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A Study of Physical Modification on Grey Cotton by Laser Irradiation

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Abstract: The surface morphology of the CO_2 laser treated grey cotton fabrics was studied which showed a characteristics sponge-like structure on cotton fibres after treating with CO_2 laser irradiation. The laser treatment parameters ranging from 100 to 150 pixel time and 40 to 70 dot per inch (dpi) were irradiated on the grey cotton fabrics directly and the degree of physical modifications, such as surface morphology, wettability and fabric strength, were changed accordingly with various laser treatment parameters. The surface morphology, wettability and tensile strength of cotton fibre treating with laser were evaluated using different instruments, such as Scanning Electron Microscope (SEM), contact angle meter and tensile strength machine. In spite of creating a sponge-like structure on fibre surface after treating with laser, the wettability of the samples was highly improved but the tensile strength was decreased.

Keywords: Laser, Cotton, Physical modification, Surface

Introduction

In this paper, the physical modification on grey cotton by laser irradation using different laser parameters would be studied. As for the cotton fabric, it has a high market share in textile industry and the grey cotton fabric was untreated, which means the effect of laser irradiation can be examined comprehensively and systematically. CO_2 laser beam with 10.6 μm wavelength was used and the type of CO_2 has higher efficiency compared with other lasers [1]. It is a fact that the laser irradiation can create morphological modifications on the surface of polymers, resulting in changes in the physical and chemical properties of the materials [2]. As for textile materials, surface modification by conventional chemical finishing methods such as acid and alkaline is not environmentally friendly and can cause safety and pollution problems [3]. The effect of different laser parameters on grey cotton fabric would be studied so as to examine the effectiveness of laser treatment applied on textile fabrics. Two parameters are used to study the surface modification by laser in this paper, which are resolution (dots per inch) and pixel time. The range of resolution used was from 40 to 70 dpi and the pixel time used was from 100 to 150 μs are studied. According to various evaluation and testing methods, the physical modifications, wettability and tensile strength will be examined.

Experimental

Sample Preparation

100 % pure plain weave grey cotton fabric (density: 60 ends/inch & 60 picks/inch; yarn count: 20×20 tex) with the fabric weight of 1.561 g/m^2. The fabric was conditioned at 21±1 ^{o}C and 65±5 % relative humidity for 24 h before experiments and evaluations.

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Laser Irradiation

Laser irradiation was performed using a commercial pulsed CO_2 laser (GFK Marcatex FLEXI-150) under atmospheric condition in air. The samples were irradiated from the laser beam directly. The pulse energy of the laser beam was in the range from 5 to 230 mJ and the wavelength was 10.6 μm. The two laser operation parameters of resolution (40, 50, 60, and 70 dpi) and the pixel time (0, 100, 110, 120, 130, 140, and 150 μs) were varied to study the effect of different laser conditions on grey cotton fabric.

Desizing Treatment

Laser treated grey cotton fabrics were desized with Invazyme L40 (Huntsman Corporation) (5 g/*l*, liquor-to-goods ratio: 200:1) at 70 ^{o}C for 1 h. The desized fabrics were rinsed with hot water (100 ^{o}C for stopping enzyme activity) and then cold water and oven-dried at 75 ^{o}C. The treated farbics were conditioned at 21±1 ^{o}C and 65±5 % RH for 24 h prior to any evaluations.

Scouring Treatment

Desized laser treated grey cotton fabrics were scoured with sodium hydroxide (Supplier: Oriental Chemicals & Lab Supplies Ltd.) (20 g/*l*, liquor-to-goods ratio: 200:1) at boil for 1 h. The scoured fabrics were rinsed with hot water first and then cold water. The fabrics were neutralized with cold 0.5% Acetic Acid (Supplier: Oriental Chemicals & Lab Supplies Ltd) and then rinsed with cold water again, finally the farbics were oven-dried at 75 ^{o}C and were conditioned at 21±1 ^{o}C and 65±5 % RH for 24 h prior to any evaluations.

Bleaching Treatment

After desizing and scouring, the fabrics were bleached with hydrogen peroxide (Supplier: Oriental Chemicals & Lab Supplies Ltd.) (conc. 35 %) with liquor ratio of 200:1 at 90-95 ^{o}C and pH 10.5-11.0 for 1 h. The bleached fabrics were rinsed with cold water and oven-dried at 75 ^{o}C, and then were conditioned at 21±1 °C and 65±5 % RH for 24 h prior to any evaluations.

