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Improvement of Mechanical And Light Transmittance Properties of PU Foam Coated Curtain Fabrics

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ABSTRACT

In foam coating, the main factors are the foam density of the coating material and the compatibility among foam structure, the coating material and the fabric surface. In this study, the results of breaking force and elongation, tear strength and light transmittance were compared according to the fabric structure, coating recipes, foam density and the foam coating layer viscosity statistically. And also, air permeability, aged under artificial light and weathering tests were evaluated. The high yarn density of warp threads per unit length in polyester woven fabric leads to an increase in tensile strength. The best results in tensile strength and elongation at break experiments were acquired at coating recipe 4. As a result, the minimum light transmittance value was 1.04 and the maximum light transmittance value was 1.12 by using coating recipe 4, respectively. Air permeability values of PU foam coated fabrics were in the range of 0-2 mm/s, whereas air permeability value of untreated polyester fabric was measured as 17.36 l/m^2/s. Maximum air permeability was obtained in coating recipe 4. The higher air permeability values also gave better barrier to air penetration. The air permeability of coated fabrics were very low due to pore size. The coating material covered the pores of the untreated fabric and restricted air permeability. The color fastness to artificial light of the PU foam coated fabric samples were very good. The fading degree of PU foam coated curtain fabrics was 6. The weathering exposure time of the blue wool scale fabric and PU foam coated fabric samples corresponded to 100 hours. The color fastness to artificial weathering of PU foam coated fabrics in the three coating layers were obtained above 6. Consequently, the low filler content, soft binder ratio and foam density had a positive effect on the mechanical, air permeability, color fastness to artificial light, color fastness to artificial weathering and light transmittance properties of foam coated fabrics.

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Polyurethane foam coating, mechanical performance, air permeability, color fastness to artificial light, color fastness to weathering, light transmittance

1. INTRODUCTION

The coating is used for technical textile production to achieve functional properties to fabrics [1]. The foam application process can be classified into direct and indirect systems. The main advantages of coating process are lower water, and chemical consumption, besides savings in energy costs [2]. In this process, the uniform foam is applied to the fabric with the foam under pressure.

The foam coating is balanced with the aid of additives. It is applied to one side of the fabric. The foam coated fabric is finally calendered under low pressure. The foam coated fabrics are used as the production of curtain covering in home textiles. The sun-protective properties of curtain fabrics are due to material parameters, weaving and coating processes. Because of curtain fabrics produced from polyester have significant mechanical performance, polyester has been used as the most popular fibre for the production of curtain covering in home textiles. The features of 100% polyester fabrics include non-allergenic, high strength, ease of use, fast drying and very good wrinkle-free properties. Besides, they are used as curtains due to their very good resistance to light.

Foam is described as a viscous material that is too stable but its penetration into the fabric is poor [3-4]. The foam coating technology has significant properties. These properties can be described as the foaming degree, foam stability, viscosity, wetting power and bubble size. Besides new technology has improved the coated-fabric physical

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properties such as tear and breaking strength, elasticity and adhesion.

The black-out foam coating method was beneficial as an unbiased way of assessing the fabric feature. The effectiveness of darkening in the case of woven foam coated fabrics is associated with their geometry and structural parameters.

In the literature, there are different studies on the compatibility of chemicals with fabrics considering in foam coating performance. These studies could be summarized as follows:

Temperature and time affected the dyeing process. The type of dyestuff used and the degradation of dyestuff were adversely affected the environment. Polluted waste water after dyeing contained large amounts of chemicals that had a negative impact on the environment [5].

The ecofriendly and sustainable new foam-coating technology were investigated. In their studies, it was emphasized that the use of less quantities of water, hazardous chemicals and less waste discharge. Also, 30% energy saving in drying was obtained [6,7,8].

The chemical and water consumption were reduced in pigment foam dyeing process with a foam controller [9]. And also, water consumption could be reduced by using foam finishing, counter-flow washing technique and solvent dyeing methods [10].

The suspension properties, foam stability and foam properties were studied [11,12,13]. Hydrolysis degree of foaming agent was affected foam stability [11]. It was used as an environmentally friendly, biodegradable foaming agent along with the sustainable production of keratin hydrolysate [12], [13].

The flame retardancy for cotton fabrics using foamed phosphonium salt precondensates and flame-retardant for PET fabrics using PTFE were used [14,15].

The performance features of different foam applications were investigated [16,17,18,19,20]. The homogeneous distribution of the finishing materials ensured crosslinking with cellulose. As a result, the wrinkle recovery angle was higher than the conventional ones. And also, the foam formation caused strength loss with decrease in density [17,18]. Also, it was stated that the foam finishing was more sustainable, economical and performed well compared to conventional padding [19]. Spider silk protein had been used in foam coating and improved the abrasion behaviour of textile material [20].

In studies [21,22,23,24,25,26], the reasonable mechanical results were achieved through selection of type of foaming agents. Strength properties of polyvinyl alcohol was better than anionic foaming agent [22]. When nano pigments were not used in the coating, the viscosity of the coating was higher [24] Also, the surface viscosity and mechanical strength increased with a more stable structure of the foam [25]. Mechanical and physical properties of encapsulant foams depend on foam cell geometries [26].

In studies [27, 28, 29,30,31], the addition of filling agents improved their mechanical properties. The small size of the calcium carbonate filling particles ensured strong adhesion between the filler and the binder. The low filler concentration of calcium carbonate resulted in positive changes in mechanical and structural characteristics [27]. The modification of filler or matrix components with chemical treatment or coating improved durability performance [28]. It was concluded that kaolin filling agent was chemically, thermally and mechanical stable, inexpensive and low risk as an allergen [29]. And also, the addition of kaolinite significantly improved the heat resistance and mechanical properties [30]. The relationship of the mechanical properties with the foam density and microstructure were studied. That relationship was considering foam cell sizes and also the cell shape [31].

In studies [32,33,34,35], density was an important parameter that influences the properties and performance of rigid polyurethane foam. Lower density was related to the effect of bubbles during foam-laying and the reduction in surface tension of the foamed-fiber dispersion [32]. It was found that the mechanical properties of rigid polyurethane foams changed with the foam density [33]. Also, the polyurethane foam density directly affected its cell structure. The tensile, tear strength, the elongation at break and the adhesive strength linearly increased with the increase of density [34]. As a final conclusion, the most significant parameters on mechanical properties in rigid PUR foams were the foam density, the temperature and material orientation [35].

In studies [36,37], the biodegradable polyurethane samples and the polyols were synthesized. The mechanical and optical properties of the PU coatings prepared were characterized [36]. And also, the density, rheology index, flexural strength, flexural modulus and compressive strength of rigid polyurethane foam increased with NCO/OH ratios [37].

