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Effect of UV Exposure on the Mechanical Properties of Polyurethane-Coated Fabrics

Memik Bünyamin Üzümcü[1] 0000-0002-5741-1199
Burak Sarı[2] 0000-0003-3079-6153
Emrah Temel[3] 0000-0002-8520-2618

[1]Gaziantep University, Department of Textile and Fashion Design, 27410, Gaziantep, Turkiye
[2]Bitlis Eren University, Department of Traditional Turkish Arts, 13100, Bitlis, Turkiye
[3]Ege University, Department of Textile Engineering, 35100, Izmir, Turkiye

Corresponding Author: Memik Bünyamin Üzümcü, buzumcu@gantep.edu.tr

ABSTRACT

Polyurethane materials can be used industrially in different ways, some of which can be used as textile materials or as auxiliary materials applied to textile materials. Polyurethane stands out as a widely used polymer for coating textile products used in outdoor applications, because of high stability at low temperature, flexibility, no or very little volatile organic component content, high water resistance, pH stability, excellent solvent resistance, weather resistance, and many other chemical and mechanical properties. In the study, cotton, PET, and viscose fabrics were coated with polyurethane and aged under UV light to investigate the causes and behavior of the mechanical degradation effects of UV on the coating material and fiber. The results indicate that the PU coating process improves the mechanical properties of textile materials while being exposed to UV rays impair the fabric structure. The deterioration in the structure of raw and coated fabrics with the effect of UV increased the air permeability. According to the results of DSC analysis, the increase in the time of UV exposure did not create significant differences in terms of thermal degradation temperatures in both cotton and viscose fabrics. The glass transition temperatures (T_g) increased with more exposure to UV rays, and the UV exposure time had a negative effect on the melting temperature (T_m) and enthalpy (ΔH) of coated PET fabrics.

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1. INTRODUCTION

The innovative activities employed to improve textile products start from the selection and/or development of the raw materials, selection of the production system, and also include pre-production and post-production treatment processes. One such treatment process involves coating the textile surfaces with suitable polymers that confer desired properties [1]. for enhancing certain strength and permeability properties that cannot be achieved through traditional finishing methods, thereby rendering the textile material suitable for its intended use. Polyurethane (PU), one of the coating materials, finds application in various forms in the industry, such as fiber, foam, film, etc. [2]. PU can create effects that improve the electrical properties, mechanical strength, and weathering resistance of textile materials when used as a coating material for them [3]. Due to its ability to increase weathering resistance, this polymer coating material emerges as an important alternative for outdoor products.

Polyurethane coatings are frequently used in the textile industry to improve the mechanical and physical properties of fabrics. Yang and Yu (2006) examined the effect of polyurethane coated fabrics on the mechanical performance and stated that the tensile strength and tear resistance increased greatly compared to uncoated fabrics, and this was due to the densely formed polyurethane layer on the surface [4]. According to the effect of PU and PVC coatings on various fabrics used in technical textile applications, Patel et al. (2015) revealed that coated fabrics showed greater water resistance, less air permeability and

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better tensile strength compared to uncoated fabrics. It has been presented as a result that PU coatings are more suitable for technical textile applications due to their better mechanical and physical properties compared to PVC coatings [5]. In their study investigating the performance of PU and PU/silicone coated fabrics in both production and sewing capacities, Bulut and Sular (2013) determined that the coating process has a significant effect on the physical properties of the fabric, and an increase in tensile strength, tear strength and abrasion resistance occurs with both coating processes. However, it has been noted that adding silicone to PU coating gives better results than coating with PU alone [6].

The application of coatings to textile products has been a subject of great interest in recent years. This is especially true in the production process of both breathable and waterproof fabrics. Padleckiene and Petrulis (2009) stated that weight loss occurs with increasing wear and therefore the air permeability values of breathable coated fabrics decrease. Cho et al. (2004) revealed that shape memory polyurethane coated fabrics showed better water vapor permeability and mechanical strength compared to uncoated fabrics [8]. Jassal et al. (2004) investigated the use of polyurethanes to develop waterproof, breathable polymeric coatings. Using various types of polyurethane dispersions, they found that the resulting coatings exhibit remarkable water-resistant and breathable properties [9]. Mondal and Hu (2007) analyzed the effect of shape memory polyurethane coatings on the water vapor permeability of cotton fabrics and the coated fabrics exhibited better water vapor permeability [10]. Kara et al. (2018) found that the abrasion resistance of polyurethane coated polypropylene fabrics increased compared to uncoated fabrics, and the increase in coating weight caused a decrease in air permeability in so-coated fabrics. Some studies highlight the importance of understanding the microstructure of coated fabrics. and how it affects properties such as breathability. Güneşoğlu and Yüceer (2018) determined that the number and length of micro cracks in coated fabrics increased with the tensile stress applied to the fabric, the crack density decreased with increasing coating thickness, and the air permeability of the fabric increased with the increase in crack density [12]. Güneşoğlu et. al. (2017) found that fabric treated with a chitosan treatment, which increases the hydrophilicity of fabrics and makes them more susceptible to cracking, has significantly higher air permeability than untreated fabric [13].

As it is known; light, heat, and oxygen have aging effects on textile materials due to their degrading properties. Since UV rays carried by sunlight have a photodegrading effect on textile surfaces, textile products, that are expected to be exposed to sunlight for a long time, must have a high UV resistance [14]. When exposing polymers to UV radiation, an undesirable result may occur. Specifically, this radiation could cause the breakdown of valuable polymer chains, thus resulting in free radicals. Due to the formation of these potentially problematic radicals, the coating on an object may become brittle over time. This issue ultimately causes a loss in mechanical properties that were once present with the original coating. Some studies have explored the effectiveness of diversified polyurethane coatings, which includes isocyanate-based polyurethanes developed from various sources such as vegetable oil and palm oil. One particular research conducted by Das et al. (2017) investigated the consequences of UV aging on the performance characteristics of these two types of polymers. The results showed that providing vegetable oil or palm oil as a component into isocyanate-based polyurethane can enhance its UV resistance by incorporating antioxidants [15]. The effects of UV aging on polyurethane coatings and methods of increasing the resistance of polyurethane coated fabrics to UV radiation have been the focus of numerous studies. Zhang et al. (2019) determined that additives containing antimony-doped tin oxide (ATO) and titanium dioxide (TiO^2) used in polyurethane coatings improve the UV resistance of polyurethane coatings due to their ability to absorb UV radiation and convert it into heat [16]. Li et al. (2009) stated that zinc oxide nanoparticles increase the UV resistance of polyurethane coatings with their ability to absorb UV radiation and prevent free radical formation [17]. Mills et al. (2012) showed that the incorporation of silica nanoparticles into polyurethane coatings leads to increased UV resistance due to their ability to inhibit and reduce the formation of free radicals resulting from exposure to ultraviolet radiation [18]. Sabzi et al. (2009) examined how the surface modification of TiO^2 nanoparticles impacted the properties of polyurethane composite coatings when coupled with a silane coupling agent [19]. Van Tran et.al. (2019) developed a new kind of polyurethane nanocomposite coatings that included silanized graphene as well as hexagonal boron nitride nanoadditives to make the coatings more resistant against the harmful effects of UV degradation. The researchers found that these new additives were effective in improving the overall UV resistance by absorbing UV radiation and preventing the formation of free radicals [20].

UV radiation is a major player in affecting the longevity and performance of textile products that come in contact with sunlight. It's particularly damaging for outdoor textiles; these could be tents, sportswear or any other kind of clothing mainly used outdoors because they are exposed to the sun for prolonged periods. As a result of extensive exposure to UV rays, textiles break down and lose their durability pretty quickly- which ultimately results in shorter product lifespans. In order to enhance the quality of textile products, it is essential to comprehend how UV exposure can impact various types of fabrics and their coatings. The main objective of this study is to investigate the effects of UV aging on the mechanical and physical properties of cotton, viscose, and PET woven fabrics coated with polyurethane. Specifically, the study aims to analyze the breaking strength, tear strength, elongation at break, and air permeability values of the coated fabrics after exposure to

UV-A radiation at an intensity of 35 W/m^2 for a range of 0-150 hours. Although previous researches have investigated the effect of polyurethane coating on the mechanical and permeability properties of fabrics, this study aims to fill this gap in the literature by examining the effect of UV aging on these properties. In addition, DSC analyzes of the coated fabrics were performed to better understand the thermal properties of the samples before and after UV exposure. The originality of this study is a comprehensive investigation of the effects of UV aging on both the mechanical and thermal properties of polyurethane coated fabrics made from different fibers commonly used in textile production. The results of this study will contribute to an understanding of the performance and durability of polyurethane coated fabrics when exposed to UV radiation.

2. MATERIAL AND METHOD

2.1 Material

In this study, three different raw woven fabrics (made from cotton, PET, and viscose) were utilized. These fabric types are commonly employed in textile production, and the objective was to examine their behavior under identical conditions, including the same coating and UV exposure time. The warp and weft yarns of these plain-woven fabrics had a linear density of Ne 30/1. The front faces of these fabrics were coated with PU (polyurethane) material, while the back faces were treated with fluorocarbon coating. The PU coating material used was an aliphatic waterborne PU dispersion specifically recommended for formulating textile coatings for outerwear. The process steps for the coating are depicted in Figure 1.

2.2 Method

The physical properties of both the raw and coated fabric samples are provided in Table 1. To subject the fabric samples to UV aging, a Prowhite UV test cabin was utilized, with exposure durations of 50, 100, and 150 hours, and a UV parameter of 35 W/cm2. The cabin temperature was maintained at 35°C. Subsequently, the mechanical and air permeability properties of the fabrics were analyzed. The testing procedures, along with the equipment and corresponding standards employed, are detailed in Table 2.

