Panel 2.8 Technologies and Design
Embellishment of Aluminum Foil Laminated Denim Fabric Using Laser Engraving Technology

YUAN Guoxiang[a], HUANG Jingjing[b], JIANG Kinor [c]
[a,b,c] Institute of Textiles and Clothing, The Hong Kong Polytechnic University, Hong Kong, China,
Email:[a]vogue@126.com, [b]15851250002@163.com, [c]kinor.j@polyu.edu.hk
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Abstract
This paper studies the use of laser engraving and aluminum foil laminating as an embellishing process to denim fabric. Laser technique is being applied in the textile and fashion industries because it is an ideal surface treatment for design application without usage of chemicals and water. This paper will explore a design method that combines laser engraving technology and metallic foil laminating for a sheening surface effect. Before the application of laser engraving, the aluminum foil is laminated on denim fabric with laminating adhesive. Then, the laminated denim fabric is engraved by the laser with a different DPI (dots per inch) as well as the pixel time (microsecond, μs). The performance of the laser engraved foil laminated denim fabric is investigated, including physical and mechanical properties. The study demonstrates an embellishment application in denim fabric, which developed metallic appearance with patterns on denim fabric combing the aluminum foil laminating and the laser engraving techniques. It carries out new possibilities for textile and fashion designs and reveals the future potential for green textile products.

1. Introduction
The innovation of textile today is driven by technology and material. The textile needs to be flexible to design, change, and produce, because the customer may want to make pattern alterations with different appearance and have shorter production period. Laser technique is rapidly expanding in industry and is a flexible alternative to textile embellishment in design and manufacturing. Although there are diverse applications for laser technique, the largest application is material processing and CO_2 lasers. (DeMaria & Hennessey, 2010). CO_2 laser is the most efficient and suitable for engraving materials that are not good conductors of heat and electricity because its wavelength can easily be absorbed by organic materials such as fabrics (Rajagopal, 2008; Ready, 1997).

CO_2 laser is usually used to engrave textiles, as the decoloration and mono-color effect can be achieved (Chow, Chan, & Kan, 2011; Kan, Yuen, & Cheng, 2010; Ondogan, Pamuk, Ondogan, & Ozguney, 2005; Pezelj, Cunko, & Andrassy, 2004; Štěpánková, Wiener, & Dembický, 2010; Tarhan, & Sariişik, 2009; Yuan et al, 2012). For this paper, aluminum foil was applied to laminate on denim fabric, and laser engraving was used to engrave the laminate denim fabric for new surface patterns. Today, foil laminating has found many applications and is increasing in popularity as a method of laminating in textile and garment products. This method can produce sheening, metallic effects by laminating an adhesive on a fabric and then applying aluminum foil with a heat transfer press (Tortora, P.G., & Johnson, 2013). To assess the performances of the untreated and laser engraved foil laminated denim fabric, measurements such as tearing strength, air resistance, surface observation, color appearance, some low-stress mechanical properties including tensile, shearing, bending and compression were investigated. Opposite to conventional processes of textile design, the laser engraving will treat the surface of fabrics within a flexible process towards unique images (Gaskill, 1992). The textile sample design results demonstrate that the integration of the laser engraving and aluminum foil laminating is an idea approach to develop sheening appearance on denim fabric.

2. Experimental
2.1 Material
The commercially available denim fabric was used for the purposes of aluminum foil laminating and laser engraving. The fabric weight was 2190.15 g/m2, with a warp density of 96 ends/inch and a weft density of 50 picks/inch. All samples were conditioned under the standard atmosphere of 20.5±0.5 ºC and relative humidity of 64±1% for 24 h before treatment and testing.

2.2 Aluminum Foil Laminating
In this process, a market-bought laminating adhesive (Patek Trading Company Ltd., HK) was screen printed onto denim fabric and a foil (0.012 mm) combines a thin polyester film with a heat-sensitive release coating, and a very thin layer of aluminum is pressed onto the fabric by using a table top platen heat pressing machine (AIT Model 1350PM, Jesse J. Heap & Son, Inc., US). The temperature of heat pressing was set at 120 and the pressing time is 30 sec with the set pressure of 3.5 bar.

2.3 Laser Engraving
The laser engraving was carried out using GFK Marcatex FLEXI-150, a commercially designed carbon dioxide (CO_2) laser machine (Eurotrend Group, Spain) coupled to a computer-controlled table. The size of the lens is 80cm (1.5 mm beam diameter). The generated wavelength of laser beam was set at 10.6 μm and the input voltage

was set at 100V (or 280W in power). The applied laser treatment software is the EasyMark® 2009. The process of laser engraving treatment on fabric surface is as follows: (1) design pattern use graphic design software, (2) convert the graphic pattern to gray scale, (3) send designed pattern to laser system, (4) set parameters and conduct laser engraving treatment. Figure 1 shows the experimental set-up for the laser treatment experiment.