Scanning Electron Microscopy (SEM)

Surface morphology of cotton specimens was investigated by the JEOL JSM-6490 Scanning Electron Microscope (SEM) at the magnification of 3000.

Wettability

The wettability of the specimens were evaluated by a Contact Angle Meter (TanTec Contact Angle Meter Model CAM-Micro) in which after a drop of water (1 μl) was placed on the fabric specimen surface, the image of the liquid droplet was projected to a contact angle micrometer (TanTec Contact Angle Meter Model CAM-Micro) and the contact angle was measured immediately.

Tensile Strength

The breaking strength and elongation of the fibres were measured according to the test method of ASTM D5034-08 using an Instron Tensile Tester 4466.

Results and Discussion

Laser Power Measurement

Figure 1 shows the laser power density with various resolution and pixel time. It reveals that when the resolution and pixel time increased, the power density became higher. As a result, the laser irradiation could induce more serious damage on the fibre at high dpi and pixel time.

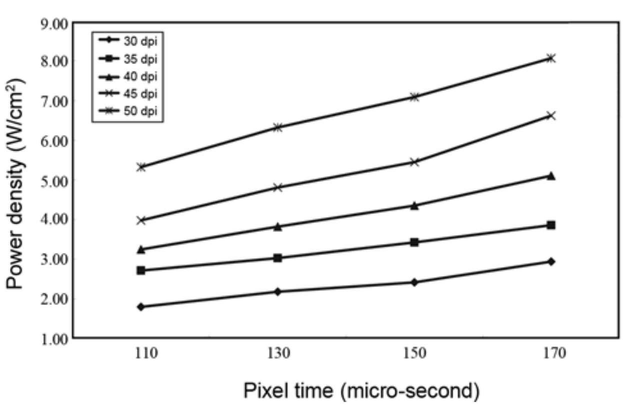

Figure 1. Power density of CO_2 Laser with different beam duration and resolution.

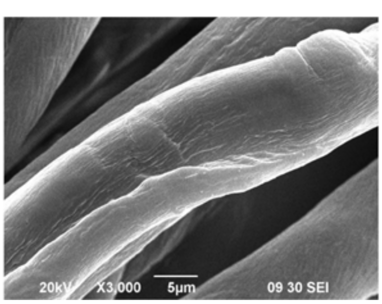

Figure 2. SEM image of control sample at 3000×.

Physical Surface Modification

Figure 2 reveals the SEM images of grey control sample at magnification of 3000×, which were the cotton sample without treating with any laser treatment. The SEM results showed the convolution of cotton fibre and the fibre surface was smooth.

Figure 3(a) and 3(f) illustrate the SEM images of grey cotton sample treated with laser directly at different pixel times and without any post treatment at 3000×. The resolution was set at 40 dpi and the pixel time was increased from 100 to 150 μs. The surface of the fibres was damaged after treating with laser, in which laser irradiation developed various sizes of pores on the cotton fibre and resulting in a sponge-like structure [4]. Furthermore, the laser irradiation is capable of etching away the cotton fibres, in which the outer parts of the fibres were engraved and the fibres