The binder used in the recipe was provided the adhesion of the fibers in the fabric. And also, this situation was increased the air permeability [38]. The chemical polymeric binder was reduced air permeability and thus ensured ease of use [38].

In studies [39,40,41], the light transmission of PU foam coated fabrics were performed with the digital image analysis method. As a conclusion, the light barrier features of PU foam coated fabrics were linked to both fabric construction parameters and fabric porosity [41]. The pores in the fabric structure were closed by polymer coating [42]. Thus, light transmittance of foam coated fabrics were decreased.

The aim of this study was to assess the mechanical performance, air permeability, color fastness to artificial light and light transmittance properties of PU foam coated curtain fabric samples.

In the literature, studies generally focused on the compatibility of chemicals with fabrics in foam coating performance. In this work, unlike the literature, it was aimed to important parameters of the foam coating and PU foam was used in order to give the mechanical, air permeability, color fastness to artificial light, color fastness to artificial weathering and light transmittance properties to produced from 100% polyester fabric. The important parameters were soft: hard binder ratio, kaolin filling agent amount, foam density, coat layer viscosity and fixing temperature for the foam coating method. Commonly used chemicals were selected for foam coating method, thus focusing only on optimum production conditions for PU foam coated curtain fabric properties. The color fastness to artificial light, air permeability, light barrier and mechanical properties of the PU foam coated curtain fabrics were evaluated through a spectrophotometer according to ISO and DIN EN test method.

2. MATERIALS AND METHOD

2.1. MATERIALS

100% polyester woven fabric was used for this study due to its wide usage in home textiles. Properties of woven fabrics were given in Table 1. The polyester fabric had a unit weight of 165 g/m^2.

Table 1. Properties of woven fabric

Property	Warp	Weft
Raw material	Polyester	
Density (1/cm)	28	16
Fabric structure	Plain weave	

Coating chemicals of; binder, foaming agent, cross-linking, fixation agent, synthetic thickener, pigment dyestuffs, filling agent were used and their properties were indicated in Table 2.

Table 2. Properties of coating chemicals

Chemical	Property
Binder	Polyurethane binder, anionic/nonionic
Foaming agent	Hydrocarbons, alkyl amine oxides, amphoteric
Cross-linking	Aromatic blocked isocyanate, non-ionic
Fixation agent	The butanone oxime-free blocked isocyanate-based crosslinking agent, anionic
Synthetic thickener	polyurethane, nonionic
Filling agent	Kaolin
Pigment colorants	

The filler characteristic determines many of the mechanical and light transmittance properties of foam coated textiles. The particle size, dispersion degree and filler content were determined to affect foam coated fabric properties.

In this study, three layers of foam coating was applied to the surface of 100% polyester woven fabric. It was produced in 1st layer of coating white, 2nd layer of coating black and 3rd layer of white. There was a crosslinker in the final (3rd) layer. In the second layer, black pigment colorant was used. The first layer was white so that the coating could reflect sunlight. The black pigment colorant in the second layer was used to significantly reduce the light transmittance. The crosslinker in the last layer coating was used to improve the breaking, tear and breaking elongation and also weathering resistance of the coated fabric.

In foam coatings, stable foam application was applied to curtain fabric samples with a knife over roller application system. The soft and hard polyurethane binder ratio of 1:1 (50:50) was used as a reference and varied in 66.5:33.5. The gap between the knife and the fabric controlled the application of foam. The coating thicknesses were 1.5 mm, 1.7 mm and 1.9 mm, respectively. The foam density changed between 197-292 g/cm^3. All the curtain fabric samples were dried at 125̊ C for 2 minutes to prevent cracking on the surface after coating. After that the coated fabric samples were cured at 165̊ C for 2 minutes. After three coating layer, the foam form is crushed with calender and the fabric surface is smoothened.

2.2. METHOD

In this study, the light transmittance and mechanical properties of the polyurethane foam coated curtain fabrics were evaluated.

The light transmittance properties of foam coated fabrics according to DIN EN 13758-1 test method was evaluated using a UV/VIS spectrophotometer. The light transmittance properties were determined within the wavelength range of 400-700 nm. Based on the experimental results, the transmittance level assessed was 0-2%. It could determine that there was very good protection against UV-Visible light by each curtain fabric samples.

PU foam coated fabrics should block the UV-VIS light. To evaluate the light transmittance properties of foam coated fabrics, a spectrophotometric measurement was used. This method was evaluated the light transmittance properties of foam coated fabrics.

ISO test methods 13937-2, 13934-1 were used for tear strength, breaking force and elongation of woven textile fabrics, respectively. All fabric samples were taken into consideration in the warp and weft directions. For mechanical tests (breaking, tearing strength and breaking elongation) as well as foam density and soft:hard binder ratio, three readings were obtained and the average was used for analysis. The microstructure of polyurethane foam was characterized with a scanning electron microscope (SEM).

Air permeability of coated fabrics according to TS 391 EN ISO 9237 test standard through the 5 cm^2 test area at 50 Pa pressure in $l/m^2/s$ was measured.

Color fastness to artificial light test with xenon arc fading lamp of PU foam coated curtain fabrics were evaluated according to ISO 105-B02 test method. This test method determined the fading degree of PU foam coated curtain fabrics. Additionally, PU foam coated polyester fabrics were exposed to artificial light with 78 hours.

Color fastness to artificial weathering test with xenon arc fading lamp of PU foam coated curtain fabrics were evaluated according to ISO 105-B04 test method. Color fastness was evaluated by comparing the color change in the fabric samples with the blue wool reference.

For foam coating method, foam density (low, medium and high), two different binder ratio (soft/rigid), two different amount of kaolin filling agent and coating thickness were determined as the independent variables and 256 different fabrics were prepared with 2^8 factorial experimental design.

For this method, fabric properties were kept constant. The fabric samples were cut to 30x35 cm dimensions according to the width and length of the machine. The foam coating recipes were shown in Table 3.

