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CO_2 Laser Cutting of Glass Fiber Reinforce Polymer Composite

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Abstract. The lamination, matrix properties, fiber orientation, and relative volume fraction of matrix of polymer structure make this polymer hard to process. The cutting of polymer composite using CO_2 laser could involve in producing penetration energy in the process. Identification of the dominant factors that significantly affect the cut quality is important. The objective of this experiment is to evaluate the CO_2 spot size of beam cutting for Glass Fiber Reinforce Polymer Composite (GFRP). The focal length selected 9.5mm which gave smallest focus spot size according to the cutting requirements. The effect of the focal length on the cut quality was investigated by monitoring the surface profile and focus spot size. The beam parameter has great effect on both the focused spot size and surface quality.

1. Introduction

The laser industry has grown rapidly for the last 35 years where researchers all over the world have been investigating the use of laser radiation to process materials. Constant demand for laser machining by industries includes cutting, drilling, welding, thermal treatment and marking process [1-4]. A laser system consists of substance, energy source, and laser resonator. The output of the laser is the laser beam, which can be focused, directed, and controlled with great precision. Currently, laser beam cutting is a machining process frequently used to cut parts of different materials including composites[5]. Composite engineered products exhibit great structural integrity, higher dimensional stability and great flexibility in terms of shaping. Many interior automotive parts, electrical component and industrial applications suit with composite. In composite materials machining, by using conventional method like turning and milling, poor quality of cut surface obtained due to spalled fibres, fuzzing, and delamination [6-8]. Laser beam machining offers an ideal mean of fiber reinforced composites cutting, being a non-contact and virtually force-free manufacturing method.

Laser cutting is a thermal process in which a focused laser beam is used to melt and vaporized material in a localized area. A co-axial gas jet is used to eject the molten material from the cut and leave a clean edge. A particular characteristic of a laser cut found in previous work is the formation of striations on the cut edge [9]. This technology stimulates major interest due to the fact that it joins various advantages such as: non-contact process without tool wear, possibility of using a controlled atmosphere, high energy density, flexibility on beam delivering, easy automation, small heat affected zone, high speed and excellent edge quality [4, 10-11]. Laser cutting of composite materials has received much attention in the literature, there are exclusive work have been published on the laser cutting of this composite product [7],[12], [8]and [13]. J. Paulo Davim et al. [12] reported some experiment on CO_2 laser cutting quality of polymer and composite material. Though much works have been conducted, there are problems in laser beam machining of composites due to exothermic chemical reaction. The exothermic chemical reaction is influenced by several factors such as materials composition, density, moisture, thermal conductivity and internal bond strength [14-15]. The degree of surface roughness of the polymer matrix plays an important role since any surface irregularities may show through thin overlays and can reduce the final quality of the panel. In laser cutting of carbon fiber reinforced polymer (CFRP) composite, controlled parameters are laser power, repetition rate, pulse duration, cutting speed and pulse energy [7]. Other parameters include type of assisting gas and its flow rate, material type and thickness, and beam properties. To understand the quality of cut surface, the burn mark on materials surface resulted from the laser processing have been investigated[13]. The laser cutting on polymer composite excessive heat may produce sufficient damage on the surface layer based on different material composition and heat conduction[6-7]. In this paper the effect of laser spot size on burn mark profile of glass fiber reinforced epoxy composite was investigated.

2. Material and experiment set-up

A beam of finite diameter is focused by a lens to obtain a smaller beam spot, as shown in Figure 1. Where D is the entrance beam diameter, F is the focal length of focus beam and d_f is the diameter of the focus beam. The Gaussian beam focuses from a lens down to a waist and then expands from the focus point. Because the order of the beam mode has great effect on both the focused spot size and the depth of focus, the beam mode structure plays an important role in laser materials processing. Thus the focal length of the focus lens should be selected properly according to the cutting requirements.

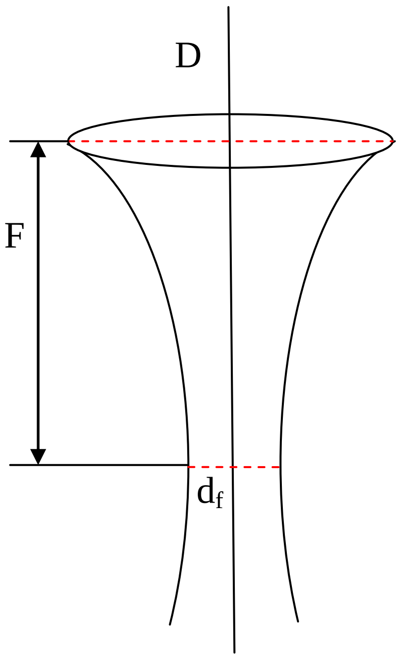

Figure 1.Schematic illustration of Gaussian beam.