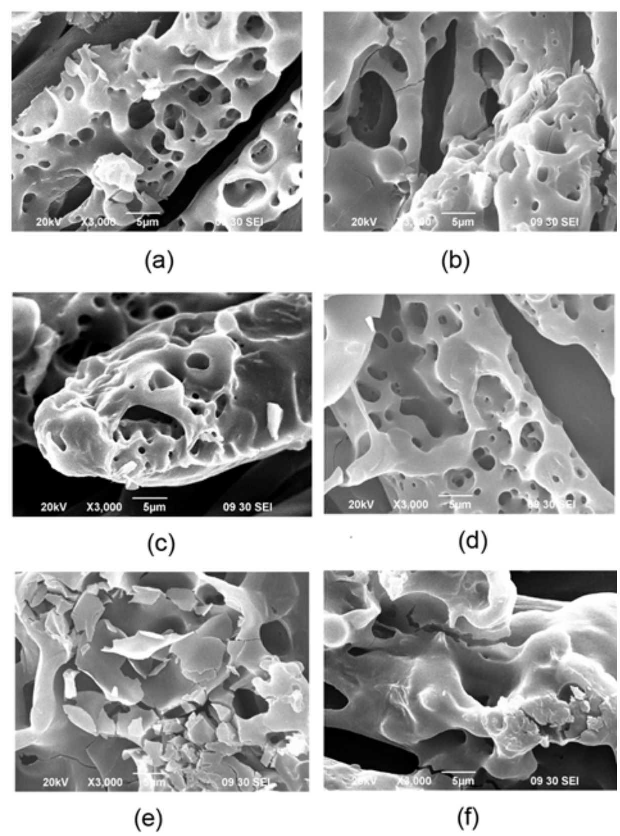

Figure 3. Relationship between the fibre surface morphological modification and pixel time of laser irradiation of the laser treated grey cotton fabric at 3000×; (a) resolution: 40 dpi, pixel time: 100 μs, (b) resolution: 40 dpi, pixel time: 110 μs, (c) resolution: 40 dpi, pixel time: 120 μs, (d) resolution: 40 dpi, pixel time: 130 μs, (e) resolution: 40 dpi, pixel time: 140 μs, and (f) resolution: 40 dpi, pixel time: 150 μs.

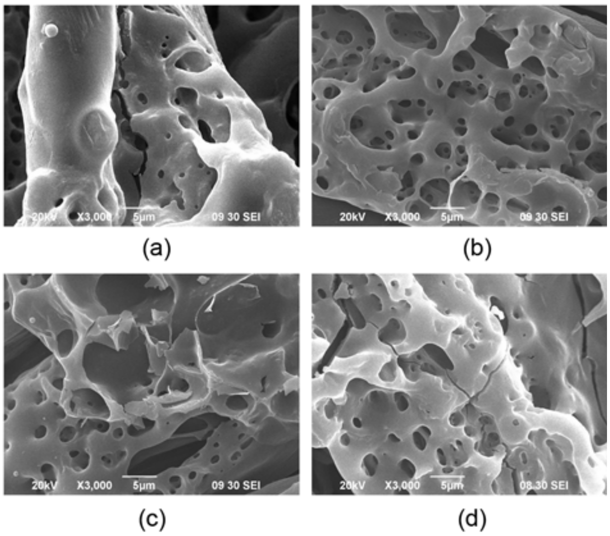

Figure 4. Relationship between the fibre surface morphological modification and resolution of laser irradiation of the laser treated grey cotton fabric at 3000×; (a) resolution: 40 dpi; pixel time: 150 μs, (b) resolution: 50 dpi; pixel time: 150 μs, (c) resolution: 60 dpi; pixel time: 150 μs, and d) resolution: 70 dpi; pixel time: 150 μs.

fragments were obtained. Moreover, the yarns were sized to enhance the yarn strength before weaving process, CO_2 laser beam is a kind of infrared laser which could give thermal energy and the sizes may be melt and adhered on the fibre surface resulting in a rougher surface [5]. With shorter pixel time, the pores are easily observed but with longer pixel time, the laser energy increased, the pore diminished and the sizing material melt seriously and filled the pores. As the pixel time means the time for laser head positioning in each of image point (in μs), the laser induced pores were merged together at higher pixel time. Thus the pores size at 100 μs pixel time was 2 μm and then increased to 5 μm at 150 μs pixel time.

Figure 4(a) to 4(d) demonstrate the grey cotton treated with laser beam at different resolution. Form the SEM images, the fibres with higher resolution laser treatment, the number of pores, cracks and engraved fragments were more densely developed. As for the resolution, it is used to control the intensity of laser spot in a particular area (dot per inch, dpi). For example, the pore density of 70 dpi is 8 pores which is greater than that of 3 pores of 40 dpi. Therefore, the number of pores and the area of laser induced pores of the samples with lower resolution were distributed less than the fabric samples treated at higher resolution.