2.4 Laser Power Density Measurement
In order to investigate the relationship between resolution (dpi), pixel time (µs) and the resultant laser power density, a 842-PE hand-held Optical Power / Energy Meter (Newport Corporation, USA) was used for measuring the laser power density of the different combinations of variables.

2.5 Tearing Strength
The tearing strength of the foil laminated denim fabrics before and after laser treatment were measured by an Elmatear Digital Tear Tester (James H. Heal & Co Ltd, England) in accordance with ASTM D 1424-96. The tear strength specimens were 80mm×100mm and were tested in both the warp and weft directions.

2.6 Air Resistance
The air resistance of the fabric samples was measured based on the constant rate of air flow at 0.04 m/s generated by the piston motion/cylinder mechanism and passed through a specimen into atmosphere using Kawabata Evaluation System (KES-F8-AP1) under air flow resistance tester (Kato Tech Co., Ltd., Japan) following the Kawabata specifications (Kawabata, &Niwa, 1996). It can measure air pressure loss and calculate air resistance in kilopascals times second per meter (kPa·s/m) when air flows through the transverse section of fabric samples.

2.7 Observation of the Fabric Surface
Micrographs of the foil laminated denim fabric samples engraved at different parameters were captured with a Leica M165 stereo microscope (Leica, Wetzlar, Germany). The micrographs of the fabrics were measured in µm for laser engraving.

2.8 Color Appearance
Color appearance was measured by using a Macbeth Color-Eye 7000Aspectrophotometer (Gretag Macbeth, New Windsor, NY, USA) interfaced to a digital PC under illuminant D65, and by using a 10° standard observer. The color parameters were recorded as spectral reflectance data in accordance with the Commission Internationale de l'Eclairage (CIE) standard.20 The corresponding colorimetric data were obtained. ΔL* is a measure of the lightness, Δa* is a measure of redness (positive direction) or greenness (negative direction) and Δb* is a measure of yellowness (positive direction) or blueness (negative direction) of an object. The color change (ΔE*) between the original and treated samples was also evaluated.

2.9 Abrasion Resistance
The abrasion properties of the laser engraved aluminum foil laminated denim fabrics were measured according to ASTM D4966-98 with a SDL Martindale abrasion tester. The treated fabrics is cut in size of 38 mm in diameter and with the defined load of 9 ± 0.2 kPa as well as rubbed against a standard abradant fabric.

3. Results and Discussion
3.1 Laser Power Density Measurement
The laser power energy expressed in terms of power density of the different combinations of resolution and pixel time was measured and is shown in Figure 1. A steady increased trend of the laser power density was observed with the prolonged pixel time and high resolution, and the laser power energy increases accordingly.

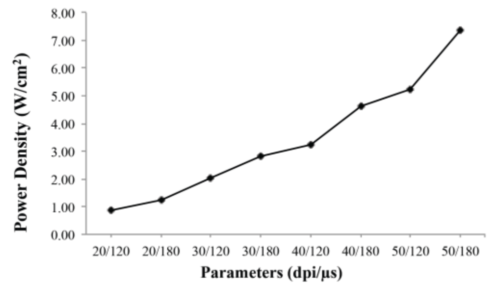

Figure 1: Laser power density of different parameters measured

The color variation of the foil laminated denim fabric with respect to the different combinations of resolution and pixel. The physical phenomenon involved in the laser-induced aluminum foil and dyestuff being removed from the denim fabric surface was the vaporization process. The material removed by laser might often be a simple vaporization process, with the absorption of laser energy at a continuously treated surface. As the laser energy was increased, the material could reach vaporization rapidly, and thus the vaporized material could simply diffuse away into the surrounding atmosphere without further interaction with the beam (Dascalu, Acosta-Ortiz, Ortiz-Morales, & Compean, 2000).

3.2 Air Resistance
Air resistance is one of the major properties of textile materials and an important factor that influences the wearer's comfort of textile materials. It is governed by factors such as fabric thickness, density, structure, and surface characteristics. Figure 2 indicates that the laser engraving could lower the air resistance of the foiled denim fabric.

