

Asian Journal of Chemistry; Vol. 28, No. 6 (2016), 1229-1233

ASIAN JOURNAL OF CHEMISTRY

<http://dx.doi.org/10.14233/ajchem.2016.19632>



Application of Laser Treatment for Enhanced Dyeability and Comfort Properties of Bleached Cotton/Polyester

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Received: 22 September 2015;

Accepted: 2 January 2016;

Published online: 29 February 2016;

AJC-17781

In this study, the effect of laser CO₂ irradiation on the dyeability of the bleached cotton/polyester fabric was studied. The fabric samples have been treated with laser CO₂ irradiation under three different lasers CO₂ power before dyeing, hot reactive dye was used for dyeing goods. CIE LAB colorimetric system was used for determination of colour difference between treated and untreated fabrics. The morphology of treated fibers was characterized by scanning electron microscopy. Scanning electron microscopy images indicate changes on the surface of fiber. The colour changes (ΔE^*) of samples are increased with laser CO₂ pre-treatment and also those samples with laser CO₂ pre-treatment are yellower in colour. The results confirmed that the laser treated fabrics higher light fastness and wet fastness, while tensile strength of fibers was affected adversely by laser irradiation. The laser CO₂ irradiation had positive effect on the wet ability of the bleached cotton/polyester fabrics as the bleached cotton/polyester fabrics became more hydrophilic. The laser irradiation also caused more air permeability the bleached cotton/polyester fabrics.

Keywords: Bleached cotton/Polyester fabric, Laser CO₂ Treatment, Changes colour, Morphology study.

INTRODUCTION

Laser treatment has been vastly employed in textile industry in recent years [1-5]. In textile, surface modification by chemical finishing methods is not environmental friendly and can cause safety and pollution problems [5,6]. As a result, laser technology applied as physical treatment methods is becoming more public and can be used in different applications to bring about an improvement and even omit several difficulties from the traditional methods [7-11]. Among different laser treatments, only laser engraving or the engraving process allows short-time surface designing of moulds with delicacy [12], desired variety, size and intensity for a wide range of textile surfaces, including knitted or woven fabrics, with minimum damage to the materials at a selected wavelength and laser power density [3,13,14].

UV lasers are used for the modification of fiber surfaces due to their high absorption of UV laser light. UV laser treatment changes the properties of synthetic fibers such as adhesion, wetting and optical in polyamide and polyester. This process can be exactly due to low wavelength of radiation. IR laser light irradiates only a few layers of fiber in textile structure

during one irradiation. Deep influence of IR laser light is caused by lower absorption of this light into the polymer. IR lasers provide a wider field of application due to cheaper light sources working with higher energy output and no use of toxic gases. CO₂ lasers, which produce light with a wavelength of 10.6 μm , are used for creation of the patterned denim fabrics in the textile industry as an alternate method to usual techniques for the fading process [15]. An infrared laser is a suitable tool for the discoloration of indigo-dye on denim fabric. In comparison with usual techniques of processing denim fabric, a laser beam provides some benefits, *e.g.*, it is environmental friendly with respect to the consumption of chemical agents, has low water consumption and offers flexibility of the process and replications of designs [16].

CO₂ lasers use a mixture of gases such as helium and nitrogen, with CO₂ being the most predominant to create a cut quality similar to that of milled edges of mild steels and can operate in continuous wave (CW) or pulses. In textile and garment industry, the CO₂ gas laser is widely and successfully applied [17].

In this research, the influences of the laser CO₂ with diverse power on dyeability of the bleached cotton/polyester fabric were studied.

EXPERIMENTAL

The bleached cotton/polyester fabric with the following characteristics was utilized from Yazd Baft Co.: weight 1688.55 g/m², width 140 cm. The fabric was washed at first and then was air-dried at room temperature. Drimarene Blue X-BLN (Reactive Blue 198) with chemical structure as showed in Fig. 1 was used.

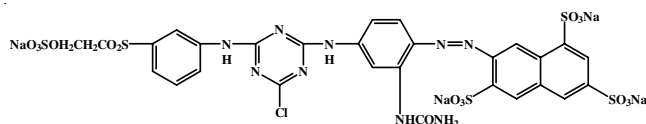


Fig. 1. Chemical structure of Reactive Blue 198

Laser engraving treatment: The laser treatment on fabrics surface was carried out Using PN-1490, a commercial pulsed CO₂ laser machine manufactured by Hans Yueming Laser. The treatment was carried out with three different powers (4.5, 5.25 and 6 w). The scanning rate of beam was set at 15 mm/min and the intensity of laser was set at 250 dpi. The samples have been irradiated before dyeing, also there were irradiated two different temps: aside and two sides' fabric.

