(REFEREED RESEARCH)

USABILITY OF THE COLORED MICROFIBER TEXTILE SURFACES AS A BUILDING MATERIAL - EFFECT OF THE UV ABSORBENTS ON THE COLOR AND TENSILE STRENGTH

BOYANMIŞ MİKROLİF TEKSTİL YÜZEYLERİN YAPI MALZEMESİ OLARAK KULLANILABİLİRLİĞİ - UV ABSORBAN MADDELERİN RENK VE ÇEKME DAYANIMINA ETKİLERİ

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ABSTRACT

Continual growth and developments in material technology and fiber composites provide structures with new materials; contribute to the development of new and modern structures in architectural designs. Textile material used in architecture while serving various purposes, with these new technical features added, allows for the closing of huge spaces in architecture, particularly due to its lightness. Coverings that are used in construction systems are called architectural textiles. Surfaces are coated for resistance to weather conditions. Different textile coatings have improved for textile surfaces in recent years, making the material more durable. Woven and unwoven textiles have become more popular in an increasingly diverse market. In this study microfiber that is used in architecture, which is lighter than other textile materials, chosen as the textile material and is applied to the UV absorbent in different concentrations during the dying process. The effect of UV absorbant materials on the tensile strength and the color of the textile materials, which are exposed to a variety of different weather conditions were investigated. At the results of the study, it was detected that the UV absorbent on the colored microfiber textile material has positive effects on the color and tensile strength especially in the UV absorbent amount in the 3 % concentration among different ratios.

Key Words: Colored microfiber, Aging tests, UV absorbent, Color difference, Tensile strength, Building textiles.

ÖZET

Her geçen gün malzeme teknolojileri ve lif kompozitlerindeki gelişmeler yapıya yeni malzemeler kazandırmakta, mimaride çağdaş strüktürlerin gelişmesine katkıda bulunmaktadır. Mimaride kullanılan tekstil malzeme, kazandırılan teknik özellikleriyle yapıda çeşitli amaçlara hizmet ederken, özellikle hafifliği yönüyle mimaride geniş boşlukların kapatılmasına olanak sağlamaktadır. Tekstil mimarisi olarak adlandırılan örtüler, dış hava koşullarına dayanıklılık kazandırılması amacıyla kaplanmaktadır. Son dönemlerde tekstil yüzeyleri için geliştirilen çeşitli kaplamalar bu malzemeyi daha dayanıklı yapmakta, dokunmuş veya dokunmamamış tekstiller bu pazarda çeşitlenerek artmaktadır. Bu araştırmada mimaride kullanılan diğer tekstil malzemelere göre daha hafif olan mikrolif tekstil malzemesi seçilerek, boyama işlemi sırasında üzerine değişik konsantrasyonlarda UV absorban madde uygulanmış, bu maddelerin dış hava koşullarına maruz bırakılan tekstil malzeme üzerindeki renk ve çekme dayanıma etkileri araştırılmıştır. Çalışmanın sonucunda renklendirilmiş mikrolif tekstil malzeme üzerindeki UV absorban maddelerin farklı oranları arasından özellikle %3 konsantrasyondaki UV absorban madde miktarının malzemenin renk ve çekme dayanımını olumlu yönde etkilediği görülmüştür.

Anahtar Kelimeler: Boyanmış mikrolif, Yaşlandırma testi, UV absorban madde, Renk değişimi, Çekme dayanımı, Yapı tekstilleri.

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1. INTRODUCTION

Continual growth and developments in material technologies and fiber composites introduce new materials to structures, which in turn contribute to the development of contemporary structures in building systems. In recent years, textile materials, besides their functional use, are opted for in contemporary building structures because of their aesthetical properties and because of the architectural design opportunities they provide. The textile material used for architecture serves various purposes in the structures. For instance, they provide technical specifications; and its lightness especially enables its durability. While making it possible to design very complex structures by the means of availability, technical textile groups particularly attain many application fields by the way of functionality (1).

The structures, in recent periods, do gradually lighten and activate with the textile materials used in the tensile system applications; and they are more environmentally-friendly due to nano technology. The textiles that are generally used on structures consist of woven or non-woven in various types of fibers, and coated or uncoated materials such as teflon, polypropylene, polyester. Furthermore, nylon (2), PVC (polyvinylchloride)-coated polyester fabric has been used for membrane buildings since the 1950s. Since the 1970s PTFE- coated glass fabric has proved its worth in an increasing number of excellent membrane constructions and transparent high-performance ETFE foil, which is often used in double- or triple- layer pneumatic constructions, has secured its own special place in this field of use. On the other hand the technologies used in working with these materials have now reached a high level of sophistication and every aspect of their long-term performance is known and documented. Furthermore, for each of the materials mentioned a wide range of different material strengths can be produced as standard (3). Nowadays, many textile materials have been investigating in the subjects of, fiber, weawing and coating.