Figures 5 to 7 present the SEM images of grey cotton sample treated with laser beam at 40 dpi and 100 μs pixel time and then followed by desizing, scouring and bleaching respectively at the magnification of 3000×. The SEM images showed a sponge-like structure was still found on the

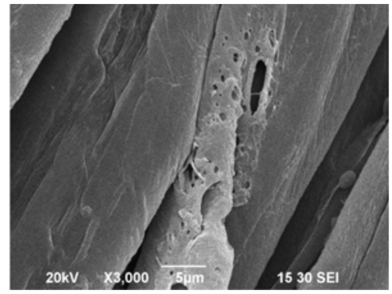

Figure 5. Laser treated and desized cotton sample.

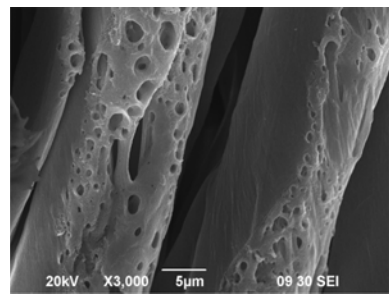

Figure 6. Laser treated, desized and scoured cotton sample.

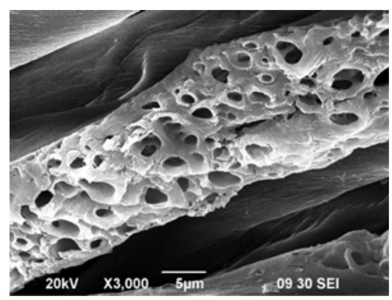

Figure 7. Laser treated, desized, scoured and bleached cotton sample.

fibre surface of the laser treated samples even though conducting three wet processes after laser treatment. As for the CO_2 laser used is a kind of pulsed laser, thus lots of pores were formed by the pulse laser irradiation. The sponge-like structure was still can be found even the treated samples underwent desizing, scouring and bleaching processes.

Figure 5 shows the SEM pictures of the grey cotton samples underwent desizing process after treating with laser. It was obvious that the unfixed fragments were removed in desizing and clearer pores and cracks were obtained. In addition, the sizing materials were removed from desizing process, the melted sizes adhered on fibres surface may be removed and hence a clear sponge-like structure on fibres were observed.

Figure 6 indicates the SEM image of the grey cotton fabrics which were scoured after treating with laser and desizing at 3000×. The sponge-like structure was still very clear after the two wet processes. In addition, the impact of laser irradiartion is permanent and the induced morphological modification can still be found even undergone desizing and scouring. Moreover, the more the laser induced fragments removed in scouring process when compared with Figure 3(a), in which there were still some fragments and residuals remained.

Figure 7 shows the SEM image of the laser treated cotton samples after desizing, scouring and bleaching at 3000×. When compared with Figure 3(a), 5 and 6, the sponge-like structure became clearer as the samples were conducted three wet processes subsequently in which the fragments, unfixed short fibres and the melted parts of fibres were removed. Moreover, the formation of pores on the cutting area indicated the fibres were etched away by laser beam.

Wettability

In Figure 8, the contact angle values decreased when the pixel time and resolution of the laser treatment increased. As shown from the followings, the contact angle value for grey cotton sample was 130^{o}, but when the cotton fabric treated with laser irradiation, the contact angle dropped to 98^{o} when the grey cotton was treated at 40 dpi and 100 μs pixel time. Moreover, the contact angle decreased when the resolution increased, the contact angle value decreased from 98^{o} of 40 dpi and 100 μs pixel time to 52^{o} of 70 dpi 100 μs pixel time. Besides, the contact angle changed from 98 to 80^{o} when the pixel time increased from 100 to 150 μs pixel time at 40 dpi. At 60 and 70 dpi, the change in contact angle became smaller; in which the curve was nearly flattened when the pixel time increased to 120-150 μs.

Since the tested sample was grey cotton fabric which did not undergo any wet process, there were lots of impurities and dirt, such as waxes, proteins, pectic substance and mineral matters, presence in the fabric and resulting in low water absorption and greater contact angle value [6]. However, the laser irradiation is abrasive in nature which is able to etch away the outer layer of cotton fibre including the sizes adhered on the cotton fibre. As a result, the laser treated cotton fabric had higher water absorption and resulting in smaller contact angle values.

