and hydrophilic silicone combinations were applied to polyamide6.6/polyurethane fabrics under two different weights employing the most used recipes of leading companies in the textile industry by using impregnation and exhaustion methods. As an alternative to the recipes, samples treated with wool hydrolysate were subjected to the same tests. The values obtained by using the exhaustion method gave better results than conventional silicone/hydrophilicity enhancer. In accordance with the firms' recommendation, 5 consecutive washes were performed, and it was observed that the values obtained with wool hydrolysate were higher.

Findings of the experiment suggests wool hydrolysate can be used instead of thermo reactive polyurethane and modified polysiloxane. These chemicals are approximately 4.5 Euro/kg and 2.5 Euro/kg, respectively. 15 L hydrolysate was obtained from 10 g of waste wool in the production of wool hydrolysate. As it is seen, it is very economical and if concentrated product is obtained instead of solution in the future, the transportation of the product will also be economical. Thus, an example of sustainable, economical and environmental work was exhibited for polyamide6.6/polyurethane blends which are used in sportswear industry regarded as an area open to development, high potential and high added value in the textile industry.

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