Sunlight exposure: the effects on the performanceof paragliding fabrice

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REZUMAT – ABSTRACT

Expunerea la soare: efectele asupra performanţei ţesăturii pentru parapante

Acest studiu a fost conceput pentru a explora relaţia dintre expunerea la soare şi proprietăţile mecanice ale ţesăturilor pentru parapante, care au diferite culori, densităţi, tipuri de fineţe şi materiale de acoperire. În acest studiu s-au prezentat 5 culori diferite de ţesături pentru parapantă (roşu, turcoaz, albastru închis, portocaliu şi alb) care au fost expuse la lumina puternică a soarelui, timp de 150 de ore în timpul verii, de la ora 9:00 până la 3:00 p.m., timp de 5 zile pe săptămână, 5 săptămâni. Înainte şi după procesul de îmbătrânire din cauza radiaţiilor UV, s-au efectuat testele de permeabilitate la aer, rezistenţă la tracţiune, rezistenţă la sfâşiere şi rezistenţă la plesnire. Rezultatele testelor au fost, de asemenea, evaluate folosind metode statistice. Conform rezultatelor, s-a constatat că ţesătura turcoaz a avut cel mai ridicat grad de estompare dintre ţesăturile studiate. S-a constatat că există o scădere semnificativă a proprietăţilor mecanice ale ţesăturilor după expunerea la soare. După îmbătrânire, ţesăturile devin considerabil mai puţin rezistente în ceea ce priveşte proprietăţile mecanice din cauza degradării atât a colorantului, cât şi a structurii macromoleculare a fibrei.

Cuvinte-cheie: expunere la soare, fotodegradare, fotoîmbătrânire, proprietăţi mecanice, ţesătură pentru parapante

Sunlight exposure: the effects on the performance of paragliding fabric

This study was designed to explore the relationship between sunlight exposure and the mechanical properties of paragliding fabrics which have different colors, densities, yarn counts, and coating materials. This study exposed 5 different colors of paragliding fabrics (red, turquoise, dark blue, orange, and white) to intense sunlight for 150 hours during the summer from 9:00 a.m. to 3:00 p.m. for 5 days a week for 5 weeks. Before and after the UV radiation aging process, the air permeability, tensile strength, tear strength, and bursting strength tests were performed. Test results were also evaluated using statistical methods. According to the results, the fading of the turquoise fabric was found to be the highest among the studied fabrics. It was determined that there is a significant decrease in the mechanical properties of the fabrics after sunlight exposure. After aging, the fabrics become considerably weaker in the case of mechanical properties due to the degradation in both the dyestuff and macromolecular structure of the fiber.

Keywords: sunlight exposure, photodegradation, photoaging, mechanical properties, and paragliding fabric

INTRODUCTION

Textile materials are usually designed and produced to be used in environmental conditions, outside, where the fabrics are subjected to different sources of radiation. One of the most important sources of radiation found in the environment is UV radiation. It can affect many properties of the materials, including the mechanical behavior. Exposure of UV radiation was found to affect the supermolecular structure of the fibers. Changes in the internal structure of the fibers lead to variation of the color absorption behavior [1]. As it is known dyes absorb UV light, which helps in reducing exposure. Darker colors tend to absorb more UV light than lighter colors, including whites and pastels, but vivid colors such as red can also substantially absorb UV rays [2]. The more vivid the color, the greater the protection; a bright yellow shirt is more protective than a pale one. But even a pale fabric can offer good protection if the weave, material, weight, etc. are effective at keeping out UV light. And many white fabrics have "optical whitening agents", chemical compounds that strongly absorb UV radiation, especially UV-A [3–4].

Damage by UV radiation is commonly the main reason for the discoloration of dyes and pigments, weathering, yellowing of plastics, loss of gloss and mechanical properties (cracking), sun burnt skin, skin cancer, and other problems associated with UV light. The manufacturers of paints, plastics, contact lenses, and cosmetics have a great interest in offering products that remain unaltered for long periods under conditions of light exposure [5–8].

Exposure to ultraviolet (UV) radiation may cause significant degradation of many materials. UV radiation causes photo-oxidative degradation which results in breaking of the polymer chains, produces free radical, and reduces the molecular weight, causing deterioration of the mechanical properties leading to useless materials, after an unpredictable time [9–10].

When polymers are used in outdoor applications, the environment negatively influences the service life. This process is called weathering [11–12]. During weathering, the term "lightfastness" becomes a significant indicator for the quality of material. Lightfastness is the ability of a fabric to stand up to light. Dyed fabrics that are exposed to light can, in time, fade or change color. Both natural sunlight and artificial lights can cause damage to color. In general, light pastel colors fade more easily than dark ones, especially pink and turquoise. But dark colors crock more than light ones [13].

The damage of light depends on the intensity of the light source and the amount of exposure, as well as the properties of the dyestuff. Weather conditions, the season of the year, height above sea level, and the distance from the equator will all affect sunlight intensity [13].