Table 3. The foam coating recipes

	Parameters	1^{st} layer	2^{nd} layer	3^{rd} layer
Recipe 1 (Foam coating method)	Foam density (g/cm^3)	244	244	244
	Soft: Hard Binder Ratio	50:50	50:50	50:50
	Fixing Temperature (℃)		165℃ for 2 minutes	
	Coating thickness (mm)	1.5	1.7	1.9
	Foam coating viscosity(cps)	1530	1565	1590
Recipe 2 (Foam coating method)	Foam density (g/cm^3)	229	232	236
	Soft: Hard Binder Ratio	50:50	50:50	50:50
	Fixing Temperature (℃)		165℃ for 2 minutes	
	Coating thickness (mm)	1.5	1.7	1.9
	Foam coating viscosity(cps)	1530	1565	1590
Recipe 3 (Foam coating method)	Foam density (g/cm^3)	197	210	210
	Soft: Hard Binder Ratio	50:50	50:50	50:50
	Fixing Temperature (℃)		165℃ for 2 minutes	
	Coating thickness (mm)	1.5	1.7	1.9
	Foam coating viscosity(cps)	1530	1565	1590
Recipe 4 (Foam coating method)	Foam density (g/cm^3)	292	292	292
	Soft: Hard Binder Ratio	66.5:33.5	66.5:33.5	66.5:33.5
	Fixing Temperature (℃)		165℃ for 2 minutes	
	Coating thickness (mm)	1.5	1.7	1.9
	Foam coating viscosity(cps)	1530	1565	1590
Recipe 5 (Foam coating method)	Foam density (g/cm^3)	280	286	286
	Soft: Hard Binder Ratio	66.5:33.5	66.5:33.5	66.5:33.5
	Fixing Temperature (℃)		165℃ for 2 minutes	
	Coating thickness (mm)	1.5	1.7	1.9
	Foam coating viscosity(cps)	1530	1565	1590

3. RESULTS AND DISCUSSIONS

3.1. Mechanical Properties

3.1.1. The effect of foam density, the amount of soft binder and filling agent on breaking strength

Figure 1 illustrated the effect of foam density, the soft: hard binder ratio and filling agent on breaking strength of foam coated curtain fabric samples. The tensile strength of a fabric, which is its resistance when a load is applied in the warp and weft direction, is affected to some extent by the construction or every property of the coating with crosslinker. In this study, the tensile strength correlated with the foam densities. In the 1st and 2nd coating application (recipe 1 and recipe 2), the foam density was medium. The breaking strength decreased with medium foam density due to decrease in the cell-wall thickness. As the foam density increased, the cell size and cell structure of the polyurethane foam decreased. In fact, it did not form the uniform cell structure. The results showed that the toughness increased with the increased foam density. Also the breaking strength increased with the increased foam density. Soft: hard binder ratio was 1:1 in the 1st, 2nd and 3rd coating layers.

The crosslinker in the 3rd layer of coating recipes was used to improve mechanical properties of foam coated fabric samples. The results showed that at the standard 50:50 soft:hard binder ratio, the breaking strength was 1009 N. This result significantly increased up to 1160 N when the soft:hard binder ratio was to 66.5:33.5. This means the breaking strength of the PU foam coated fabric samples was enhanced 15% on the warp direction and 3% on the weft direction when the soft binder amount was increased 33% in recipe 4.

Although the coating recipes generally increased the breaking strength values, it was concluded that 66.5:33.5 soft:hard binder ratio had a positive effect on breaking strength value in recipe 4.

Breaking strength for the foam specimens as function of density was increased. At the same time, crosslinking affected the structure and mechanical properties.

The relative effect depends on the soft:hard binder ratio.

3.1.2. The effect of foam density, the amount of soft binder and filling agent on tearing strength

The foam coating process applied to fabric is an important factor in the tear strength of the fabric. As the process applied to the fabric prevents the movement of the yarn groups all together, the fabric tears more easily. In the coated fabrics, tear strength was decreased as the movement of the threads was increased. The tearing strength of foam coated fabric samples was given in Figure 2.

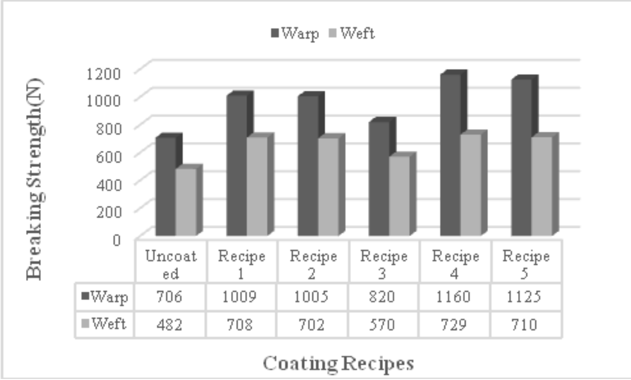

Figure 1. The diagram of breaking strength in the warp and weft directions

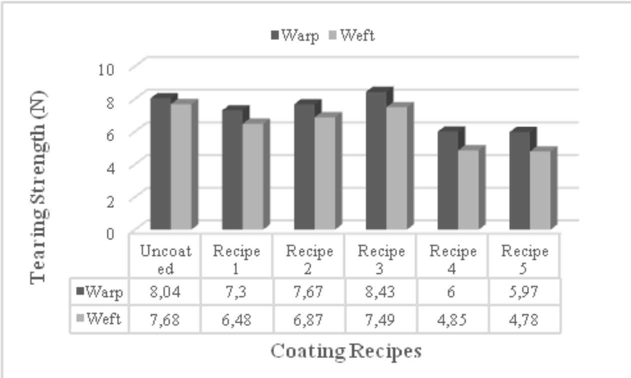

Figure 2. The diagram of tearing strength in the warp and weft directions

As shown in Figure 2, the decrease in tearing strength was observed when compared to the reference. Tear strength of woven fabrics depends on many factors such as fiber, yarn, fabric properties and coating processes applied to the fabric. Therefore, different results can be obtained after coating.

However, according to the results of PU foam coated fabrics, tear strength values decreased when compared to uncoated fabric. Foam density and the amount of kaolin filling agent had a negative effect on tear strength results.

The foam density and the amount of soft binder affected the tearing strength of foam coated fabric samples.

The tear strength decreased under the high foam density condition. The tear strength could reach up to 6.0 N/mm and the foam density was about 292 g/cm^3.

The 50:50 soft: hard binder ratio had a tearing strength of 7.30 N in the warp direction. The least tearing strength recorded was 5.97 N in the warp direction. It could be concluded that the tearing strength of the PU foam coated fabric samples reduced with increased foam density.

From the results, it could be observed that the tearing strength increased from 7.30 N up to 7.67 N at 50:50 soft:hard binder ratio and 244 g/cm^3 medium foam density. It decreased from 6 N up to 5.97 N at 66.5:33.5 soft:hard binder ratio and the high foam density was 292 and 286 g/cm^3, respectively.

This tearing strength of foam coated fabric samples significantly decreased to 6 N when the soft:hard binder ratio was to 66.5:33.5. This means the tearing strength of the PU foam coated fabric samples decreased 25.37% when the soft binder amount was increased 33%.

3.1.3. The effect of foam density, the amount of soft binder and filling agent on breaking elongation

In the tests, PU foam coated 100% PES fabric samples had minimum breaking elongation values at recipe 3. The foam coated fabric samples had more elongation in the warp direction. These elongations could be associated with the low foam density and the 50:50 soft:hard binder ratio.

Cross-linking occurred between the chemical substance molecules in the coating recipes. However, the cohesion force between the molecules caused deformation.

Elongation in the warp direction was greater than that of the weft direction. On the other hand, in the breaking strength test, the foam coated 100% PES woven fabric samples had the lowest elongation.