In this study, while the usability of microfiber material has been researched, it's adaptation to framed systems has also been investigated. For this reason, tensile strength tests have been performed. The textile material that is investigated for outdoor use were fibers, termed microfibers, which are produced from various chemical raw materials in the textile industry and are thinner than synthetic fibers. Microfibers can be defined as fibers which are 1.0 dtex or thinner or filaments (4). Microfibers are generally produced from polyester and nylon polymers. The pitches in the woven fibers can be 30 000 filament cm^{-2} because of their thin diameters and tight intertextures. This feature enables the circulation of air and water steam as well as its impermeability against e water.

A microfiber has a larger surface since it contains four times more fibers, compared with a normal fiber, at the same volume. As the fibers get thinner, the softness and looseness of the product increases. Moreover, with the addition of the polyester's features such as non-creasing, ease of cleansing, fast drying, and size stability, the products that are produced from microfibers have a wide variety of usage areas.

The microfibers also enable protection against wind and rain since the pores between their fibers and threads are small. Although there are many existing textile materials that provide these features, the fact that microfiber material enables the passing of air and water steam at the same time makes it possible to use this material in frame coated systems or covering systems.

It is required that the microfiber used in the structure- like the case in other building materials- should have the determined lifespan and the necessary functions. The durability in the textile surfaces is enabled basically enabled by fiber components and coating materials applied over the surface. The durability is resistance against the conditions which cause a decrease in the material's endurance and other mechanical properties, fading in color, and crushing factors.

The most important external climatic factor is the effect of ultraviolet rays. As a consequence of ultraviolet rays, negative changes in the structure of the material can be encountered. While the changes occur in the external temperature of the material from the effect of sun radiation, some chemical changes also occur in its internal structure. In example, α particles, brought forth by UV rays, ruin the molecular structure of organic materials especially, and cause wear and color changes (5). Oxygen in the environment can interact with other chemical groups and can accelerate these reactions (6).

The UV absorbent can be effective on textile products by decreasing the UV ray transmissivity's degree of packing, and enable protection by obstructing the negative effects of the received sunlight on the material. UV absorbers have an ability to decrease the UV transmittance degree on fabrics and provide solar protection These materials are applied during the fiber production or ending procedures (7- 10).

The UV absorbents are the substances which have the features to absorb UV radiation at a significant level and returning this absorbed energy without harming the environment, with organic (o-hidroxybenzophenone, o-hidroxyphenylbenzotriazole, and o-hidroxyphenyltriazine compounds) and inorganic (titanium dioxide etc.) structures (11).

The effect mechanisms of the UV absorbent on the various structures of different polymer materials are well documented in a variety of academic studies: In a study conducted on colored polyester textiles, in which the effect of UV protection factors are examined, it was observed that UPF (Ultraviolet Protection Factor) increased on dark colored, double-layered fabric that was last treated with the UV absorbent (11); and the UPF value reached very high levels in a study in which single coloring agents and benzotriazole-based UV absorbents are applied to three different types of cotton fabrics (12).

In the study on polypropylene fibers, in which the effect of UV densities on the fiber strength was examined by applying outdoor climatic conditions and accelerated outdoor tests, on the other hand, demonstrated that UV density affected the tensile strength, compared with the original sample, a decrease in the tensile strength values with a ratio of 55.32% in outdoor conditions after one year was observed while the tensile strength value decreased with a ratio of 54.89%, as regards to the UV density, in the accelerated conditions after 280 hours (13).

Studies also exist regarding the comparative investigation of benzotriazole-based UV absorbent on the light fastness of colored polyester fibers (14), examinations of the fabric-color relation of the degradation caused by the effect of absorbent in which benzotriazole derivatives are used (15) and investigations of the proportions and effects of the color, and UV absorbent on the light and sublimation fastness values of the colored polyester samples on which two different benzotriazole derivatives are used as the UV absorbent (16). In the study regarding the investigation of the effect of UV absorbent concentration on color durability (17) and tensile strength features of the uncolored and colored microfiber material after aging, on the other hand, it was stated that the UV absorbent contributed positively to the color durability. However, this contribution was not related to the concentration of the UV absorbent (17, 18).

In this study, by using the UV absorbent for the purpose of protection against the effects of UV radiance that initiates the degradation in the materials, the effect of absorbent, at different concentration the color change and tensile strengths were investigated.