Dyeing: The bleached cotton/polyester fabrics were steeped in the dye bath with liquid-to-goods ratio of 50:1 prepared by 1 % o.w.f. dye, 1 % NaOH and NaCl. The dyed samples were rinsed with cold water and finally dried at ambient temperature (Fig. 2).

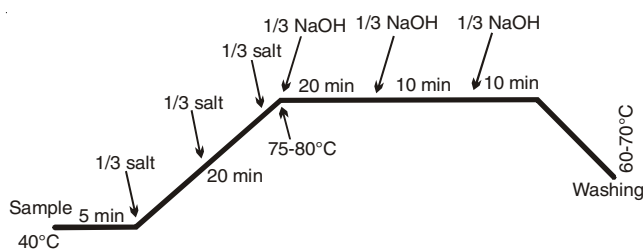


Fig. 2. Dyeing graph

Colour difference measurements: Colour quantity, quality and spectrum were evaluated by means of CIE L*a*b* system for the original and treated fabrics and the CIE L*a*b* parameters were calculated for the CIE illuminant D₆₅ and 10° standard observer conditions.

UV-visible spectroscopy: Ten different concentrations of reactive dye (0.005, 0.006, 0.007, 0.008, 0.009, 0.01, 0.02, 0.03, 0.04 and 0.05 g/mL) were prepared and their absorbance was obtained by UV-visible spectrophotometer. We selected maximum of absorbance, then based on the measuring absorption and concentration of the solution chart of absorption (Y) on the concentration (X) is plotted and following equation was obtained:

$$Y = 0.0367 \times X + 0.015 \quad (1)$$

where Y is UV absorbance of dye in maximum wavelength and X is density of dye in maximum wavelength. Then we obtained concentration of dye in west water measurements from equation.

Determination of colour fastness: The wash-fastness properties of the samples were measured according to ISO

105-C01 and ISO 105-X12. The colour hue changes of the fabric and the degree of staining on the adjacent fabrics were measured after drying. For light-fastness measurements, the fabrics were exposed to the daylight for 4 days according to the daylight ISO 105-B01 and the changes in the colour were assessed by the blue scale.

Tensile strength: Tensile strength of fabric strips was determined as described in ASTM-D 5035. An INSTRON 4411 tensile testing machine (INSTRON Corporation, Canton, MA, USA) was used to obtain the tensile strength of the untreated and treated testing specimens. The samples were balanced at 25 °C and a relative humidity of 60 % for 24 h before testing. The samples were in dimension of 200 mm × 30 mm and were experimented in the warp directions. The distance between the grips was fixed at 100 mm with a pulling speed at 60 mm/min.

Scanning electron microscopy: The morphology of samples was investigated by scanning electron microscopy (SEM) (XL30, Netherland) and all of the samples were gold-coated (Swiss, Bal-Tec Co.).

Comfort properties: The vertical drop test was carried out on fabrics with BS 4554. A drop of distilled water was placed onto the fabric sample and the time for which the liquid required to sink into the fabric completely was recorded. The more wettable fabric, shorter the time was required. Also, the contact angle with water droplet (volume 4 μL) was carried out by a system that is equipped with software for measuring the contact angle. This system is produced by Dataphysics Co. (OCA 15 plus).

A Shirley air permeability tester was employed to measure the air permeability of the fabric samples based on BS 5636; the air permeability in this test is defined as the volume of air in milliliters passed in 1 s through 5 cm² of the fabric at a pressure difference of 100 Pa. The equation 2 was used to calculate the air permeability of the samples.

$$\text{Air permeability} = \frac{\text{Air flow}}{5} \quad (2)$$

RESULTS AND DISCUSSION

Testing of laser engraving: The samples of bleached cotton/polyester were treated by laser engraving under different powers. The results show that the lower power of 5.25 w made slight damage on fabric surface; with the higher parameter of 6 w, it could burn the fabric. It also shows that the ideal power for laser treatment is 4.5 w.