In this study, glass fiber reinforced epoxy composites of 2.5 mm thickness were laser scanned. The fiber reinforcement material was E-glass fiber and the matrix material used was medium viscosity epoxy resin. The fabrication of the polymer composite was conducted at room temperature using curing polyamine hardener (K-6). The preliminary laser cutting experiment set-up of GFRP composite is shown in figure 2. The laser beam was focused on the sample surface using a Synrad CO_2 low power laser machining system with 30 W was used to produce profiles on the GFRP composites. Samples were mounted on two axes computer controlled table with integrated software.

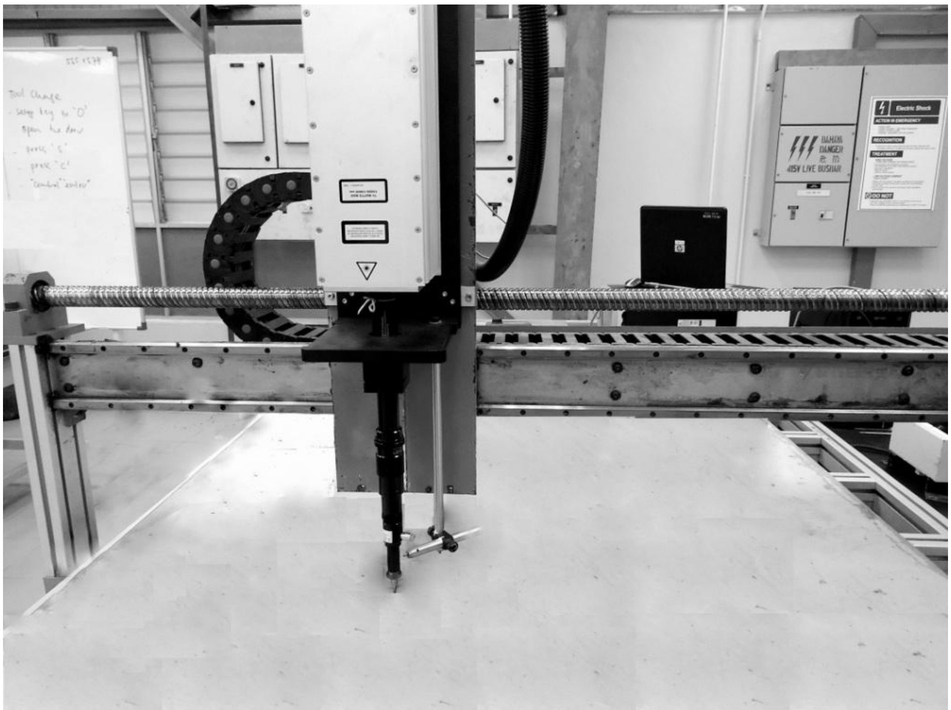

Figure 2. Experiment set-up of laser cutting.

The constant parameters of laser cutting of the composite were shown in the table 1. Parameter consider in the preliminary experiment was length of focal lens. The length was set-up differently for each test with range of between 6.0mm to 13.5mm from workpiece surface. The quality of CO_2 laser cutting was evaluated by standard process. The dimension of the burn and focus spot size was study by microscope, with low magnification. Power and the cutting speed were constant which are 10W and 2mm/s in order to investigate the interaction behavior laser beam and material. The 2.5mm glass fiber composite workpiece was set in flat surface position. The glass fiber composite was cut in rectangle shape with dimension of 10mm x 20mm.

Table 1. Parameters for laser cutting process.

Parameters	**Setting**
Laser wavelength	10.6 um
Power range	10W
Cutting speed	2mm/s
Cutting position	Flat surface

3. Result and Discussion

Laser cutting of GFRP composite is considered and the influence of laser focus setting on focus spot size and surface profile is investigated. The focus spot size, profile depth and material removal were evaluated and measured shown in the figure 3 and 4. The depth and removal rate of glass fiber reinforce polymer (GFRP) composite shows small changes with manipulating number of focal length. The fiber compound blocks the intensity of beam and reduced the depth and material removal.

