CUTTING CARBON FIBER REINFORCED POLYMER USING MULTIPLE LASER WAVELENGTHS

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ABSTRACT

Forces exerted by mechanical cutting of Carbon Fiber Reinforced Polymer (CFRP) composites can lead to delamination. Laser cutting can significantly reduce delamination because there is no mechanical force exerted on the composite. However the heating induced by conventional laser cutting can decompose the polymer near the cut edge, which also degrades the mechanical integrity of the composite. Laser cutting using multiple wavelengths overcomes these issues and creates a clean laser-cut edge with minimal Heat-Affected Zone (HAZ).

1. INTRODUCTION

Mechanical tools like routers and ultrasonic knives exert significant stresses on carbon fibers during the cutting process [1]. These stresses can result in displacement of the fibers and in severe cases delamination of layers. This in turn leads to degradation of the structural properties of the CFRP composite.

Laser cutting is a non-contact process, so it does not cause the kind of edge damage that is characteristic of mechanical cutting processes. However, conventional laser cutting can create excessive heating near the cut edge. For example, a 1.06µm wavelength Yb-doped fiber laser can cut through a CFRP composite, however the resulting cut is not optimal because the polymer matrix material is largely transparent to this wavelength [2, 3]. The carbon fibers absorb the 1.06µm laser energy, converting it to heat. The heat vaporizes the carbon fibers cleanly, but residual heat is conducted down the length of the fibers causing decomposition of the polymer matrix material and leaving a large HAZ.

A CO_2 laser, with a characteristic wavelength of 10.6µm, can also cut through a CFRP composite. Both the carbon fibers and the polymer matrix material will readily absorb the 10.6µm laser energy, however the amount of energy needed to vaporize the carbon fibers is usually much greater than the energy needed to vaporize the polymer. This again leads to excessive decomposition of the polymer matrix material in the vicinity of the cut edge.

A unique solution to this issue can be realized by combining two laser wavelengths into a single, coaxial laser beam. The hybrid laser beam is composed of a CO_2 laser beam with a wavelength of 10.6µm, and an Yb-doped fiber laser beam with a wavelength of 1.06µm. The 10.6µm laser wavelength cleanly ablates the polymer matrix material while the 1.06µm laser wavelength simultaneously cuts the carbon fibers. This leads to a superior cut quality with minimal HAZ and no delamination.

2. EXPERIMENTATION

2.1 Equipment

All laser processing was performed using an XLS10 MultiWave Hybrid™ (XLS10MWH™) platform from Universal Laser Systems. Two lasers were installed on the platform; a 40 watt Yb-doped fiber laser with a wavelength of 1.06µm, and a 75 watt CO_2 laser with a wavelength of 10.6µm. The XLS10MWH platform is equipped with MultiWave Hybrid technology, which allows the individual laser beams to be combined into a coaxial beam with a common focal plane as shown in Figure 1. The laser beams can also be operated independently.

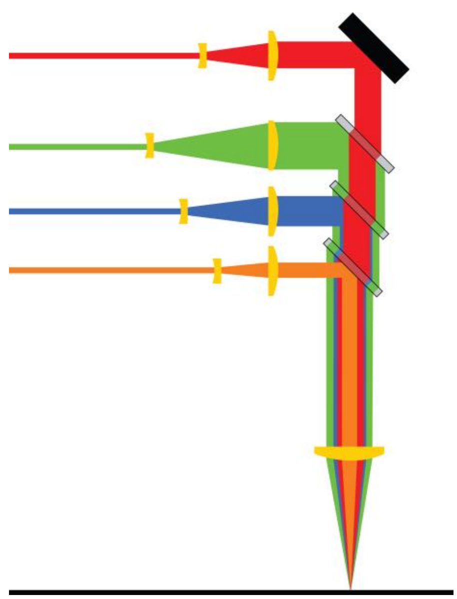

Figure 1. Schematic representation of the MultiWave Hybrid optics system, which allows laser beams of differing wavelengths (indicated by colors) to be combined into a single, coaxial beam.

2.2 Material

Multiple-wavelength laser cutting was investigated using 1/16" thick carbon fiber reinforced polymer sheet stock that was obtained through McMaster-Carr.

2.3 Experimental Methods

The laser cutting process was optimized to provide the best balance between 1.06µm laser energy and 10.6µm laser energy. Cut quality was observed microscopically using an Olympus DSX500 Opto-digital microscope.