The L*, a*, b*, C and h* values of bleached cotton/polyester of irradiated and untreated, are given in Table-1. These samples have been irradiated aside' and two sides' fabric. The results of aside' samples show that an increase in power of laser leads to a minute change in L*, a*, an increase in b* and C that shows yellowing and brightening on treated sample and a decrease in h*, also the results of two sides' samples show that increase in power of laser leads to an increase in L*, a*, b* and C and a decrease in h*. It means that increase in power of laser leads to an increase in yellow colour and brightness of samples. Fig. 3 shows the ΔE* (colour difference intensity) of the treated fabrics of aside' and two sides'. The results show

TABLE-1
COLORIMETRIC PROPERTIES OF BLEACHED COTTON/POLYESTER BEFORE DYEING

Colour properties	Aside				Two sides			
	Untreated	4.5 w	5.25 w	6 w	Untreated	4.5 w	5.25 w	6 w
L*	95.4	95.5	95.7	96.6	95.4	95.5	95.9	95.9
a*	-0.6	-0.6	-0.6	-0.6	-0.6	-0.6	-0.5	-0.5
b*	-0.5	-0.2	1.0	2.0	-0.5	0.0	1.8	2.0
C	0.8	0.6	1.2	2.1	0.8	0.6	1.9	2.1
h°	215.9	196.2	121.9	106.8	215.9	177.3	107.4	103.1

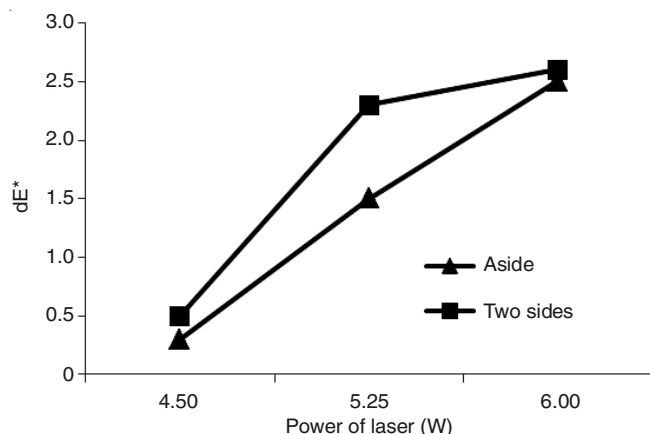


Fig. 3. Colour change of bleached cotton/polyester before dyeing

that increase in power of laser leads to an increase of ΔE^* of samples. The process of laser irradiation on bleached cotton/polyester is likely to damage the surface and oxidation of cellulose that lead to reduced white.

Colorimetric measurements: Quantity, quality and spectrum of colour were evaluated in CIELAB colour space, the three axes being L^* , a^* and b^* . The L^* is the colour coordinate which represents the lightness of samples and can be measured independent of the colour hue. Any decrease in the lightness of samples could be concluded as the lower reflectance of textiles. The a^* stands for the horizontal red–green colour axis. The b^* represents the vertical yellow–blue axis. The C^* shows the brightness or dullness of the samples. Any increase in the C^* of samples could be concluded as greater brightness of the composite. The hue angle (h°) stands for hue, which is the actual colour recognized by the human eye and identified as orange, yellow, beige, brown, pink or any of the other colours visible to humans. It is expressed in degrees, with 0° being a location on the $+a^*$ axis, continuing to 90° for the $+b^*$ axis, 180° for $-a^*$, 270° for $-b^*$ and back to $360^\circ = 0^\circ$.

The L^* , a^* , b^* , C and h° values of laser-treated dyed bleached cotton/polyester fabrics and untreated, are given in Table-2. The results of a sides' and two sides' samples show

that increase in power of laser (until 6 w) leads to a decrease in L^* that this decrease is related to more dyes penetration into the fabrics which allows the results of exhaustion values; while in power of 6 w, less dyes penetration into fabric could be due to damage pores. Fig. 4 shows the ΔE^* of the treated fabrics, the results show that increase in power of laser leads to an increase of ΔE^* .