In addition to assessing the mechanical and permeability properties of the fabrics, surface and structural properties were examined using Thermo Scientific Apreo S Scanning Electron Microscopy (SEM) and TA DSC Q2000 Differential Scanning Calorimetry (DSC) equipment. SEM images were captured at magnifications of up to 5000x (HV: 3.00 KV, WD: 9.3-10.8 mm, spot size: 5.0) to evaluate the surface characteristics of the fabrics. DSC analyses were conducted in a nitrogen environment, with temperature intervals ranging from 0 to 350°C and a temperature rise rate of 10°C/min. Figure 2 presents SEM images of the raw and coated cotton, viscose, and PET fabrics

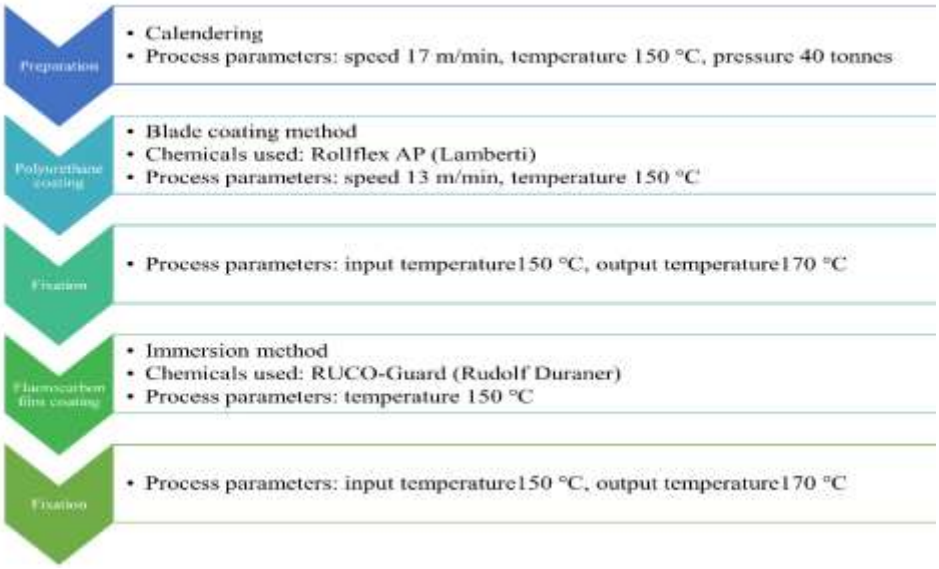

Figure 1. Coating process steps

Table 1. Physical properties of fabric samples

Fabric material	Fabric codes	Warp density (warp/cm)	Weft density (weft/cm)	Thickness (mm)	Weight (g/m^2)
100% Cotton	Co	42	27	0.20	125
	Coat-Co	42	27	0.21	128.2
100% PET	PET	37	23	0.31	160.8
	Coat-PET	37	23	0.32	164.8
100% Viscose	Vis	30	23	0.22	116.4
	Coat-Vis	30	23	0.24	120.8

Table 2. The equipment and the standards of the tests

Fabric properties	Test equipment	Standards
Weight	-	EN ISO 12127
Thickness	SDL-Atlas M034A	EN ISO 5084
Density	-	EN 1049-2
Breaking strength and elongation	Zwick Z010 (Roell)	EN ISO 13934-1
Tear strength	Zwick Z010 (Roell)	EN ISO 13973-2
Air permeability	FX3300 (Textest)	EN ISO 9237

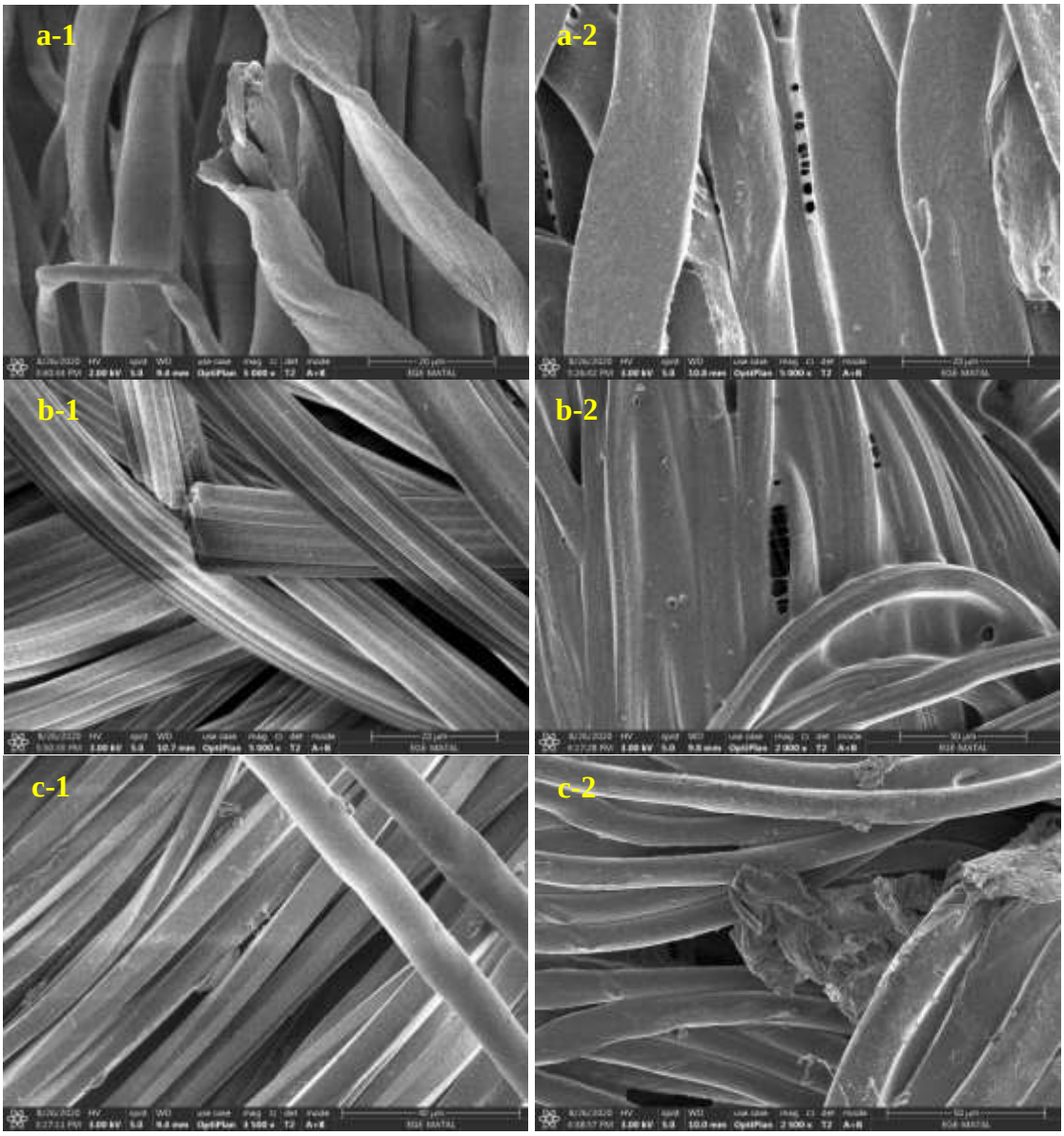

Figure 2. SEM images of raw (1) and coated (2) cotton (a), viscose (b), and PET (c) fabrics before UV exposure

The scope of this study was to investigate in detail the mechanical, thermal and air permeability properties of the UV resistance of fabrics with different fiber types. The mechanical and air permeability properties of fabrics with different fiber types, which are frequently used in textile production, were analyzed when exposed to UV. The results were analyzed in two different steps. In the first one, raw and coated fabrics of each fiber type were evaluated among themselves. In this evaluation phase, UV-A type aging process was applied at 0 hours, 50 hours, 100 hours and 150 hours intervals. In order to determine the UV effect in general, a detailed analysis was made for each fiber type as raw fabric (RF), coated fabric (CF), raw fabric- UV exposed (RF-UV) and coated fabric-UV exposed (CF-UV) subgroups, regardless of the UV exposure time. One-way ANOVA analysis was done for statistical evaluations using IBM SPSS

Statistics 20 Software. The general effects were determined by interpreting the significance values (p), which are the decision-making factor in the ANOVA method, and in situations where the factor is significant (α=0.05), post hoc tests were also carried out for further analysis.

3. RESULTS AND DISCUSSION

The main purpose of the study was to understand how different fibers commonly used in textiles are affected by UV-A rays when coated with the same PU coating under the same parameters. Therefore, several properties of the coated and raw fabrics were comparatively investigated, including breaking strength, breaking elongation, tear strength, and air permeability. Additionally, some of these fabrics were exposed to a UV aging process with different exposure times to understand the effect of exposure time. The strength and permeability results of the fabric samples are provided in Table 3.

3.1 Breaking strength

Significant decreases occur in the mechanical properties of the materials, because of the molecular level degradation caused by the effect of UV rays [21]. According to our findings, it has been determined that as the UV exposure time increases, the breaking strength decreases for all sample groups (Figure 3 and Figure 4) which is consistent with previous studies [22-25]. The samples that were not exposed to the aging effect of UV treatment exhibited the highest strength values, as expected for coated fabrics, where the coating layer had an enhancing effect on the breaking strength [26,27]. In both types of cotton fabric samples, the highest tensile strength values were observed in the samples that were not subjected to UV treatment, while the lowest tensile strength values were observed in the samples treated for 150 hours. In the warp direction, considering the 150-hour samples of raw and coated cotton fabrics that were not exposed to any UV effect, a strength loss of around 50% was observed. For all PET fabrics, it was determined that while high rates of decrease occurred in raw fabrics for 100-150 hours, the breaking strength decrease in coated samples was more limited. Viscose fiber is known to have the lowest strength compared to other fibers used in the study [28]. The breaking strength, which was affected by the structural degradation caused by UV treatment, resulted in 60-75% strength decreases in the warp direction at the end of 150 hours in viscose fabrics.

Table 3. Mechanical and air permeability results of the fabric samples (before and after UV exposure)

Fabric codes	UV aging duration	Breaking strength (N) (warp)	Breaking strength (N) (weft)	Breaking elongation (%) (warp)	Breaking elongation (%) (weft)	Tear strength (N) (warp)	Tear strength (N) (weft)	Air permeability ($l/m^2/s$)
Co	Unaged (0h)	451.39	366.85	7.51	24.41	7.37	10.80	632.80
	50 h	282.92	188.63	6.42	20.88	3.40	4.46	640
	100 h	230.95	144.35	5.80	18.21	2.42	3.30	627
	150 h	212.17	114.32	4.98	15.36	1.82	2.87	655
Coat-Co	Unaged (0h)	552.17	439.62	9.30	30.71	9.80	14.60	15.40
	50 h	357.37	234.08	8.10	26.42	5.14	7.41	17
	100 h	293.44	186.32	7.09	24.92	2.84	4.02	62.40
	150 h	227.08	130.92	6.01	23.36	1.17	2.96	207.40
PET	Unaged (0h)	892.99	485.08	24.80	47.32	21.58	30.69	208.60
	50 h	512.32	321.77	21.31	43.95	16.52	24.11	208.2
	100 h	305.22	122.34	18.85	42.25	12.80	18.19	213.4
	150 h	280.37	102.85	16.06	40.03	10.83	15.24	219.6
Coat-PET	Unaged (0h)	1206.40	711.72	13.70	35.75	41.62	57.24	55.80
	50 h	876.36	726.49	12.67	20.24	34.66	40.92	179
	100 h	785.72	648.49	11.79	19.16	25.08	31.70	201.20
	150 h	618.14	554.90	11.32	15.99	20.24	28.01	231.2
Vis	Unaged (0h)	340.51	210.50	20.91	40.02	8.62	11.53	563.80
	50 h	209.23	104.70	10.74	27.28	4.77	6.25	607
	100 h	101.53	29.95	7.26	17.84	1.55	3.48	630.80
	150 h	91.51	13.59	5.71	14.07	0.46	1.35	633.60
Coat-Vis	Unaged (0h)	537.12	328.32	22.49	28.23	9.53	13.52	18.80
	50 h	377.98	249.26	20.63	25.48	5.62	8.36	89.20
	100 h	250.67	186.19	18.05	22.18	3.36	6.15	145.80
	150 h	214.14	138.40	14.34	17.85	2.14	4.03	177.60

Table 4. ANOVA results for the effects of UV exposure time on breaking strength for all fabric types