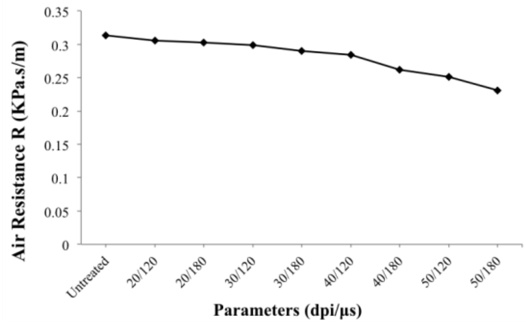

Figure 2: Air resistance of untreated and laser engraved samples

A higher air resistance means that a smaller amount of air could flow through. After coating process, the fabric surface was covered by foil and adhesive which hinder the air flow through the fabric, so the air resistance is high. The results indicate a decrease from about 2.2 % (20 dpi/120 µs) to 26.2% (50 dpi/180 µs) in air resistance of the laser engraved fabrics compared with the untreated one. It shows that only slight changes of the air resistance when the laser engraving resolution applied at 20 dpi from 120 µs to 80 µs, because only the laser beams affected a minimal amount of laminated foil and fibers. The greater changes in air resistance were possibly due to the melting and evaporation of the foil and fibers by laser beams. After laser engraving with stronger laser engraving parameters, more air spaces between the fibers and fabrics resulted, so it became therefore possible for more air to pass through the fabric resulting in lower air resistance. The result indicates the laser engraving do not influence the fabric structure, therefore the change in R values is related to the surface characteristics of foil laminated denim fabric.

3.3 Surface Observation

Figure 3 shows the micrograph images of the laser engraved foil laminated denim fabric surface with different resolutions and pixel times. With the application of different treatment parameters, the fabrics show related engraved effects.

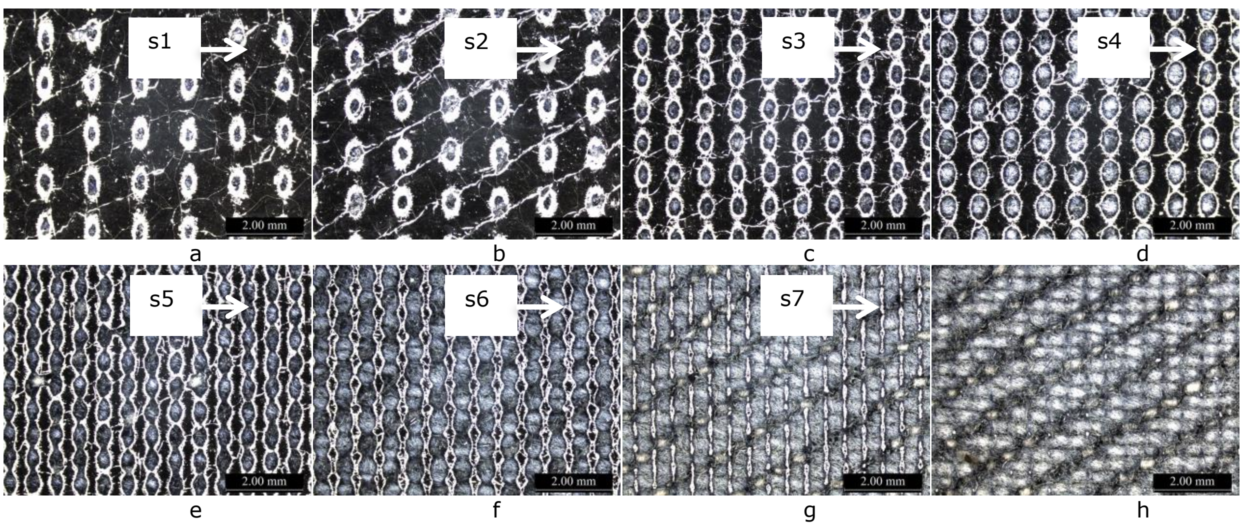

Figure 3: Surface micrographs of laser engraved samples under eight different parameters: (a) 20 dpi/120 µs; (b) 20 dpi/180 µs; (c) 30 dpi/120 µs; (d) 30 dpi/180 µs; (e) 30 dpi/180 µs; (f) 40 dpi/120 µs; and (g) 40 dpi/180 µs

Figure 3(a) shows through laser engraving with a lower resolution and shorter pixel time, few foils and fibers were burned to form some small spots (s1 and 2) on fabric surface. After prolonged laser treatment, more energy is focused on the fabrics as shown in Figures 4(c) and (d), so more foils and fibers were melt and evaporated to form some bigger engraved spots (s3 to 7). When fabric was treated at 50 dpi/180 µs, all the laminated foils were evaporated and the original denim fabric structure emerged and observed. In the present study, it was observed that with the increment of resolutions and pixel times, more laser energy could be applied on fabric surface, and the laminated foils and some surface fibers were engraved and evaporated.

