

A STUDY ON SPECIFYING THE EFFECT OF LASER FADING PROCESS ON THE COLOUR AND MECHANICAL PROPERTIES OF THE DENIM FABRICS

LASER SOLDURMA PROSESİNİN DENİM KUMAŞLARIN RENK VE MEKANİK ÖZELLİKLERİ ÜZERİNE ETKİSİNİN BELİRLENMESİ

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ABSTRACT

The laser fading process is acknowledged as a very strong alternative compared to the conventional physical and chemical processes used for aged-worn look on denim fabrics. In this study, the beams from a CO₂ (10.6 μm) laser was used for the fading of denim fabrics. The effects of laser beam on the physical properties of denim fabrics such as tensile strength, tear strength, abrasion resistance, and static and kinematic friction coefficient were investigated and optimum process conditions were determined. In order to investigate the effect of laser fading treatment on colour change, the fabrics were washed and colour efficiency, L a b values and yellowness index were measured after washing process. In terms of both colour and mechanical properties, it is found that 100 and 150 μs pulse times are suitable for laser fading process of denim fabrics.

Key Words: Laser beam, CO₂ laser, Denim fabric, Fading, Mechanical properties.

ÖZET

Lazerle soldurma prosesi, denim kumaşlarda eskitilmiş görünüm kazandırmak için kullanılan konvansiyonel fiziksel ve kimyasal işlemlerle kıyaslandığında, çok güçlü bir alternatif olarak kabul edilmektedir. Bu çalışmada, denim kumaşların soldurulması için CO₂ (10.6 μm) lazer kaynağı kullanılmıştır. Lazerle işlemin denim kumaşların kopma mukavemeti, yırtılma mukavemeti, sürtünme mukavemeti, maksimum ve kinematik sürtünme katsayısı gibi özellikleri üzerine etkisi araştırılmış ve optimum çalışma koşulları belirlenmiştir. Renk değişimi üzerine lazerle soldurma işleminin etkisinin belirlenmesi için, kumaşlar yıkanmış ve renk verimlilikleri, L a b değerleri ve sarılık indeksleri ölçülmüştür. Hem renk hem de mekaniksel prosesler açısından, denim kumaşların lazerle soldurulması prosesinde 100 ve 150 μs puls sürelerinin uygun olduğu belirlenmiştir.

Anahtar Kelimeler: Lazer kaynağı, CO₂ laseri, Denim kumaş, Soldurma, Mekanik özellikler.

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1. INTRODUCTION

Denim trousers, commonly known as 'blue jeans', have maintained their popularity for many years. For the purpose of supporting customers' purchasing behaviour and to address their aesthetic taste, companies have been trying in recent years to develop various techniques to improve the visual aspects of denim fabrics (1).

By the time, there has long been a demand for blue jean or denim pants that have a worn appearance and

tendency to the faded and worn out look denim trousers raised. Therefore a fading process including several washing steps is applied after desizing (2). It is possible to manufacture customized denim garments applying different physical processes such as sanding, sand spraying, brushing, embroidering; and chemical processes such as pre-washing, rinsing, stone washing, sand washing, snow washing, stone washing with enzymes, bleaching (1, 3).

Although conventional technologies are very beneficial in point of mass customization, production of discoloured jeans using those technologies involves large quantities of water most of which being highly contaminated by chemical products used in the process. An alternative technology, which might eliminate several drawbacks of conventional methods, is the laser fading (4).

The laser is a source of energy which can be directed on desired objects and

whose power and intensity can be easily controlled. Use of the laser enables to cut a great variety of material from metal to fabric. Starting off from this point, it would be possible to transfer certain designs onto the surface of textile material by changing the dye molecules in the fabric and creating alterations in its colour quality by directing the laser to the material at reduced intensity (5).

The laser action on the coloured denim fibers is mainly carried out with the indigo colour, by thermal effect. A pair of high-speed computer-controlled mirrors moves the laser beam on the denim material. Various levels of colour removal with little or no damage to the denim material are achieved by using different laser parameters. Advantages of laser-based finishing technology over other conventional processing techniques are: less pollution of the environment by reduction of chemical agents and water consumption; process flexibility; by using automated control of laser-faded technology the manufacturers can change the finish style to another without retooling; micrographics can be applied on the garment; special logos or characters can be applied to denim products (6).

