Wei Du[1],
Rajib Chandra Gosh[2],
Dan-ying Zuo[1],
Han-tao Zou[2],
Lei Tian[3],
Chang-hai Yi[1,2,3]*

# Discoloration of Cotton/Kapok Indigo Denim Fabric by Using a Carbon Dioxide Laser

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[1]School of Materials Science and Engineering, Wuhan Textile University, Wuhan, China
*E-mail: yichanghailaoshi@163.com.

[2]School of Textile Science and Engineering, Wuhan Textile University, Wuhan, China

[3]Guangdong Jun'an Denim Research Institute, Shunde, China

**Abstract**

*In this work, a carbon dioxide laser was used for the color-fading treatment of cotton/kapok denim fabrics. The results were analysed thoroughly and compared with those of cotton denim fabric and PET denim fabric. Results showed that with laser treatment, the fabrics were colour-faded, and the K/S value of cotton/kapok fabric was reduced, while there was little change in the thickness and permeability. Because the internal air of the kapok fiber was squeezed out, the tensile strength of the fabric was decreased. The influence of laser power and speed on the kapok denim was also investigated. With an increase in the laser power and decrease in the speed, both the K/S values and strength decreased significantly. However, the changes were negligible for the thickness and permeability of the cotton/kapok denim fabric. It is therefore concluded that kapok is a good denim fabric material for the laser process.*

**Key words:** *kapok fibre, denim fabric, laser treatment, colour-fading, air permeability.*

## Introduction

Jeans have been consistently fashionable in the world. This fabric has inspired strong opinions from historians, teenagers and movie stars, and has acquired different styles throughout the years [1]. In the 21st century, the human being has entered an era of advocating environmental protection. Consumers prefer pollution-free green textiles for both the environment and human [2, 3]. Kapok fibre is a natural fibre and is more environmentally-friendly than man-made fibres. It is the best warm natural fibre material, which keeps a hollow degree of 90 percent [4, 5]. Kapok also has a good natural anti-bacterial and drive mite effect, with the driving mite rate reaching 87.54% and an anti-bacteria rate of 99.4% [6]. Kapok fibre has 64% cellulose, 13% lignin, 8.6% water, 1.4 - 3.5% ash, 4.7 - 9.7% water-soluble substances, 2.3 - 2.5% xylan and 0.8% waxes. The development of high performance and environmentally friendly products using the superior characteristics of kapok fibre is of long term interest for the transformation of cheap labour products to high-tech products especially after China's denim enterprises were reshuffled. Furthermore the price of kapok fibre is only about half of that of cotton fibre, and hence kapok products have a high market competitiveness.

The production of discoloured jeans using conventional chemical technologies involves large quantities of water and brings more water pollution as well as environmental pollution. The alternative technology in this field is carbon dioxide ($CO_2$) laser technology for fading dyed denim. The carbon dioxide ($CO_2$) laser mainly acts on the indigo dye in colored denim fibres by means of the thermal effect. Various levels of colour can be removed without damaging the denim material, which are achieved by using different laser parameters controlled by a computer [7]. Compared with most conventional processing techniques, there are three advantages of laser-based finishing technology. Firstly people could reduce the chemical agents and water consumption through using a carbon dioxide ($CO_2$) laser for the colour-fading treatment of denim fabrics. Secondly, because the processing parameters can be carefully controlled by a computer, micrographics can be applied to the garment, and special logos or characters can be given to denim products [8]. Finally process flexibility allows replication of existing stonewash designs or the creation of new finish styles.

In this work, kapok denim fabric was treated by laser treatment. The structure and performance of the kapok denim fabric after laser treatment were compared with that of cotton denim fabric and PET denim fabric. As a kind of material of denim fabric, the advantages and problems of kapok fibre were analysed. It is expected that this research can provide some guidance in the development of kapok production for denim enterprises.

## Experiments

### Materials

Three types of denim fabrics (Guangdong Jun'an Denim Research Institute, China) containing different cotton contents were used, as shown in ***Table 1***.