In order to measure lightfastness in the home conditions, aging under sun light exposure could also be performed under direct sun light. All-day exposure is better, however, in this method, the samples need to be placed behind glass and exposed to sun at least from 9:00 a.m. to 3:00 p.m., in which sunlight intensity is the highest. The samples should be placed where shadows from objects in the vicinity will not fall upon them. The test should be repeated for approximately five summer days or eight winter days. Running the test for consistent lengths of time allows for making comparisons between a number of exposures [13].

Drapery fabric, on the other hand, is tested for eighty hours, canopy fabric for 160 hours, and automobile fabrics go up to 300 hours [13].

Paragliding fabrics are used under the exposure of sunlight and it causes photo degradation in the fiber structure, which can cause change in tensile properties and air permeability. Tensile properties have vital importance and air permeability is an indicator of fabric porosity, which directly changes the lift force of air. Since the mechanical properties and air permeability of these fabrics have great importance, the effect of sunlight on the physical properties of paragliding fabrics is an important parameter which should be investigated.

MATERIALS AND METHODS

Materials

The experiments were conducted using 5 different paragliding fabrics, which were produced in different densities, yarn counts and colors. They were selected since the most commonly used paragliders are made from them and are commercially available. The basic properties of the fabrics are summarized in table 1.

As seen in table 1, all fabrics were coated with a special coating material (polyurethane), a thin film of resin, to increase their strength and resistance to solar radiation and abrasion. In addition, the aim is to decrease air permeability. Therefore, coating is an important part that affects the performance of the paragliding fabric. Although there are numerous materials used for this purpose, polyurethane is one of the most used polymers. Polyurethane coated fabric offers advantages over other polymeric coatings such as low-temperature flexibility, overall toughness (very high tensile, tear strength, and abrasion resistance, requiring much less coating weight), and softer handle [14]. There are various types of it and some polyurethane based coating materials exhibit high strength combined with high flexibility, good cold flexibility, and high elasticity, however, it has a poor to oxygen and light [15]. They could develop extensive yellowing and photo-oxidation in the sunlight which is an important disadvantage during usage [16–17]. One of the solutions to avoid this disadvantage is to apply a silicone layer on the polyurethane coating.

Silicones are chemically inert and maintain their properties for a long time at temperature extremes [14]. Silicone elastomers and silicone dispersions consist of polydimethylsiloxane with reactive groups. They are water-repellent and, dirt-repellent, thermally stable between –50 and +200 °C, flame retardant, have a high resistance to chemicals, and are transparent [15]. There are aging studies that indicate their performance durability over time [14]. Therefore, a combined coating of polyurethane and silicone on a paragliding fabric was included (Turquoise sample) in the study to compare its performance.

Methods

For the experiment, paragliding fabrics were tested for their physical properties such as, breaking strength, tearing strength, bursting strength, and air permeability. Later, they were exposed to sun light for 150 hours in August. For this purpose, the samples were placed behind glass and exposed to sun from 9:00 a.m. to 3:00 p.m. for 25 days. The solar angle was adjustedto 60° (degrees from vertical), which is

Table 1

	Red	Turquoise	Dark blue	White	Orange
Weft Density (picks/cm)	41.0	22.3	27.2	27.3	26.3
Warp Density (ends/cm)	49.5	24.2	43.5	41.3	48.8
Fabric Density (yarns/cm^2)	90.5	46.5	70.7	68.6	75.1
Total Mass per Square Meter (g/m^2)	39.2	44.4	44.1	41.5	55.1
Thickness (mm)	0.132	0.188	0.126	0.202	0.184
Material	PA 6.6	PA 6.6	PA 6.6	PA 6.6	PA 6.6
Construction	Ribstop	Ribstop	Ribstop	Ribstop	Ribstop
Coating Material	Polyurethane	Polyurethane + Silicone	Polyurethane	Polyurethane	Polyurethane

the optimum angle for the solar collectors to have the best solar aging for the system in the selected month (figure 1).

After aging, they were tested again, to determine the change before and after exposure. Tests were performed under standard atmosphere conditions (20±2°C temperature and 65%±4% relative humidity).

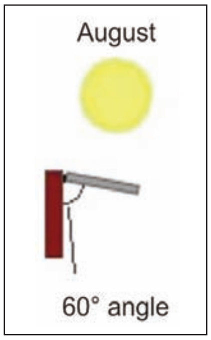


Fig. 1. Solar angle degrees from vertical

The tensile properties of the fabrics were measured using a Zwick Z010 Tensile Strength Tester. The breaking strength was conducted according to the EN ISO 13934-1 strip method. Tearing strength was conducted according to the ISO 13937-2 standard. Fabric thickness was measured according to EN ISO 5084 and the bursting strength test was determined according to EN ISO 13938-1. The air permeability test was performed according to the ISO 9237 standard using a Textest FX 3300 air permeability tester with 2.5 kPa pressure through a 5 cm^2 specimen area. The Specular Component Included (SCI) Hunter Lab Ultra Scan PRO Spectrophotometer (Measurement geometry: d8, observation angle: 10°, and light source: D65) was used for color measurement. Each measurement was repeated four times and the average value was recorded. The results were expressed as CIE (Commission Internationale de l'Eclairage) L*, a*, and b* coordinates.