In this study, laser beams from CO₂ laser (λ : 10600 nm) applied to denim fabric in various pulse times. Changes of the physical properties in the faded zones of denim fabric samples were examined. Thus, the effects of laser beam on the faded denim fabrics and optimum process conditions were determined.

2. EXPERIMENTAL

In order to determine the optimum process conditions of laser fading technology, a laser surface design machine was used. The specifications of the machine are as follows and schematic view of laser set-up is given in Figure 1.

- The system includes a laser source operating along a wavelength selected according to the surface to be designed, a galvanometer consisting of a mirror and a computer

operating program that controls the galvanometer mirrors and the power of the laser beam.

- The laser beam strength can be adjusted to an impact width within a range of 0–1000 μ s.
- Nominal power of the machine is 250 Watt; wavelength of the laser beams is 10600 nm.

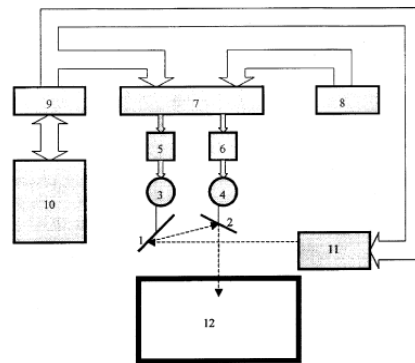


Figure 1. Schematic view of laser set-up (Reference numbers: (1) X-mirror, (2) Y-mirror, (3) X galvanometer, (4) Y-galvanometer, (5) X-servo, (6) Y-servo, (7) Digital transformer, (8) Power source, (9) Laser beam and galvanometer control card, (10) Computer, (11) CO₂ Laser, (12) Scanner area)

The structural properties of the denim fabric are given in Table 1.

In order to designate the optimum pulse time in accordance with optimum loss in the colour and mechanical properties of the denim fabric, the laser fading process was applied in different pulse times, such as 50, 100, 150, 200, 250, 500 and 1000 μ s. In order to compare the mechanical properties of the fabrics faded with different pulse times, the untreated denim fabric was also tested. Laser faded samples as well as untreated fabrics were conditioned at standard atmosphere conditions (20 \pm 2°C and 65 \pm 4% relative humidity).

In order to determine the damage in fabric structure occurred due to the fading process by laser treatment, tensile and tear strengths of the fabrics were measured by using Lloyd LR 5 K

universal tensile strength tester according to TS EN ISO 13934-1 and TS EN ISO 13937-2 respectively. Tensile strength test was carried out with the samples prepared in the size of 50x350 mm whereas for tear strength test samples in the size of 50x200 were used.

Abrasion resistance of the fabrics were tested according to TS EN ISO 12947-2 on Martindale abrasion and pilling tester and test was carried out until two yarn breakages were realized.

Friction coefficients of the fabrics were measured by Frictorq instrument, developed in Minho University. It is novel laboratory equipment based on a new method of accessing fabrics coefficient of friction, using a rotary principle and, therefore, measuring torque. A contact sensor, with 3 touching pads, is placed over the fabric sample. This is forced to rotate around a vertical axis at a constant angular velocity, as given in Figure 2. μ_{kin} (kinematic or dynamic coefficient of friction), which is worked out using the mean value of the friction torque is measured during the interval from 5 to 20 seconds and average value is calculated (7).

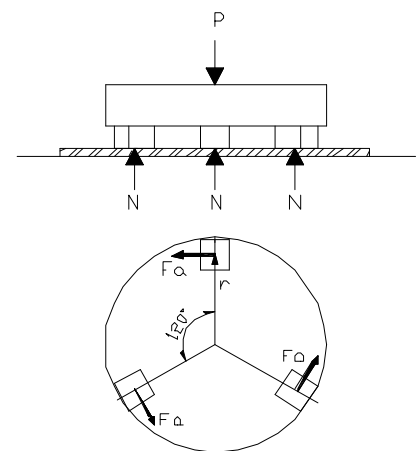


Figure 2. Schematic design of Frictorq instrument

As laser process changes the colour of the denim fabric, for the purpose of determining the optimum colour changes, colour efficiency values (K/S), **CIE** (Commission Internationale de l'Eclairage) **L a* b*** coordinates and yellowness index (according to ASTM D 1925) were measured by using Minolta CM-3600d spectrophotometer. The colour change (ΔE^*) values of the faded samples were calculated by using the following formula.