3.4 Color Appearance

The fabric that underwent different laser engraving parameters could result in color change effect. Figure 4 shows the results of the color change of the laser engraved foil laminated fabrics at different resolutions.

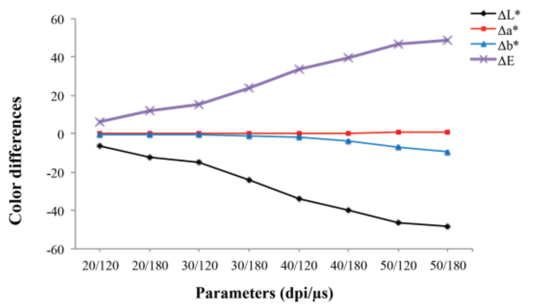

Figure 4: Color values of laser engraved samples

Figure 4 shows the differences in color value, such as lightness, redness and greenness, yellowness and blueness, and total color difference of fabrics. All of the color values resulting from untreated and laser engraved foil laminated denim fabrics are compared. ΔL* indicates the lightness of the sample. The higher the ΔL* value, the lighter the shade of sample will be. In this study, the denim fabric was laminated with foil for laser engraving, with the increase of laser power densities, the laminated foil and some fibers were removed from the fabric surface, resulting in a darker and greyer surface appearance, so The ΔL* value decreased with the increase of pixel time and resolution. When compared with untreated fabric, The ΔL* value of the fabrics after engraving from 20 dpi/120 μs to 50 dpi/180 μs was decreased that ranging from -6.235 to -48.215.Hence it can be said that the laser engraving is an effective color fading process for foil laminated fabric. The Δa* value represents the redness and greenness of a sample. Figure 5 shows the engraved fabric has a slight positive decrease from 0.251 to 0.041 that indicates with the increase of applied laser power, the laminated fabric tended to have a greenish color than the fabric engraved with the lower laser power. Because with the increment of laser power, some surface cotton fibers were burned, together with the remaining blue indigo dye present on the surface of the fabric, could express a greenish color. The Δb* value describes the yellowness and blueness of a sample. The higher the negative value of b*, the more bluish the sample will be. As indicated in Figure 5, it appeared that the laser engraved foil laminated fabrics tended to have a bluish shade that ranging from -0.165 to -7.71with the prolonged pixel time and increased resolution. It was obvious that, with the increment of laser power, more foil with some surface fibers could be removed from the fabric surface, resulting in a paler blue shade with the decreasing Δb* values. The figure also shows the total color difference value (ΔE) increased by 6.29 to 49.11.Compared with other color values, it obviously indicates the change of ΔE mainly due to the light change. This is because the laminated foil after laser engraving was evaporated and the original denim fibers and yarns remain.

3.5 Tear Strength

The tearing strengths of the fabrics in both the warp and weft directions were evaluated and the results are shown in Figure 5.

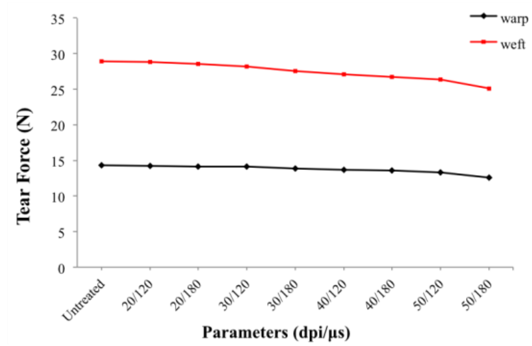

Figure 5: Tear strength of untreated and laser engraved samples

The test results show that there is a decrease in the tearing strength from about 0.7 % (20 dpi/120 μs) to 12.3 % (50 dpi/180 μs) in the warp direction and 0.4 % (20 dpi/120 μs) to 13.1 % (50 dpi/180 μs) in the weft direction for the treated fabrics. This is due to the reason that some fibers are engraved and melted by the laser beams, so that the strength of the fabrics decreases.

3.6 Abrasion Resistance

The abrasion resistance was evaluated by the number of abrasion cycles completed at the time of breaking. The testing machine records the number of cycles to which the fabric is exposed until an end point is reached.