Based on the Wenzel's equation [8], surface roughness should be taken into account as a parameter of contact angle (Figure 9). The surface roughness greatly increases the inherent hydrophobic or hydrophilic nature of a surface [9]. As shown from the SEM images, the laser treatment created the sponge-like surface structure with many pores on the cotton fibres, thus the fibre surface roughness increased. Moreover, the cotton is hydrophilic and the water drop follows the topography and hence causing reduction in contact angle [10]. In addition, the spreading of liquid on the rough laser treated surface could much faster than on the flat surface [11,12].

As shown in SEM images, when the resolution increased from 40 to 70, the pore density increased. Therefore, the increased amount of pores acted as a reservoir providing fast spreading and more space for retaining liquid [11]. Furthermore, the porosity on fibre could produce sufficient capillary action to transport the liquid and retain [13]. The contact angle results of desized, scoured and bleached laser treated cotton samples could not be evaluated due to the water droplet was absorbed within 3 seconds. Since the laser treated cotton samples were purified in desizing and scouring, the impurities and sizes were removed, the water absorption of cotton were highly improved.

Tensile Strength

Figures 10 to 13 indicate the breaking load of the fabric

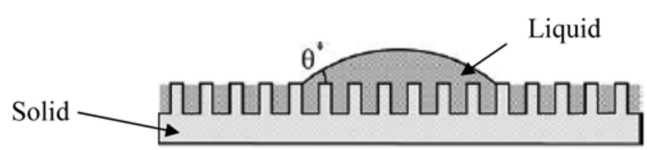

Figure 9. The effect of surface roughness on wetting.

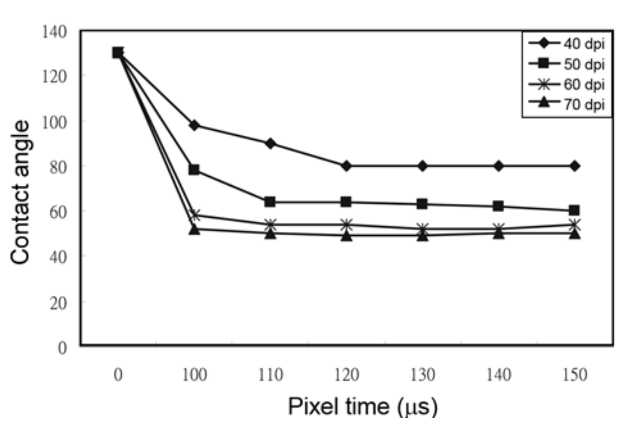

Figure 8. The contact angle of laser treated grey cotton fabrics with various resolution and pixel time.

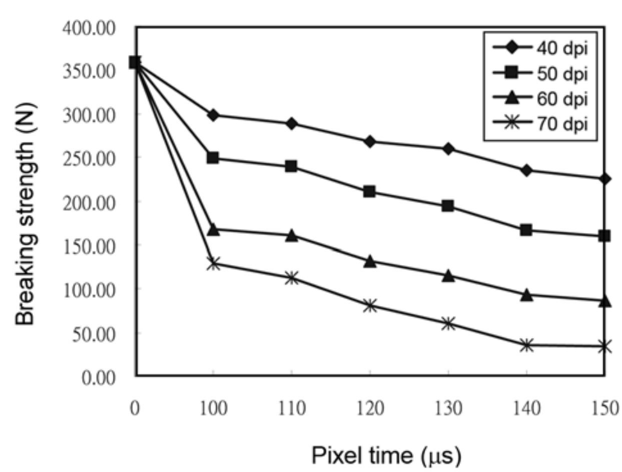

Figure 10. Breaking strength of the grey cotton fabric treated with laser.

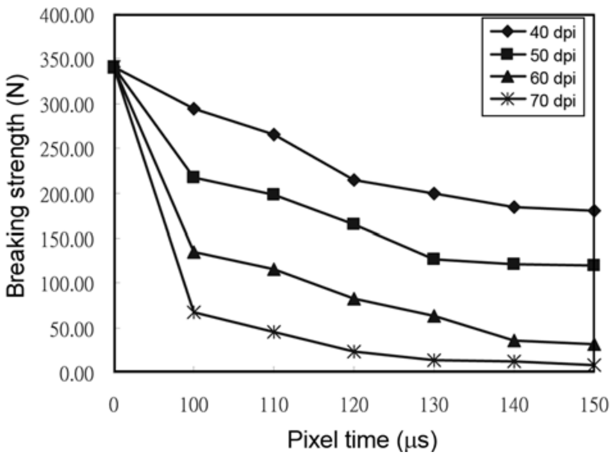

Figure 11. Breaking strength of the desized cotton fabric treated with laser.