Fabric Type	Warp direction		Weft direction	
	F Value	Significance	F Value	Significance
Co	61.659	.000*	67.165	.000*
Coat-Co	105.186	.000*	186.160	.000*
PET	378.279	.000*	17.257	.001*
Coat-PET	62.600	.000*	27.371	.000*
Vis	34.763	.000*	878.123	.000*
Coat-Vis	191.774	.000*	108.445	.000*

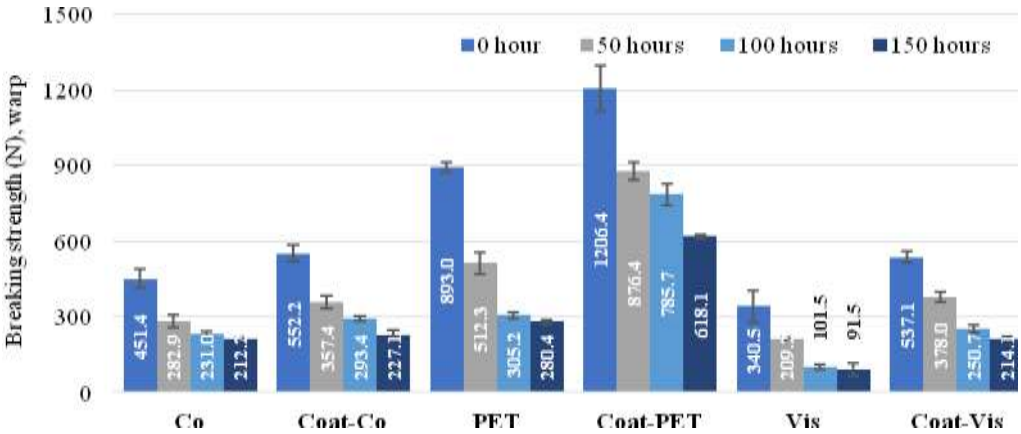

Figure 3. Breaking strength of the fabrics (warp direction)

In studies examining the mechanical properties of fabrics, it is generally observed that measurements taken in the weft direction, which contains fewer yarns compared to the warp direction, yield lower breaking strength values [29]. Similarly, it was found that the warp yarns of each fabric examined had higher linear densities than the weft yarns, resulting in lower breaking strength values in the weft direction. After exposure to UV, the breaking strength of all fabric samples decreased in both the warp and weft directions. In terms of UV exposure time, a strength loss of approximately 75% was detected in the breaking strength of cotton-containing fabrics in the weft direction when comparing samples with 0-150 hours of exposure. Although the inherent low strength potential of weft yarns resulted in more pronounced effects, especially in uncoated PET samples, the strength decrease in coated samples was also observed at lower rates, particularly in the weft direction, as reported in previous studies [22]. Similar to studies examining the UV effect on viscose fabrics [30], lower breaking strength values were measured in all viscose samples after UV exposure. Especially in raw viscose fabrics, a strength loss of up to 95% was observed at the end of 150 hours (Figure 4).

The results of the analyses independent of the UV exposure time indicated that the coating process was a significant factor in enhancing the tensile strength of all fabric samples (Table 5). The coating process provided an additional surface layer on the fabric and increased resistance to forces acting on the fabric from various directions. In terms of tensile strength, the lowest values were observed in raw and coated cotton samples exposed to UV. The abrasive effect of UV treatment led to significant decreases in the tensile strength of cotton fabrics, with a higher decrease of approximately 60% in the weft direction. Conversely, in cotton fabric samples without UV exposure, the coating process resulted in significant increases in tensile strength, with strength values measured to increase by 25% in both directions. For PET fabrics, the lowest tensile strength was observed in raw samples treated with UV in both the warp and weft directions. In the warp direction, the coating process resulted in a 35% increase in strength and a 40% decrease was calculated with UV treatment. In the weft direction, the strength increased by 45% with coating and decreased by 37% with UV exposure. Notably, the coating process prevented strength decreases caused by UV, especially in the weft direction, which is problematic in terms of breaking strength. In viscose fabrics, higher strength values were obtained in the warp direction. The coating process led to a proportional increase of approximately 60% in both the weft and warp directions. Similarly, to other analyses, UV treatment resulted in strength decreases in both directions due to structural distortions. The decreases observed in raw viscose samples were higher in the weft direction, with a rate of 75%, compared to 60% in the warp direction (Figure 5).

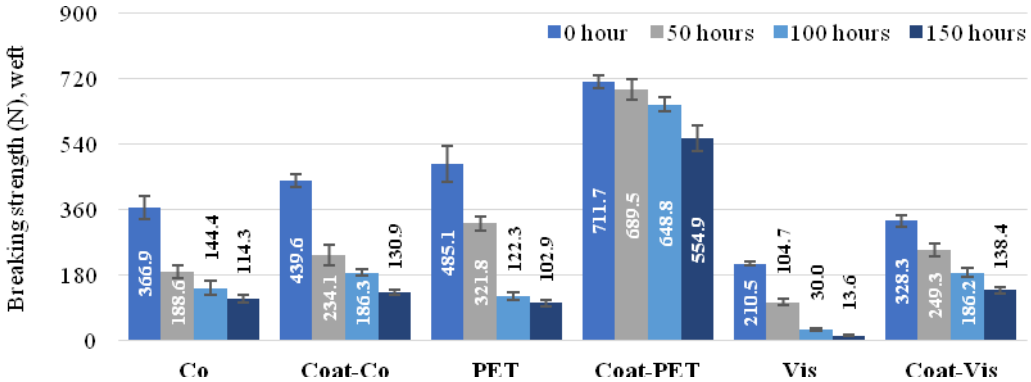

Figure 4. Breaking strength of the fabrics (weft direction)

Table 5. ANOVA results for the effects of UV exposure and coating process on breaking strength regardless of UV exposure time

Fabric Types	Warp direction		Weft direction	
	F Value	Significance	F Value	Significance
Co and Coat-Co	42.871	.000*	56.614	.000*
PET and Coat-PET	55.701	.000*	43.254	.000*
Vis and Coat-Vis	32.206	.000*	40.934	.000*

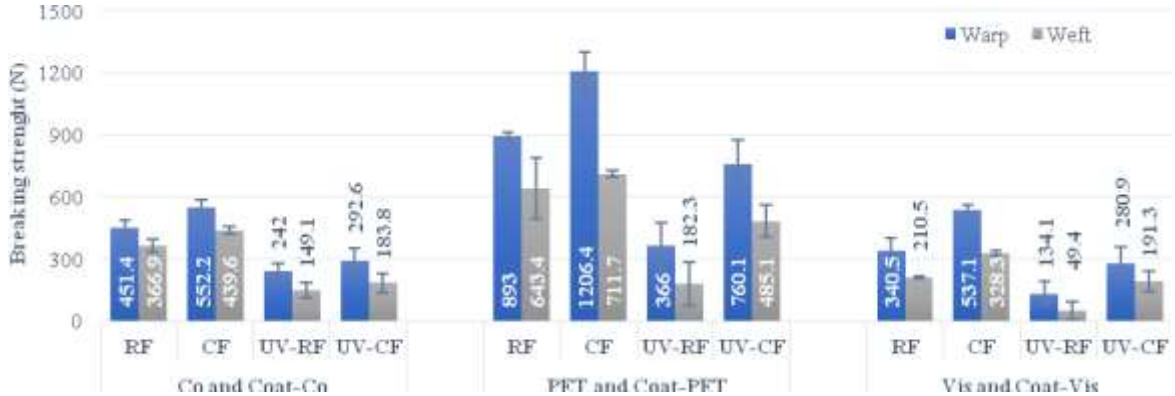

Figure 5. Breaking strength of raw and coated fabrics independent of UV exposure time for all fabric types

3.2 Breaking elongation

Similar to the breaking strength, it was observed that increasing UV exposure time had a detrimental effect on the breaking elongation values of all fabrics. Consistent with previous studies [24,25,31,32], fabric ruptures occurred at lower elongation values due to structural degradation caused by UV exposure. In the case of cotton fabrics, the highest elongation values were obtained in the warp and weft directions for samples that were not exposed to UV, while the lowest elongation values were observed at 150 hours, representing the most severe UV exposure. The increase in UV exposure time negatively affected the elongation at break of both raw and coated PET fabrics. Notably, different responses were observed depending on the measurement direction for raw and coated PET fabrics. The decrease in elongation at break in the warp direction of raw PET fabrics progressed proportionally with the duration of UV treatment. However, the coated PET fabrics exhibited a limited abrasive effect in the warp direction, likely due to the fabric structure acquiring a more rigid form through the coating process. In the case of raw viscose fabrics, significant decreases in elongation at break were observed after 50 hours, aligned with the decline in tensile strength resulting from UV-induced structural degradation. Subsequent decreases were less pronounced as the exposure time prolonged. Coated viscose fabrics showed a parallel decrease in elongation at break with increasing UV exposure time (Figure 6).

Table 6. ANOVA results for the effects of UV exposure time on breaking elongation for all fabric types

Fabric Type	Warp direction		Weft direction	
	F Value	Significance	F Value	Significance
Co	19.059	.001*	32.521	.000*
Coat-Co	19.974	.000*	13.757	.002*
PET	19.013	.001*	15.317	.001*
Coat-PET	7.094	.012*	82.143	.000*
Vis	26.600	.000*	179.942	.000*
Coat-Vis	21.189	.000*	50.410	.000*

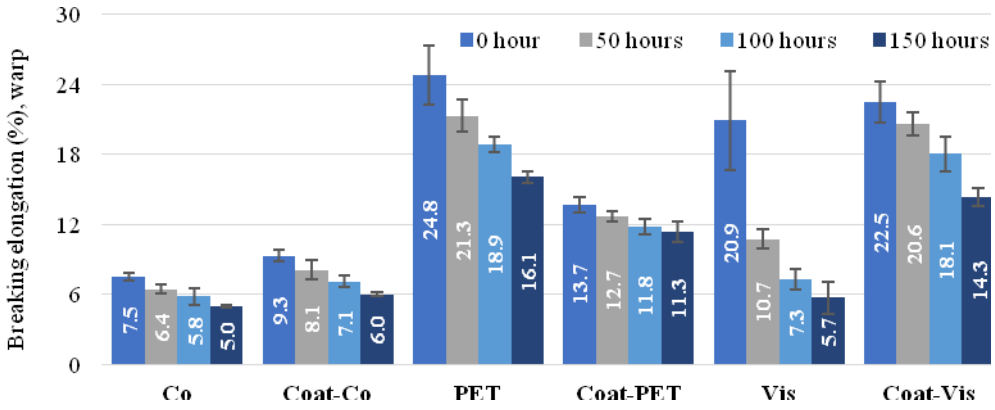

Figure 6. Breaking elongation of the fabrics (warp direction)

Due to the tensions experienced by warp yarns during their positioning in the fabric and the production process, it is observed that fabrics exhibit lower elongation values in the warp direction compared to the weft direction [33]. This trend was consistent across all fabric types, with higher elongation at break values observed in the weft direction. In raw cotton fabrics, the decrease in elongation at break in the weft direction was found to be proportional to the UV exposure time, whereas in coated cotton samples, the decrease in elongation at break values stabilized after 50 hours. The high breaking elongation values observed in raw PET fabrics can be attributed to the high tenacity and elongation characteristics of the yarn used [28]. In coated PET fabrics, the elongation at break values in the weft direction decreased significantly after 50 hours, and the rate of decrease stabilized, similar to coated cotton fabrics. After 150 hours, a 55% decrease in elongation at break was observed in the weft direction of coated PET fabrics. Raw viscose fabrics experienced a 65% decrease in elongation at break in the weft direction after 150 hours. In the case of coated viscose fabrics, the decrease in elongation at break in the weft direction was determined to be 35% after 150 hours (Figure 7).