***Table 1.*** *The fabric composition.*

| Sample | 1 | 2 | 3 |
|---|---|---|---|
| Chemical composition | Cotton 70%<br>Kapok 30% | Cotton 100% | Cotton 75.0%<br>Viscose 2.0%<br>Polyester 21.2%<br>Spandex 1.8% |
| Weft density, strips/10 cm | 198 | 178 | 232 |
| Warp density, strips/10 cm | 338 | 302 | 322 |
| Fabric mass, g/m$^2$ | 322.4 | 409.2 | 354.0 |

*__Table 2.__ Orthogonal experimental factors; (Untreated is WD0).*

| V, mm/min \ P (w) | 225 | 240 | 255 |
|---|---|---|---|
| 10000 | WD1 | WD 4 | WD 7 |
| 11000 | WD 2 | WD 5 | WD 8 |
| 12000 | WD 3 | WD 6 | WD 9 |

### Laser treatment

The laser process was formulated as follows: a fixed length of 1650 mm, start delay time 300 µs, end of the delay time 300 µs, laser power 240 W and working speed 10000 mm/min. The different parameters of the laser to process the cotton/kapok fabrics are summarized, as shown in ***Table 2***. The power and speed were varied from 225 to 255 W, and from 10000 to 12000 mm/min, respectively, while the fixed length, start delay time and the end of the delay time were not changed.

### Characterization

The morphology of three samples was observed using a scanning electron microscopy (SEM) (JSM-6510LV, Japan). The surface property of three samples was investigated by FTIR (TENSOR-27. Germany), with the wavelength ranging from 500 to 4500 cm$^{-1}$, at a fixed scan time of 256 s. The colour strength (K/S) was determined by an X-rite Color I 7 spectrophotometer (X-Rite company, USA). The load and elongation at break (tensile strength) was measured by a mechanical property tester (YG026H, China), the air permeability by an air permeability tester (YG461E, China), and the fabric thickness by a thickness tester (YG(B)141D, China) [9].

## Result and discussion

### FTIR analysis

***Figure 1*** shows infrared spectra of the treated and untreated sample fabrics. It can be found that there is no new organic function group generated, although the fibres were etched by laser. The absorption peaks at 3352.2 cm$^{-1}$, 3496.5 cm$^{-1}$ and 3333.3 cm$^{-1}$ are between 3550 cm$^{-1}$ to 3100 cm$^{-1}$ and assigned to the hydroxyl groups [10]. The peaks at 2926.0 cm$^{-1}$ and 2914.4 cm$^{-1}$ are attributed to the C-H groups. The -COO- group showed absorption peaks at 1618.2 cm$^{-1}$ and 1614.1 cm$^{-1}$, and the C-O-C the peak exhibited absorption peaks at 1000 - 1500 cm$^{-1}$ [11]. All of them are typical polysaccharide