A maximum elongation could occur as a result of the minimum cohesion force between the chemical substance molecules in the coating recipes.

From the results, it could be observed that the breaking elongation increased from 37.77 % at coating recipe 5 up to 38.95 % at recipe 4. In coating recipes 5 and 4, the soft:hard PU binder ratio was prepared at 66.5:33.5. The least breaking elongation obtained was 29.65 % in warp direction and 50:50 soft:hard binder ratio at recipe 3.

When recipe 1, recipe 2 and recipe 3 were investigated, it was observed that the coating recipes had affected results negatively. The movement of weft and warp yarns under the break elongation load caused a decrease with the effect of the 50:50 and 66.5:33.5 soft: hard binder ratio.

Breaking elongation values increased with increasing foam density in coating recipes 4 and 5.

The highest breaking elongation (%) recorded was 38.95 at coating recipe 4 in the warp direction. It could be concluded that the breaking elongation (%) of the PU foam increased with increasing foam density and soft: hard binder ratio.

Breaking elongation for the foam coated specimens were increased with increasing foam density.

3.1.4. The effect of soft:hard binder ratio and foam density on cracking

In woven fabrics, the surfaces of the weft and warp threads covered with kaolin filling material and the coated fabric had gain a fuller attitude.

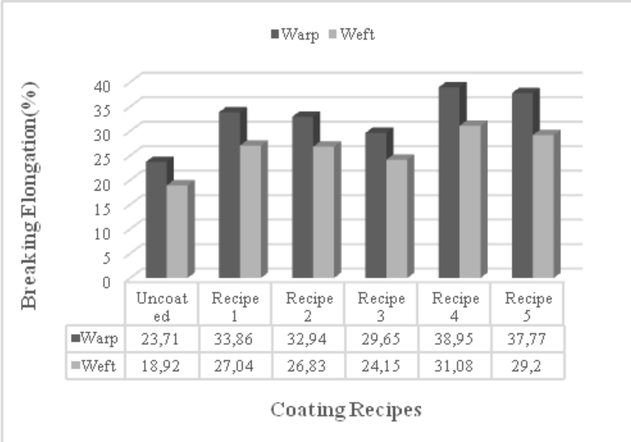

Figure 3. The diagram of percentage of elongation in the warp and weft directions

Because of the fact that the fabric samples coated with 50:50 soft:hard binder ratio coating recipe were hard handle, cracking was occurred on the coating surface. As the foam density of the coating recipe was decreased, cracking was observed on the recipe 3 coating surface. In this recipe, foam density was decreased due to the formation of weakest links such as allophonate.

In the coating recipes, the viscosity difference in each coating layer was expressed as the cohesion force between the coating chemicals. At the same time, the amount of cracking on the coating surface also depended on the viscosity in the coating recipes.

There was a difference in viscosity due to the difference in the content of coating chemicals.

In addition, as the viscosity was increased, the cohesive force interacting between the coating chemicals also increased.

PU polymer was created a bond with kaolin filler in the coating recipe.

The polymer has formed a bond with the filling agent. However, it was observed that the polymer did not have a significant effect on the cracking behavior. In addition, the water absorbed by the polymers evaporated during drying, causing crack formation on the coating surface. The SEM images obtained from 50:50 soft: hard PU binder ratio samples after drying were presented in Figure 4.

This was because it is necessary to use the crosslinker to bond the PU binder with the kaolin filler.

Due to the high adhesion in fabric samples coated with high PU foam density, no cracking occurred on the surface of the coated fabric samples. In addition, when the soft: hard binder ratio was increased in the coating recipes, the high adhesion was provided in the PU foam coated fabric samples.

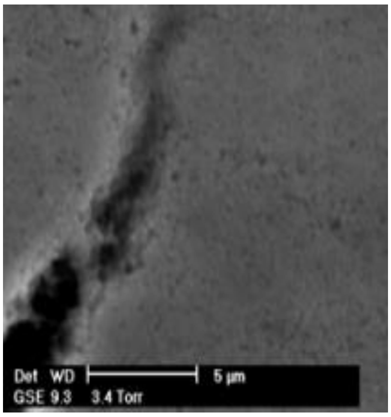

Figure 4. SEM views of the cracking obtained from 50:50 soft: hard PU binder samples after drying

Kaolin content in coating recipes affected mechanical properties of PU foam coated fabric samples. Increasing kaolin content in coating recipes, increased the PU foam coating density.

On the other hand, cracking in the coating surface would result in increased light transmittance.

3.2. The effect of each layer of coating on the light transmittance

In many cases, filling agent and pigment were used to modify the properties of the polymer structures [43].

In this study, the light transmittance properties of each layer of 100% polyester curtain fabric samples coated with polyurethane foam were evaluated. Transmittance measurements were evaluated at every 40 nm. The arithmetic calculated light transmittance values were in the range of 420-700 nm. The light transmittance properties of PU foam coated fabric samples were presented in Figure 5 and in Figure 6. The light transmission of foam coated fabric samples did not exceed 2%.

In this study, two types of recipes were used. Hard and soft PU binder ratios were used equally in the coating recipes 1, 2 and 3. In the coating recipes 4 and 5, the amount of soft binder was increased 33%. In the PU foam coating process, each layer coating application had a certain viscosity.

As the foam density was increased, the light transmittance reduced significantly due to the small pores on the surface of the coated fabric samples.

The low amount of kaolin filling agent in the coating recipe 1 and 2 decreased the light transmittance of foam coated fabric samples. However, the foam density was kept at a medium level in the coating recipe 1 and recipe 2. The low amount of kaolin in the coating recipe 1 and recipe 2 provided an advantage the light transmittance of the foam coated fabric samples, as presented in Figures 5 and 5a.

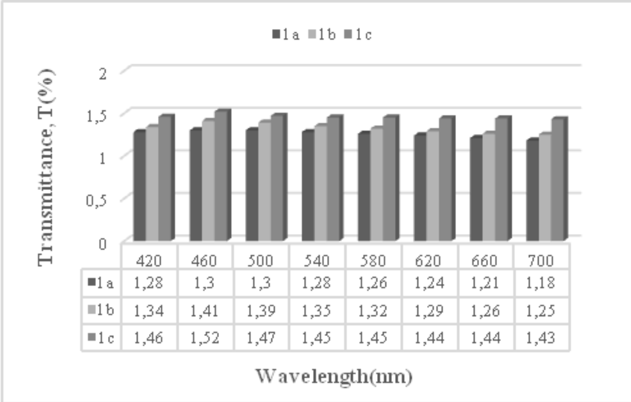

Figure 5. Spectral transmittance T (%) of foam coated fabrics at 420-700 wavelength λ (coating recipe 1) 1a (3rd layer), 1b (2nd layer), 1c (1st layer)

At the same time, when foam density was increased as seen in Figure 5a, the light transmittance of foam coated fabric samples decreased. In recipe 2, the foam density was 236 g/cm^3.