According to the analyses conducted independently of the UV exposure time parameter, both coating and UV exposure were found to have a statistically significant effect on the elongation at break properties of all examined fabrics (Table 7). Furthermore, due to the inherent physical characteristics of weft yarns in terms of stretchability, it was observed that weft yarns exhibited higher elongation at break values compared to warp yarns in all fabrics. The elongation at break results of cotton fabrics indicated that UV treatment played a significant role in reducing the elongation at break. However, it was determined that the effects caused by UV exposure were somewhat mitigated by coating the fabric surfaces. Conversely, in coated samples that were not exposed to UV, the elongation values were measured at the highest level, highlighting the stretchable nature of the coated fabric surface. The integration of coating and UV treatment in PET fabrics had a negative impact on the elongation at break. The lowest breaking elongation values were observed in samples that were both coated and exposed to UV, due to the hardening effect of the coating process[8] and the deterioration in the fabric structure caused by the UV exposure. Regarding the elongation at break results, the coating process led to a 45% decrease in elongation at break in the warp direction, while UV treatment resulted in a 25% decrease. In the weft direction, the coating process caused a 25% decrease, while UV treatment led to a 12% decrease. In terms of elongation at break in viscose fabrics, UV exposure had a significant effect. The viscose fabric samples exhibited the lowest elongation at break values due to UV exposure, with a 60% decrease in the warp direction and a 50% decrease in the weft direction. Although the coating process did not have a significant effect in the warp direction, it provided the

highest elongation values and mitigated the negative impact of UV exposure. In the weft direction, the coating process contributed to a decrease in elongation values by increasing fabric density and reducing stretching abilities, resulting in a 30% decrease in elongation at break (Figure 8).

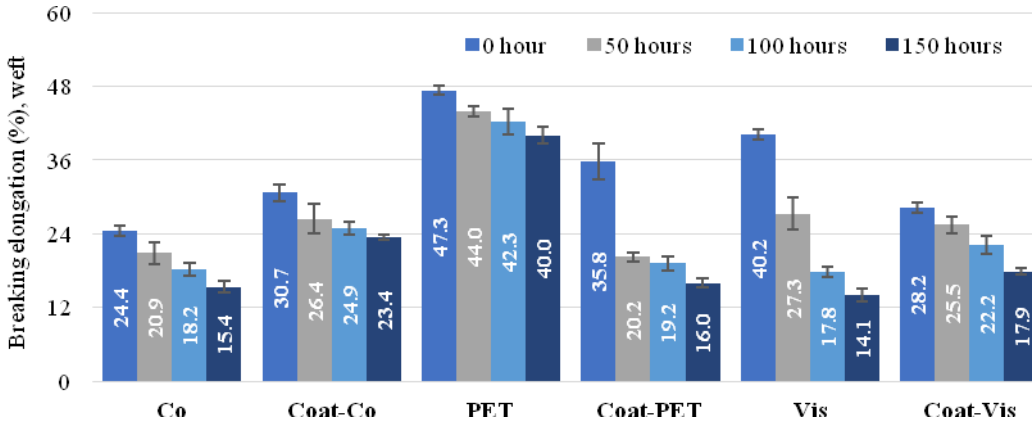

Figure 7. Breaking elongation of the fabrics (weft direction)

Table 7. ANOVA results for the effects of UV exposure and coating process on breaking elongation regardless of UV exposure time

Fabric Types	Warp direction		Weft direction	
	F Value	Significance	F Value	Significance
Co and Coat-Co	15.287	.000*	32.318	.000*
PET and Coat-PET	47.169	.000*	242.923	.000*
Vis and Coat-Vis	33.801	.000*	17.752	.000*

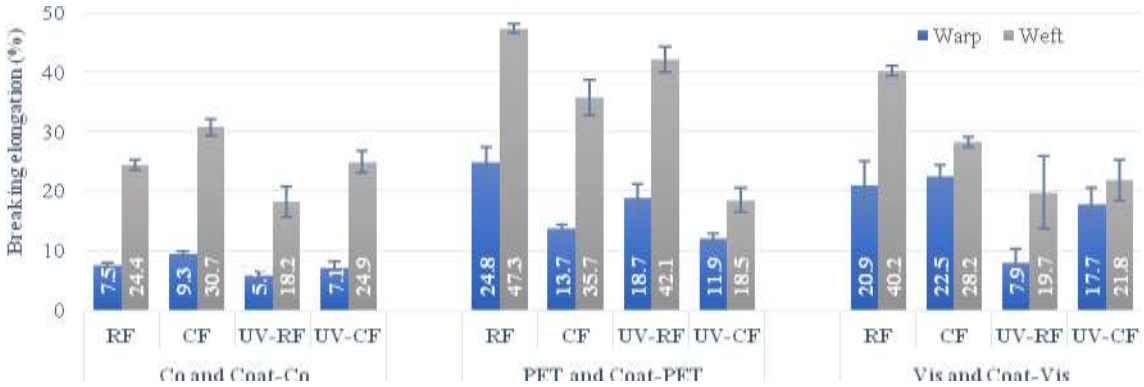

Figure 8. Breaking elongation of raw and coated fabrics independent of UV exposure time

3.3 Tear strength

The tear strength of a fabric is influenced by factors such as the breaking strength of the yarns that form the fabric and the mobility of the yarns within the fabric [34]. Consistent with previous studies in the literature [22,24,30-32], the degrading effect of UV exposure on the fabric structure has a negative impact not only on the breaking strength but also on the tear strength properties. The tear strength results of all fabrics revealed statistically significant differences attributed to the effect of UV exposure (Figure 9 and Figure 10). Similar to the breaking strength, according to the tear strength test results, the lowest values in all cotton fabric samples were determined in the samples exposed to 150 hours of UV treatment. Due to the damage caused by UV effect in the fabric structure, there were decreases in tear strength in both warp and weft directions. It was determined that PET fabrics without UV exposure had the highest tear strength values due to the abrasive effect of UV in raw and coated fabric samples. In both PET fabric groups, the tear strength reduction rates were parallel to the exposure time and 50% decreases were measured when compared to the 150-hour samples and 0-hour samples. The increase in UV exposure time also had a negative effect on

viscose fabrics and the lowest tear strength values were determined after 150 hours. Strength reductions of up to 95% in the warp direction after 150 hours due to UV were calculated for raw viscose fabrics. Especially in both viscose fabrics, the decreases after 50 hours were higher.

Due to the higher mobility of weft yarns compared to warp yarns in the fabric, they tend to move and stay closer to each other in the region of tearing under the influence of tear forces [34, 35]. Consistent with previous studies [36-38], higher tear strength values were observed in the weft direction for all fabric types. In both raw and coated cotton fabrics, approximately 80% loss in tear strength was determined in samples exposed to UV in both warp and weft directions. The effects of coating and UV exposure on PET fabrics exhibited a similar trend in both directions. While tear strength values in the weft direction were relatively higher for viscose fabrics, reductions of 70% and 90% were observed in the weft direction for raw and coated viscose fabrics, respectively, after 150 hours of UV exposure (Figure 10).

In the evaluation conducted independently of the UV exposure time, it was determined that both the coating process and UV exposure had a statistically significant impact on the tear strength of all fabrics, as shown in Table 9. Despite the beneficial effect of the coating process, it was found that the strength of all fabric types was significantly reduced due to UV exposure. In the case of cotton fabrics, the tear strength decreased by 70% in both warp and weft directions under the influence of UV. However, for the fabric samples not exposed to UV, the coating process led to a significant improvement in tear strength. Measurements conducted in both warp and weft directions showed strength increases of 35%. The positive impact of the coating process was evident in the tear strength results of PET fabrics, with nearly 100% increases observed in both directions. A comparison between the RF and UV-CF PET fabrics revealed an increase in tear strength due to the coating process, despite the abrasive effect of UV treatment. However, the effect of UV resulted in a decrease of 35-40% in tear strength for PET fabrics in both directions. Regarding fabric samples containing viscose, the tear strength-reducing effects of UV treatment were observed. Raw viscose fabrics experienced decreases of 70% in both directions as a result of UV treatment. Even in coated viscose samples, reductions of up to 60% were observed. While there was a 15% increase in tear strength in the weft direction due to the coating process, it remained relatively low.

Table 8. ANOVA results for the effects of UV exposure time on tear strength for all fabric types

Fabric Type	Warp direction		Weft direction	
	F Value	Significance	F Value	Significance
Co	314.933	.000*	179.418	.000*
Coat-Co	138.256	.000*	137.657	.000*
PET	29.201	.000*	42.716	.001*
Coat-PET	50.775	.000*	137.627	.000*
Vis	289.149	.000*	179.388	.000*
Coat-Vis	107.766	.000*	67.140	.000*

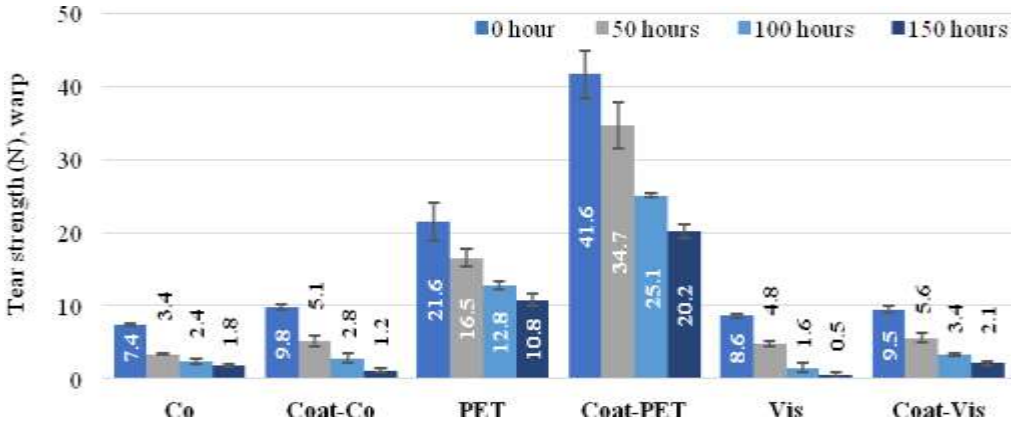

Figure 9. Tear strength of the fabrics (warp direction)