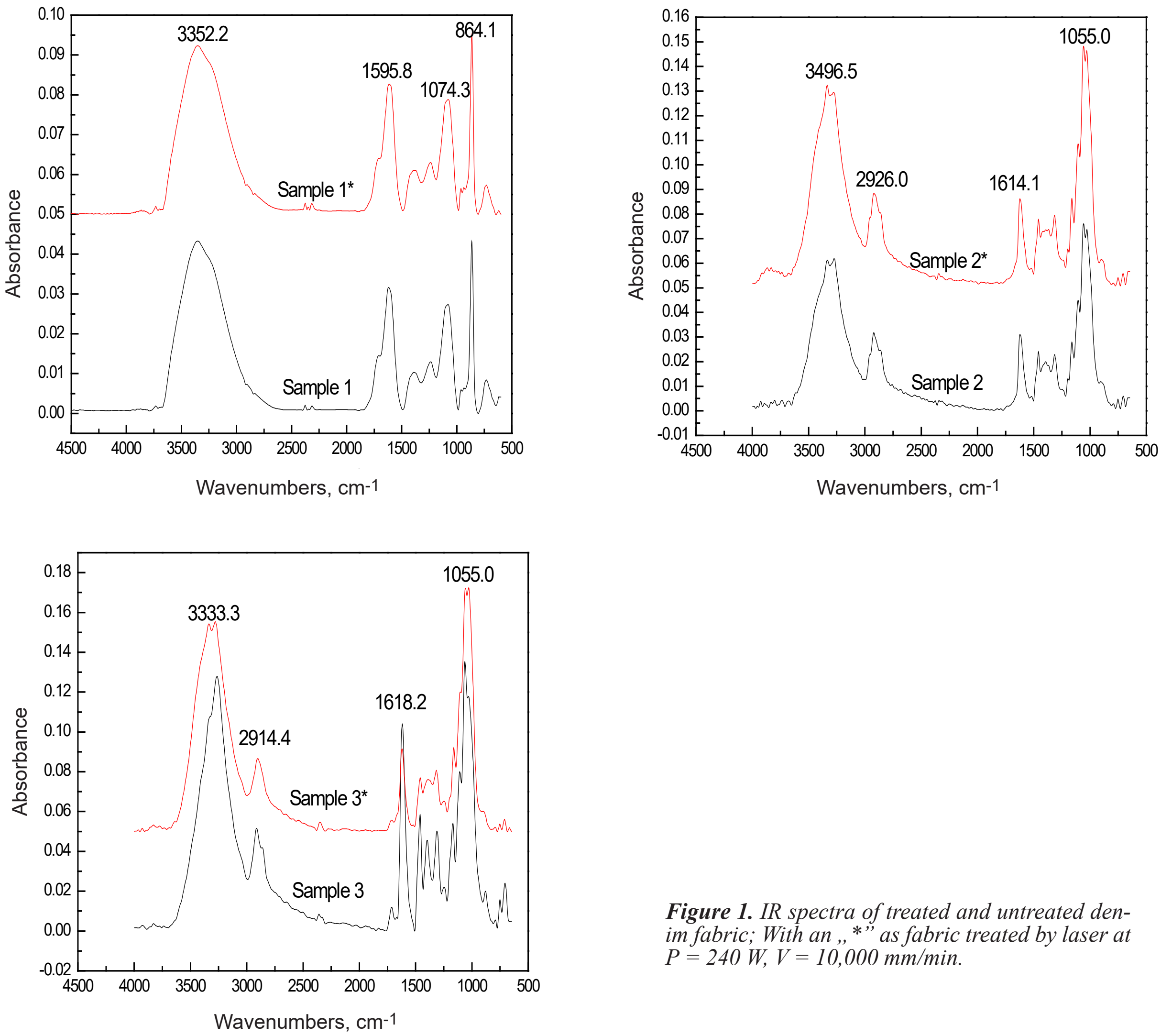


***Figure 1.*** *IR spectra of treated and untreated denim fabric; With an „*" as fabric treated by laser at P = 240 W, V = 10,000 mm/min.*

absorption peaks. The absorption peak at 1595.8 $cm^{-1}$ was observed for kapok fibre, corresponding to conjugated carbonyl groups of lignin in the kapok fibre. After laser treatment, there were no new organic function groups found, indicating that the laser treatment is a physical change, and an environmental way [12].

### Scanning electron microscope

The SEM technique was used to observe the morphology of the fibre before and after laser treatment. The morphology of untreated denim is shown in ***Figures 2.A***, ***2.C*** and ***2.E***, and that of treated denim is shown in ***Figures 2.B, 2.D*** and ***2.F***. As shown in ***Figure 2.A***, the kapok fibre is hollow and has a high hollow degree. After laser treatment, fibres were partially removed, with their surfaces having lots of pores, as shown in ***Figures 2.B, 2.D*** and ***2.F***. The surface of these primal samples is smoother than the treated sample. This is because the cellulose of cotton fibre was decomposed by much heat originating from the laser scanning, revealing that the main reason for colour-fading is that fibre of the fabric surface was etched by the laser.

### Influence of laser treatment on the K/S value

The K/S values of three samples are reported in ***Table 3***. The colour strength of the denim fabrics was significantly decreased after the laser treatment. As is common, the K/S value is smaller and the colour lighter. In this research, the laser treatment effect is very strong. It can be seen that the rate of decrease in the K/S value of sample 1 is 70.40%, which is a little smaller than for samples 2 and 3. The reason for this phenomenon is the different decomposition temperature of different materials. All the denim fabrics were dyed just in the warp. The warp of all the three samples was made of cotton, but the weft of the fabrics was made of different materials. Sample 1 contains 70% cotton and 30% kapok, sample 2 - 100% cotton, and sample 3 - 75% cotton and 21.2% PET. The decomposition temperature of kapok fibre, cotton fibre and PET fibre is 280 - 300 °C, 150 °C and 256 °C, respectively. When laser treatment was used on the fabric surface, the dye would weaken and the colour became faded. Kapok fibre has a high hollow degree, absorbs more heat, and hence the decomposition temperature of kapok fibre is highest, exhibiting the lowest rate of decrease in the K/S value. Cotton fibre

