# Colour Quality of $CO_2$ Laser-Treated Denim Fabric

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Abstract: $CO_2$ laser processing was used in this study for engraving denim fabric. By controlling the laser process parameters, i.e. pixel time (μs) and resolution (dot per inch), laser with different powers can be produced which were used for engraving a square pattern in denim fabric. After laser engraving, the shade and related colour properties of the denim fabric were measured and compared with the untreated one.



## 1 INTRODUCTION

$CO_2$ laser treatment has been applied to different areas of textile industry in recent years (Dascalu et al., 2000); (Ozguney, 2007); (Tarhan and Sariisik, 2009). By altering the laser power, various amount of the surface fibres and dye molecules from fabric surface can be removed causing change in fabric colour quality values. Therefore, laser treatment can have the ability of being applied to textile material for achieving colour fading effect. In recent denim fabric finishing, colour fading shares one of the most important finishing effect. Generally speaking, the colour fading effect can be achieved by using mainly chemical such as pre-washing, rinsing, stone washing, sand washing, snow washing, stone washing with enzymes and bleaching. However, these treatments may cause pollution problem in the effluent and inconsistent surface outcomes (Dascalu et al., 2000); (Ozguney, 2007); (Tarhan and Sariisik, 2009). In addition, the chemical treatments are time-consuming and product quality is quite difficult to control. In order to cope with these problems, a novel treatment that does not have the drawbacks involved in the conventional chemical colour fading technologies should be adopted for treating the denim fabric. The laser treatment, being a dry treatment, will be an alternative to the conventional technologies. With the selection of laser intensity precisely, it is easy to apply certain design effect onto the textile surface with desired colour quality values (Esteves and Alonso, 2007); (Kamata and Suzuki, 2004); (Naruse and Suzuki, 2004). In the present study, laser engraving will be applied to the denim fabric in order to evaluate its effect on fabric shade and colour related properties.

## 2 EXPERIMENTAL

### 2.1 Material

Blue indigo-dyed denim fabric was used. The fabric weight was 384g/m$^2$ with warp density 20 ends/cm (80tex) and weft density 20 picks/cm (60tex). The denim fabric was conditioned under standard atmosphere of 65±2% relative humidity and 20±2°C before further treatment.

### 2.2 $CO_2$ Laser Processing

The laser process was conducted with a $CO_2$ source laser (wavelength: 10.6μm) engraving machine (GFK, Spain) which is computer-controlled. A square pattern of size 200mm x 200mm as shown in Figure 1 was input into the computer system. During the laser processing, the square pattern was transferred to denim fabric by laser engraving. The resolution of the computer-controlled laser beam was set to 30, 60, 80 and 100 dot per inch (dpi) with pixel time of 110, 160, 220 and 300μs. Totally, 16 combinations were made.

Figure 1: Square pattern with size 200mm x 200mm.

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### 2.3 Laser Power Measurement

In order to investigate the relationship between resolution (dpi) and pixel time (µs) to give the laser power density, a 842-PE hand-held Optical Power/Energy Meter was used for measuring the laser power energy of the 16 parameter combinations.

### 2.4. Colour Measurement

Colour measurement was performed by a spectrophotometer of GretagMacbeth Color-Eye7000A. $D_{65}$ Daylight with a 10° standard observer was used during colour measurement. Totally, four measurements were done for each sample. The samples were conditioned at 20 ± 2°C and the relative humidity of 65±2% before taking the measurements. Reflectance curves, $K/S_{sum}$ and CIE L*a*b* values were obtained.

## 3 RESULTS AND DISCUSSION

### 3.1 Laser Power Measurement

The laser power (expressed in $W/cm^2$) of the corresponding combinations of resolutions and pixel time were described in Figure 2. For pixel time, it is a unique parameter in computer graphical file to control the time for laser head positioning in each image point in µs. The long pixel time means more energy focused on the fabric causing a higher degree of engraving effect. Resolution (in term of dpi) is a parameter to control the intensity of laser spot in a particular area; the higher dpi means a higher resolution. However, too high resolution may cause the fabric burnt. A steady increased trend of the power density was observed with the prolonged pixel time and high resolution.