$$\Delta E^* = [(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2]^{1/2}$$

Table 1. The structural properties of the denim fabric

	Fabric construction	Yarn count (Ne)		Yarn density (yarn count/cm)		Fabric mass per area (g/m ²)
		Weft	Warp	Weft	Warp	
Denim fabric	Twill 2/1	10/1	7/1	18.5	24.3	328

Table 2. The tensile strength (N) and percentage of decrease in tensile strength values of denim fabrics faded by different laser pulse times

Tensile strength values (N)								
Laser Pulse Times (µs)	Without any treatment	50	100	150	200	250	500	1000
Warp direction	1244.2	1231.0	1177.3	1136.7	1056.0	1016.0	603.0	117.2
Weft direction	542.1	502.6	530.1	523.2	519.8	444.5	186.8	55.3
Decrease in tensile strength values (%)								
Warp direction	-	1.06	5.38	8.64	15.13	18.34	51.54	90.6
Weft direction	-	7.29	2.21	3.49	4.11	18.00	65.54	89.80

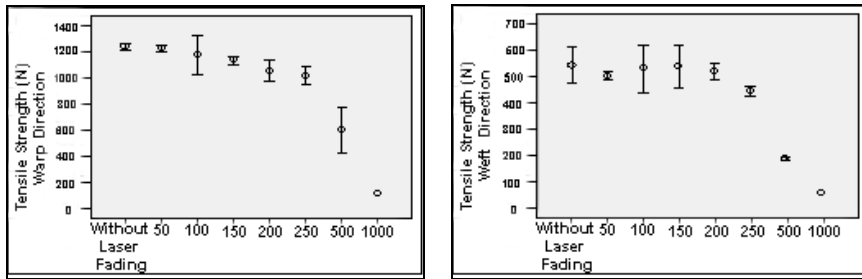


Figure 3. Significant intervals for the tensile strength values

Table 3. The tear strength values of denim fabrics faded by different laser pulse times

Tear strength values (N)								
Laser Pulse Times (µs)	Without any treatment	50	100	150	200	250	500	1000
Warp direction	42.8	43.0	43.8	43.9	39.8	38.7	18.5	2.7
Weft direction	23.2	22.1	21.5	20.2	19.4	19.3	11.6	3.8
Decrease in tear strength values (%)								
Warp direction	-	-0.46	-2.33	-2.57	7.00	9.58	56.78	93.70
Weft direction	-	4.74	7.33	12.93	16.38	16.81	50.00	83.62

a*: Red (+) – Green (-)

b*: Yellow (+) – Blue (-)

L*: White (+) – Black (-)

The colour measurements were carried out between 400-700 nm wavelength and the values were taken from the wavelength where the reflection values were the smallest. The K/S values of the faded samples were calculated using the following "Kubelka-Munk" formula.

$$K/S = (1-R)^2 / (2 \cdot R)$$

R: Reflection value in maximum absorption wavelength

K: Absorption coefficient

S: Scattering coefficient

As the yellowness of the laser faded fabrics is not permanent due to the carbon particles on the fabric surface, the samples were washed 5 minutes with 30°C water and 5g/l wetting agent.

After drying, colour efficiency (K/S), **L***, **a***, **b*** coordinates and yellowness index of the fabrics were measured.

For the evaluation of the changes in the surface characteristics of the fabrics, the photographs of the fabrics were taken by using Leica S8APO camera integrated stereo microscope with the magnification of 25x.

In order to determine the effect and optimum pulse time in terms of the loss in mechanical properties of the fabrics faded by laser beams, for each property, one way variance analysis was performed and the significance intervals of means values were compared by using statistical software. In order to decide the statistical importance of the variables on the related property, p value is used. The higher the p-value, the less it can be believed that the observed relation between variables in the sample is a reliable indicator of the

relation between the respective variables in the population.

3. RESULTS AND DISCUSSION

The tensile strength values of the denim fabrics subjected to different laser pulse times and the decrease in tensile strength values of the treated fabrics calculated based on untreated denim fabric tensile strength are represented in Table 2.