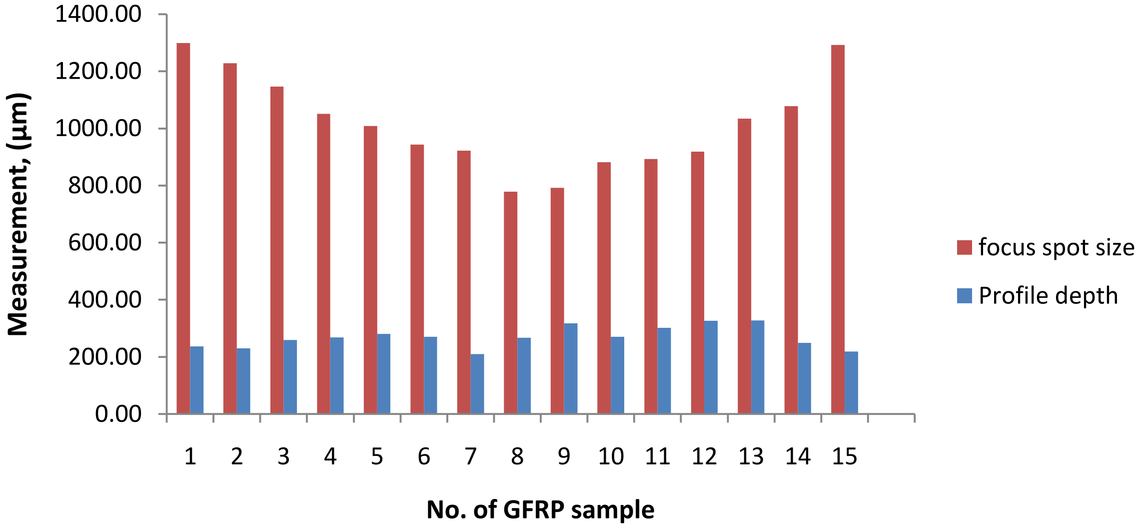

Figure 3. Result of focus spot size and profile depth of each glass fiber reinforced polymer (GFRP) composite sample.

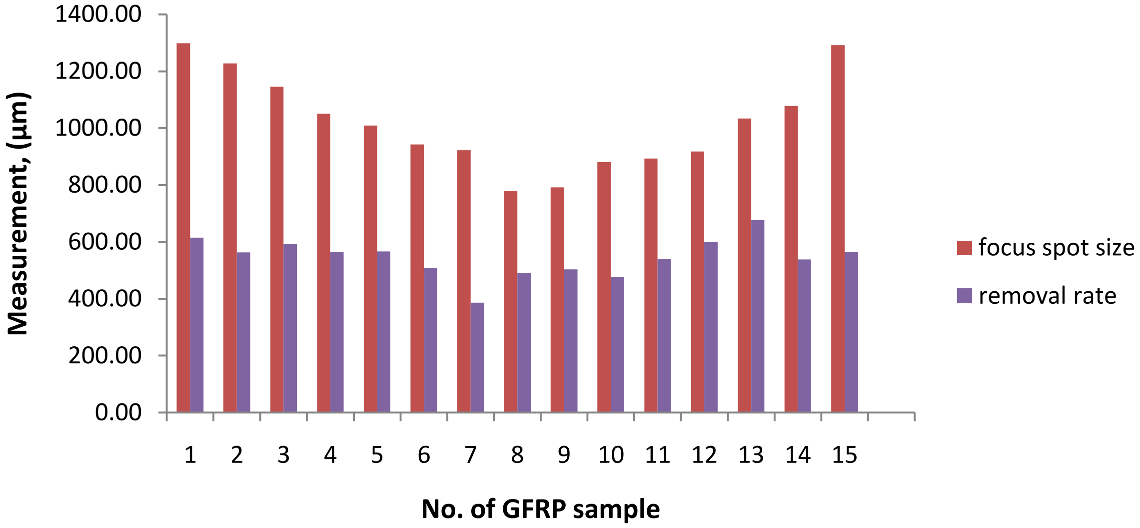

Figure 4. Result of focus spot size and material removing rate of each glass fiber reinforced polymer (GFRP) composite sample.

In the experiment, the sample eight shows the smaller value of focus spot size on the surface but the image of burn mark was shown clearly in the figure 4a. After continue with difference setting length the beam width value became larger. This is consequently related to the Gaussian beam focuses. The beam throughout lens down to a waist at 9.5mm length and then expands from the focus point. In this case, the nominal beam waist position of the focusing lens moves into the workpiece. This is due to that the beam divergence has significant influence the focus spot size when the nominal beam waist position is set at the workpiece, the beam power intensity distribution becomes more and the effective focus spot diameter becomes large as the beam penetrates into the workpiece. Therefore, molten material was removed at the surface and creates preferable value of depth in the figure3. But high intensity of beam with low cutting rate generates heat on the surface.