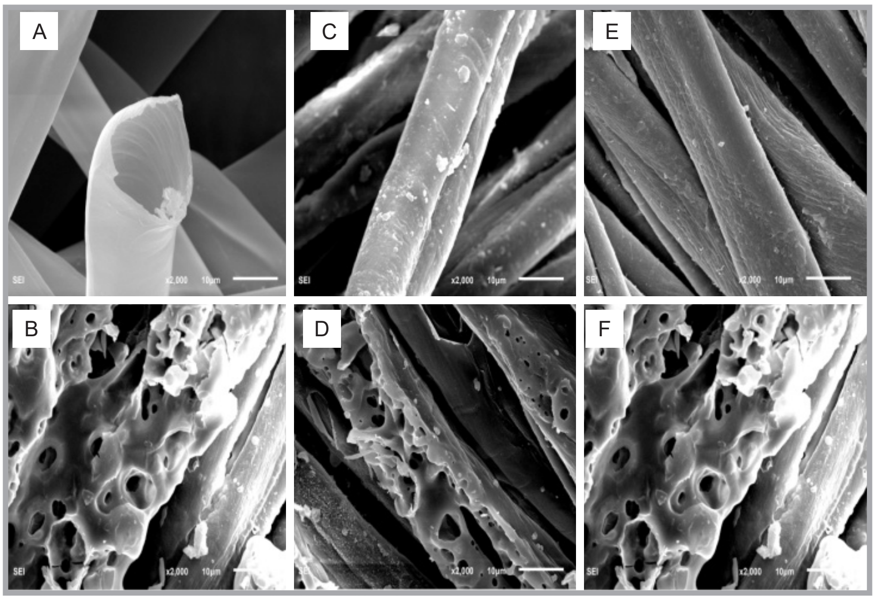


***Figure 2.*** *SEM photographs of denim samples; A: sample 1, B: treated sample 1, C: sample 2, D: treated sample 2, E: sample 3, F: treated sample 3. P = 240 W, V = 10000 mm/min.*

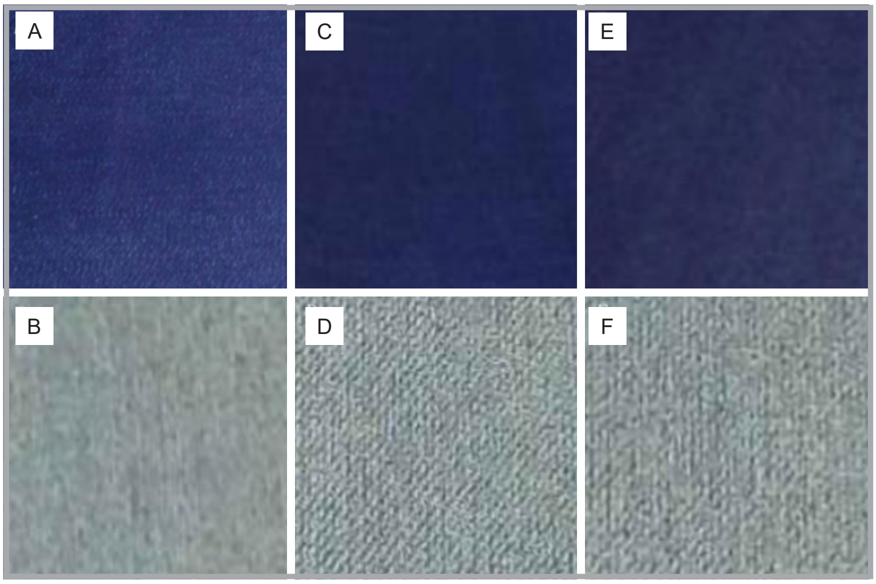


***Figure 3.*** *Photographs of denim samples; A: sample 1, B: treated sample 1, C: sample 2, D: treated sample 2, E: sample 3, F: treated sample 3. P = 240 W, V = 10000 mm/min.*