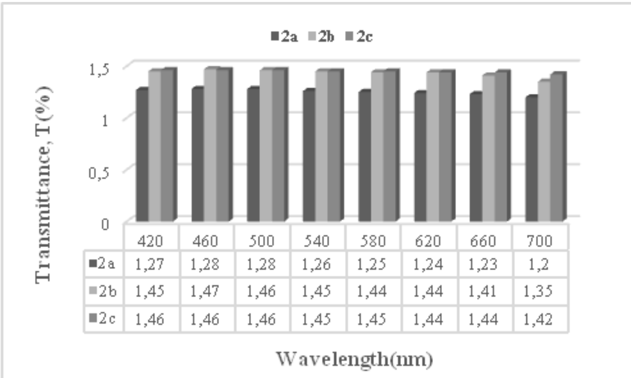

Figure 5a. Spectral transmittance T (%) of foam coated fabrics at 420-700 wavelength λ (coating recipe 2) 2a (3rd layer), 2b (2nd layer), 2c (1st layer)

However, the soft: hard binder ratio was 50:50 in recipes 1, 2 and 3. The amount of kaolin in the recipe 1 and 2 was 150 gram. The foam density was 244 g/cm^3 and 236 g/ cm^3, respectively. It was kept at a medium level.

After coating with recipe 1, 2 and 3, the fabric samples were dried at 125℃ for 2 minutes and then fixed at 165℃ for 2 minutes. After the fixation process, calendering process was applied to the coated fabric samples.

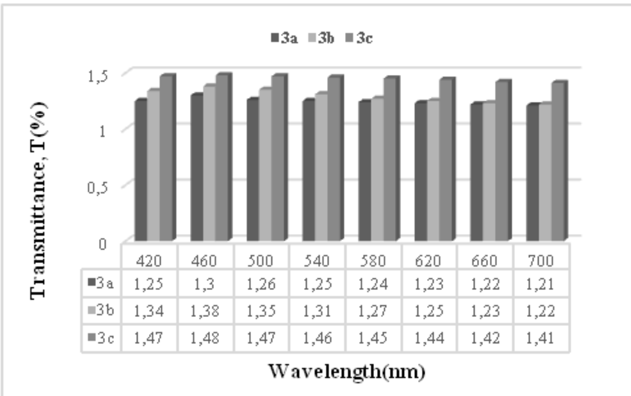

Figure 5b. Spectral transmittance T (%) of foam coated fabrics at 420-700 wavelength λ (coating recipe 3) 3a (3rd layer), 3b (2nd layer), 3c (1st layer)

In recipe 3(3a), low foam density caused less foam cells per unit cross-section. Low foam density had more pores on the fabric surface. That meant less covering. This would lead to a significant increase in light transmittance, as presented in Figure 5b.

Although the foam density was kept at a medium level, it was observed that the amount of kaolin and the drying time were not important.

In this study, the coating application in which soft binder was increased 33% in coating recipe 4 and recipe 5, as indicated in Figure 6 and 6a.

The high amount of kaolin and foam density in the coating recipe 4 was ensured that the light transmittance of the coated fabric sample was minimal. Light transmittance was obtained the least in recipe 4(4a-4b-4c) owing to its chemical structural and good adhesion features of PU foam coated fabric samples. The light barrier property of the fabric sample coated with recipe 4 was the best, as presented in Figure 6.

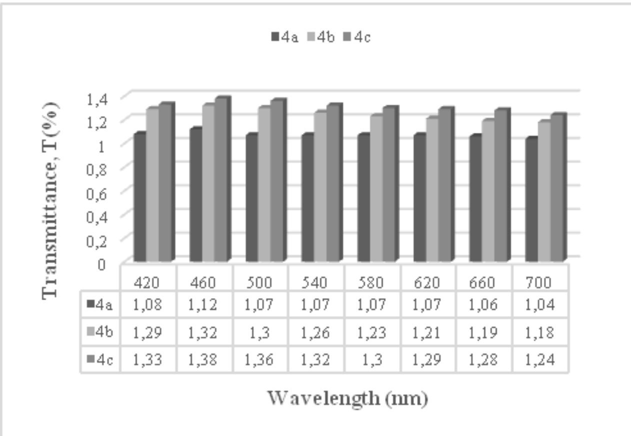

Figure 6. Spectral transmittance T (%) of foam coated fabrics at 420-700 wavelength λ (coating recipe 4) 4a (3rd layer), 4b (2nd layer), 4c (1st layer)

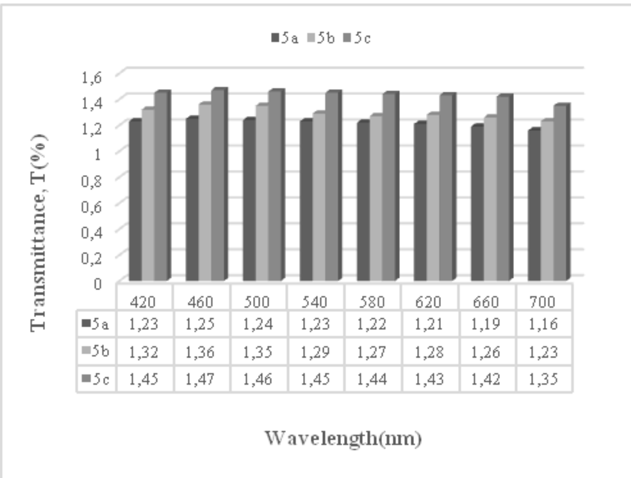

Figure 6a. Spectral transmittance T (%) of foam coated fabrics at 420-700 wavelength λ (coating recipe 5) 5a (3rd layer), 5b (2nd layer), 5c (1st layer)

The effect of the coating recipes on the light transmittance showed a significant change among the 420-700 nm wavelengths. In this wavelength range, the lowest light transmittance was obtained in recipe 4 and the highest light transmission was obtained in recipe 3. As could be seen from Figure 6b, the mostly effective light barrier feature was obtained after coating recipe 4 application.