Due to the fact that, any decrease in tensile strength values indicates damage in fabric structure, laser fading process cause a decrease in tensile strength values in every pulse times. However, the most significant decrease is occurred after 250 µs pulse times since the significant intervals calculated according to the significant level (α) of 0.05 are all in the range of each other for the tensile strength values of the denim fabrics faded by 50,100, 150, 200 and 250 pulse times. The loss in tensile strength values is higher for warp direction compared than weft direction. Moreover, one way variance analysis showed that the effect of the pulse times on tensile strength in both warp and weft direction was statistically important, since the p values were 0.000 for the significant level (α) of 0.05. The significant intervals for each tensile strength values of the denim fabrics are given in Figure 3.

The tear strength values of denim fabrics and the decrease in tear strength values of the laser faded denim fabrics are given in Table 3.

As it can be seen from Table 3, it can be stated that laser fading process causes a decrease in tear strength values in warp direction for the 200, 250, 500 and 1000 pulse times whereas for the weft direction the decrease in tear strength values is for all the pulse times. According to the significant intervals, it can be stated that the changes in the tear strength values of the fabrics in warp direction are not significant until 500 pulse times and for the weft direction the significant decrease occurs after 500 pulse times. The loss in tensile strength values is higher for warp direction compared than weft direction. Moreover, one way variance analysis showed that the effect of the pulse times on tear strength in both warp and weft direction has statistically important, since the p values are 0.000 for the significant level (α) of 0.05. The significant intervals for each tear strength values of the denim fabrics are given in Figure 4.

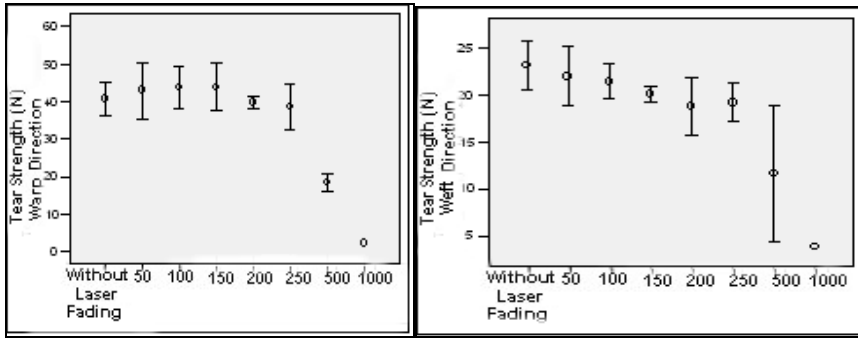


Figure 4. Significant intervals for the tear strength values

Table 4. The maximum (μ_{max}) and kinematic friction coefficient (μ_{kin}) of the denim fabrics

Laser Pulse Times (μs)	Without any treatment	50	100	150	200	250	500	1000
μ_{max}	0.22660	0.22437	0.254633	0.25277	0.24888	0.25517	0.24185	0.25817
μ_{kin}	0.19013	0.19857	0.21790	0.20826	0.21007	0.21245	0.20220	0.20177

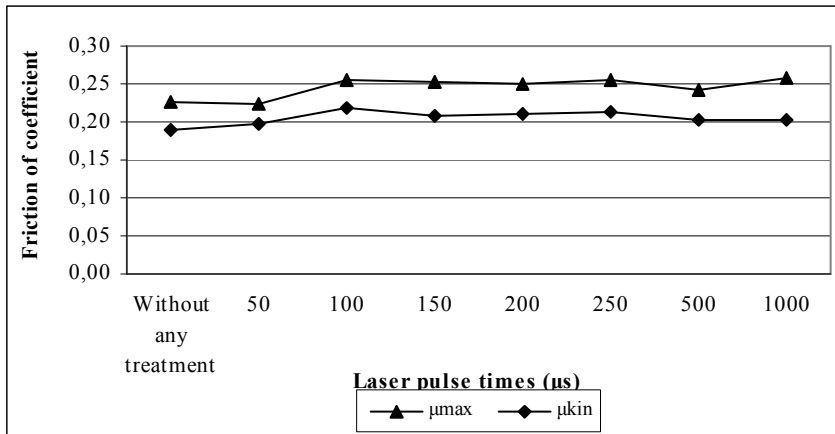


Figure 5. The graphics of μ_{max} and μ_{kin} of the denim fabrics

Table 5. The abrasion resistance of the denim fabrics

Laser Pulse Times (μs)	Without any treatment	50	100	150	200	250	500	1000
Abrasion resistance (number of revolution)	53000	52000	39000	35000	27300	27000	17500	4700

