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Note

Colour Fading Effect of Indigo-dyed Cotton Denim Fabric by CO_2 Laser

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Abstract: In this study, denim fabric was treated with CO_2 laser under different combination of laser process parameters, i.e. resolution and pixel time, in different irradiation directions, i.e. warp and weft directions. Experimental results revealed that the laser power increased with increment of resolution and pixel time. The colour fading effect was increased with the increase of laser power but an optimum colour fading effect was achieved. Meanwhile, the colour levelness of the laser treated denim fabric was good according to quantitative measurement. However, it was noted that the direction of laser irradiation did not affect the colour fading effect and colour levelness.

Keywords: Laser, Denim, Colour fading, Colour levelness

Introduction

CO_2 laser treatment has been used in different areas of textile industry for several years because it allows short-time surface designing of patterns with good precision, desirable effect, various size and intensity without much damaging the bulk properties of the textile materials [1-4]. The CO_2 laser treatment, considered as a dry treatment, can be applied to textile materials as an alternative of conventional wet treatment such as stone washing, sand washing and bleaching for achieving faded look and worn out effects [5-7]. Previous studies showed that with the selection of laser power precisely, it was easy to apply certain design effect onto the textile surface by removing the dye present at the fabric surface and creating alternation in its colour quality values [8-12]. In the case of denim fabric, CO_2 laser treatment is proved to be an effective method for fading the colour from denim fabric surface in short time depending much on the laser process parameters [13]. However, the direction of laser irradiation, i.e. laser irradiating in warp or weft directions, on the final colour fading effect and colour levelness is seldom reported. Thus, this study will investigate the relationship of colour fading effect and colour levelness on the laser process parameters and laser irradiation direction.

Experimental

Denim Fabric

Commercially available indigo-dyed 100 % cotton denim fabric (well singed, desized, pre-skewed and pre-shrunk) was obtained from local manufacturer. The fabric weight was 378 g/m^2 while the fabric density was 25 ends/cm (88 tex) and 20 picks/cm (57 tex). The denim fabric was conditioned under standard atmosphere of 20±2 ^{o}C and relative humidity of 65±2 % before laser treatment.

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Laser Treatment

The laser treatment process was conducted with a CO_2 laser engraving machine (GFK, Spain) with its specifications being shown in Table 1. During the laser treatment, the resolution of the laser beam was set to 30, 60 and 80 dot per inch (dpi) with the pixel time of 110, 160, 220 and 300 μs respectively. The resolution (expressed in term of dpi) is defined as a parameter to control the intensity of laser beam positioning in a particular area. Meanwhile, pixel time (expressed in term of μs) is defined as a parameter to control the time for laser beam positioning in a particular area. A square pattern of size 20×20 cm (Figure 1) was engraved in accordance with the various combinations of resolution and pixel time. Two sets of samples were prepared according to the direction of laser irradiation which were (i) laser beam

Table 1. Specifications of laser engraving machine

Manufacturer/Model:	GFK Marcetex FLEXI-150
Excitation frequency:	81 MHz
Laser medium:	CO_2
Wavelength	10.6 μm
Wave mode	Pulsed
Power (W) / Energy (mJ/p)	Power: 100 W (60-230 W) Pulse energy: 5-230 mJ; Pulse activation time: <45 μs
Polarisation	Linear polarization perpendicular to the bottom of the Laser head

Figure 1. Square pattern with size 20×20 cm.

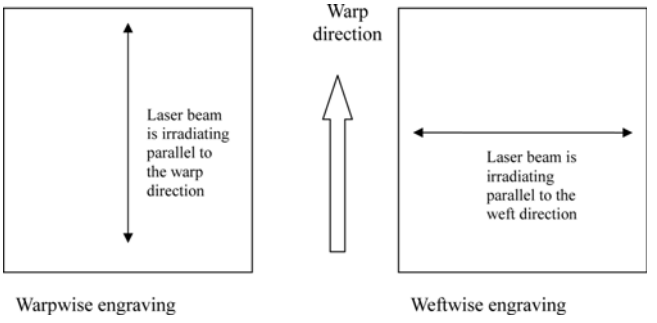

Figure 2. Direction of laser irradiation.

was parallel to warp direction (warpwise engraving) and (ii) laser beam was parallel to weft direction (weftwise engraving) as shown in Figure 2.