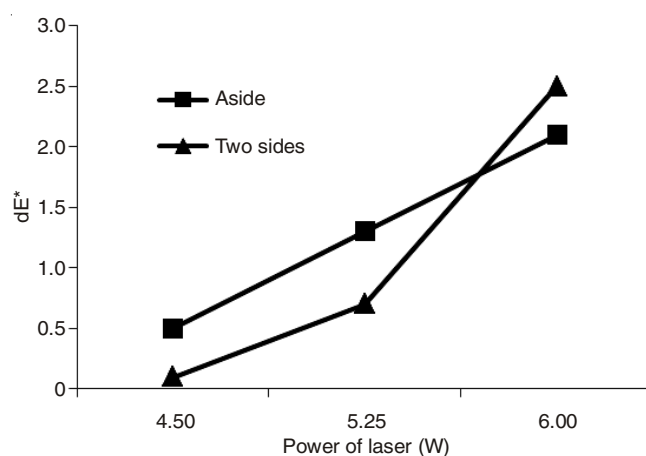


Fig. 4. Colour change of bleached cotton/polyester

UV-visible spectroscopy: Fig. 5 reveals concentration of dye in wastewater for bleached cotton/polyester (aside' and two sides' fabric of irrational). The results show that the increase in power of laser causes a decrease in concentration of dye, as absorbed dye increases until 6 w. It means that bleaching removed grosses and fats then laser product pores and sponge-like structure; as treated samples absorb more dye and more powers damage fibers and absorb less dye.

Colour fastness: The wash and light fastness of laser on the bleached cotton/polyester samples that have been dyed were tested and the results are listed in Tables 3 and 4. The results indicate that the wash and light fastness of the laser-irradiated samples are similar to that of the unirradiated samples. Thus the laser irradiation has no significant influences on the colour fastness. This can be due to the similar interaction

TABLE-2
COLORIMETRIC PROPERTIES OF BLEACHED COTTON/POLYESTER

Colour properties	Aside				Two sides			
	Untreated	4.5 w	5.25 w	6 w	Untreated	4.5 w	5.25 w	6 w
L*	60.3	60.3	59.9	60.2	60.3	60.3	60.2	60.3
a*	-6.4	-6.7	-6.3	-6.8	-6.3	-6.4	-6.5	-7.6
b*	-33.3	-32.8	-31.2	-32.0	-33.2	-33.3	-32.5	-31.1
C	33.9	33.5	32.9	32.8	33.8	33.9	33.2	32.0
h°	259.0	258.4	258.0	258.5	259.2	259.0	258.7	256.1

TABLE-3
WASH FASTNESS OF THE BLEACHED COTTON/POLYESTER

Sample	Staining				Change colour			
	0 w	4.5 w	5.25 w	6 w	0 w	4.5 w	5.25 w	6 w
Aside	4-5	4-5	4-5	4-5	5	5	4-5	4-5
Two sides	4-5	4-5	4	4	5	5	4-5	4

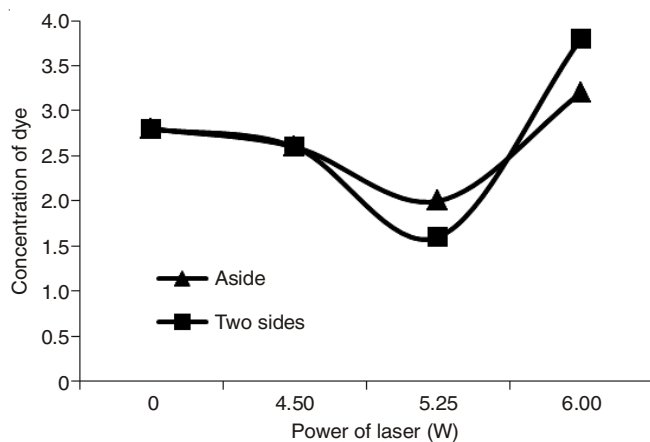


Fig. 5. Concentration of dye in waste water after and before laser irradiation

TABLE-4
LIGHT FASTNESS OF THE BLEACHED COTTON/POLYESTER

Sample	0 w	4.5 w	5.25 w	6 w
Aside	7-8	7-8	7-8	7-8
Two sides	7-8	7-8	7-8	7-8

of dyes with laser-irradiated fabrics. These results have been confirmed by Montazer *et al.* [17] on the polyester fabrics irradiated by laser CO₂.

Tensile strength: Breaking load and tensile strain of the bleached cotton/polyester samples with and without laser irradiation are listed in Table-5. Irradiation could reduce both the breaking load and tensile strain of the sample. The reduction could be due to the fact that the induced ripples on the surface created more weak points to the fiber and eventually reduced both strength and extensibility. Another reason may be due to the deposition of debris as the debris could give a harder surface to cotton/polyester, making it more rigid and resulting in lower strength.