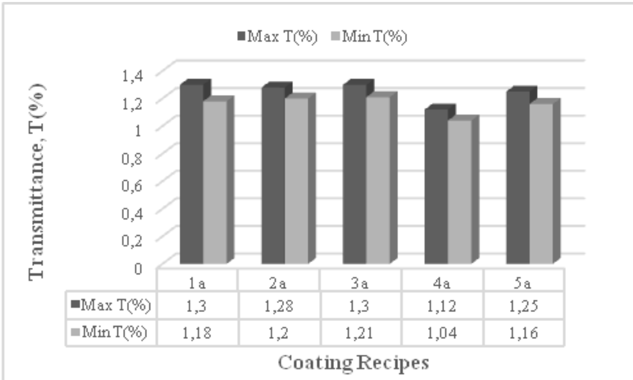

Figure 6b. Spectral transmittance T (%) of PU foam coated fabrics 1a (recipe 1), 2a (recipe 2), 3a (recipe 3), 4a (recipe 4), 5a (recipe 5)

3.3. Air Permeability of PU Foam Coated Curtain Fabrics

Air permeability properties of the coated fabric samples were analyzed. This test method is for measuring the permeability of fabrics to air and is applicable to industrial fabrics that are permeable to air. It was observed that the PU foam coating recipes significantly reduced the air permeability values. As a result, the air permeability analysis of PES fabrics, it was revealed that the coating recipes had a primary effect. The air permeability values in coated PES fabrics decreased by 100% in coating recipe 4. Air permeability, which measures the fabric's ability to allow air to pass through has direct relationship with pore size. An increase in pore size led to an increase in air permeability. The higher air permeability values also gave better barrier to air penetration. The air permeability of coated fabrics were very low. In this study, PU foam coated fabrics air permeability values in the range of 0-2 l/m^2 /s , whereas untreated polyester fabric shows air permeability value of 17.36 l/m^2 /s. Maximum air permeability was obtained in coating recipe 4. Fabric air permeability measurement results were given in Table 4.

The air permeability of PU foam coated fabrics showed 88.47 % decrease in recipe 3 and 100 % decrease in recipe 4 compared to the air permeability of the uncoated PES fabric (Table 4). In woven fabrics, the air flow passes vertically through the gaps between the warp and weft yarns. And also, the coating process reduced the porosity of the fabric. Coating of polyester fabrics led to a decrease in air permeability values. The coating material covered the pores of the untreated fabric and restricted air permeability. As a consequence, air permeability of PU foam coated fabrics decreased significantly due to greater PU foam adhesion to the textile material.

Table 4. Fabric air permeability measurement results

Coated Fabric Samples	Air Permeability (l/m^2 /s)	Air Permeability Change (%)
K0 (uncoated fabric)	17.36	-
K1(1a)(recipe 1)	1	94.24
K2 (2a)(recipe 2)	0.66	96.19
K3 (3a) (recipe 3)	2	88.47
K4 (4a) (recipe 4)	0	100
K5 (5a)(recipe 5)	0.33	98.09

3.4. Evaluation of Color Fastness to Artificial Light of PU Foam Coated Curtain Fabrics

Color fastness to artificial light test with xenon arc fading lamp of PU foam coated curtain fabrics were assessed according to ISO 105-B02 test method. Color fastness is the degree to which a colourant resists fading due to light exposure. Fading is related to factors such as the light, proportion of UV and humidity. In this test, samples were exposed to approximately 5 times more energy than normal daylight. This test method was determined textile materials fading degree. The fading degree of number 1 blue wool scale fabric is the worst, while the fading degree of number 8 blue wool scale fabric is the best. The difference between the part exposed to light and the parts not exposed to light at number 6 of the blue wool scale continued until 4 was obtained. In this test, the exposure time of the blue wool scale fabric and PU foam coated fabric samples corresponded to 78 hours. In addition, blue wool fabric scale 4 faded up to grey scale 4. This fading expressed as grey scale grade 4. The main factors that affect the fading of color are: light, light source, intensity, duration of effect, chemical structure of the coating, type of fiber, environment, atmospheric conditions, humidity and temperature. The color fastness to artificial light test results of five PU foam coated polyester fabrics were shown in Table 5 and Figure 7.

The minimum color fastness to artificial light value required for 100 % polyester fabrics was 4 according to standard ISO 105 B02.

At the same time, this test method determined the fading degree of PU foam coated curtain fabrics. PU foam coated PES fabrics were exposed to Xenon arc fading lamp for 78 hours of exposure. As seen in Table 5 and Figure 7, the color fastness to artificial light of PU foam coated fabrics in the three coating layers were obtained above 6. In other words, the color change degree of polyurethane foam coated fabric samples were above 6. In general, the color fastness to artificial light of the PU foam coated fabric samples were very good. Exposure of PU foam coated fabrics to artificial sunlight affected the performance and behavior of functional apparel. In this study, the color fastness to artificial light process had no effect on the surface changes of the PU foam coated fabrics. Consequently, the color fastness to artificial light with xenon arc fading lamp did not affect the appearance and fading degree.

Table 5. The color fastness to artificial light test results of PU foam coated polyester fabrics

Coated Fabric Samples	Color Fastness to Artificial Light (according to ISO 105-B02 test method)		
	1st layer	2nd layer	3rd layer
K0 (uncoated fabric)		4 (shade change)	
K1(1a)(recipe 1)	6+	6+	6+
K2(2a)(recipe 2)	6+	6+	6+
K3(3a)(recipe 3)	6+	6+	6+
K4(4a)(recipe 4)	6+	6+	6+
K5(5a)(recipe 5)	6+	6+	6+

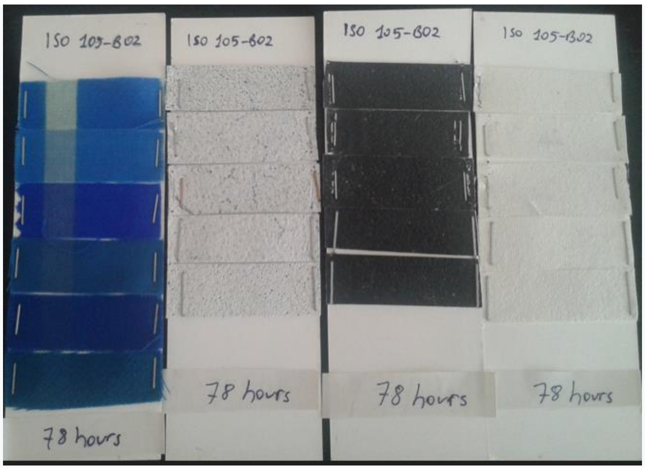

Figure 7. The color fastness to artificial light test results according to ISO 105-B02 test method: (a). blue wool reference fabric samples, (b).3rd layer PU foam coated fabric samples, (c). 2nd layer PU foam coated fabric samples, (d). 1st layer PU foam coated fabric samples, respectively.