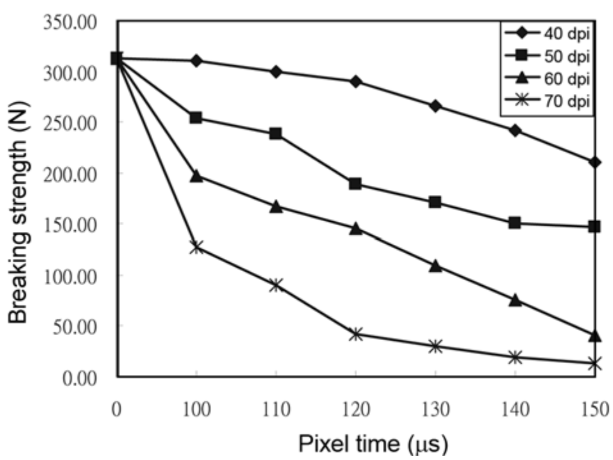

Figure 12. Breaking strength of the desized and scoured cotton fabric treated with laser.

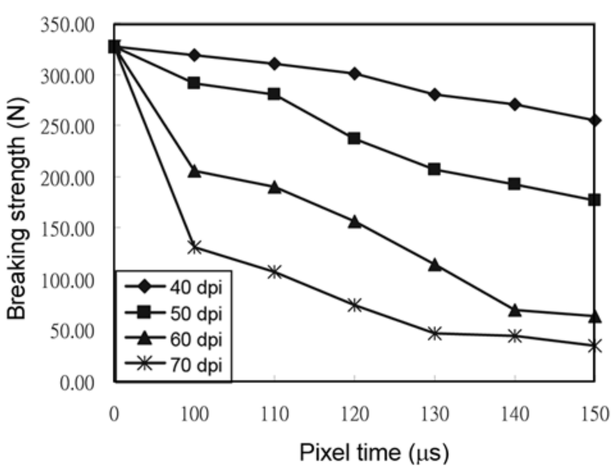

Figure 13. Breaking strength of the desized, scoured and bleached cotton fabric treated with laser.

firstly treated with laser and subsequently being desized, scoured or bleached.

As shown from the above, the tensile strength of the laser treated grey cotton fabric was decreased after desizing, scouring and bleaching. Besides, when the pixel time increased, the reduction in tensile strength increased; when the resolution increased, the higher reduction in tensile strength was obtained. The reduction could be due to fact that the induced pores and cracks on the surface, as shown in SEM pictures, created weak points and even reduced the breaking strength [7].

Figure 10 to 13 show similar results, in which the strength of the cotton fabric had highest tensile reduction at 70 dpi. It may be due to the abrasive power of laser irradiation, the bundle of fibres may be engraved seriously and highly reduced the breaking strength of the fabric. In addition, the breaking strength decreased when the pixel time increased. The CO_2 laser irradiation could give serious physical damage on the fabric, which cause the breaking strength fabric greatly decreased. Lastly, the reduction of breaking load at 60 and 70 dpi were too great that the treated fabrics may not be possible to be used for making cloth as the fabrics were not strong enough.

Conclusion

As shown in the SEM images, the CO_2 laser could cause significant surface modification on grey cotton fabric. This morphological modification was permanent and the characteristics sponge-like structure was obviously obtained after three wet processing, including desizing, scouring and bleaching. By changing the parameters of resolution and pixel time, the level of laser effect could be controlled and give a desired result. In addition, the wettability of laser treated cotton fabrics was improved a lot. Due to the ability of morphological modification and engraving effect, some of the impurities on the grey cotton fabrics were etched and resulting in a sponge-like structure, thus the water absorption of laser treated grey cotton was increased. However, the laser irradiation could cause damage on the fibre according to the tensile strength results. When the resolution and pixel time increased, the reduction in breaking strength of samples was increased.

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