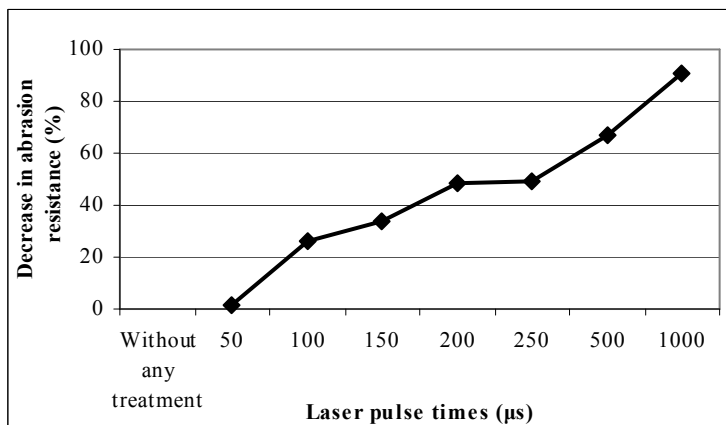


Figure 6. The decrease in abrasion resistance values of laser faded denim fabrics (%)

The maximum (static) and kinematic friction coefficient values of the denim fabrics (μ_{kin}) are indicated in Table 4 and Figure 5.

As it can be seen from Table 4, laser fading process causes increment in both static and dynamic friction coefficients and this increase was found to be statistically important since the p values are 0.0000. The first obvious significant increment was occurred in 100 μs pulse time. There is no clear difference with the higher pulse times.

The abrasion resistances of the denim fabrics were measured according to the revolution number until the two yarn breakages realized and the values are given in Table 5.

As it can be seen from Figure 6, even with 100 μs pulse time % 26.4 loss in abrasion resistance value is occurred after fading process and with the higher pulse times, the decrease in abrasion resistance values is much more apparent.

The colour measurement values and changes in yellowness index of the laser faded denim fabrics are given in Table 6 and Figure 7.

As it can be seen clearly from Table 6 and Figure 7, Figure 8, there wasn't an important change in b^* axis when laser fading was realized in 50 μs and 100 μs pulse times, as the L^* values increased significantly at the same time. When laser fading was realized in 150 μs pulse time, the increase in L^* value continued ($\Delta L^* = +18,53$) and a significant increase was determined in b^* value in positive direction of the axis for the first time ($\Delta b^* = +6,67$). Consequently, the first important change in yellowness index (from -37,84 to -2,95) was occurred in 150 μs as well. According to the findings, it can be said that, fiber yellowing and degradation was occurred in the cotton fibers with the effect of laser beam in 150 μs pulse time, together with the fading of the samples. Fading and the yellowness index of the samples continued to increase together in 200 μs and higher pulse times.

The K/S values of the laser faded samples can be seen from Figure 8. The K/S values of the samples faded until 150 μs pulse time, decreased significantly. However, the decreases of K/S values were less in 200 μs pulse time and for higher pulse times.

The colour measurement values and changes in yellowness index of the washed laser faded denim fabrics are given in Table 7 and Figure 9.

Table 6. The values obtained after colour measurement of laser faded samples

Laser Pulse Times (μs)	ΔL^*	Δa^*	Δb^*	ΔE^*	Yellowness
0**	-	-	-	-	-37,84
50	2,69	-0,12	-2,20	3,47	-48,14
100	11,42	-1,66	-0,76	11,57	-35,06
150	16,75	-1,89	6,67	18,13	-2,95
200	18,53	-1,52	10,62	21,41	11,09
250	17,44	-1,23	11,76	21,07	15,41
500	21,34	-0,33	18,40	28,18	34,88
1000	26,38	1,57	23,37	35,28	47,02