2. MATERIAL AND METHOD

2.1. Materials

In this study as a textile material, 100% polyester microfiber fabric with wefts or a warp thread count of 72 Td and 70 Td, respectively and twill 2/1 Z pattern, which does not contain optical whitener and has 40 ends/cm warps and 36 picks/cm at 115g/m² were used. As coloring agent, Foron Blue ASBL was used. Benzotriazole derivate was used as an UV absorbent disperser. And also, Setalan DFT – Setas; Setacid PBN2- Setas materials were used for buffer substance.

The characteristics of the test samples used in the test and their codes are presented in Table 1. The samples containing no UV absorbent and UV absorbent at four different concentrations were grouped as aged and unaged colors. Each code represents five samples.

Table 1. Test samples

Code	Unaged Colored Fabrics
1	Fabric containing no UV absorbent
2	Fabric containing 1% UV absorbent
3	Fabric containing 2% UV absorbent
4	Fabric containing 3% UV absorbent
5	Fabric containing 4% UV absorbent
	Aged Colored Fabrics
6	Fabric containing no UV absorbent
7	Fabric containing 1% UV absorbent
8	Fabric containing 2% UV absorbent
9	Fabric containing 3% UV absorbent
10	Fabric containing 4% UV absorbent

2.2. Methods

2.2.1. Preparing Experimental Samples

Application of the UV Absorbent and Coloring Agent on the Fabric:

In the coloring of the test samples and applications of the UV absorbent, laboratory type HT coloring machine (Polimat HT Sample Coloring Machine – Type A11612 N–Emsey Technics) were used, while the Weatherometer Xenotest 150 S-ATLAS-device was utilized in the accelerated aging tests of the fabrics.

The application consisted of coloring and the UV absorbent in the same bath, on the microfiber fabric were implemented by using the Foron Blue ASBL coloring agent and UV absorbent (Liquid benzotriazole derivate). For the homogenous distribution of the UV absorbent in the solution, disperser (Setalan DFT) was utilized; and, for leveling the pH value of the medium, the buffer substance (Setacid PBN2) was used. The procedure was started at 30°C then; the temperature was increased to 130°C, at a rate of 1.5°C/min, and finally, the application was performed at this temperature for 30 minutes. Next, the samples were rinsed in the coloring machine, with a liquior ratio of 1/50, at 30°C for 5 minutes. Following this process, they were dried in the open air without any pressure; every application was repeated five times. The coloring and UV absorbent applications during the coloring process were performed, according to the formula displayed in Table 2, by using the saturation method.

Table 2. Coloring and UV absorber application recipe

Material amount	: 1.9 grams
Liquior Ratio	: 1:20
Foron Blue ASBL	:1%(a.m.w.)
Liquid -UV absorbent	: 0%, 1%, 2%, 3% and 4%
Setalan DFT disperser	: 0.8 g/l
Setacid PBN2 Bufer Substance (pH 5.5)	: 0.5 g/l (pH: 5.5)

2.2.2. Accelerated Aging Tests

Accelerated aging tests were performed on the microfiber colored fabric samples which were conditioned according to TS EN ISO 139: 2006 (19). The ASTM E 632-82 standard (20) was used for the selection of the method to be carried out to determine the durability of the material in the usage period. During the test process to determine the effects of the UV light, temperature, and water on the test samples (21), EN ISO 105- B04: 1997 standard (22) was used.

The Weatherometer test mechanism, used in these tests, consists of the 2200 W xenon arc lamp with air cooling features, a filter system that simulates sunlight or outside air conditions behind a SPD glass, a rotating sample shelf with a capacity of 1320 cm^2, rain spraying system, black standard thermometer that can control the temperature of the test volume and a ultrasonic humidifying system.

In the accelerated aging mechanism, the value of radiation radiance in the interval between the xenon arc dispersion and the 300-400 nm wavelengths is 42 W/m^2. This value of 42 W/m^2 was kept constant to prevent the possibility that, the[accelerated purposed dense radiation radiance compared to the natural medium conditions, it would not be realistic, and the high values obtained in the test parameter would cause degradations that would not occur in reality (20, 21, 22, 23). The values taken for establishing relations with Turkey's climate conditions for the South of France was selected, among the climatic conditions programmed in the test mechanism, and the calculation methods developed by the Atlas Firm were used. The required calculations for the simulation of outdoor conditions enabled by the mechanism, and the annual mean radiance dispersion ratios, to be used in the calculations, are presented in Table 3 and Formula 1 (23).