Cellulase Treatment [14]

Denim fabric was cut into square pieces of 20×20 cm. A neutral cellulase enzyme (Lava Cell NNM, supplier: DyStar) with activity 130 EGU/g (One EGU/g (Endo-glucanase activity) unit is defined as the amount of enzyme required to reduce the viscosity of a solution of carboxymethylcellulose to one-half) in powder form was used for treating the denim fabric. Cellulase treatment was carried out using a Launder-Ometer (Atlas Material Testing Technology LLC, Chicago) with a thermostatically controlled water bath system where stainless steel containers can be mounted. The containers were mounted on a horizontal shaft and rotated at a speed of 40-45 rpm. The denim fabric was treated with 0.1 % (owf) cellulase with a liquor ratio of 50:1 at 50 °C for 30 minutes. The pH value of the cellulase treatment was set at 6-7 with buffer solution and mechanical agitation was simulated by using 50 stainless steel balls of 6 mm diameter. After cellulase treatment, the denim fabrics were rinsed with deionized water to lower the temperature quickly and to wash away abraded fibers attached on fabrics. The denim fabrics were then treated with deionized water at 80 °C to deactivate the enzyme action. After that, the denim fabrics were squeezed to remove excessive water and were dried in an oven at a temperature of 70 °C. After drying for two hours in the oven, the denim fabrics were placed for conditioning under standard atmospheric pressure at 65±2 % relative humidity and 20±2 °C for at least 24 hours before further evaluation.

Laser Power Measurement

In order to study the relationship between resolution (dpi), pixel time (μs) and the resultant laser power, a 842-PE hand-held optical power/energy meter was used for measuring the laser power of the different combination of laser parameters.

Colour Measurement

The colour characteristics of the denim fabric samples were measured by a Macbeth Colour Eye 7000A Spectro-photometer with D65 illuminant and 10 ° standard observer. The colour yield expressed as *K/S* value (=$(1-R^2)/(2R)$) could be obtained from the reflectance curve ranging from the visible spectrum wavelength of 400 nm to 700 nm. The K/S_{Sum} value was calculated from the individual *K/S* values over the visible spectrum wavelength. The lower the K/S_{Sum} value, the lower colour yield will be, i.e. better colour fading effect. The colour fading percentage (CF%) was calculated by equation (1)

$$\text{Colour fading percentage (\%)} = \frac{(K/S_{Sum})_i - (K/S_{Sum})_f}{(K/S_{Sum})_i} \times 100\ \% \quad (1)$$

Where $(K/S_{Sum})_i = K/S_{Sum}$ value before laser treatment, $(K/S_{Sum})_f = K/S_{Sum}$ value after laser treatment

Colour Levelness

Spectrophotometric technique was used to assess the degree of colour levelness of the sample in quantitative terms by establishing a relative unlevelness index (RUI) [15]. Reflectance values at 8 different locations on the denim fabric were measured by Spectrophotometer (Macbeth Colour Eye 7000A) with D65 Illuminant and 10 ° standard observer within the visible spectrum (400 nm to 700 nm). RUI of the sample was calculated by equations (2) and (3).

$$S_\lambda = \sqrt{\frac{\sum_{i=1}^{n}(R_i - R_m)^2}{n-1}} \quad (2)$$

where S_λ is standard deviation of reflectance values, R_i is reflectance value of the *i*th measurement for each wavelength and R_m is mean of reflectance values of n measurements for each wavelength.

$$RUI = \sum_{400}^{700} C_\lambda V_\lambda = \sum_{400}^{700} \frac{S_\lambda}{R_\lambda} V_\lambda \quad (3)$$

where V_λ is photopic relative luminous efficiency function.