In order to determine the "Strength Loss (SL)" of the fabrics mechanical properties, "Breaking Force Loss", "Tearing Force Loss", and "Bursting Strength Loss" values were calculated by the given formula (equation 1).

$$SL = \frac{Strength\ (BE) - Strength\ (AE)}{Strength\ (BE)} \times 100 \qquad (1)$$

SL = Strength Loss, indicating "Breaking Force Loss", "Tearing Strength Loss" and "Bursting Strength Loss";
Strength (*BE*)= Strength Before Exposure;
Strength (*AE*)= Strength After Exposure.

RESULTS AND DISCUSSION

Statistical evaluation

The breaking strength, bursting strength, and tearing strength values of the fabrics were measured and afterall the fabric performance tests, an ANOVA and Student-Newman-Keuls tests were conducted to determine whether the effect of paragliding fabric types on fabric properties is statistically significant at a 95% confidence level ($p<0.05$). In addition to this, an Independent Samples T-Test was conducted to analyze the differences between the before and after sun light exposure. The results are given in table 2, table 3 and table 4.

The relationships between the mechanical properties and color changes were examined. Since the turquoise sample indicates completely different performance, correlations were performed with and without this sample. The related R^2 values of the correlations were calculated and are given in table 5.

Results of colour measurement

The results of the color measurements (L*, a*, and b* coordinates) are given in table 6. The overall colour change, ΔE, was calculated using the CIE 2000 formula.

Color fading is photo degradation and the color which is seen is based upon the chemical bonds and the amount of light that is absorbed in a particular wavelength. Ultraviolet and infrared rays can break down the chemical bonds and thus fade the colors. It may be more noticeable in brighter and more intense colors [18].

The data in table 2 indicates that, the color changeof the turquoise sample was found as the greatest among the samples, when photo aging was carried out. This result was followed with the results of the dark blue, orange, and red samples.

Results of air permeability

The fabrics were tested for their air permeability under a pressure difference of 2500 Pascal and a test area of 5 cm^2 before and after sunlight exposure. However, none of fabrics was found as air permeable according to the measurement procedure of the TS 391 EN ISO 9237 standard.

Table 2

	Red	Turquoise	Dark blue	White	Orange
Breaking Strength on Warp Direction	0.096	0.028*	0.010*	0.104	0.282
Breaking Strength on Weft Direction	0.000*	0.075	0.041*	0.349	0.379
Elongation on Warp Direction	0.043*	0.063	0.017*	0.008*	0.010*
Elongation on Weft Direction	0.003*	0.025*	0.024*	0.394	0.230
Bursting Strength	0.000*	0.000*	0.003*	0.001*	0.020*
Tearing Strength on Weft Direction (Warp Tearing)	0.002*	0.000*	0.008*	0.005*	0.010*
Tearing Strength on Warp Direction (Weft Tearing)	0.003*	0.000*	0.001*	0.258	0.455

* Significant according to $\alpha = 0.05$

Table 3

	Paragliding fabric type	N	Before exposure			After exposure			
			Subset			Subset			
			1	2	3		1	2	3
Breaking force on warp direction	Turquoise	5	243.24			Turquoise	197.53		
	Orange	5		325.86		Red	280.69		
	Red	5		368.12		Orange	291.83		
	White	5			468.04	Dark Blue	299.94		
	Dark Blue	5			522.29	White		449.670	
	Sig.		1.000	.117	.052		.110	1.000	
Breaking force on weft direction	Orange	5	344.56			Dark Blue	190.09		
	Dark Blue	5	349.88			Red	200.20		
	Turquoise	5	379.06	379.06		Orange	294.04	294.04	
	Red	5		402.81		Turquoise		313.38	
	White	5		408.31		White			402.56
	Sig.		.103	.177		Sig.	.119	.180	
Elongation (Warp direction) (%)	Orange	5	18.4533			Orange	13.0800		
	Turquoise	5	20.1967			Dark Blue	13.6633		
	White	5	20.5967			Red	16.8067	16.8067	
	Red	5	20.8000			Turquoise		17.7533	
	Dark Blue	5	21.6500			White		18.4533	
	Sig.		.209			Sig.	.056	.490	
Elongation (Weft direction) (%)	Red	5	21.1833			Red	14.6767		
	White	5	21.1833			White	15.4633		
	Dark Blue	5	21.5167			Dark Blue	18.2033		
	Orange	5	22.1400			Orange	19.1933		
	Turquoise	5		24.7533		Turquoise	19.2200		
	Sig.		.814	1.000		Sig.	.432		