Table 3. Years based on average radiation circulation ratio (23)

Region	295-3000nm Global, MJ/m^2	295-800 nm UV+ Visible, MJ/m^2	295-400 nm UV MJ/m^2
Florida	5850	3400	355
Arizona	8000	4600	485
Central Europe	3550	2050	215
South of France	5000	2900	300

$$t\ (s) = \frac{\text{Radiation Radiance (H) (Ws/m}^2\text{)}}{\text{Radiance (E) W/m}^2} \qquad t\ (h) = \frac{H}{E\ \text{W/m}^2 .3600} = \frac{300.10^6}{42.\ 3600} = 1984\ \text{h} \quad (1)$$

The test samples were positioned at an angle of 90° and 100 mm away from the light source, corresponding to discoloration in the 7- L8 level of the wool reference, for 320 hours; being exposed to 1 minute for sprinkling and 29 minutes for the drying period at 40% humidity medium (19). For the use of investigated material in the structure, it was considered that taking radiance angle at 90° would affect the results; thus the discoloration period was doubled (640 hours) by corresponding it to the condition of material and a radiance angle of 45° (24).

2.2.3. Color Measurement Tests

In the color measurements, performed by using the Datacolor Spectra Flash 600 plus reflectance spectrophotometer, the CIE L*a*b* system was taken as the basis (25); the reflectance % values of the samples at 350-700 nm wavelengths with intervals of 10 nm; and the color values according to ΔL*(lightness-darkness), Δa*(red-green axis), Δb*(yellow-blue axis), and ΔE*(total color difference) were also determined. The color measurements were performed in the conditions determined by the standard using the 10° observer and the D65 light source.

2.2.4. Tensile Strenght Tests

In the tension-stress tests conducted by using the Instron 4411 (100±10 mm/min) device, the ASTM D5035-1995 standard was used (26). Each sample, was taken at 25±1 mm in width and 150 mm in length; and five measurements were performed in a warp direction for each measurement result.

3. RESULTS AND DISCUSSION

The color measurement results, and tensile strength and elongation % values of the colored test sample that contains no UV absorbent (Code 1, 6), and colored test samples containing the UV absorbent at different concentrations before (Code 2, 3, 4, and 5) and after the aging procedure (Code 7, 8, 9, and 10) were compared.

3.1. Color Measurement Results

The first step, for the unaged fabrics, the sample that contains no UV absorbent (Code 1) was accepted as standard and then compared with the samples containing UV absorbent at different concentrations (Code 2, 3, 4, and 5) (Table 4, Figure 4). A reflectance was used and the test period % values for the test samples in this group were measured at 360-700 nm with intervals of 10 nm; and the curves formed from the results of these measurements were displayed.

In the next step the aged fabrics were evaluated. By accepting the colored sample that contains no UV absorbent (Code 6) as the standard, it was comparatively used and the test period evaluated with the samples containing UV absorbent at different concentrations (Code 7, 8, 9, and 10) (Table 5).

When the measurement results are evaluated, it was determined that the “unaged” colored sample containing 1% UV absorbent’s (Code 2) color lightened (ΔL*); its green and blue nuance increased (Δa,* Δb*); and a difference in colors was observed. In the “unaged” colored sample containing 2% UV absorbent (Code 3), on the other hand, the color darkened; the red and blue nuance increased; and a color difference was observed. The “unaged” colored sample containing 3% UV absorbent’s (Code 4) color lightened; its green and blue nuance increased; and the color difference was found to be between the acceptable values (ΔE*≤ 1). Lastly, for the “unaged” colored sample containing 4% UV absorbent (Code 5), the color lightened; the green and yellow nuance increased; and a color difference occurred (Table 4).

Table 4. Color measurement values before the aging procedure (CIEL*a*b*/10°/D65)*

Code No- UV absorbent concentration	Δ E *	ΔL*	Δa*	Δb*
Code 2 – 1 %	1.79	0.31	-0.73	-1.61
Code 3 - 2 %	1.25	-1.04	0.63	-0.30
Code 4 – 3 %	1.04	-0.22	-0.84	-0.56
Code 5- 4 %	2.10	0.41	-2.01	0.46

Table 5. Color measurement values after the aging procedure (CIEL*a*b*/10°/D65)*

Code No- UV absorbent concentration	ΔE*	ΔL*	Δa*	Δb*
Code 7 - 1%	2.38	0.99	-0.08	2.16
Code 8 - 2 %	1.58	-1.28	-0.20	- 0.91
Code 9 - 3 %	0.72	0.01	-0.14	0.71
Code 10 - 4 %	2.50	-1.30	-0.04	2.13