The degree of levelness is described according to the RUI value obtained; the suggested interpretations of RUI values are shown in Table 2 [15].

Results and Discussion

Laser Power Measurement

If a higher resolution is used, the dots in specific area will

Table 2. Suggested interpretations of RUI values [15]

RUI	Visual appearance of levelness
<0.2	Excellent levelness
0.2-0.49	Good levelness
0.5-1.0	Poor levelness
>1.0	Bad levelness

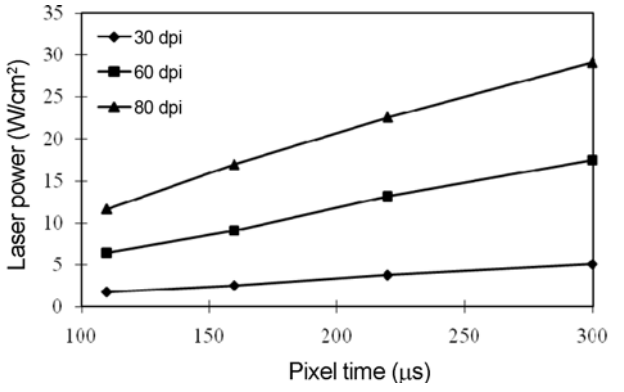

Figure 3. Laser power of different parameters measured.

be denser. However, too high resolution would cause too much energy to be applied on fabric leading to damage of fabric. On the other hand, pixel time means time of each pixel point which laser beam positioning on the fabric surface. Longer the pixel time, more energy will be given to the point, so the engraving effect would be greater. Figure 3 shows the laser power of the different combinations of resolution and pixel time. When resolution increases, the laser power would be increased proportionally. In terms of pixel time, the laser power increases linearly in 110, 160, 220 and 300 μs.

Colour Fading Percentage (CF%)

The degree of colour fading in this study is expressed by colour fading percentage (CF%). The greater the CF% value, the greater will be the colour fading effect. Figure 4 shows the colour fading effect in the denim fabric under the influence of various combinations of resolution and pixel time. It is clearly shown that with the increment of resolution and pixel time, the colour fading effect in the denim fabric increases accordingly. Figure 5 shows the relationship between laser power and CF% in different directions of laser treatment and it is clear to find out that the CF% increase gradually with the increase of laser power. It is expected that with the increase of laser power, more dye would be removed and hence the percentage of dye removal would be intensified leading to a greater CF% [13]. However, the colour fading

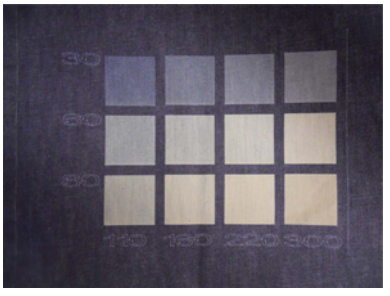

Figure 4. Colour fading in denim fabric under the influence of different combinations of resolution and pixel time.

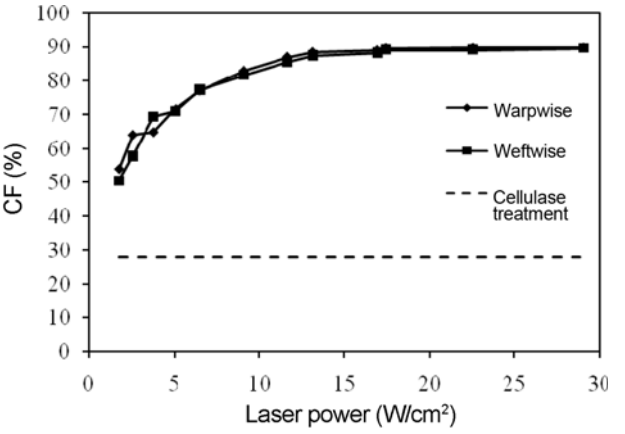

Figure 5. Relationship between laser power and colour fading percentage with cellulase treatment as a comparison.