Morphological study: Fig. 6(a-i) indicates the SEM images of bleached cotton/polyester sample with x1000, x2500 and x7500. The pictures (a-c) point out that the bleached cotton/polyester sample without laser irradiation has the convolution of cotton fiber with smooth fiber surface. The images (d-f) show the bleached cotton/polyester sample treated with laser irradiation at power of 4.5 w, in inner part of the fabric was also shown clearly without damage. The pictures (g-i) show the bleached cotton/polyester sample after laser irradiation with 6 w power, increased pores on the cotton/polyester fiber and resulting in a sponge-like structure.

In general, the fibers with a higher power laser irradiation have more pores with increased fiber damage. The sponge-like structure was very clear; the pores, cracks and melted impurities on fibers became clearer. These images are in accordance with the images obtained by Kan *et al.* [3] on laser CO₂ irradiated gray cotton.

Water drop adsorption time: The water adsorption experiments were carried out on the bleached cotton/polyester after and before laser irradiation. The results indicate that the time required for adsorption of water droplet on the untreated bleached cotton/polyester sample was 4 s, whereas the water droplet was adsorbed immediately on the laser irradiated samples. This can be due to the high purity of the bleached cotton/polyester fabric as the most of the impurities including waxes have been removed in previous treatments such as scouring and bleaching. This leads to obtaining of higher hydrophilicity on the laser-irradiated bleached cotton/polyester fabrics. Table-6 shows contact angles of the drop on the surfaces of the samples. The contact angle of the untreated bleached cotton/polyester is 66.225° that reduces with increase of laser power. A reduced wetting time was observed for the bleached cotton/polyester sample. The laser irradiations cannot create roughness on the bleached cotton/polyester fabrics due to lack of waxes on the surface which results in no composite surface. The increased surface oxygen content due to surface oxidation by laser CO₂ and the reduced contact angle caused the lower wetting time. This is because the polar groups of the laser-irradiated bleached cotton/polyester have increased. This increased polarity lead to an increase in the attraction force between the modified surface and the polar water molecules [1].

TABLE-6
CONTACT ANGLE OF THE BLEACHED COTTON/POLYESTER FABRIC AFTER AND BEFORE LASER IRRADIATION (Degree)

Bleached cotton/polyester			
0 w	4.5 w	5.25 w	6 w
66.225	63.35	62.31	62.21

Air permeability: Air permeability is one of the major properties of textile materials and is governed by factors like the fabric structure, density, thickness and surface characteristics. Table-7 indicates that the fabric air permeability of the laser-irradiated bleached cotton/polyester increased and that may be due to the increase in the air passages of the fabrics. This

TABLE-5
BREAKING LOAD AND ELONGATION-AT-BREAK

Sample	Breaking load (N)				Tensile strain (%)			
	0 w	4.5 w	5.25 w	6 w	0 w	4.5 w	5.25 w	6 w
Aside	97.34	66.88	30.54	19.79	18.53	12.25	8.27	3.47
Two sides	97.34	65.68	26.47	11.98	18.53	11.18	6.92	1.56