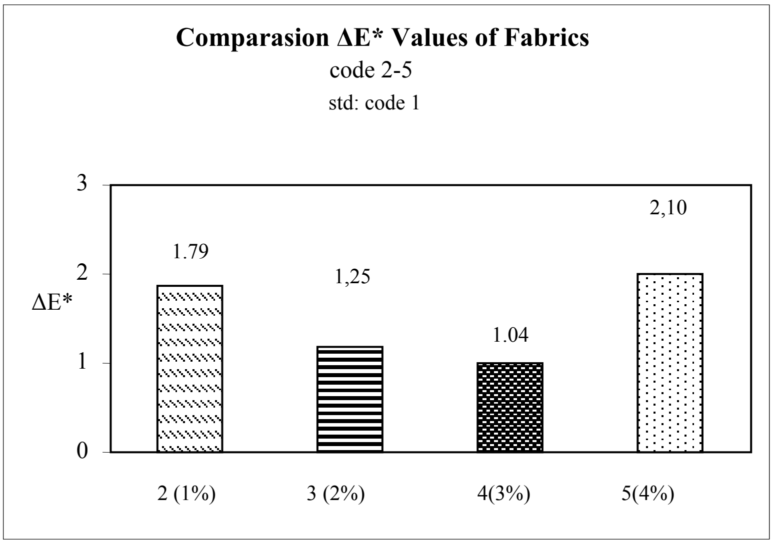


Figure 1. ΔE* values of the fabrics (Code 2-5) before aging

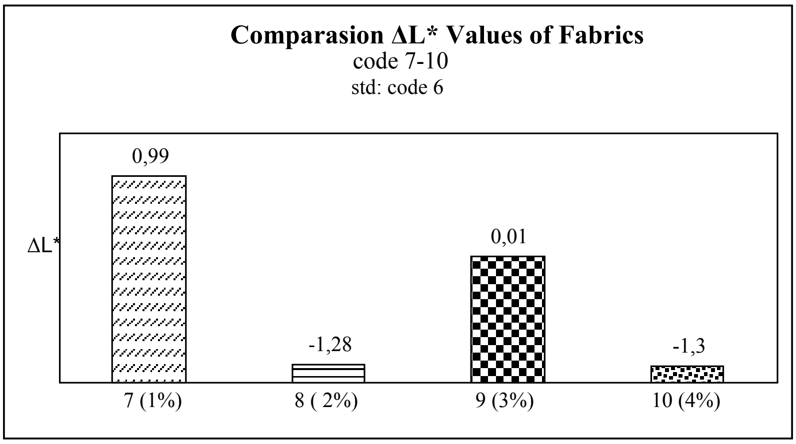


Figure 2. ΔL* values of the fabrics (Code 7-10) after aging

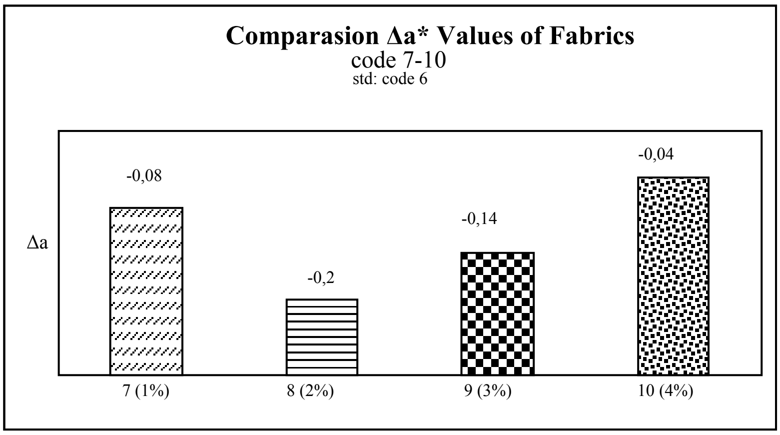


Figure 3. Δa* values of the fabrics (Code 7-10) after aging

When the values obtained "after the aging procedure" are compared, for the "aged" colored sample containing 1% UV absorbent (Code 7), it was found that the color lightened; the green and yellow nuance increased; and a color difference was observed. The aged colored sample containing 2% UV absorbent's (Code 8) color darkened; its green and blue nuance increased; and a difference in colors was observed. For the aged colored sample containing 3% UV absorbent (Code 9), however, it was found that the color lightened; the green and yellow nuance increased; and the color difference (ΔE*) was found to be between the acceptable values for this fabric sample (ΔE*≤ 1). It was determined that the aged colored sample containing 4% UV absorbent's (Code 10) color darkened; the green and yellow nuance increased; and a color difference occurred Table 5 and Figure 1- 5.