***Table 3.*** *Results of three types of denim fabrics containing different percentages of cotton K/S values.*

| Sample | | 1 | 2 | 3 |
|---|---|---|---|---|
| K/S | Untreated | 14.252 | 15.833 | 14.863 |
| | Treated | 4.219 | 3.793 | 3.933 |
| Rate of decrease, % | | 70.40 | 76.04 | 73.54 |

***Table 4.*** *Permeability and thickness of three types of denim fabrics containing different percentages of cotton. P = 240 W, V = 10000 mm/min.*

| Sample | | 1 | 2 | 3 |
|---|---|---|---|---|
| Untreated | Permeability, mm/s | 34.62 | 95.98 | 41.34 |
| | Thickness, mm | 0.44 | 0.68 | 0.79 |
| Treated | Permeability, mm/s | 32.21 | 94.06 | 38.18 |
| | Thickness, mm | 0.41 | 0.67 | 0.78 |

***Table 5.*** *Tensile strength of three types of denim fabrics; P = 240 W, V = 10000 mm/min.*

| Sample | | 1 | 1* | 2 | 2* | 3 | 3* |
|---|---|---|---|---|---|---|---|
| Warp | Breaking strength, N | 1450.70 | 1030.44 | 1187.60 | 1071.00 | 1103.40 | 1018.80 |
| | Strength loss rate, % | 0 | 28.97 | 0 | 9.82 | 0 | 7.67 |
| | Elongation at break, % | 127.30 | 109.50 | 22.50 | 21.58 | 61.44 | 62.36 |
| Weft | Breaking strength, N | 384.60 | 278.20 | 816.00 | 553.40 | 761.00 | 256.60 |
| | Strength loss rate, % | 0 | 27.67 | 0 | 32.18 | 0 | 66.28 |
| | Elongation at break, % | 37.80 | 35.24 | 18.34 | 16.18 | 98.90 | 74.00 |

***Table 6.*** *Different laser parameters processed for cotton/kapok denim K/S values, permeability and thickness.*

| Sample | K/S | | Permeability, mm/s | Thickness, mm |
|---|---|---|---|---|
| | K/S Value | Rate of decrease, % | | |
| WD0 | 14.252 | 0 | 34.62 | 0.44 |
| WD1 | 5.577 | 60.87 | 33.21 | 0.41 |
| WD2 | 5.967 | 58.13 | 33.80 | 0.41 |
| WD3 | 6.618 | 53.56 | 34.00 | 0.42 |
| WD4 | 4.219 | 70.40 | 32.21 | 0.41 |
| WD5 | 5.342 | 62.52 | 32.93 | 0.42 |
| WD6 | 5.112 | 64.13 | 33.11 | 0.45 |
| WD7 | 3.378 | 76.30 | 31.60 | 0.43 |
| WD8 | 3.867 | 72.87 | 31.72 | 0.42 |
| WD9 | 4.113 | 71.14 | 32.14 | 0.44 |

***Table 7.*** *Different laser parameters processed for cotton/kapok denim Brad tensile strength.* ***Note****: BS: breaking strength, BE: elongation at breaking, LR: loss rate.*

| Sample | warp | | | weft | | |
|---|---|---|---|---|---|---|
| | BS, N | BE, % | LR, % | BS, N | BE, % | LR, % |
| WD0 | 1450.70 | 127.30 | 0 | 384.60 | 37.80 | 0 |
| WD1 | 1139.78 | 109.50 | 21.43 | 322.32 | 35.80 | 16.19 |
| WD2 | 1154.28 | 113.02 | 20.43 | 311.34 | 38.18 | 19.05 |
| WD3 | 1183.25 | 124.12 | 18.44 | 340.42 | 29.12 | 11.49 |
| WD4 | 1030.44 | 109.50 | 28.97 | 278.20 | 35.24 | 27.67 |
| WD5 | 962.44 | 104.62 | 33.66 | 288.52 | 29.72 | 24.98 |
| WD6 | 1031.66 | 107.28 | 28.89 | 306.64 | 27.82 | 20.27 |
| WD7 | 843.58 | 94.14 | 41.85 | 229.90 | 22.04 | 40.22 |
| WD8 | 863.06 | 106.32 | 40.51 | 250.48 | 28.86 | 34.87 |
| WD9 | 957.62 | 115.56 | 33.99 | 261.96 | 27.70 | 31.89 |

has the lowest decomposition temperature among the three materials, and thus the more the cotton content is, the worse the colour fastness is. Therefore the rate of decrease in the K/S value of sample 2 is bigger than for the others.