Table 4

	Paragliding fabric type	N	Before exposure				After exposure				
			Subset				Subset				
			1	2	3	4		1	2	3	4
Bursting strength	Orange	5	664.8				Turquoise	581.9			
	Turquoise	5		743.3			Orange		677.9		
	Red	5			841.1		Red		679.9		
	Dark Blue	5				945.9	Dark Blue			766.16	
	White	5				950.6	White			794.90	
	Sig.		1.000	1.000	1.000	.772	Sig.	1.000	0.923	0.222	
Warp tearing strength	Red	5	29.6				Turquoise	16.7			
	Orange	5	30.7				Red		21.0		
	Turquoise	5		36.0			Orange			24.3	
	White	5			41.9		Dark Blue			30.0	
	Dark Blue	5			44.4		White				37.8
	Sig.		.557	1.000	.202		Sig.	1.000	1.000	.640	1.000
Weft tearing strength	Dark Blue	5	22.9				Turquoise	11.5			
	Turquoise	5	24.2				Dark Blue	15.9			
	Red	5		26.1			Red		22.8		
	Orange	5			29.7		Orange			28.8	
	White	5				38.4	White				37.7
	Sig.		.192	1.000	1.000	1.000	Sig.	0.834	1.000	1.000	1.000

Table 5

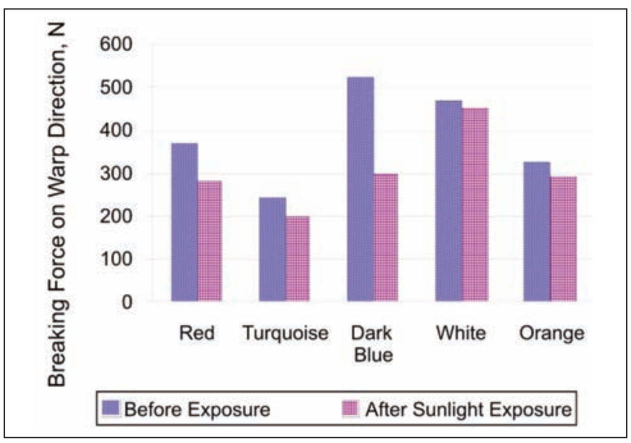
	Color change (ΔE)	
	With all samples	Without turquoise sample
Breaking Strength Loss on Warp Direction	0,12	0,82
Breaking Strength Loss on Weft Direction	–0,11	0,58
Elongation Loss on Warp Direction	–0,25	0,99
Elongation Loss on Weft Direction	0,23	0,80
Bursting Strength Loss	0,82	–0,83
Tearing Strength Loss on Weft Direction (Warp Tearing)	0,91	0,80
Tearing Strength Loss on Warp Direction (Weft Tearing)	0,89	0,74

Table 6

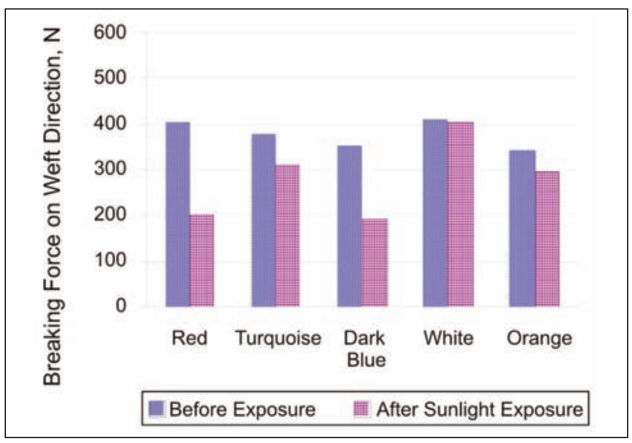
Fabrics	Status	L*	a*	b*	ΔE*
Red	Before Exposure	41.28	52.59	27.18	3.17
	After Exposure	44.4	52.33	27.64	
Turquoise	Before Exposure	61.16	–39.52	–25.07	35.33
	After Exposure	75.3	–25.56	4.14	
Dark Blue	Before Exposure	38.1	15.43	–51.92	7.92
	After Exposure	39.46	9.69	–46.63	
Orange	Before Exposure	57.03	57.88	53.51	5.15
	After Exposure	57.11	52.86	52.4	
White	Before Exposure	91.39	–1.26	4.9	0.44
	After Exposure	91.28	–1.17	4.49	

Results of breaking force and breaking elongation

According to table 3, it can be stated that in most cases there is a significant difference between the results measured before and after sunlight exposure. As seen in figure 2, the breaking force results for both the warp and weft directions decrease in all fabric types after sunlight exposure. According to figure 2, *a*, it can be denoted that the dark blue and white samples have the highest breaking force for warp direction values, while the turquoise sample has the lowest before sunlight exposure. However, after exposure, the white sample has significantly higher breaking strength than the other samples. The decrease in the breaking strength value seen both before and after the exposure was not found statistically significant for the white and orange samples as seen in table 3. Fabrics generally lose their tensile strength after sunlight exposure. In the case of the breaking force on the weft direction results (figure 2, *b*), the white sample which has the highest fabric thickness value (table 1), again has the highest force value both before and after sunlight exposure.