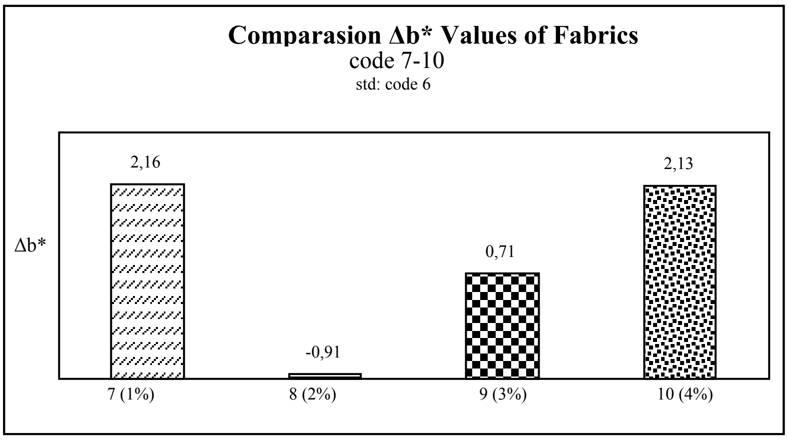


Figure 4. Δb* values of the fabrics (Code 7-10) after aging

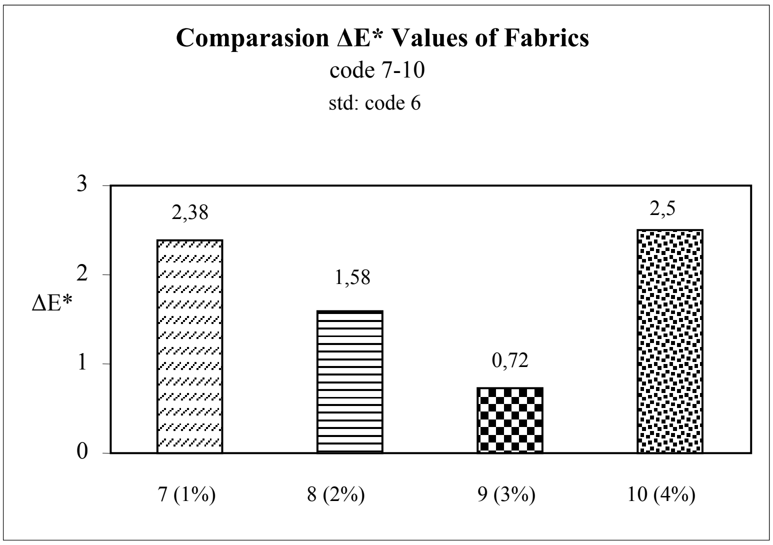


Figure 5. ΔE* values of the fabrics (Code 7-10) after aging

When the effect of the ratios of the UV absorbent content on the color change occurring in the material was evaluated, by accepting the aging test results as data, it was observed that the total color change values (ΔE*) belonging to the fabric containing 3% concentration of the UV absorbent was between the acceptable values (ΔE*≤1) (Figure 5).

When the reflentance % curves of the test fabrics before and after the aging procedure were examined, it was determined that the maximum absorption of the coloring agent, as its characteristic feature, did not change on all the test fabrics; and this value was found to be λmax = 620 nm.

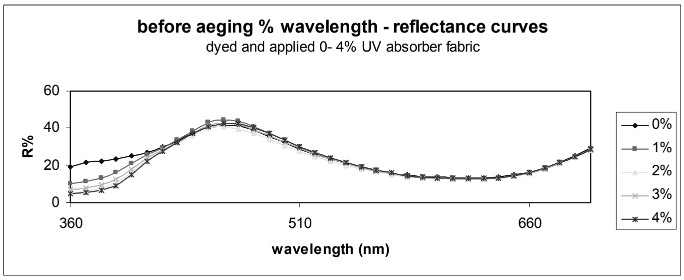
Moreover, it was observed, for all the unaged and aged samples, that the increase in the UV absorbent concentration was not effective on the maximum color absorption, (λmax) which is a characteristic feature of the coloring agent (Figure 6).

UV resistance tests of the fabrics, were made according to UV visibility of spectrofotometer (Labsphere Transmittance Analyzer, SDL ATLAS / M284D) and AS/NZS 4399: 1996 standarts). The samples' of UV transmitances ranged from 290 nm to 400 nm were measured. Interspaces between the samples were 5nm. Also each samples' UPF (Ultraviolet Protection Factor) were calculated according to the same standards.