## Influence of laser treatment on permeability and thickness

The air permeability and thicknesses of three samples after laser treatment are presented in ***Table 4*** (see page 65). Firstly the thicknesses of denim fabrics remain almost stable, while their air permeability is lower than that of pristine fabrics. After treating the fabrics with the laser, the yarns were worn out and hairiness had been generated, being the reason why the gap between yarns is reduced, which leads to a decrease in the air permeability of the fabrics treated. After the laser treatment, there were some residues of the dye on the fabric surface, which were responsible for the reduction in air permeability. Secondly after laser processing, the thickness of sample 1 is thinner than before, the main cause of which being that kapok fibre is of the hollow kind, whose degree is more than 90%. After laser treatment, the fibres were etched and the internal gas extruded, which was why the fabric was thinner. Thirdly compared with a significant change in the permeability rate, the thickness of the fabric remained stable after the laser treatment, due to there being no mechanical action of the laser treatment; only dyes on the surface of the fibre were removed by the laser, which had no effect on the structure of the fibre nor on the fabric's construction itself [13].

## Influence of tensile strength

***Table 5*** depicts the mechanical properties of three untreated and treated samples. The main difference in the fracture strength depended on the fabric mass (mass per square meter) and different density. The greater the fabric weight is, the smaller the density is, and the thicker the yarns are, the greater the tensile strength of the fabrics. For example, for sample 2, due to the maximum fabric mass of 409.16 g/m$^2$ and the smaller warp density, 302 strips/10 cm, its tensile strength was less than for sample 1. The chemical composition is the second main issue here. The warp of all the three samples was made of cotton, but the weft of the fabrics was made of different materials. Sample 1 was produced with 70% cotton and 30% kapok, sample 2 - 100% cotton, and sample 3 was a composite of 75% cotton, 21.2% PET (Polyester), 2% viscose and 1.8% spandex. Because of the different materials, the fabrics have different properties. Kapok fibre is a hollow fibre whose hollow degree is more than 90% and the volume ratio is as four times that of cotton. Kapok fibre is of short length, low intensity and poor cohesion; hence the fabric made of kapok fibre had poor mechanical properties with other materials. The weft breaking strength is the smallest - 278.20 N before the laser process, but the loss rate is lowest 27.67%. Kapok's special structure is the main cause of it. The sample 3's strength loss rate is the highest (66.28%), the reason being that the crystalline of the PET fibre was broken by the heat from laser processing, and the orientation of crystallisation was disordered. The laser used high temperature to etch the fibres, which could reduce the orientation of crystallisation of PET fibre, and decrease the tensile strength of denim fabric. It shares a similar trend with the warp. The warp density of sample 1 is the highest (338 strips/10 cm), and the thickness is the smallest (0.44 mm); hence the loss rate is the largest (28.97%).

## Different parameters of laser treatment for cotton/kaopk fabrics

***Table 6*** shows the K/S values, air permeability and thicknesses of cotton/kapok denim fabrics with different laser process parameters. After treating, the colour strength of the kapok denim fabrics significantly declined, and the treated sample looked lighter than the untreated one (***Figure 4***). It was established that the higher the power, the slower the