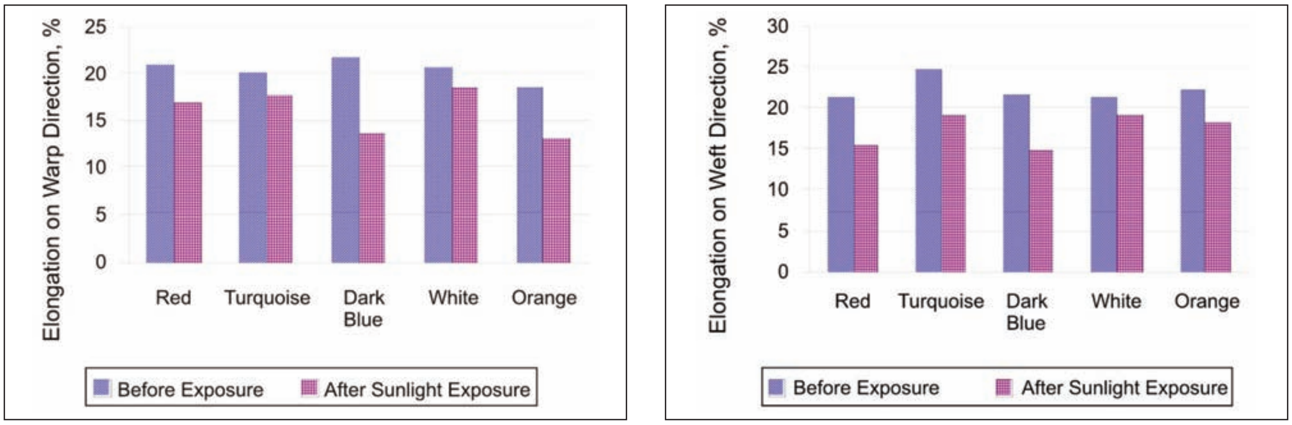


a



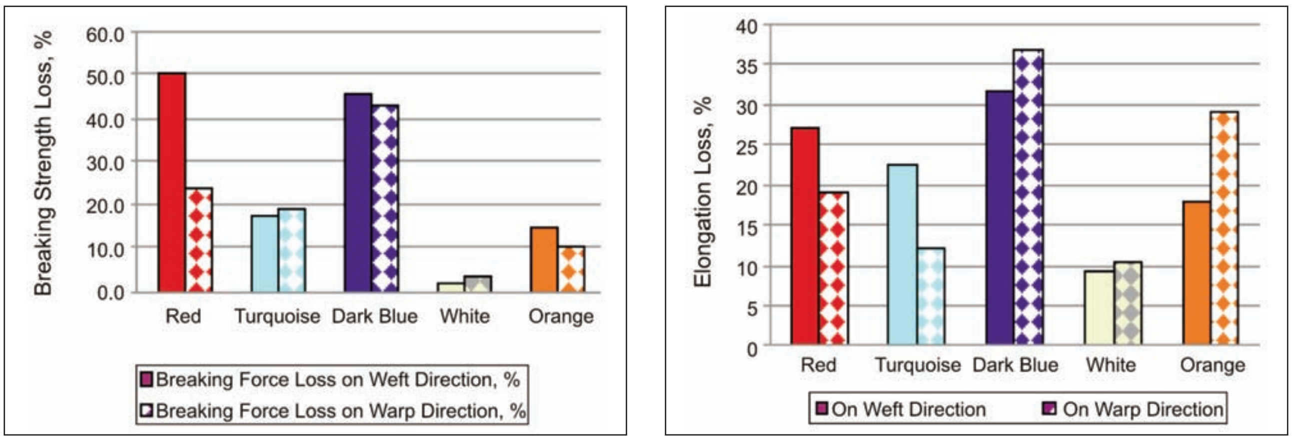
b

Fig. 2. Breaking Force Results: *a* – on Warp Direction; *b* – on Weft Direction



a *b*

Fig. 3. Elongation Results: *a* – on the Warp Direction; *b* – on the Weft Direction



a *b*

Fig. 4. Breaking Strength Loss and Elongation Loss of the Fabrics

When the elongation values were evaluated, the results generally decrease after sunlight exposure (table 3) and the differences between the values were mostly found statistically insignificant. The turquoise sample has a higher elongation value on the weft direction before exposure; however it loses it after exposure. In most cases, the measured values were found close to each other.