The different characteristic of glass fiber reinforced polymer (GFRP) composite and low heat conduction produced combustion during the process [6]. Thus, burn marks was appeared on the profile due to the high intensity of focus beam effect on the profile. Based on the surface profiles, burn marks have been seen decreasing due to expanding beam width. This is because of the material removed in the form of dross during matrix melting and accumulated fiber compound in the samples. In laser cutting, roles of gas assist were importance to eject the molten material and prevented flammability occurs during the process. Although, the cutting process does not occur, surface profile show that fiber was cut in the process can be seen in the figure 4b and 4c. No ejection and solidification on melting matrix give difficulties to cut more fiber and increase the cutting depth. Consequently, factor may cause the uncut and melted material is solidified back after cutting process. It is because this melted material has not been removed from the specimen. Therefore, gas assist plays an important role in laser cutting in order to make a material cut successfully [15], [16]. The gas helps much to eject the melt from the cutting zone and thus leaves a clean cut. It should be noted that the assisting gas under goes the exothermic reaction with the molten metal resulting in excessive energy in the cutting section.

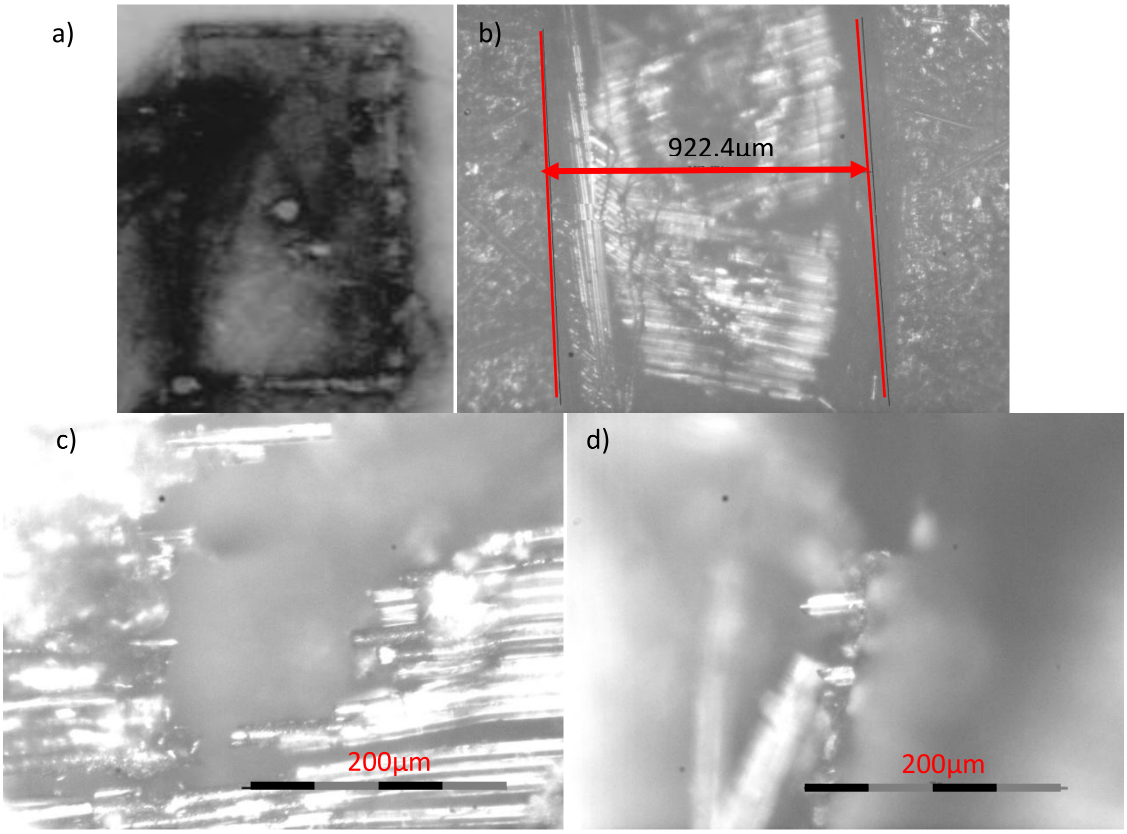

Figure 4. The focus beam width profile of GFRP composite a) surface profile the focal lens of 9.5 mm b)focus spot of the profile c) detail at the front surface and d) detail at the beside surface profile.

4. Conclusion

This preliminary experiment shows that the beam mode has great effect on the focused spot size, profile depth, material removal rate and surface quality. The focus beam parameter of laser cutting influence the behavior of surface, focus spot size, depth and removal rate in GFRP composite. This is due to that the beam divergence produce intensity energy distribution at the surface material. In this preliminary experiment was failed to cut the glass fiber composite but according to the profile fiber compound was cut with focal length of 9.5mm which gave smallest focus spot size. Therefore, other parameter such as power, cutting speed and pressure assist gas should give attention during cutting process of the polymer composite.

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