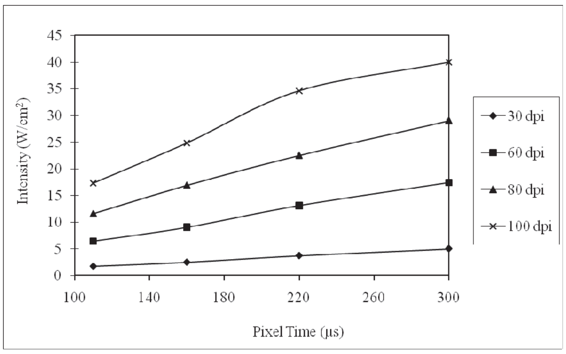


Figure 2: Power density of different parameters.

The laser power plays an important role in the $CO_2$ laser treatment on the denim fabric which is closely related to the indigo removal process of textile. The physical phenomena involved in the indigo removal process will be the vapourisation process. The material removal by laser may often be a simple vapourisation process with absorption of the laser energy at a continually treated surface. As the laser energy increases, the material reaches vapourisation conditions more rapidly (Dascalu et al., 2000).

### 3.2 Reflectance Measurement

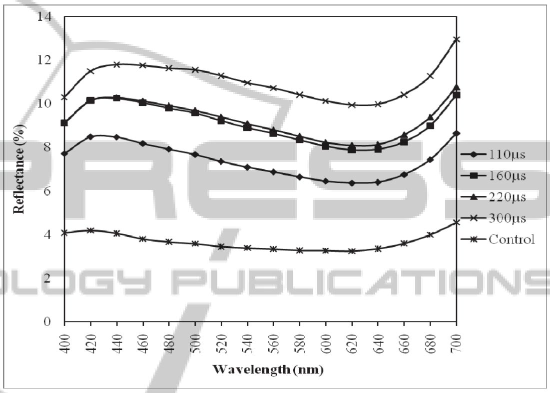


Figure 3: Reflectance of laser-engraved denim fabrics at 30dpi.

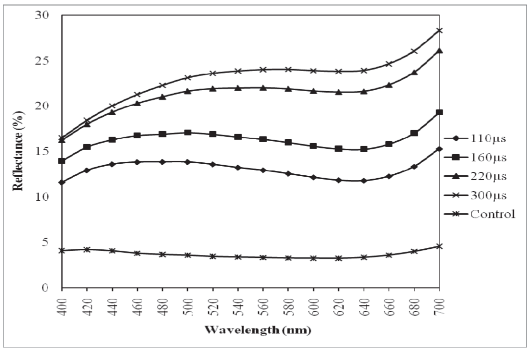


Figure 4: Reflectance of laser-engraved denim fabrics at 60dpi.

Figures 3 to 6 present the reflectance curves of different laser-engraved denim fabrics. The reflectance values of denim fabrics increased as the resolution and pixel time were enhanced when compared with the control fabric. At 30 dpi as shown in Figure 3, one peak representing the reflectance curve of all the selected pixel time were located at the wavelength 400-430nm (indicating blue shade). When the resolution and pixel time increased as shown in Figures 4 to 6, there was no sharp peak appeared with a band shifting to longer wavelength at around 460-560nm (indicating green-yellow shade).

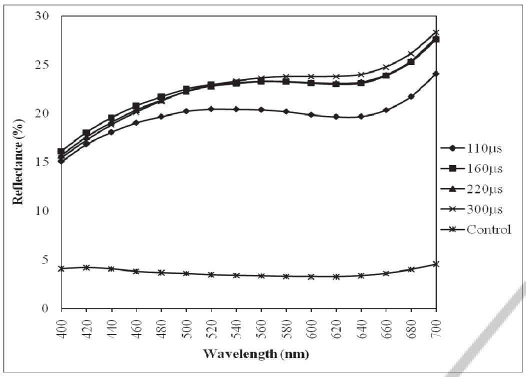


Figure 5: Reflectance of laser-engraved denim fabrics at 80dpi.