3. RESULTS

A comparison was made between cutting a CFRP sheet with a CO_2 laser, an Yb-doped fiber laser and a multiple wavelength laser beam. The result is shown in Figure 2. The upper circle in the figure is the result with only the CO_2 laser. The 10.6µm wavelength of the CO_2 laser was absorbed efficiently by the polymer matrix material, causing it to decompose and vaporize. However, it was not possible to cut through the carbon fibers due to their relatively high vaporization threshold [3]. It should be noted that it is possible to cut through carbon fibers with a 10.6µm wavelength laser beam, but it requires significantly more power than the 75 watts used in this analysis.

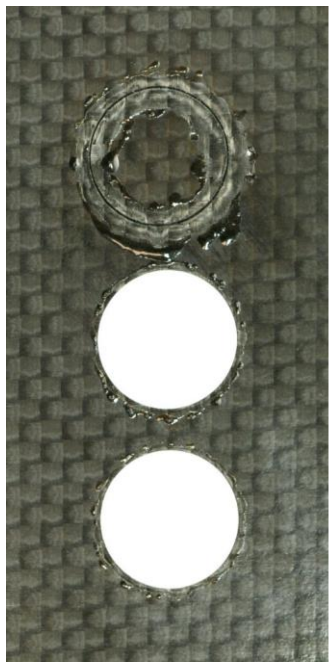

Figure 2. CFRP sheet cut with CO_2 laser (top circle), Yb-doped fiber laser (middle circle) and a multiple-wavelength laser beam (bottom circle).

The middle circle in Figure 2 was cut using only the 1.06µm wavelength Yb-doped fiber laser. This wavelength is absorbed efficiently by the carbon fibers, however the polymer matrix material is transparent to this wavelength. The result is that the carbon fibers that are directly in the laser beam's path are vaporized efficiently. The matrix material is vaporized indirectly, through conduction of heat down the carbon fibers. This leads to significant degradation of the polymer matrix material near the cut edge, as shown in Figure 3. The exposed carbon fibers shown in the figure can lead to delamination, and degradation of mechanical properties.

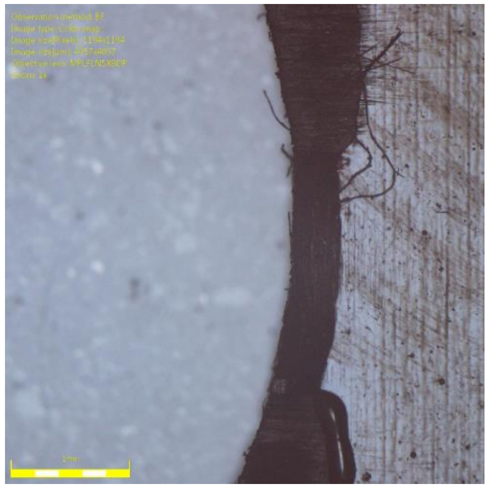

Figure 3. Microscopic image of the cut made using only the Yb-doped fiber laser showing significant loss of polymer matrix material and exposed carbon fibers (middle cut in figure 2).

The bottom circle in Figure 2 was cut using both lasers simultaneously. The benefit of this approach is that the carbon fibers are heated and vaporized directly by the 1.06µm laser beam, and the polymer matrix material is heated and vaporized directly by the 10.6µm laser beam. This minimizes overheating of the polymer matrix material. Figure 4 shows that a much better cut quality can be obtained with the multiple-wavelength laser beam and that the HAZ is significantly reduced.

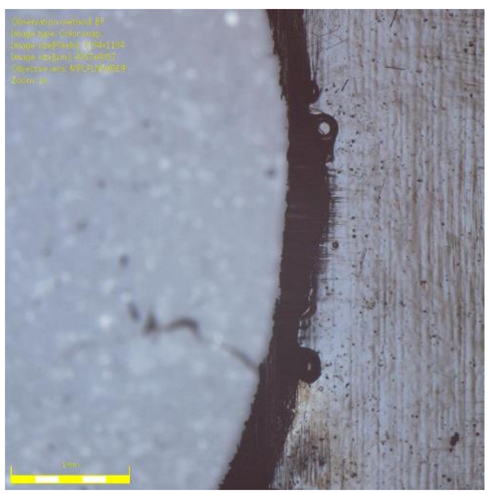

Figure 4. Microscopic image of the cut made using the 1.06µm laser beam and the 10.6µm laser beam simultaneously (bottom cut in Figure 2).

4. CONCLUSIONS

An efficient process for cutting CFRP has been developed using two laser beams simultaneously. Each of the two laser beam wavelengths were selected to heat and vaporize one of the components of the composite sheet. By using this multiple-wavelength laser cutting technology the CFRP can be cleanly cut using relatively low power lasers. This technology can be extended beyond CFRP, to other types of composite sheets through appropriate selection of the laser wavelengths.

5. REFERENCES

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