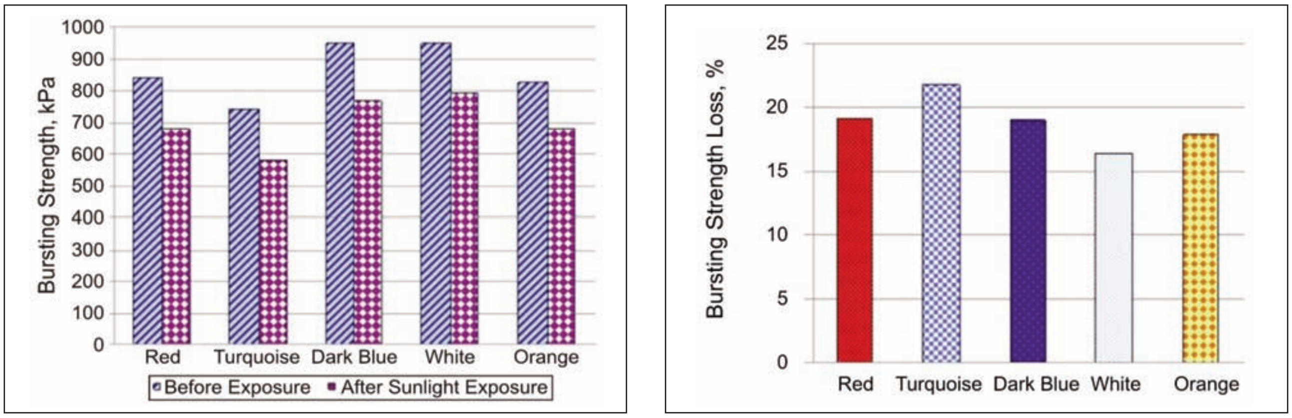
The paragliding fabrics were affected with the exposure to sun light differently and to compare them with each other the "Breaking Strength Loss" and "Elongation Loss" values were calculated according to equation 1. The results are given in figure 4.

It is thought that; dark blue and red paragliding fabrics absorb more solar radiation. For this reason, dark blue and red colored fabrics are more affected with sunlight exposure (photo aging) than the other fabrics. The breaking strength loss of the turquoise sample is relatively lower than the dark blue and red samples. Besides its lighter color, this result is also related with the additional silicone coating on the fabric surface. It supports the material and therefore the breaking strength loss of this fabric is lower. Since the solar radiation absorption is lower for the white and orange samples, the breaking strength loss of these fabrics were found as the lowest.

Results of bursting strength

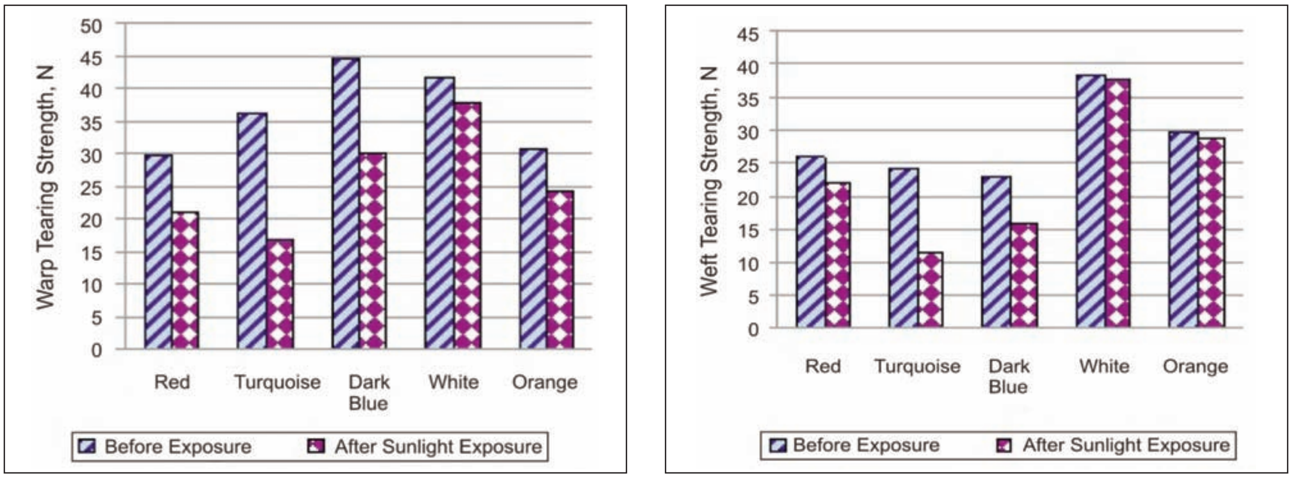
According to the bursting strength values given in figure 5 and the statistical evaluation results given in table 5, it was pointed out that the white and dark blue samples have the highest values and the difference between them was found statistically insignificant. Similar to the breaking strength results, the turquoise sample has a comparatively lower bursting strength. For all fabric types, sunlight exposure has a significant decreasing effect on the bursting strength (table 3).

According to the bursting strength loss values, which were calculated according to equation 1, the highest strength loss was observed in the dark blue, turquoise, and red samples, however, the orange sample has a comparatively lower strength loss. The white sample has the lowest loss among the studied fabrics. Although the tensile strength loss of the turquoise sample is lower, the bursting strength loss value was found to be higher. It is thought that the additional silicone coating on the turquoise sample decreases the elasticity of the fabrics and that the fabric reaches the bursting limit easily, which results in a low bursting strength value [19–20].



a *b*

Fig. 5. Bursting Strength Results Before and After Sunlight Exposure (a); Bursting Strength Loss After Sunlight Exposure (b)



a *b*

Fig. 6. Tearing strength test results

Results of tearing strength

When the warp tearing strength values were examined (figure 6, *a*), it can be seen that the white sample has a higher tear strength value before and after sunlight exposure. The results were found to be parallel to the results of the breaking strength for the dark blue sample.