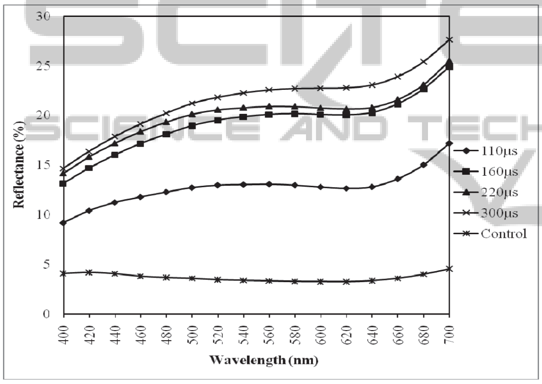


Figure 6: Reflectance of laser-engraved denim fabrics at 100dpi.

In addition, the reflectance curve provides the information of the shade of the material in the visible spectrum. When the reflectance value is large, a pale shade will be and vice versa. It is clear that the shorter the pixel time, the darker the shade of the laser-engraved fabric will be. It had been proved that the short pixel time would have a lower laser power for the engraving process such that a fewer amount of dyes could be removed from the denim fabric surface resulting in a darker shade. Similarly, when the resolution was taken into consideration, the reflectance values increased accordingly with the enhanced resolution. As shown in Figure 2, the higher the resolution, larger the laser power will be and resulting in more dye removal and paler shade. Although a band shifting was noted, there was no obvious change in the overall shape of the reflectance curves.

## 3.3 Colour Yield

The colour yield of the denim fabrics after laser treatment were expressed as K/S value, i.e. $K/S = (1-R)^2/2R$. Since there was a slight band shifting in the reflectance curves, thus the $K/S_{sum}$ value (which is the summation of K/S values over the visible spectrum from 400 nm to 700 nm) was then used for evaluating the effect of laser engraving process on the colour yield of the denim fabric. Figure 7 represents the $K/S_{sum}$ value of the laser-engraved denim fabrics in which the higher the $K/S_{sum}$ value, the more the dye uptake would be. It was very clear to find out that the $K/S_{sum}$ values decreased in each resolution category with respect to different pixel times. The $K/S_{sum}$ value of the untreated fabric was 396.32 but the $K/S_{sum}$ values dropped significantly when compared with different laser-engraved denim fabrics. As a result, the colour yield of the denim fabrics decreased due to dye removal in laser engraving process.



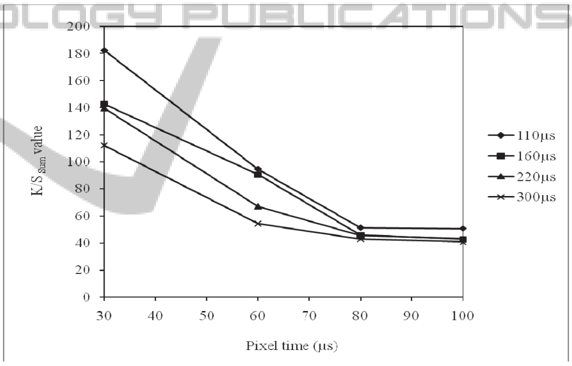


Figure 7: Colour yiled of differently laser-engraved denim fabrics.

## 3.4 CIE L*a*B* Values

CIE L* value indicates the lightness of the sample. The higher the CIE L* value, the lighter the shade of sample will be. The CIE L* value increased with the pixel time and resolution resulting in a lighter surface appearance as shown in Table 1. The CIE L* value of the control denim fabric value was 21.63. When compared, the laser engraving process could increase the CIE L* of the treated denim fabrics significantly. As indicated in Figure 2, the laser power level was related closely to the level of pixel time and resolution. The increment in pixel time together with the resolution would provide more laser power in the laser engraving process. As a result, more fibre materials together with the blue indigo dyes could be removed from the fabric surface, leading finally to a paler shade.