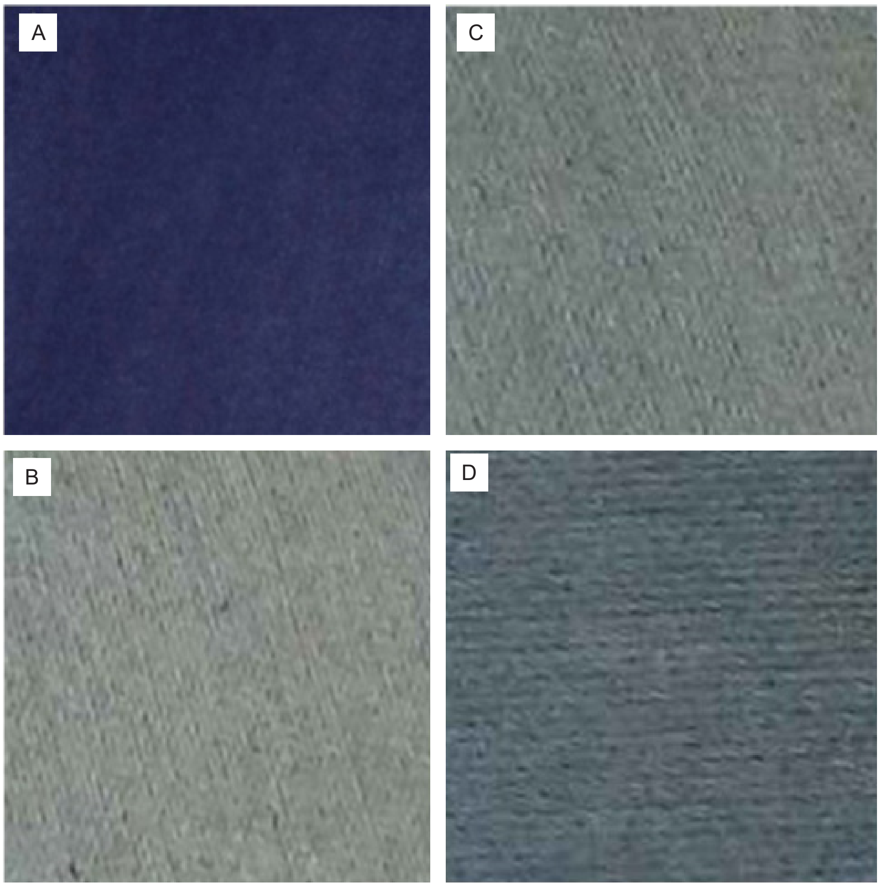


***Figure 4.** Photographs of denim samples; A: WD0, B: WD7, C: WD8, D: WD9.*

speed, and the smaller the K/S value is. Thus the smallest one is WD7 (255 W, 10,000 mm/min), with a K/S value of 3.378 and rate decrease of 76.30%. All the fabrics' rate of decrease is higher than 53.56%, hence the cotton/kapok denim is suitable for laser to fade the colour. Compared with the K/S value, the air permeability and thicknesses show little change. The data are just a little smaller than before, the reason being that when the laser etched the fibre, the cloth became thinner. And there were some residue of the decomposed cotton fibre on the fabric surface, which was responsible for the reduction in air permeability**.**

***Table 7*** depicts the mechanical properties of untreated and treated samples. It can be found that the loss rate of the weft is less than 27.67% when the power is less than 240 W. The weft of these samples was made of 70% cotton and 30% kapok. Kapok fibre is a natural hollow fibre, which has a 90% hollow degree, and thus the mechanical properties of kapok are poor; however, they would not change sharply after laser treatment. The warp of these fabrics is produced from cotton. The data changes in the warp shares a similar trend with the K/S value: the higher the power, the slower the speed, and the loss rate of the fabric is higher. It is suggested that in order to use a laser to process cotton/kapok denim, the power should be kept under 240 W.

## Conclusions

In this work, we compared the effect of laser treatment on cotton/kapok, cotton and PET denim fabric. The results showed that laser treatment is an effective method to remove the colour of denim because the indigo on the surface of denim fabric distinctly faded. During the process, there is no new organic function group to form, although the fibres were etched by laser. Kapok fibre is a kind of hollow fibre whose hollow degree is more than 90%. It has poorer mechanical properties than other fibres. After laser treatment, the internal air of the kapok fibre was squeezed out, reducing the thickness of the fabric, but there was little change in the strength loss rate. Because of the hollow structure, it could absorb more heat, and the decomposition temperature of kapok fibre is the highest; hence the rate of decrease in the K/S value of cotton/kapok fabric is the lowest. In general, kapok is a material as good as cotton or PET for denim fabrics in laser treatment, but we need to keep the laser power under 240 W.

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