3.5. Evaluation of Color Fastness to Artificial Weathering of PU Foam Coated Curtain Fabrics

In this test, fabric samples coated with PU foam were sprayed with water and exposed to light with a xenon arc lamp under certain conditions. At the same time, 6 blue wool references were exposed to light, protected from the sprayed water by a window glass. Fastness evaluation was evaluated by comparing the color change in the fabric samples with the blue wool reference. A glass filter was placed between the xenon arc lamp and the sample and blue wool references for uniform reduction of ultraviolet rays. The light transmittance of this glass filter should be 0% between 290 nm and 300 nm, and at least 90% between 380 nm-750 nm. As seen in Table 6 and Figure 8, the color fastness to artificial weathering of PU foam coated fabrics in the three coating layers were obtained above 6. The test samples and blue wool references were exposed to weather conditions until the contrast between the unexposed and exposed parts of reference 6 was equal to 4 on the grey scale. In this test, the weathering exposure time of the blue wool scale fabric and PU foam coated fabric samples corresponded to 100 hours. The reference number showing the contrast closest to the contrast in the test sample expressed the color fastness value. The color fastness to artificial weathering test results of five PU foam coated polyester fabrics were shown in Table 6 and Figure 8.

Table 6. The color fastness to artificial weathering test results of PU foam coated polyester fabrics

Coated Fabric Samples	Color Fastness to Artificial Weathering (according to ISO 105-B04 test method)		
	1st layer	2nd layer	3rd layer
K0 (uncoated fabric)	4 (shade change)		
K1(1a)(recipe 1)	6+	6+	6+
K2(2a)(recipe 2)	6+	6+	6+
K3(3a)(recipe 3)	6+	6+	6+
K4(4a)(recipe 4)	6+	6+	6+
K5(5a)(recipe 5)	6+	6+	6+

As indicated in Table 6 and Figure 8, the color fastness to artificial weathering of PU foam coated fabrics in the three coating layers were obtained above 6. In other words, the color change degree of polyurethane foam coated fabric samples were above 6. In this study, the color fastness to artificial weathering process had no effect on the surface changes of the PU foam coated fabrics.

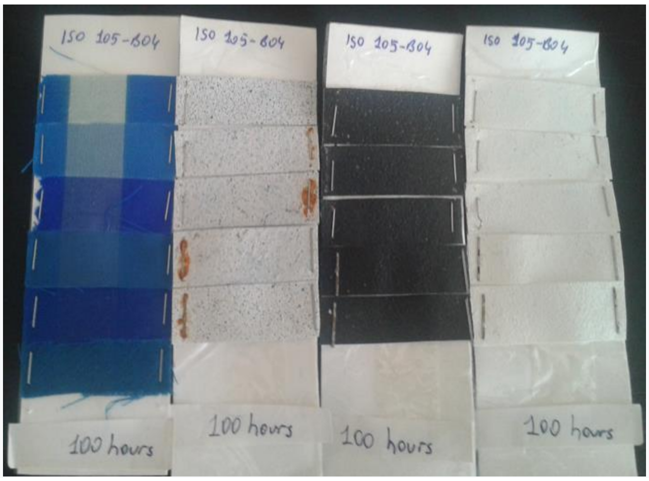

Figure 8. The color fastness to artificial weathering test results according to ISO 105-B04 test method: (a). blue wool reference fabric samples, (b).3 rd layer PU foam coated fabric samples, (c). 2nd layer PU foam coated fabric samples, (d). 1st layer PU foam coated fabric samples, respectively.

3.6. Statistical Analysis

The resulting model is statistically significant at α=0.05 with R=0.95 and R^2 =0.9025. The significant factors were coating recipes.

In this study, the effect of the coating recipes used on the breaking, elongation, tearing strength values in the warp and weft directions were determined by performing a one-way analysis of variance in the SPSS statistical program and the results were given in Table 7-12. The effect of the coating recipes used on the light transmittance in the wavelength range of 400-700 nm were determined by performing a one-way analysis of variance in the spss statistical program and the results were presented in Table 13-20. As seen in Table 13-20, the lowest light transmittance values were acquired at coating recipe 4. As a consequence, the most effective light barrier feature was obtained after coating recipe 4 application, as presented in Table 13-20 and Figure 6b. As seen in Table 7-8 and Table 11-12, the highest breaking strength and breaking elongation values were acquired at recipe 4 in both warp and weft directions. The least tensile strength and elongation values were acquired at recipe 3. Conversely, the lowest tear strength values were acquired at recipe 5, as presented in Table 9-10.

Breaking Strength

Warp and weft directions

Tables 7-20, in which the results of Kruskal Wallis test for mechanical performance and light transmittance are summarised, shown as, df- the degrees of freedom of the test, Asymp.Sig(p).-the statistical significance level, N-sample number.

Table 7. Ranks

Result	Recipe	N	Mean Rank
Warp	Raw fabric	3	2.00
	Recipe 1	3	10.67
	Recipe 2	3	8.33
	Recipe 3	3	5.00
	Recipe 4	3	17.00
	Recipe 5	3	14.00
	Total	18	
Weft	Raw fabric	3	2.00
	Recipe 1	3	13.67
	Recipe 2	3	10.00
	Recipe 3	3	5.00
	Recipe 4	3	17.00
	Recipe 5	3	9.33
	Total	18	

Table 8. Test Statistics

		Result
Warp	Qi-Square [a]	16.392
	df	5
	Asymp.Sig.	0.006
Weft	Qi-Square [a]	15.830
	df	5
	Asymp.Sig.	0.007

a. Kruskal wallis test, b. Grouping variable: recipes

Tearing Strength

Warp and weft directions

Table 9. Ranks

Result	Recipe	N	Mean Rank
Warp	Raw fabric	3	14.00
	Recipe 1	3	8.00
	Recipe 2	3	11.00
	Recipe 3	3	17.00
	Recipe 4	3	4.33
	Recipe 5	3	2.67
	Total	18	
Weft	Raw fabric	3	15.00
	Recipe 1	3	8.00
	Recipe 2	3	11.00
	Recipe 3	3	16.00
	Recipe 4	3	5.00
	Recipe 5	3	2.00
	Total	18	

Table 10. Test Statistics

		Result
Warp	Qi-Square [a]	16.251
	df	5
	Asymp.Sig.	0.006
Weft	Qi-Square [a]	16.175
	df	5
	Asymp.Sig.	0.006

a.Kruskal wallis test, b. Grouping variable:recipes

Breaking Elongation

Warp and weft directions

Table 11. Ranks

Result	Recipe	N	Mean Rank
Warp	Raw fabric	3	2.00
	Recipe 1	3	11.00
	Recipe 2	3	8.00
	Recipe 3	3	5.00
	Recipe 4	3	17.00
	Recipe 5	3	14.00
	Total	18	
Weft	Raw fabric	3	2.00
	Recipe 1	3	11.00
	Recipe 2	3	8.00
	Recipe 3	3	5.00
	Recipe 4	3	17.00
	Recipe 5	3	14.00
	Total	18	

Table 12. Test Statistics

		Result
Warp	Qi-Square [a]	16.579
	df	5
	Asymp.Sig.	0.005
Weft	Qi-Square [a]	16.579
	df	5
	Asymp.Sig.	0.005

a.Kruskal wallis test, b. Grouping variable: recipes

Transmittance (%) -Wavelength

In order to verify the level of barrier properties, the light transmittance was determined with a wavelength ranging from 400 to 700 nm. Transmittance measurements were evaluated at every 50 nm in 6 rectangular samples taken from each specific area of the fabric. Asymptotic significances are not illustrated in 400 nm.