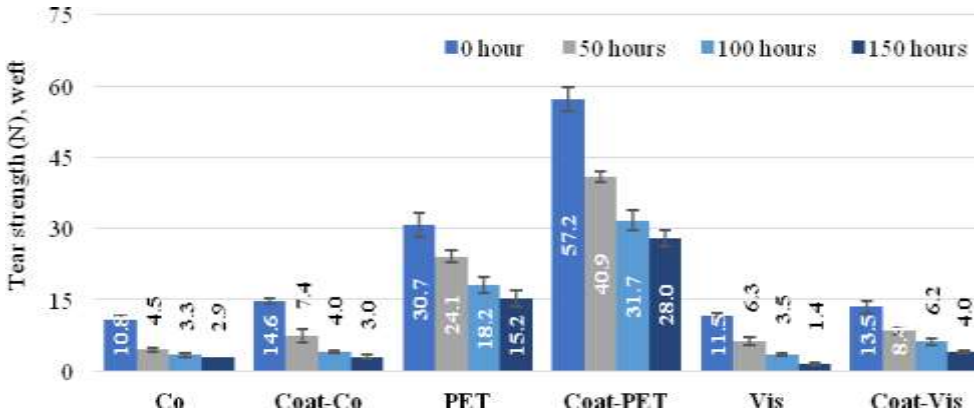

Figure 10. Tear strength of the fabrics (weft direction)

Table 9. ANOVA results for the effects of UV exposure and coating process on tear strength regardless of UV exposure time

Fabric Types	Warp direction		Weft direction	
	F Value	Significance	F Value	Significance
Co and Coat-Co	35.012	.000*	54.077	.000*
PET and Coat-PET	30.618	.000*	50.777	.000*
Vis and Coat-Vis	22.731	.000*	26.826	.000*

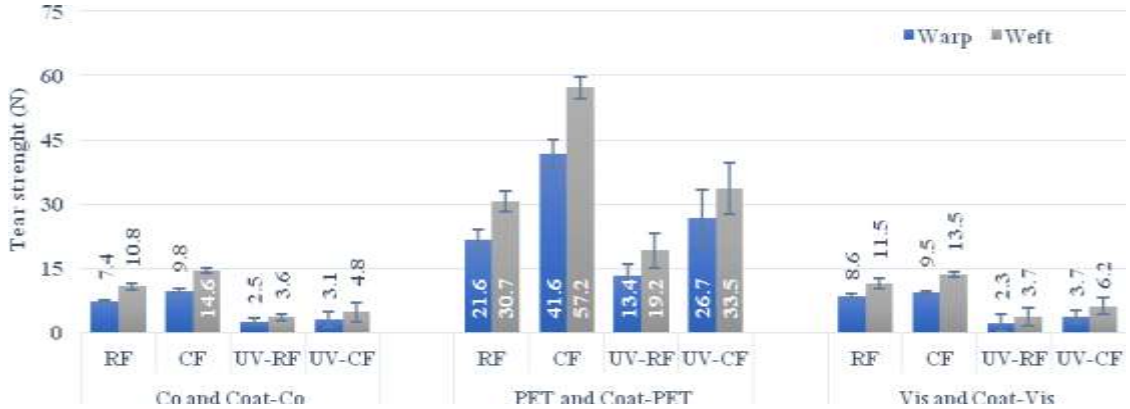

Figure 11. Tear strength of raw and coated fabrics independent of UV exposure time

3.4 Air permeability

According to the results of the statistical analysis regarding air permeability, it was observed that the UV exposure time did not have a significant effect on the air permeability of raw cotton and raw PET samples (Table 10). However, the effect of UV exposure time on raw viscose fabrics and all coated fabric types was found to be statistically significant, as indicated in Table 10. In the case of raw viscose fabrics, an increase in air permeability was observed with UV exposure during the initial 50 hours, and this increase was maintained at a constant level thereafter. After 50 hours of UV exposure, a 7% increase in air permeability was observed, while at the end of 150 hours, the air permeability showed a 12% increase compared to the air permeability of the raw viscose fabrics at 0 hours (Figure 12).

Table 10. ANOVA results for the effects of UV exposure time on air permeability for all fabric types

Fabric Type	F Value	Significance
Co	2,179	.079
Coat-Co	292,951	.000*
PET	0,754	,536
Coat-PET	71,269	.000*
Vis	10,594	.000*
Coat-Vis	108,275	.000*

The results of the air permeability tests revealed that the changes in the fabric surface structure due to increased UV exposure time were most pronounced in the coated fabric samples. In woven fabrics, air flow passes perpendicularly through the gaps between the warp and weft yarns [39]. Consistent with previous studies [40-43], it was observed that the coating process restricted the fabric's porosity, which is responsible for allowing vertical air movement

[44]. Consequently, the fabrics that were not exposed to UV exhibited significantly low air permeability properties (Figure 12). In coated cotton fabrics, the coating effect remained relatively stable within the first 50 hours of UV exposure. However, after 100 and 150 hours, there was a significant increase in air permeability values. For coated PET fabrics, the abrasive effect of UV exposure became apparent after 50 hours, and the highest air permeability values were observed after 150 hours. Notably, deep cracks and ruptures (indicated by red arrows) appeared in the fibers and coated layer of coated PET fabrics after 150 hours of UV exposure, resulting in air permeability values similar to those of raw PET fabrics (Figure 13). In the case of coated viscose samples, the covering effect produced by the coating surface, which reduces permeability, underwent significant changes with increased UV exposure time. The most permeable coated viscose fabric structure, in terms of air permeability, was observed after 150 hours of UV exposure.

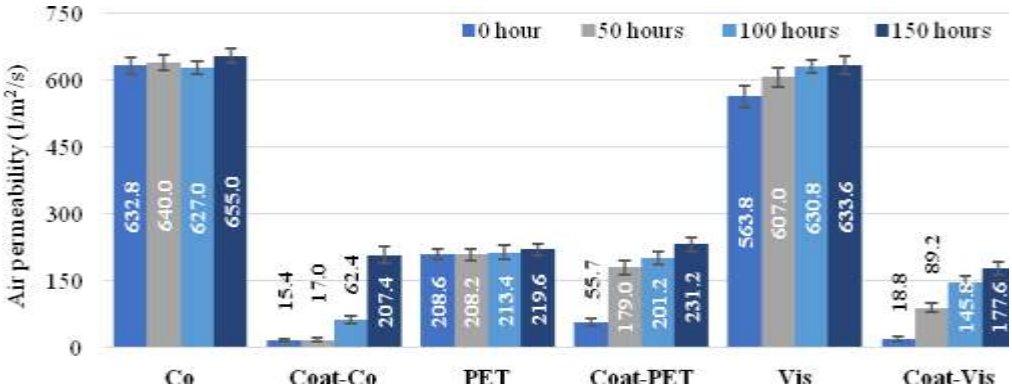

Figure 12. Air permeability of the fabrics

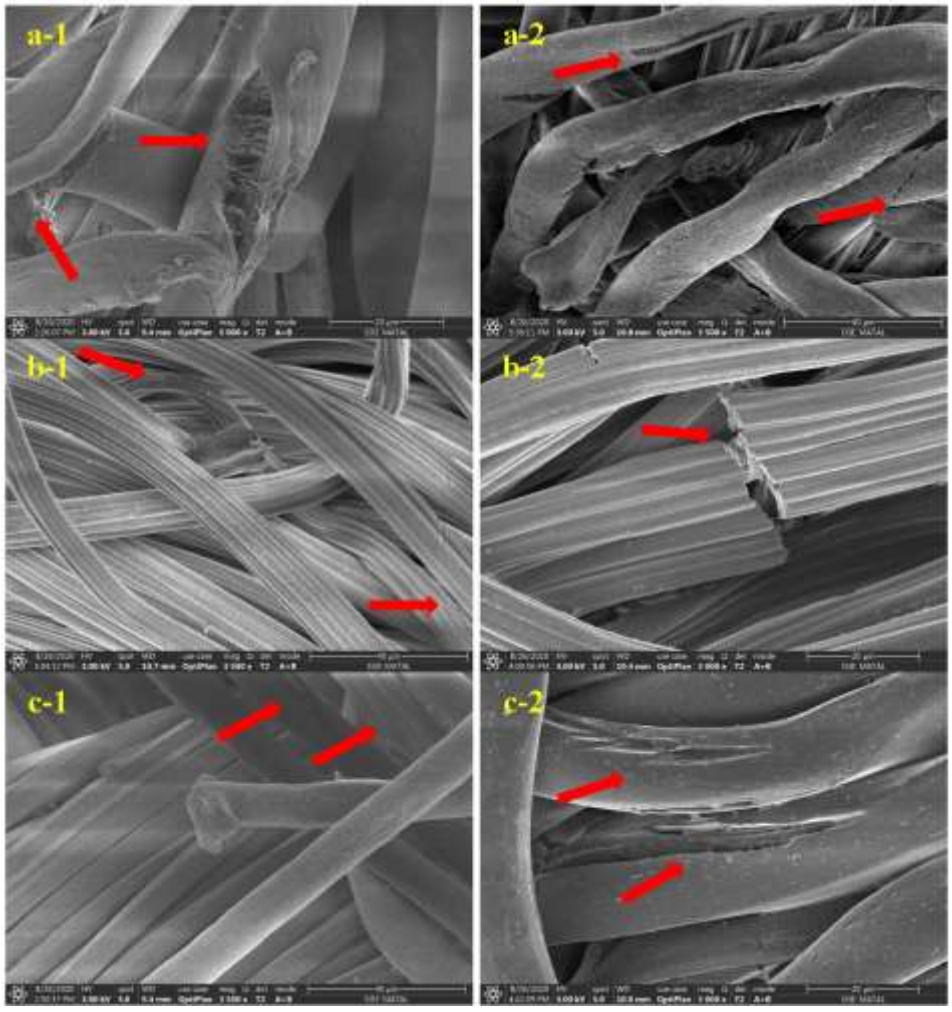

Figure 13. Deep cracks and ruptures observed on the raw cotton (a-1), coated cotton (a-2), raw viscose (b-1), coated viscose (b-2), raw PET (c-1), and coated PET (c-2) fabrics after 150 hours of UV exposure

The results of the air permeability test analysis for all fabrics, regardless of UV exposure time, indicated that the coating process had the greatest impact on the fabric's vertical air permeability. It was observed that the coating process significantly reduced the air permeability values. In the case of coated cotton fabrics, although the coating effect led to decreased permeability values, it was hypothesized that the surface abrasion effect of UV might create new air passage channels. This effect was not observed in raw cotton fabrics, where both UV-exposed and non-exposed samples exhibited similar air permeability properties. Regarding the air permeability analysis of PET fabrics, it was determined that the coating process had a primary effect, while the interaction between the coating and UV treatment had a secondary effect. The air permeability values in coated PET fabrics decreased by 75%. However, in the UV-CF group of PET fabrics, where the coating effect was expected to be dominant, the covering effect was not detected. The UV exposure seemed to diminish the impact of the extra surface created by the coating, and the distortions caused by UV on the coating surface allowed for the reestablishment of gaps required for vertical air movement. In the case of viscose fabrics, both the coating and UV treatment had significant effects, leading to statistically distinct groups based on air permeability levels. The CF group of viscose fabrics exhibited very low air permeability. However, UV exposure caused deterioration in the coating surface and fabric structure, resulting in the formation of new spaces for air movement. A comparison between RF and UV-CF fabrics of viscose revealed a 75% reduction in air permeability due to the coating process, despite UV exposure (Figure 14).