**For the fabric without laser fading, the L^*, a^*, b^* values are 26.66, 0.30 , -7.27 respectively

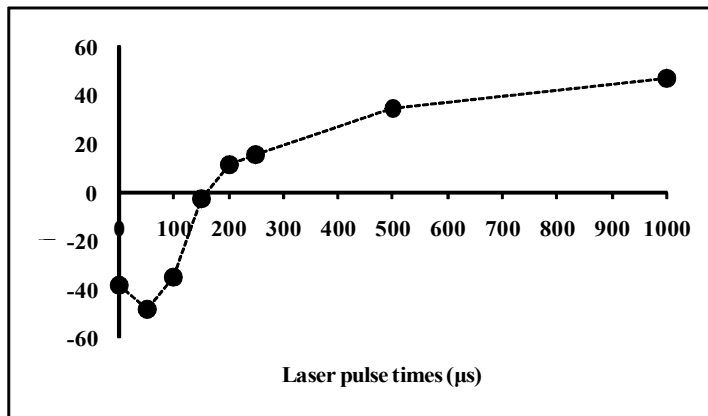


Figure 7. Changes in the yellowness index of laser faded samples. (0: fabric without treatment)

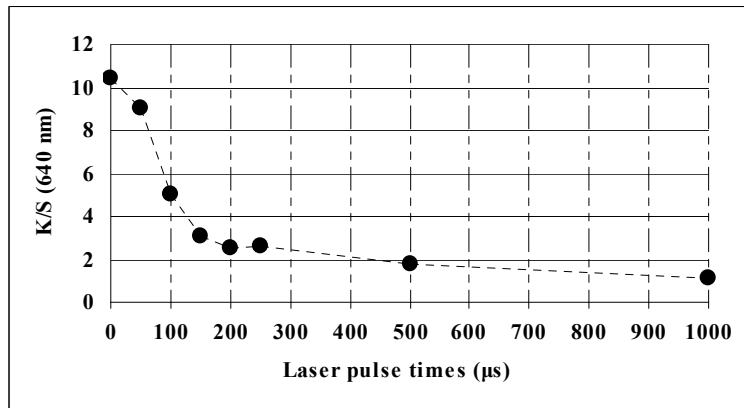


Figure 8. Changes of the K/S values of laser faded samples. (0: fabric without treatment)

Table 7. The values obtained after colour measurement of washed laser faded samples

Laser Pulse Times (μs)	ΔL^*	Δa^*	Δb^*	ΔE^*	Yellowness
0**	-	-	-	-	-37.84
50	-0,50	0,12	-1,02	1,14	-45.70
100	4,51	-0,53	-1,26	4,71	-41.59
150	9,40	-1,06	-0,59	9,48	-34.82
200	12,58	-2,14	-1,74	12,88	-32.43
250	16,79	-2,59	0,28	16,99	-28.54
500	26,62	-2,55	7,71	27,83	-0.27
1000	27,95	-2,37	7,21	28,96	-1.19

**For the fabric without laser fading, the L^*, a^*, b^* values are 26.66, 0.30 , -7.27 respectively

As it can be seen from Table 7 and Figure 9, due to the removal of carbon particles from the fabric surface, a significant change occurred in the b (blue-yellow coordinate) value of washed laser faded fabrics compared to the unwashed fabrics. The b values of washed laser faded fabrics after 150 pulse times were changed in the direction of $+b$ coordinate, which means that the washed fabrics were bluer than the unwashed ones. The change in the b values of the washed fabrics was also supported by the results of yellowness index.

The K/S values of the laser faded samples can be seen from Figure 10. The K/S values of the washed fabric samples decreased until 250 μs pulse time significantly, whereas after 500 μs pulse times, there is nearly no change in colour efficiency values.

The microscopic photographs of the laser faded and washed denim fabrics are given in Figure 11. As it can be seen from the photographs, there is really a big difference in yellowness of the washed laser faded fabrics compared to the unwashed laser faded fabrics due to the removal of carbon particles remained on the surface of the fabric after laser treatment. Besides, the mechanical damage of higher pulse times can be easily recognized from the views of the fabric.

As a conclusion, it can be said that, desired fading effect can be obtained exposing the fabric to laser beam between 100-150 μs pulse times without occurring of yellowness on faded area in an undesired intensity. In higher pulse times, fading effect becomes weaker and fiber yellowing due to the degradation of cotton fibres increases due to the effect of laser beam.