CIE a* value represents redness and greenness of a sample. The more positive the value of CIE a* is, the redder the shade of the sample will be and vice versa. In Table 1, the laser engraved denim fabrics resulted in all negative values of CIE a* with the magnitude of the values tending to increase. The CIE a* value of the untreated denim fabric was 0.50, which indicating that the original denim fabric was redder than the laser-engraved fabrics. Upon the laser treatment with different pixel time and resolution, the pixel time of 110 µs gave the least reduction in CIE a* followed by 160, 220 and 300 µs respectively. Since the yarns in denim fabric were blue indigo ring-dyed, the core of the yarn remained white in colour. In laser engraving, the fibre together with the blue indigo dyes in the sheath of yarn were removed from fibre surface leaving a paler blue colour remaining in the yarn. Owing to the thermal effect occurred during laser engraving, thermal oxidation would occur resulting in yellow surface colour in the yarn. The yellowing in cotton yarn together with the remaining blue indigo dye remained in the fabric surface contributes to a greenish effect on the fabric surface. Since the laser power increases correspondingly with the increment of pixel time and resolution, thus the enhanced thermal oxidation effect contributing to more yellow surface colour would be obtained resulting in increased greenish effect.

Table 1: CIE L*a*b* values of differently laser engraved denim fabrics.

| Sample | | CIE L* | CIE a* | CIE b* |
|---|---|---|---|---|
| Control | | 21.63 | 0.50 | -4.45 |
| Pixel time (µs) | dpi | | | |
| 110 | 30 | 31.89 | -0.77 | -4.05 |
| | 60 | 42.56 | -1.34 | -1.55 |
| | 80 | 51.99 | -1.49 | 3.20 |
| | 100 | 52.45 | -1.55 | 5.44 |
| 160 | 30 | 35.59 | -1.03 | -3.65 |
| | 60 | 42.78 | -1.38 | -0.23 |
| | 80 | 53.76 | -1.53 | 5.06 |
| | 100 | 54.91 | -1.65 | 6.30 |
| 220 | 30 | 35.89 | -1.13 | -3.06 |
| | 60 | 47.42 | -1.49 | 3.65 |
| | 80 | 54.15 | -1.57 | 5.39 |
| | 100 | 54.98 | -2.23 | 6.73 |
| 300 | 30 | 39.29 | -1.26 | -2.49 |
| | 60 | 51.48 | -1.59 | 3.70 |
| | 80 | 55.23 | -2.00 | 5.76 |
| | 100 | 55.70 | -2.36 | 6.82 |

Table 1 shows CIE b* values of the denim fabrics after the laser engraving with different process parameters. Generally speaking, CIE b* value describes the yellowness and blueness of a sample. The higher the positive the value of b*, the more the yellowish of the sample will be and vice versa. The CIE b* value of the untreated denim fabric was -4.45 but after laser treatment, the CIE b* values increased. The laser engraved fabrics tended to have a yellowish shade with the prolonged pixel time and increased resolution. According to Figure 2, the increase in pixel time and resolution would increase the laser power in the engraving process. Thus, more fibres containing the blue dye could be removed from the fabric surface resulting in a paler blue shade with increasing CIE b* values. In addition, the thermal oxidation effect imparted onto the fibre could give yellowing effect on the fabric surface also increase the CIE b* values.

## 4 CONCLUSIONS

Denim fabrics were engraved by laser with different process parameters, i.e. resolution and pixel time. Experimental results revealed that the increased resolution and pixel time would increase the laser power density accordingly. Under the influence of high laser power, a paler surface appearance was noted on the denim fabric. At the same time, the $K/S_{sum}$ values were reduced accordingly, indicating that the amount of blue dye on denim fabric was decreased significantly. Meanwhile, the measurement results of CIE L*a*b* values revealed that a lighter shade was obtained for the laser-engraved denim fabrics and also a green-yellow look was observed for the denim fabrics. In conclusion, with the suitable selection of various laser process parameters, the laser engraving process could be technically used as a novel dry surface treatment for creating different shading effects on denim fabric.

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