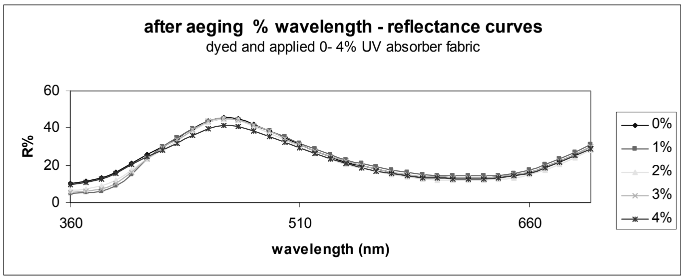
For the white sample without UV absorbent, the UPF value was 61,74 before and after ageing process were 268,71 and 268,75.

As a result it's stated that, ageig process did'nt affect UPF value of the UV absorbant applied samples negatively.

Furthermore, the fact that 320 hours, which corresponds to the value of "7" that keeps the discoloration degree constant according to the Blue Wool Standard (Table 6), was used as the test period and this value was described as excellent according to the light fastness in the standard, indicated that the selected colored material could be suitable for long term outdoor use.



(a)



(b)

Figure 6. Wavelength- Reflectance % curves of colored fabrics, which contain and does not contain UV absorbent, (a) before and (b) after aging procedure

Table 6. (1-8/ L2-L9) Light Exposure Conditions for Blue Wool Reference (1-8/ L2-L9)

Fastness values / Reference values	**Assessment**	**Colour Index No**	**Colour Fading Period (**hour)
1 - L2	very poor	C.I.Acid Blue 104	5
2- L3	poor	C.I.Acid Blue 109	10
3- L4	fair	C.I.Acid Blue 83	20
4- L5	average	C.I.Acid Blue 121	40
5- L6	good	C.I.Acid Blue 47	80
6- L7	very good	C.I.Acid Blue 23	160
7- L8	excellent	C.I.Sol.Vat Blue 5	320
8- L9	outstanding	C.I.Sol.Vat Blue 8	640

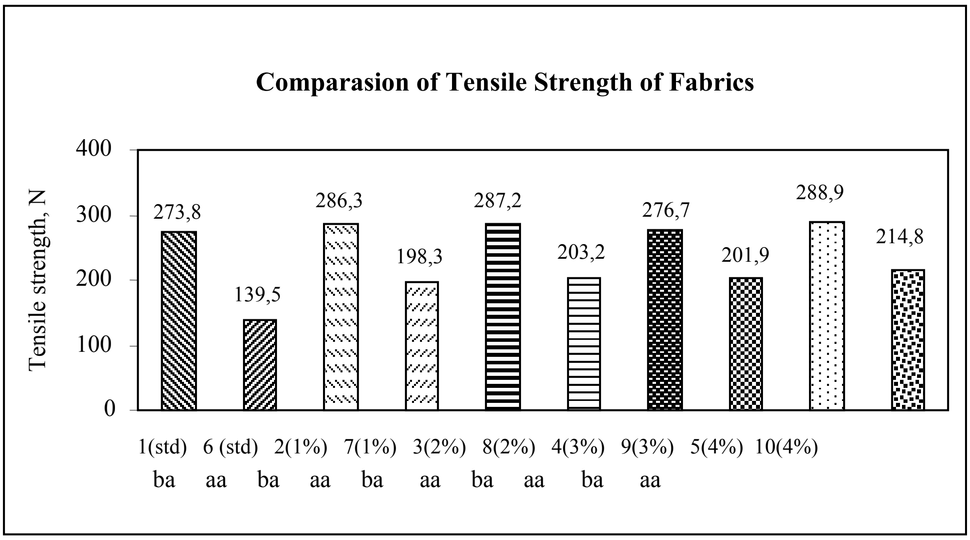
3.2. Comparison of the Tensile Strength and Elongation Values

In the tensile strength test systematic, the samples which contain no UV absorbent and the samples which contain UV absorbent different concentrations were first compared with each other as unaged and aged.

The tensile strength and elongation % values of the colored samples that contain no UV absorbent material (Code 1, 6), and samples that contain %1 (Code 2, 7), %2 (Code 3, 8), %3 (Code 4, 9), and %4 (Code 5, 10) UV absorbent material were compared with each other (Figures 7, 8).