The dark blue fabric has the highest warp tearing strength, however, it has a very low value on the weft direction. The turquoise sample with its lowest fabric density has a low tearing strength in both directions. The tear strength in both directions generally decreases after sunlight exposure (table 3) apart from the white and orange samples. Tearing strength values of these two samples did not decrease significantly after exposure.

The calculated tearing strength loss values (figure 7) were found parallel to the results of the bursting strength loss values. Figure 7 emphases the low loss in the white and orange samples and a high loss in the red, blue, and turquoise samples. The high tearing strength loss of the turquoise sample is associated with the lower elongation of the yarns. The breaking elongation of the yarns used in the fabric structure affects the distance between the yarns in the tearing point and therefore, changes the dimensions of the tearing triangle and the number of yarns which are torn. In conclusion, the higher breaking elongation increases the tearing strength of the fabric [21]. The additional silicone coating on the turquoise sample decreases the elongation of the yarns and causes a higher loss in the tearing strength. Moreover, yarns that can group together by lateral movement during tearing give a better tearing resistance. Since, the silicone coating on the turquoise

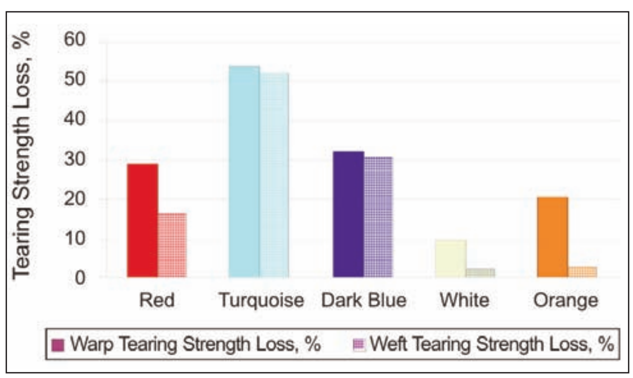


Fig. 7. Tearing strength loss after sunlight exposure

sample also decreases the grouping ability, a lower tearing strength value was measured for this type of fabric [22].

CONCLUSIONS

In this article, 5 different paragliding fabrics different in colors, densities, and yarn counts were investigated. In order to simulate the usage during flights, all fabrics were exposed to sunlight for 150 hours. Changes in the breaking, tearing, bursting strength, and air permeability were researched using statistical methods. Another aim was to clarify how different colors affect the absorption of light in a material and change the aging. The following results were found in this study:

- In normal usage, polyamide fiber is not durable to solar radiation and for this reason lamination materials such as polyurethane and silicone are used to increase its resistance. Nevertheless, it was determined that there is a significant decrease in the mechanical properties of the investigated fabrics after sunlight exposure. The fabrics aged under sun light become considerably weaker in the case of their mechanical properties. UV and IR radiation results in an important amount of degradation in both the dyestuff and macromolecular structure of the fiber.
- According to the breaking strength test results, photo aging affects the results of the blue, red, and turquoise samples under the conditions used in the experiments significantly. However, for the orange and white samples the breaking strength change was not found statistically significant.
- The turquoise sample lost approximately 50% of its initial tearing strength, while dark blue was over 30%. Tearing strength change of orange sample was found lower than 20%. The white sample was not nearly as affected from sun light exposure, by means of tearing strength, which emphasizes the importance of color in aging.
- Polyurethane and silicone coatings which were used on the turquoise sample support the material and therefore, the breaking strength loss of this fabric was found to be lower. However, these coatings decrease the elasticity of the fabrics and result in a higher bursting strength loss. In addition to this, they cause higher tearing strength loss, due to the decrease in the elongation of the yarns and decrease in the grouping ability of the yarns.
- In the air permeability test, no permeability value could be detected under the measurement conditions. Therefore, it is thought that 150 hours of photo aging does not change the air permeability value that could cause a safety problem during flight.
- It is thought thatthe blue, turquoise, and red paragliding fabrics are affected by sunlight exposure (photo aging) more than the other fabrics. This results in higher tensile strength loss in the fabric structure.

The use of paragliding fabrics exposes them to sunlight and therefore, there is an important amount of aging which changes the fabric properties significantly. The decrease in tensile properties and the increase in air permeability of the fabric can be accepted, to some extent, as a result of photo aging. However, if the air permeability of the fabric increases to a certain point, the paraglider loses altitude rapidly, which is not desired. In addition to this, a decrease in the tensile properties can also be of vital importance for not supplying the requirements for the needed strength values.

According to the results, it was concluded that selected paragliding fabrics lost some of their mechanical properties after sun light exposure, while the air permeability of the fabrics did not increase.