4. CONCLUSION

In order to determine the effect and optimum pulse time in terms of colour and mechanical properties, the denim fabrics were faded with different pulse times. According to the results, the conclusions are as follows:

- The desired colour fading effect can be obtained with 100-150 μs pulse times. The higher pulse times do not influence the colour changes; therefore it can be suggested to process until the 150 μs pulse time in terms of colour. After washing of the laser faded fabrics, the most significant colour change was obtained with 150 and higher pulse times. Due to removal of carbon particles, the yellowness index changed quite significantly after washing.

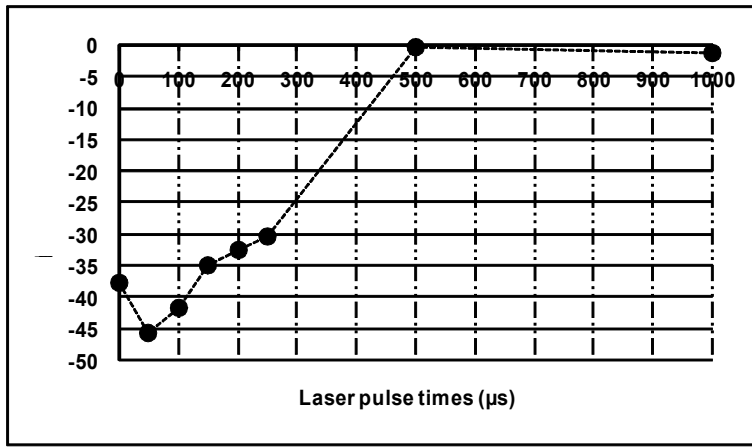


Figure 9. Changes in the yellowness index of washed laser faded samples. (0: fabric without treatment)

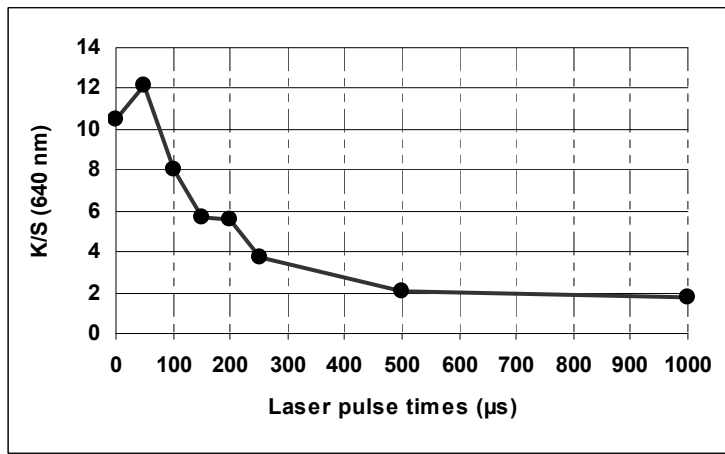


Figure 10. Changes of the K/S values of washed laser faded samples. (0: fabric without treatment)

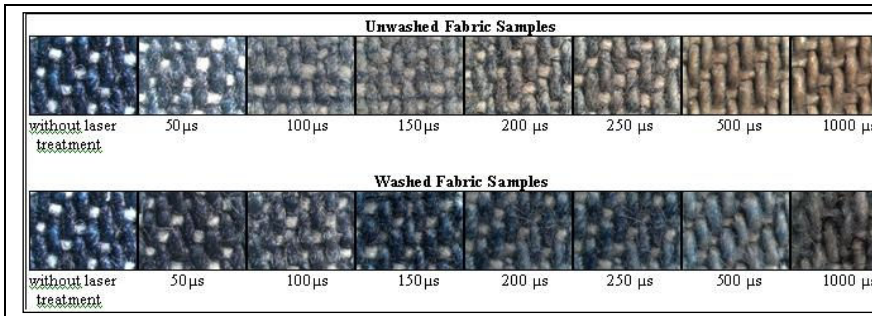


Figure 11. Photographs of the unwashed laser treated and washed laser treated fabric samples (x25)

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As for the mechanical properties, optimum process conditions are determined by considering the minimum loss in each property. In terms of tensile strength, the minimum decrease realize with 250 µs pulse time, whereas 500 µs pulse time is optimum in tear strength values. Concerning the friction properties, for friction coefficient and abrasion resistance values, 100 µs pulse time is optimum.

- When considering both colour and mechanical properties, it can be stated that 100-150 µs pulse times is suitable for laser fading process of denim fabrics.

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