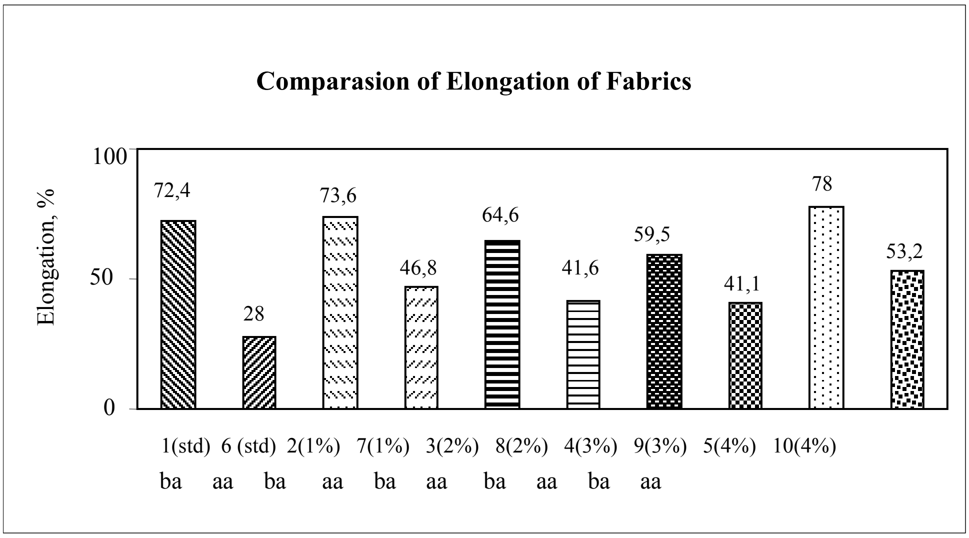
As can be seen in Figures 7 and 8; for each test sample, decreases were observed in their tensile strength and elongation % values of before and after the aging procedure.

When the aging test results are accepted as data and the effect of the UV absorbent concentrations used on the material on the tensile strength and elongation % values are examined the tensile strength and elongation % ratios of the microfiber fabric that contain no UV absorbent displayed a decrease in ratios that extends to 50%. As the content of the UV absorbent applied on the fabric increased, the tensile strength and elongation % values of the textile material decreased.



ba: before aging **aa:** after aging

Figure 7. Comparasion of the tensile strength values before and after aging



ba: before aging **aa:** after aging

Figure 8. Comparison of the elongation % values before and after aging

Table 7. Decrements in the tensile strength and elongation % values before and after aging

UV absorbent material	Tensile loss (%)	Elongation % loss
0 %	49.0	61.3
1 %	30.7	36.4
2 %	29.2	35.6
3 %	27.0	31.0
4 %	25.7	32.0

4. CONCLUSION

When all of the results are evaluated, microfiber polyester fabric, as being lighter when compared with all the other textile materials, was observed to be suitable for use in the systems in which lightness is preferred; and differing from other fabrics, the application of a coloring agent that contains UV absorbent can be made on this one. It was also identified that outdoor use of a textile item containing the UV absorbent contributed positively to the color and tensile strength values of the material.

When the correlation with “Formula 1” is established, it was observed that the discoloration was kept constant after a (1984 / 640 = 3.1 ratio) 12 months/ 3=“4” months.

The total color difference values belonging to the application of 3% the UV absorbent concentration being at the desired interval, especially, and the fact that the tensile strength loss is at low levels at this ratio, makes this concentration preferable. Moreover, the losses in the elongation % values were the lowest for the 3% UV absorbent concentration; and these findings indicate that this fabric can be used in the "tensile systems".

With the application of other additional coating materials for the purpose of increasing strength, the effectiveness degree of the materials and comparisons of the strength values belonging to colored and uncolored fabrics could be evaluated in future studies.

Symbols

λmax: Maximum absorption

CIE; Commission Internationale de l' Éclairage

D65: Daylight 6500 ° K

Twill 2/1 Z pattern: texture that forms diagonal lines from left towards upper direction on the fabric

Liquior Ratio: g material / ml solution

g/m^2 : Weight of the 1 m^2 fabric in grams

H: Radiation radiance, E: Radiance

h: hours

L*: (+)lightness- (-) darkness,

Δa*: (+)Red, (-)green axis,

Δb*: (+)Yellow,(-)blue axis,

ΔE*: Total color difference

a.m.w: according to the material weight

N: Newton (force unit)

Nm: Nanometer - 1×10^{-9} m

pH: Power of Hydrogen, it is a measurement unit that defines the acidity and basicity level of solution

SPD cam: Suspended Particle Devise

Td: Titer denier, its number is 1Td for 9000 m thread at 1 gram weight.

tel/cm: Number of wefts or warp threads for 1 cm fabric

UV: Ultraviolet, UPF: Ultraviolet Protection Factor

W/m^2: MJ/m^2: Radiation radiance

ba : before aging,

aa : after aging

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