Table 11. ANOVA results for the effects of UV exposure and coating process on air permeability regardless of UV exposure time

Fabric Type	F Value	Significance
Co and Coat-Co	357.042	.000*
PET and Coat-PET	73.403	.000*
Vis and Coat-Vis	916.286	.000*

3.5 DSC Analyses

DSC analyses were performed on PU-coated fabrics within the temperature range of 0-350°C. The DSC analysis results of the coated fabrics were examined for two groups: cellulosic fabrics (cotton and viscose) and PET fabrics, after 0-150 hours of UV exposure. It was observed that the DSC graphics of the cellulosic fabrics exhibited a distribution similar to previous studies in the literature [45]. The first noticeable endothermic peak was attributed to moisture present in the fibers, and the moisture evaporation peak values (T_{peak}) were measured to be around 65°C in untreated (UV) cellulosic fabrics [46]. It was determined that the increase in UV exposure time of coated cotton and viscose fabrics (Figure 15 and Figure 16) increased the moisture evaporation peak temperatures (T_{peak}) and evaporation offset temperatures (T_{offset}). The literature suggests that the moisture management properties of fibers change due to the oxidation of hydroxyl side groups in cellulosic fibers under the influence of UV radiation [47]. Notably, the coated viscose fabrics exhibited higher values at both temperature values of the first endothermic peak after 150 hours of UV exposure (Table 12). Cellulosic fibers, which contain more moisture in their structure, generally exhibit higher evaporation temperature values [48]. It is presumed that these temperature differences arose due to the higher moisture-holding capacity of viscose fibers (12-14%) compared to cotton fibers (7-8%) [46].

The second peak in the DSC graphs of cellulosic fabrics corresponds to the onset of thermal degradation of the fibers [49], which is consistent with previous studies in the literature [50-52]. The onset temperature value (T_{onset}) of cotton fabrics not exposed to UV was observed to be 327.92°C, while for viscose fabrics, it was 306.77°C (Figure 15, 16). This difference can be attributed to the higher degree of polymerization and crystallinity of cotton fibers, which leads to a higher onset temperature for thermal degradation compared to viscose fibers [46,51]. Furthermore, it was found that the coated cotton fabrics exhibited higher onset thermal degradation temperature values compared to the coated viscose fabrics. Although the effects of UV exposure on the mechanical properties of cellulosic fabrics were evident, the increase in UV exposure time did not result in significant differences in terms of thermal degradation temperatures for both cotton and viscose fabrics (Table 12).

Figure 14. Air permeability of raw and coated fabrics independent of UV exposure time

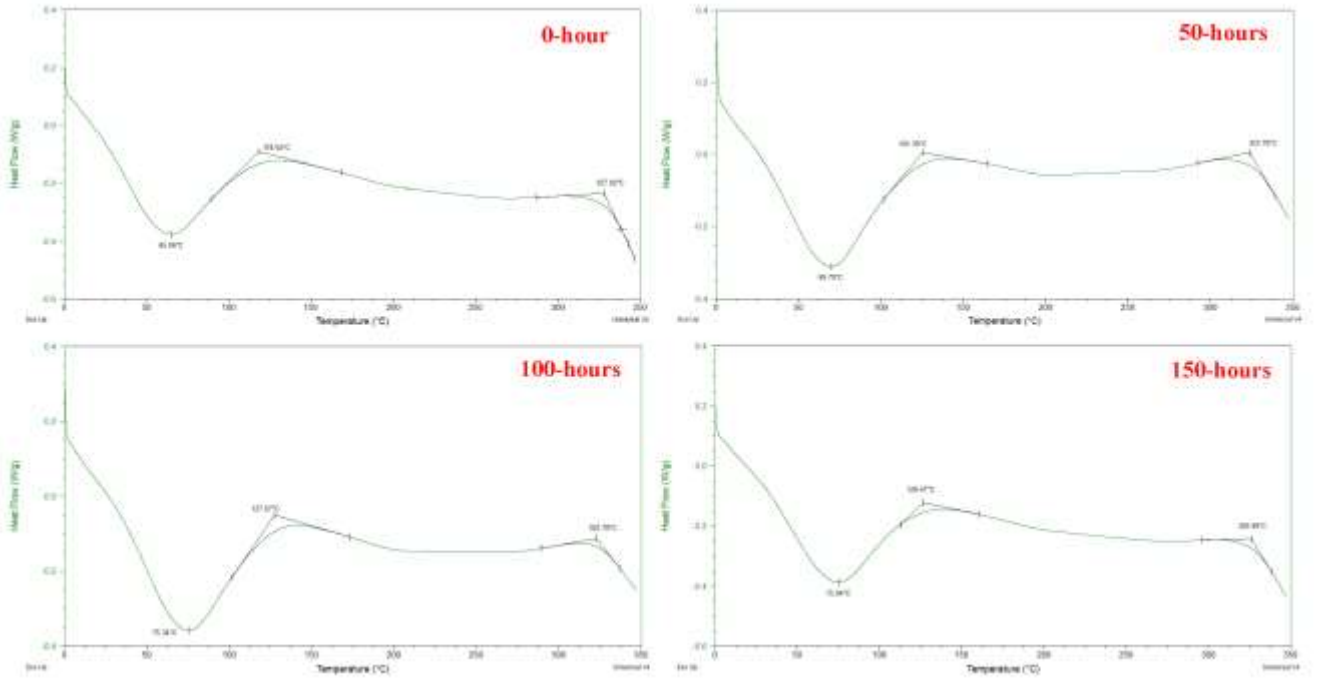

Figure 15. The DSC graphs of coated cotton fabrics

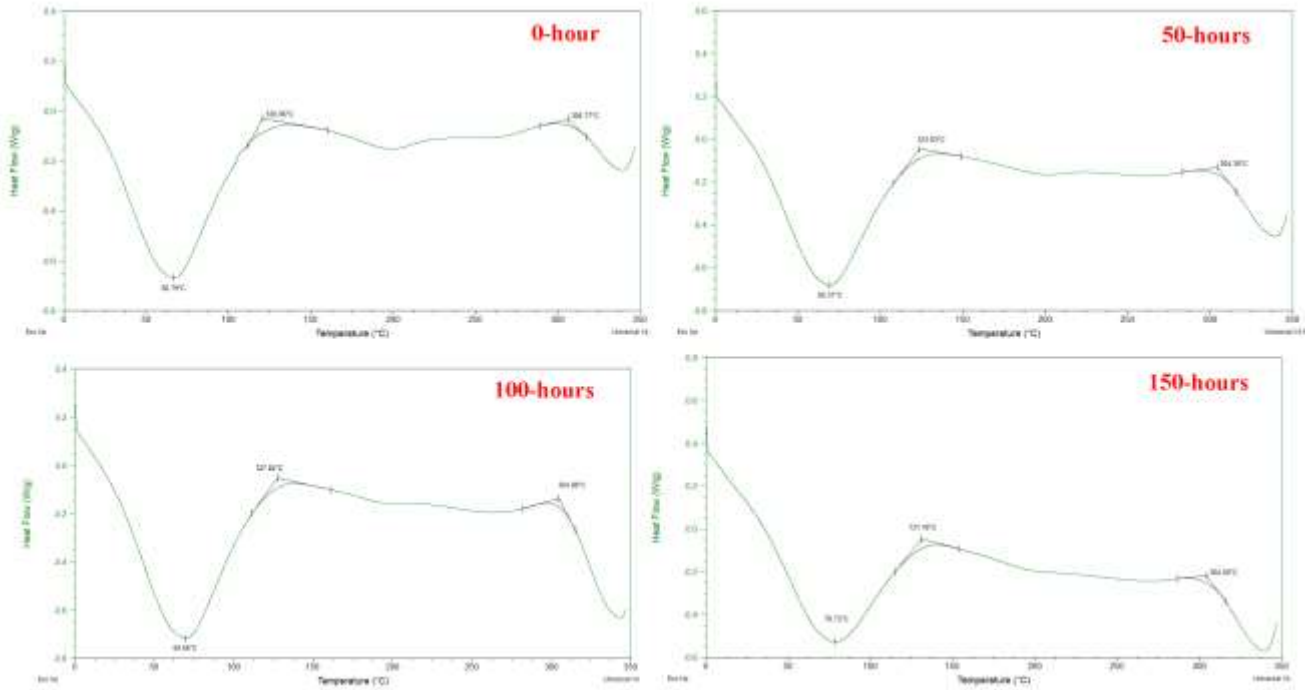

Figure 16. The DSC graphs of coated viscose fabrics

Table 12. Moisture evaporation and thermal decomposition in DSC analyses of cellulosic fibers

UV-Exposure Time	Moisture Evaporation Peak (T_{peak} / °C)		End point of Evaporation (T_{offset} / °C)		Start of Thermal Decomposition (T_{onset} / °C)	
	Coat-Co	Coat-Vis	Coat-Co	Coat-Vis	Coat-Co	Coat-Vis
0 hours	65.06	66.79	118.04	120.86	327.92	306.77
50 hours	69.79	69.31	125.39	123.83	323.78	304.36
100 hours	75.34	69.66	127.67	127.65	322.78	304.88
150 hours	75.04	78.72	126.47	131.16	325.99	304.60

The first peak in the DSC graphs of coated PET fabrics corresponds to the glass transition temperature (T_g), as reported in previous studies [53-55]. The observed changes in T_g values, which increased significantly after 50 hours of UV exposure, indicate the effect of UV aging on PET fabrics (Table 13). Previous studies have also shown an increase in T_g temperatures with prolonged exposure to UV rays [56,57]. This change is attributed to a slight increase in the crosslinking density induced by the UV effect [58-60].

The other notable region in the DSC analysis of coated PET fabrics corresponds to the melting temperatures (T_m), as mentioned in previous studies [61,62]. Consistent with earlier researches [63,64], an increase in UV exposure time was found to have a negative impact on the melting temperature (T_m) and enthalpy (ΔH) values of coated PET fabrics (Table 13). UV exposure leads to photodegradation and photooxidation, causing damage to basic bond structures such as ester bonds and a decrease in molecular weight. As a result of these degradations, PET fibers exhibit lower melting points and reduced enthalpy values [65,66].

4. CONCLUSION

Coating conventional fabrics with a suitable layer offers numerous functional properties, particularly enhanced resistance against physical impacts. In the context of textile products designed for outdoor use, the photodegradation effect caused by UV rays stands as a significant concern. In this study, the effects of UV exposure on the mechanical properties of different polyurethane-coated fabrics types were investigated. The results demonstrated that UV exposure time caused significant decreases in the breaking strength, breaking elongation, tear strength, and air permeability of the fabric samples.

The breaking strength of all fabric types decreased as the duration of UV exposure increased. Coated fabrics exhibited higher strength values compared to raw fabrics, indicating the enhancing effect of the coating layer. Cotton fabrics showed the highest tensile strength in samples without UV treatment, while the lowest values were observed in samples exposed to 150 hours of UV. PET fabrics experienced high rates of strength decrease in raw samples, but the decrease was more limited in coated samples. Viscose fabrics had the lowest strength and showed significant strength reductions after UV exposure.