BIBLIOGRAPHY

[1] Moezzi, M., Ghane, M., Semnani, D. *Predicting the tensile properties of UV degraded Nylon66/Polyester woven fabric using regression and artificial neural network models*, In: Journal of Engineered Fibers and Fabrics, 10(1), pp. 1–11 (2015).

[2] Gies, P. *Photoprotection by clothing*, In: Photodermatol Photoimmunol Photomed, 23, pp. 264–274 (2007).

[3] CIE (International Commission on Illumination) Technical report, *UV protection and clothing*, CIE 172:2006 CIE Central Bureau, Vienna, Austria, (2006).

[4] Osterwalder U, Schlenker W, Rohwer H, et al. *Facts and fiction on ultraviolet protection by clothing*, In: Radiat Prot Dosimetry, 91(1), pp. 255–259 (2000).

[5] Galdi, A., Foltis, P., Shah, A. *UV Protecting composition and methods of use*, Application: US patent, 2010–118415 (2010).

[6] Pospisil, J., Pilar, J., Billingham, NC., Marek, A., Horak, Z., Nespurek, S. *Factors affecting accelerated testing of polymer photostability*, In: Polymer Degradation Stabilization, 91, pp. 417–422 (2006).

[7] Bojinov, V. B., Grabchev, I. K. *Novel functionalized 2-(2-hydroxyphenyl)-Benzotriazole-Benzo[de]isoquinoline-1,3-dione fluorescent UV absorbers: Synthesis and photostabilizing efficiency*, In: Polym Photochem Photobiol,172, pp. 308–315(2005).

[8] Goldshtein, J., Margel, S. *Synthesis and characterization of polystyrene/2-(5-chloro-2Hbenzotriazole-2-yl)-6-(1,1-dimethylethyl)-4-methyl-phenol composite microspheres of narrow size distribution for UV irradiation protection*, In: Colloid Polym Sci., 289, pp. 1863–1874 (2011).

[9] Yousif, E., Haddad, R. *Photodegradation and photostabilization of polymers*, In: Especially Polystyrene: Review, Springer Plus, pp. 1–32 (2013).

[10] Pal, S. K., Thakare, V. B., Singh, G., Verma, M. K., *Effect of outdoor exposure and accelerated ageing on textile materials using in aerostat and aircraft arrester barrier nets*, In: Indian Journal of Fiber & Textile Research, 36, pp. 145–151 (2011).

[11] Zweifel, H. *Stabilization of polymeric materials*, In: Springer-Verslag, Berlin Heidelberg (1998).

[12] Wypych, G., *Handbook of Material Weathering*, 4. Toronto: Chemtec Publishing, (2008).

[13] Hargrave, H. *From fiber to fabric*, In: The Essential Guide to Quiltmaking Textiles, 144 pages (2009).

[14] Sen, A.K. *Coated textiles principles and application*, In: International Standard Book Number 13: 978-1-4200-5345-6 (Hardcover), 34-1652008 (2008).

[15] Shishoo, R. (Edited by) *Textiles in sport*, The Textile Institute, CRC Press, Woodhead Publishing Limited, Stegmaier, T., Mavely, J., Schneider, P., *Part II Innovative fibres and fabrics in sport;* In: High-Performance and High-Functional Fibres and Textiles (2005).

[16] Singh, R. P., Tomer, N. S., Bhadraiah, S. V. *Photo-oxidation studies on polyurethane coating: Effect of additives on yellowing of polyurethane,* In: Polymer Degradation and Stability, 73(3), pp. 443–446 (2001), web: http://www.sciencedirect.com/science/article/pii/S0141391001001276 - COR1

[17] Bayer Material Science, *The chemistry of polyurethane coatings*, In: A General Reference Manual, web:https://www.pharosproject.net/uploads/files/cml/1383145151.pdf

[18] http://rtp.net.au/images/Understanding_Colour_Matching_Colour_Limitations_and_Colour_Fading.pdf

[19] Özdil, N., Kumaşlarda *Fiziksel Kalite Kontrol Yöntemleri*, Ege Üniversitesi Tekstilve Konfeksiyon Araştırma-Uygulama Merkezi Yayını, Yayın no: 21, 120 pages (2003), ISBN 975-483-579-9

[20] Bozdoğan, F. *Fiziksel Tekstil Muayeneleri (Kumaş Testleri*), Ege Üniversitesi Tekstilve Konfeksiyon Araştırma-Uygulama Merkezi Yayını, Yayın no: 32, 162 pages (2009), ISBN 978-975-483-860-2

[21] Okur, A. *Tekstil Materyallerinde Mukavemet Testleri*, In: Dokuz Eylül Üniversitesi Mühendislik Fakültesi Yayınları, No: 323, İzmir (2002).

[22] Saville, B. P. *Physical testing of textiles*, Woodhead Publishing Ltd, Cambridge England, ISBN 0849305683, 310 pages (1999).

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