Table 13. Ranks

Result	Recipe	N	Mean Rank
450 nm	Recipe 1	3	2.33
	Recipe 2	3	8.00
	Recipe 3	3	5.00
	Recipe 4	3	13.67
	Recipe 5	3	11.00
	Total	15	

Table 14. Test Statistics

	Result
Qi-Square [a]	12.333
df	4
Asymp.Sig.	0.015

a.Kruskal wallis test, b. Grouping variable:recipes

Table 15. Ranks

Result	Recipe	N	Mean Rank
500 nm 550 nm 600 nm	Recipe 1	3	2.33
	Recipe 2	3	8.33
	Recipe 3	3	4.67
	Recipe 4	3	13.67
	Recipe 5	3	11.00
	Total	15	

Table 16. Test Statistics

	Result
Qi-Square [a]	12.667
Df	4
Asymp.Sig.	0.013

a.Kruskal wallis test, b. Grouping variable:recipes

Table 17. Ranks

Result	Recipe	N	Mean Rank
650 nm	Recipe 1	3	2.33
	Recipe 2	3	7.67
	Recipe 3	3	5.00
	Recipe 4	3	13.33
	Recipe 5	3	11.67
	Total	15	

Table 18. Test Statistics

	Result
Qi-Square [a]	12.467
Df	4
Asymp.Sig.(p)	0.014

a.Kruskal wallis test, b. Grouping variable:recipes

Table 19. Ranks

Result	Recipe	N	Mean Rank
700 nm	Recipe 1	3	2.33
	Recipe 2	3	7.00
	Recipe 3	3	5.67
	Recipe 4	3	13.67
	Recipe 5	3	11.33
	Total	15	

Table 20. Test Statistics

	Result
Qi-Square [a]	12.267
Df	4
Asymp.Sig.(p)	0.015

a.Kruskal wallis test, b. Grouping variable:recipes

Depending on the Table 15-16, it can be seen that, light transmittance (%) had a statistically significant effect ($p= 0.013 < 0.05$) in recipe 4. Additionally, on the Table 7-8, breaking strength had a statistically significant effect ($p= 0.006 < 0.05$) in recipe 4 in the warp direction. Polyurethane foam coating had a statistically significant effect ($p=0.005<0.05$) on the breaking elongation values of the fabric (Table 11-12).

The highest light barrier and the least light barrier values were acquired at recipe 4 and recipe 3, respectively. The low light transmittance was related to the low porosity in the fabric structure. This could be accomplished by the kaolin filler, the soft binder ratio and the high foam density. As the foam density at coating recipes was decreased, cracking was observed at the recipe 3.

Asymptotic significances (2-sided tests) are illustrated. The significance level is 0.05.

4. CONCLUSIONS

In this paper, the breaking strength, elongation, tearing strength, air permeability, color fastness to artificial light, color fastness to artificial weathering and light transmittance properties of PU foam coated curtain fabric samples were investigated. After mechanical, air permeability, color fastness to artificial light, color fastness to artificial weathering and light transmittance tests conclusions can be emphasized. The main results are summarized as follows:

There were significant differences between pairs of breaking strength, elongation and tearing strength through the fabrics in both directions.

The results showed that soft: hard binder ratio significantly affected the mechanical properties of the polyurethane foam coated fabric samples. In order to get good breaking strength, the adhesion property of the binder to the yarn surface should be good. Polyurethane foam coating had showed a good adhesion feature to fabric.

For polyurethane foam coatings, mechanical properties were evaluated as a function of foam density and structure of the foams. The mechanical properties of a cellular foam depend on the polymer material and the cell wall. Important structural properties in tension were foam density and closed foam cell. Due to the small size of the cells, the anisotropy of the mechanical properties of these foams is also lower. The microstructural feature of the cell is related to the microstructure and the foam density.

Foam density is an important parameter that influences the mechanical properties of PU foam coated fabrics. The water and chemical absorption increased with decrease in foam density. Due to increase in the cell size and decrease in the cell-wall thickness.

The penetration effect of the PU foam coating into the fabric caused to decrease of the tear strength of fabric samples. For foam coating method, the foam density significantly changed the breaking strength and optimal conditions were at 292 g/cm^3 and 165℃ with 2 minutes of fixing temperature. As the foam density was increased, the cell size and cell structure of the polyurethane foam decreased.

The low filler concentration resulted in positive changes in mechanical properties due to bonding mechanism between filler, the coating material and the fabric surface. The use of a greater quantity of kaolin filling agent has led to the deterioration of mechanical properties. For that reason, the quantity of kaolin filler should be under 150 g/kg in coating recipe.

The amount of filling agent (kaolin) significantly improved the mechanical properties of coated fabric samples. When the amount of kaolin (filling agent) was increased, cracking was observed on the surface of the PU foam coated fabric samples after preparing recipe 3 and also, drying at 125°C for 2 min.

The coating material covered the pores of the untreated fabric and restricted air permeability. It was determined that the coating process reduced the air permeability values due to pore size. The air permeability values in PU foam coated PES fabrics decreased 88.47% in recipe 3 and 100 % in recipe 4 compared to the air permeability of the uncoated PES fabric. PU foam coating technique affected the penetration of the coating material into the fabric and had a important effect on the air permeability of the coated fabric. Consequently, air permeability of PU foam coated fabrics decreased significantly due to greater PU foam adhesion to the textile material.

The color change degree of polyurethane foam coated fabric samples were above 6. In general, the color fastness to artificial light of the PU foam coated fabric samples were very good. Exposed to artificial sun light of PU foam coated fabrics affected the behavior of functional apparel. Consequently, the color fastness to artificial light did not affect the appearance and fading degree.

The color fastness to artificial weathering of polyurethane foam coated fabric samples were above 6. In this study, the color fastness to artificial weathering process had no effect on the surface changes of the PU foam coated fabrics. And also, the weathering resistance of PU foam coated curtain fabrics is related to the filling material and foam density.

The low light transmittance is related to the fabric porosity. This can be accomplished by the kaolin filler, the soft binder ratio and the high foam density.

The foam coating was to create barrier properties on the fabric. The light barrier property of PU foam coated fabrics provided comfort sensation.

Due to good mechanical, adhesion and also good light barrier properties, PU foam coated fabrics have used as coating of curtain fabrics.

More detailed studies can be performed by changing the binder ratios and foam density in order to minimum the light transmittance of coated fabric samples.

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