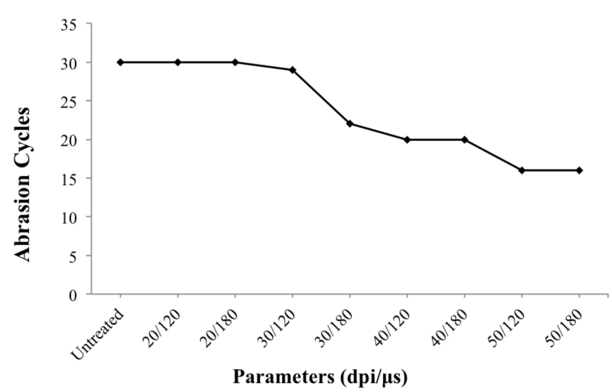

Figure 6: Abrasion resistance of untreated and laser engraved samples

Figure 6 shows the abrasion resistance of the laser engraved foil laminated fabrics are different. The number of movements of the fabric treated by higher laser parameters was less than the untreated and lower parameters treated foil laminated denim fabrics. With the higher treatment parameters, more laser energy is applied and some surface foils and adhesives were engraved and evaporated easier. This meant that the abrasion resistance of the fabrics is affected by the parameters including resolution and pixel time of laser engraving under the same foil laminating condition.

4. Design Application

The denim fabric sample was laminated using metallic aluminum foil and then treated by means of laser engraving at different parameters. By changing laser treatment parameters, different desired engraved fabric appearances are achieved.

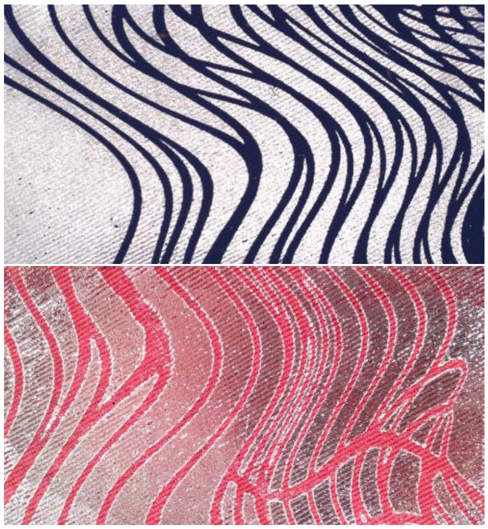

Figure 7: Metallic aluminum foil laminated fabrics engraved using laser for single shade effect

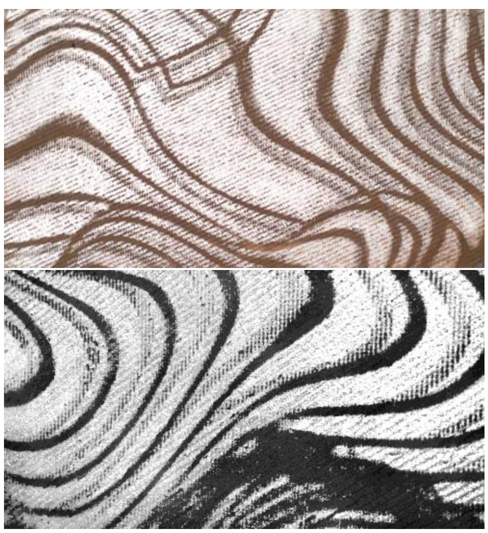

Figure 8: Metallic aluminum foil laminated fabrics engraved using laser for multi-shades effect

As Figure 7 shows that the laser engraving could engrave on the aluminum foil laminated denim fabrics to make clear patterns with the original fabric colors such as blue and red remains at 50 dpi/180μs. To achieve the comparing results with clear and vague patterns with shinning metallic aluminum foil laminated background on denim fabric, the fabrics were engraved by laser at 30 dpi/120 μs and 40 dpi/180 μs in accordance with the designed wave patterns as shown in Figure 8. Some laminated aluminum foils on the fabric surface were ablated and burnt which resulted in different shades with original denim colors of brown and black. The un-engraved areas retained the aluminum laminated sheening color against the engraved areas. These designs demonstrate the possibilities to combine foil laminating method with laser engraving technique to develop new effects and color appearance on denim fabric.

5. Conclusion

The experiment and design results revealed that different pixel time and resolution of laser engraving treatment can alter the surface morphology and some properties, which indicates that laser engraving is the most efficient in etching surface laminated foil on fabric surface. The laser engraving could remove the surface laminated foil on fabric surface at short time with different treatment parameters. The changes in the physical and mechanical properties are related to the surface laminated foil and inter-fiber/inter-yarn frictional force. A decrease in the air resistance of the laser engraved fabrics is found which is due to the increment of laser energy that could decrease the amount of laminated foil and adhesive with fibers, and also change the fabric surface morphology. It is observed that the changes are mainly due to the laser engraving action on fabric surface with laminated foil and adhesive, the changed properties can act as an alternatives to improve foil laminated fabric for textile surface design and products. To conclude, the laser engraving has a potential application to achieve surface treatment on foil laminated fabric and could make pattern design environmentally friendly.

6. References

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