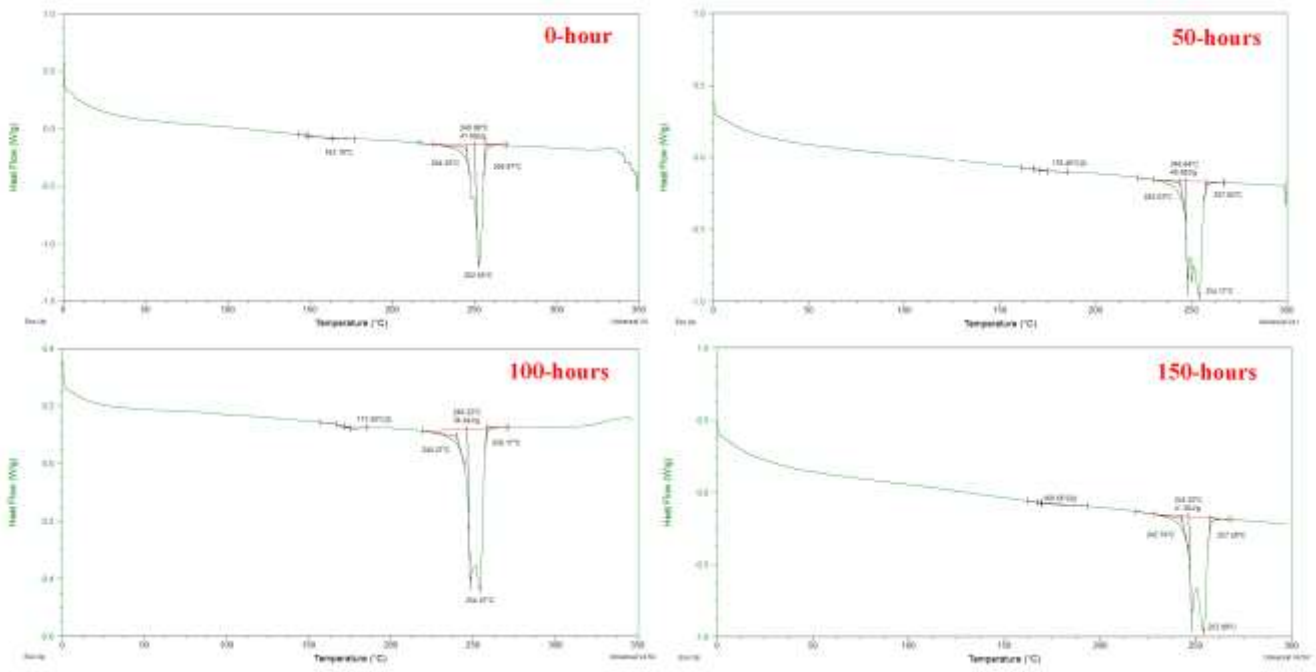

Figure 17. The DSC graphs of coated PET fabrics

Table 13. Glass transition temperatures and melting temperatures of coated PET fibers

UV-Exposure Time	Glass Transition Temperature (T_g /°C)	Melting Temperature (T_m /°C)	ΔH (Jg^{-1})
0 hours	163.10	249.98	41.00
50 hours	170.46	246.64	40.08
100 hours	171.50	246.22	34.44
150 hours	169.56	246.32	34.72

Breaking elongation, which measures the ability of a fabric to stretch before breaking, was also affected by UV exposure. Increasing exposure time resulted in lower elongation values for all fabrics. Similar to breaking strength, the decrease in elongation was more pronounced in the warp direction compared to the weft direction. Coating the fabrics and UV exposure both had a significant impact on elongation at break properties. Coating the fabrics increased elongation values, while UV exposure decreased elongation. Cotton fabrics showed a decrease in elongation at break values with UV exposure, but the coating process mitigated the negative effects. PET fabrics exhibited a decrease in elongation values with both coating and UV exposure. Viscose fabrics showed a significant decrease in elongation at break with UV exposure, but the coating process helped maintain elongation values.

The tear strength of the fabrics was also influenced by UV exposure. UV exposure led to decreases in tear strength in both warp and weft directions for all fabric types. The decrease in tear strength was more pronounced in the weft direction compared to the warp direction. Coated fabrics generally exhibited higher tear strength values compared to raw fabrics, but still experienced reductions in tear strength with UV exposure. Cotton fabrics showed an approximately 80% loss in tear strength with UV exposure. PET fabrics showed parallel reductions in tear strength with increasing exposure time. Viscose fabrics had the lowest tear strength values after 150 hours of UV exposure.

Air permeability, which measures the fabric's ability to allow air to pass through, was affected by UV exposure and the coating process. UV exposure had a significant effect on air permeability for raw viscose fabrics and all coated fabrics. Raw viscose fabrics showed an increase in air permeability with UV exposure, while coated fabrics exhibited changes in porosity and increased air permeability after extended UV exposure. The coating process generally reduced air permeability values, but UV exposure caused changes in the coated fabric samples, leading to higher air permeability.

According to the results of the analyses performed independently of the UV exposure time, it was found that polyurethane coating and UV exposure had significant effects on the mechanical and air permeability of the fabrics. The coating process proved to be effective in enhancing the breaking strength of all fabric samples by providing an additional surface layer that increased resistance to external forces. However, UV treatment had an abrasive effect on the fabrics, leading to a significant decrease in breaking strength, especially in cotton fabrics. Nevertheless, the coating process helped mitigate the strength reduction caused by UV exposure, particularly in the weft direction where breaking strength was more vulnerable.

The elongation at break properties were also influenced by both the coating process and UV exposure. While UV treatment generally reduced the elongation at break, the coating process resulted in higher elongation values, indicating the stretchable nature of the coated fabric surface. However, in PET fabrics, the integration of coating and UV had a negative impact, leading to lower breaking elongation values due to the hardening effect of the coating process and structural deterioration caused by UV exposure. The coating process had varying effects on the elongation at break of viscose fabrics, with increased elongation values in the warp direction but decreased values in the weft direction due to increased fabric density and reduced stretching abilities.

The tear strength of all fabric types was significantly reduced by UV exposure, while the coating process improved tear strength in fabric samples not exposed to UV. PET fabrics showed a remarkable increase in tear strength due to the coating process, despite the abrasive effect of UV treatment. However, the tear strength of PET fabrics was still negatively affected by UV exposure. Similarly, UV treatment caused reductions in tear strength for viscose fabrics, even in coated samples.

Regarding air permeability, the coating process had a significant impact on reducing vertical air permeability values. However, the surface abrasion effect of UV treatment in cotton fabrics created new air passage channels, which counteracted the coating effect. In PET fabrics, the coating process primarily decreased air permeability, but the interaction with UV treatment diminished the covering effect. UV exposure resulted in distortions on the coating surface, allowing for the reestablishment of gaps required for air movement. In the case of viscose fabrics, both the coating process and UV treatment had significant effects on air permeability, leading to distinct groups based on permeability levels.

The DSC analyses conducted on PU-coated fabrics provided valuable insights into the thermal behavior of different fabric types under UV exposure. The results revealed significant changes in moisture evaporation and thermal degradation characteristics, as well as glass transition and melting temperatures, due to UV aging. For cellulosic fabrics (cotton and viscose), the DSC graphs displayed typical patterns observed in previous studies. The first endothermic peak corresponded to moisture evaporation, and it was observed that UV exposure time increased the evaporation peak temperatures. This can be attributed to the oxidation of hydroxyl side groups in cellulosic fibers under the influence of UV radiation. Notably, coated viscose fabrics exhibited higher evaporation temperature values compared to coated cotton fabrics, which can be attributed to the higher moisture-holding capacity of viscose fibers. The second peak in the DSC graphs indicated the onset of thermal degradation, with cotton fabrics (327.92°C) exhibiting higher onset temperature values compared to viscose fabrics (306.77°C),

owing to their higher degree of polymerization and crystallinity. UV exposure had noticeable effects on the mechanical properties of cellulosic fabrics but did not result in significant differences in thermal degradation temperatures.

In the case of PET fabrics, the first peak in the DSC graphs corresponded to the glass transition temperature (T_g), which significantly increased after 50 hours of UV exposure. This increase in Tg values is consistent with previous studies and can be attributed to the crosslinking density induced by UV aging. The DSC analysis also revealed changes in the melting temperatures (T_m) and enthalpy (ΔH) values of coated PET fabrics. Prolonged UV exposure had a negative impact on T_m and ΔH, indicating photodegradation, photooxidation, and damage to the molecular structure of PET fibers. These changes resulted in lower melting points and reduced enthalpy values.