effect reaches an equilibrium when the optimum laser power is at about 13 W/cm^2 in this study. Although Figure 3 illustrates that the laser power intensified with the increasing resolution and pixel time, similar colour fading effect could still be obtained if the pixel time is fixed while varying the resolution as shown in Figure 3. As a result, it could conclude that laser power was not only the key factor to fade the fabric surface colour but also the combination of process parameters, i.e. resolution and pixel time, would enhance it. Therefore, by carefully adjusting the laser treatment parameters, different degree of colour fading effect could be achieved. If the direction of laser treatment is taking into consideration, there is no significant difference in the CF% of the denim fabric being laser treated in either warpwise or weftwise direction. When comparing the CF% of laser treated denim fabrics with CF% of conventional cellulase treatment, laser treatment can provide greater colour fading effect than cellulase treatment depending on the laser power used, i,e, the various combination of laser processing parameter. According to Figure 5, it is noted that colour fading effect in denim fabric induced by laser treatment can be easily controlled.

Colour Levelness

Traditionally, levelness is judged by visual assessment or by comparing similar samples in order to determine colour difference [15]. However, such assessment is subjective in nature which may give a lot of argument especially in stone washed, sand washed and bleached denim fabric. Thus, in this study, the reflectance values at appropriate wavelength are used for determine the colour levelness of laser treated denim fabric using equations (2) and (3). Figure 6 shows the colour levelness values with different laser power which are measured in different laser treatment directions.

Figure 6 shows that the colour levelness of the laser treated denim fabric is independent on the laser power. The colour levelness of the laser treated denim fabrics is about

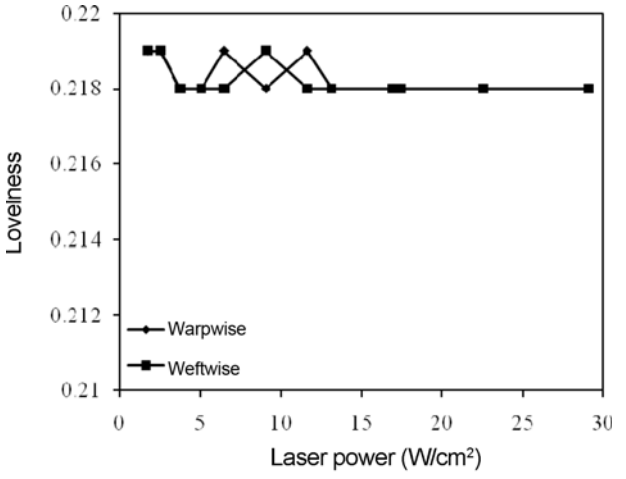

Figure 6. Levelness and laser power.

0.22 and the colour levelness of laser treated denim fabric is good (refers to Table 2). Based on the information from Figure 5 and Figure 6, it can conclude that the increase of laser power can effectively fade the colour from the denim fabric but the levelness of colour fading effect is also good. This indicates that with careful selection and control of laser process parameters, good colour fading effect with good colour levelness can be achieved in the laser treated denim fabric. In addition, it is noted that the colour levelness is not depending on the direction of laser irradiation.

Conclusion

In this paper, denim fabric was treated with CO_2 laser using different combination of laser process parameters, i.e. resolution and pixel time. In order to study the effect of the direction of laser irradiation, laser was irradiated in warpwise and weftwise direction of the denim fabric. Experimental results revealed that laser power was generally increased with the increase of resolution and pixel time. The colour fading effect measured by CF% showed that increase laser power would increase the CF% indicating that greater colour fading effect could be achieved. However, the colour fading effect reached an equilibrium level with an optimum laser power of about 13 W/cm^2. Although the colour fading effect increased with laser power, the colour levelness in the laser treated denim fabric was considered as good levelenss. In addition, the colour fading effect and colour levelness of the laser treated denim fabric were found independent on the direction of laser irradiation. Therefore, this study could concluded that laser treatment can be a useful tool to treat denim fabric with good colour fading effect but also have good colour levelness by controlling the laser process parameters.

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