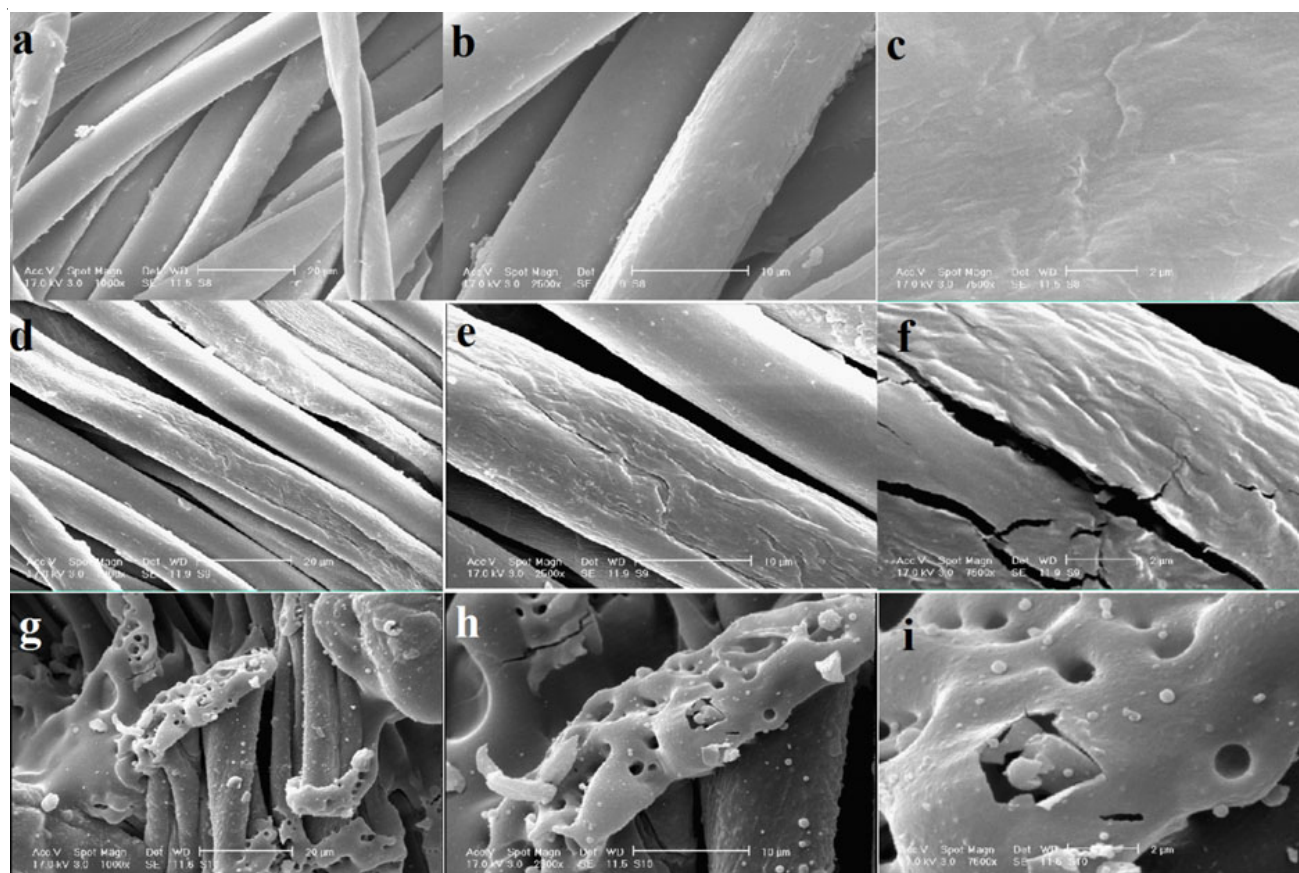


Fig. 6. SEM images of a) bleached cotton/polyester untreated at the x1000, b) bleached cotton/polyester untreated at the x2500, c) bleached cotton/polyester untreated at the x7500, d) bleached cotton/polyester of 4.5 w at the x1000, e) bleached cotton/polyester of 4.5 w at the x2500, f) bleached cotton/polyester of 4.5 w at the x7500, g) bleached cotton/polyester of 6 w at the x1000, h) bleached cotton/polyester of 6 w at the x2500, i) bleached cotton/polyester of 6 w at the x7500

can be as a result of (a) opening of yarn structure after the laser irradiation and (b) creation of the discontinuous tubes on the fiber surface after laser irradiation as seen in Fig. 6g-i.

bleached cotton/polyester fabric with more hydrophilic and air permeability characteristics.

TABLE-7
AIR PERMEABILITY OF THE LASER-IRRADIATED
BLEACHED COTTON/POLYESTER

Bleached cotton/polyester (100 Pa)			
0 w	4.5 w	5.25 w	6 w
64.7	66.3	70.3	75.3

Conclusion

In this paper, dyeability of the bleached cotton/polyester fabrics was studied through the high- and low-power laser CO₂ irradiation. Dyeability of samples increased up to power of 6 w; while in power of 6 w and higher, laser irradiation caused damage in fibers and dyes penetration decreased. However, the yellowing of the bleached cotton/polyester fabric after laser irradiation as a result of cellulose oxidation cannot be prevented. The SEM results have shown a localized surface degradation with a sponge-like structure, presumably because of the swelling and evolution of gaseous products. This morphological modification was permanent and by changing the power of laser irradiation, the degree of laser-induced modification was different. Colour fastness of samples improves after laser irradiation. The laser irradiation resulted in creation of the

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