REFERENCES

1. Sen A.K., 2007.*Coated textiles: principles and applications*. Boca Raton-Florida: CRC Press.
2. Clemitson, I.2012. *Polyurethane Casting Primer*. Boca Raton-Florida: CRC Press..
3. Arshad N, Zia K.M., Jabeen F., Anjum M.N., Akram N., Zuber M.2018. Synthesis, characterization of novel chitosan based water dispersible polyurethanes and their potential deployment as antibacterial textile finish, *Int. J. Biol. Macromol.*, May, Vol. 111, 485–492.
4. Yang F.,Yu W.2006. Study on Mechanical Properties of PU Coated Fabric. *International Forum on Textile Science and Engineering for Doctoral Candidates*.
5. Patel J.P., Patel P.R., Mahera H.K., Patel P. 2015.Effect of PU And PVC Coating on Different Fabrics for Technical Textile Application. *IJSTE -International J. Sci. Technol. Eng.*, 1 (11), 279–284.
6. Bulut Y., Sular V.2013. Manufacturing and sewing performance of polyurethane and polyurethane/silicone coated fabrics. *Mater. Manuf. Process.*, 28 (1), 106–111.
7. Padleckiene I., Petrulis D. 2009. Effect of abrasion on the air permeability & mass loss of breathable-coated fabrics. *Fibres Text. East. Eur.*, 73 (2), 50–54.
8. Cho J.W., Jung Y.C., Chun B.C., Chung Y.C. 2004. Water vapor permeability and mechanical properties of fabrics coated with shape-memory polyurethane. *J. Appl. Polym. Sci.*, 92 (5), 2812–2816.
9. Jassal M., Khungar A., Bajaj P., Sinha T. J. M. 2004. Waterproof breathable polymeric coatings based on polyurethanes. *J. Ind. Text.*, 33 (4), 269–280.
10. Mondal S., Hu J.L. 2007. Water vapor permeability of cotton fabrics coated with shape memory polyurethane. *Carbohydr. Polym.*, 67 (3), 282–287.
11. Kara S., Yesilpinar S., Aksit A. 2018. Permeability properties and abrasion resistance of coated polypropylene fabrics. *Vlakna a Text.*, 25 (2), 40–47.
12. Güneşoğlu S., Yüceer M. 2018. A modeling study of micro-cracking processes of polyurethane coated cotton fabrics. *Text. Res. J.*, 88 (24), 2766–2781.
13. Gunesoglu S, Cerci E., Topalbekiroglu M. 2017. The improved breathability of polyurethane coated cotton fabric via micro-cracking. *J. Text. Inst.*, 108 (10),1815–1821.
14. Rubeziene V., Varnaite S., Baltusnikaite J., Padleckiene I. 2012. "Effects of light exposure on textile durability," in *Understanding and Improving the Durability of Textiles*, Elsevier, 104–125.
15. Das, S., Pandey, P., Mohanty, S., & Nayak, S. K. 2017. Study of UV aging on the performance characteristics of vegetable oil and palm oil derived isocyanate based polyurethane. Korean Journal of Chemical Engineering, 34(2), 523–538.
16. Zhang, W., Yao, J., & Wang, S. 2019. Multifunctional outdoor fabrics with ATO and TiO2 embedded PU coatings. Pigment & Resin Technology, 48(4), 344–352.
17. Li, J. H., Hong, R. Y., Li, M. Y., Li, H. Z., Zheng, Y., & Ding, J. 2009. Effects of ZnO nanoparticles on the mechanical and antibacterial properties of polyurethane coatings. Progress in Organic Coatings, 64(4), 504–509.
18. Mills, D. J., Jamali, S. S., & Paprocka, K. 2012. Investigation into the effect of nano-silica on the protective properties of polyurethane coatings. Surface & Coatings Technology, 209, 137–142.
19. Sabzi, M., Mirabedini, S. M., Zohuriaan-Mehr, J., & Atai, M. 2009. Surface modification of TiO2 nanoparticles with silane coupling agent and investigation of its effect on the properties of polyurethane composite coating. Progress in Organic Coatings, 65(2), 222–228.
20. Van Tran, T., Abedin, F., Usta, A., & Asmatulu, R. 2019. Polyurethane nanocomposite coating with silanized graphene and hexagonal boron nitride as nanoadditives for improved resistance against ultraviolet degradation. Journal of Composites Materials, 53(10), 1387–1399.
21. Yousif, E., & Haddad, R. 2013. Photodegradation and photostabilization of polymers, especially polystyrene: Review. SpringerPlus, 2(1).
22. Zhang, Y., & Zhang, M. 2017. Aging properties of polyvinylidenefluoride-coated polyesters used in tensioned membrane structure: Effect of loading protocol environment. Advances in Materials Science and Engineering.
23. Jana, R. N., & Bhunia, H. 2010. Accelerated hygrothermal and UV aging of thermoplastic polyurethanes. High Performance Polymers, 22(1), 3–15.
24. Houshyar, S., Padhye, R., Nayak, R., & Shanks, R. A. 2016. Deterioration of polyaramid and polybenzimidazole woven fabrics after ultraviolet irradiation. Journal of Applied Polymer Science, 133(9), 1–7.
25. Pal, S. K., Thakare, V. B., Singha, G., & Verma, M. K. 2011. Effect of outdoor exposure and accelerated aging on textile materials used in aerostat and aircraft arrester barrier nets. Indian Journal of Fibre & Textile Research, 36(2), 145–151.
26. Abbott, N. J., Lannefeld, T. E., Barish, L., & Brysson, R. J. 1971. A study of tearing in coated cotton fabrics: Part III: The influence of fabric construction. Journal of Coating and Fibrous Materials, 1(3), 4–17.
27. Bulut, Y., & Sülar, V. 2011. Effects of process parameters on mechanical properties of coated fabrics. International Journal of Clothing Science and Technology, 23(4), 205–221.
28. Morton, W. E., & Hearle, J. W. S. 2008. Tensile properties. In Physical Properties of Textile Fibres (pp. 274–321). Woodhead Publishing.
29. Özdemir, H., & Mert, E. 2013. The effects of fabric structural parameters on the tensile, bursting, and impact strengths of cellular woven fabrics. Journal of the Textile Institute, 104(3), 330–338.
30. Zuber, M., Zia, K. M., Bhatti, I. A., Ali, Z., Arshad, M. U., & Saif,

M. J. 2012. Modification of cellulosic fibers by UV-irradiation. Part II: After treatments effects. International Journal of Biological Macromolecules, 51(5), 743–748.

31. Mengüç, G. S., Temel, E., & Bozdogan, F. 2018. Sunlight exposure: The effects on the performance of paragliding fabric. Industrial Textile, 69(5), 381–389.
32. Eichert, U. 1994. Residual tensile and tear strength of coated industrial fabrics determined in long-time tests in natural weather conditions. Journal of Coated Fabrics, 23, 311–327.
33. Hu, J., & Xin, B. 2008. Structure and mechanics of woven fabrics. In Structure and Mechanics of Textile Fibre Assemblies (pp. 27-60). Woodhead Publishing.
34. Scelzo, W. A., Backer, S., & Boyce, M. C. 1994. Mechanistic role of yarn and fabric structure in determining tear resistance of woven cloth: Part I: Understanding tongue tear. Textile Research Journal, 64(5), 291–304.
35. Krook, C. M., & Fox, K. R. 1945. Study of the tongue-tear test. Textile Research Journal, 15(11), 389–396.
36. Jahan, I. 2017. Effect of fabric structure on the mechanical properties of woven fabrics. Advanced Research in Textile Engineering, 2(2).
37. Eryuruk, S. H., & Kalaoglu, F. 2015. The effect of weave construction on tear strength of woven fabrics. Autex Research Journal, 15(3), 207–214.
38. Temel, E., Bozdogan, F., & Mizmizlioglu, D. 2020. Structural investigation of UV aged tent fabrics. Tekstil ve Konfeksiyon, 29(3), 246–252.
39. Çay, A., Vassiliadis, S., Rangoussi, M., & Tarakcioglu, I. 2007. Prediction of the air permeability of woven fabrics using neural networks. International Journal of Clothing Science and Technology, 19(1), 18–35.
40. Pakdel, E., Daoud, W. A., Afrin, T., Sun, L., & Wang, X. 2017. Enhanced antimicrobial coating on cotton and its impact on UV protection and physical characteristics. Cellulose, 24(9), 4003–4015.
41. Ugur, Ş. S., Sarıışık, M., & Aktaş, A. H. 2011. Nano-TiO2 based multilayer film deposition on cotton fabrics for UV-protection. Fibers and Polymers, 12(2), 190–196.
42. Broasca, G., Borcia, G., Dumitrascu, N., & Vrinceanu, N. 2013. Characterization of ZnO coated polyester fabrics for UV protection. Applied Surface Science, 279, 272–278.
43. Gunaydin, G. K. 2019. Effect of coating ratio and weft density on some physical properties of upholstery fabrics. Industrial Textile, 70(4), 379–385.
44. Havlová, M. 2013. Air permeability and constructional parameters of woven fabrics. Fibres and Textiles in Eastern Europe, 98(2), 84–89.
45. Hatakeyama, T., Nakamura, K., & Hatakeyama, A. 2000. Vaporization of bound water associated with cellulose fibres. Thermochimica Acta, 352(353), 233–239.
46. Yang, P., & Kokot, S. 1996. Thermal analysis of different cellulosic fabrics. Journal of Applied Polymer Science, 60(8), 1137–1146.
47. Wypych, G. 2020. Handbook of UV Degradation and Stabilization (3rd ed.). Toronto: ChemTec Publishing.
48. Oliveira, F. R., et al. 2016. Tinctorial behavior of curaua and banana fibers and dyeing wastewater treatment by porous alumina membranes. Desalination and Water Treatment, 57(6), 2750–2758.
49. Shafizadeh, F., & Bradbury, A. G. W. 1979. Thermal degradation of cellulose in air and nitrogen at low temperatures. Journal of Applied Polymer Science, 23(5), 1431–1442.
50. Fan, F., Zhang, W., & Wang, C. 2015. Covalent bonding and photochromic properties of double-shell polyurethane-chitosan microcapsules crosslinked onto cotton fabric. Cellulose, 22(2), 1427–1438.
51. Xu, Y., Lu, Z., & Tang, R. 2007. Structure and thermal properties of bamboo viscose, Tencel and conventional viscose fiber. Journal of Thermal Analysis and Calorimetry, 89(1), 197–201.
52. Giesz, P., Mackiewicz, E., Nejman, A., Celichowski, G., & Cieślak, M. 2017. Investigation on functionalization of cotton and viscose fabrics with AgNWs. Cellulose, 24(1), 409–422.
53. Kong, Y., & Hay, J. N. 2002. Multiple melting behaviour of poly(ethylene terephthalate). Polymer, 44(3), 623–633.
54. Peng, G., et al. 2008. Effects of nano ZnO on strength and stability of unsaturated polyester composites. Polymer Advances in Technology.
55. Samyn, P. 2016. Tribological properties and thermomechanical analysis of unsaturated polyester fabric composite in oscillating line-contact sliding. Tribology International, 99, 127–139.
56. Boubakri, A., Guermazi, N., Elleuch, K., & Ayedi, H. F. 2010. Study of UV-aging of thermoplastic polyurethane material. Materials Science and Engineering: A, 527(7–8), 1649–1654.
57. Younis, A. A. 2016. Evaluation of the flammability and thermal properties of a new flame retardant coating applied on polyester fabric. Egyptian Journal of Petroleum, 25(2), 161–169.
58. Pegoretti, A., & Penati, A. 2004. Effects of hygrothermal aging on the molar mass and thermal properties of recycled poly(ethylene terephthalate) and its short glass fibre composites. Polymer Degradation and Stability, 86(2), 233–243.
59. Wang, M., et al. 2019. Fabrication of highly durable polysiloxane-zinc oxide (ZnO) coated polyethylene terephthalate (PET) fabric with improved ultraviolet resistance, hydrophobicity, and thermal resistance. Journal of Colloid Interface Science, 537, 91–100.
60. Allen, N. S., Edge, M., Mohammadian, M., & Jones, K. 1994. Physicochemical aspects of the environmental degradation of poly(ethylene terephthalate). Polymer Degradation and Stability, 43(2), 229–237.
61. Nejman, A., Kamińska, I., Giesz, P., & Cieślak, M. 2015. Thermal stability of polyester fabric with polyacrylic coatings. Fibres & Textiles in Eastern Europe, 23(4), 73–82.
62. Yildiz, Z., Gungor, A., Onen, A., & Usta, I. 2016. Synthesis and characterization of dual-curable epoxyacrylates for polyester cord/rubber applications. Journal of Industrial Textiles, 46(2), 596–610.
63. Abidi, H., et al. 2021. Accelerated weathering of textile waste nonwovens used as sustainable agricultural mulching. Journal of Industrial Textiles, 50(7), 1079–1110.
64. Zhang, H., et al. 2006. Effects of solar UV irradiation on the tensile properties and structure of PPTA fiber. Polymer Degradation and Stability, 91(11), 2761–2767.
65. Kijchavengkul, T., Auras, R., Rubino, M., Alvarado, E., Camacho Montero, J. R., & Rosales, J. M. 2010. Atmospheric and soil degradation of aliphatic-aromatic polyester films. Polymer Degradation and Stability, 95(2), 99–107.
66. Sang T., Wallis C.J., Hill G., Britovsek G. J. P. 2020. Polyethylene terephthalate degradation under natural and accelerated weathering conditions. *Eur. Polym. J.*, 136 (June), 109873.