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# High speed laser piercing of CFRP using 1W nanosecond UV laser pulses

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**Abstract**

Laser piercing of 1.6 mm-thick Carbon Fiber Reinforced Plastics (CFRPs) was demonstrated for the first time, using a pulsed laser with a wavelength of 258 nm, generated by fourth harmonic generation of a 1030 nm laser. The laser power, pulse duration and repetition rate of the 258 nm laser pulses were 1 W, 7 ns and 10 kHz respectively. The linearly-polarized laser pulses of diameter 20 μm were focused on the surface of CFRP. A single piercing was completed in about 0.13 second. Piercing holes were observed by X-ray CT and the hole diameters of the input and output surfaces were about 30 μm and 5 μm, respectively. The aspect ratio of the pierced hole was greater than 50. The resin of the CFRP top surface irradiated by laser pulses evaporated with a diameter of 50 μm, but no heat-affected zone was observed at the surface of piercing holes by X-ray CT observation. 6x6 hole arrays with 200 μm interval was also demonstrated by laser piercing.

Keywords: CFRP; Piercing; high-aspect; HAZ-free

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## 1. Introduction

Carbon Fiber Reinforced Plastics (CFRPs) are expanding their applications in various fields in recent years. Specifically, in the aviation and automobile industries, the lightweight, strong and durable characteristics of CFRPs are utilized to reduce the body weights while retaining their structural strengths. Conventional methods for cutting, drilling and shaping CFRPs are machining and water jets, but problems still remain with machining accuracy and running costs for further utilization of the material. Laser processing are researched since as an alternative technology for the cutting of CFRPs (Niino *et al.*, 2015; Finger *et al.*, 2013; Sato *et al.*, 2017), but the heat-affected zone (HAZ) deteriorated by the irradiation of laser light is widely known to be an unavoidable problem, and is a major obstacle for employing laser cutting as a standard process.

Recently, we have shown that a single-scanned path of a nanosecond-pulsed UV laser is capable of cutting a 1.6 mm-thick CFRP with a narrow groove (20 μm width typ.), and with no to thin (< 5 μm typ.; depending on the definition of HAZ) layer of HAZ; this corresponds to a groove aspect ratio greater than 80 (Moriyama *et al.*, 2018). Here, we scanned the laser from outside of the CFRP sample, and thus the cut-line started from an edge. Because our mode of operation is single-scan cutting, it is not trivial whether the process can start from the middle of the sample, and with the same level of quality.

In this work, in order to further evaluate the potential of the above described CFRP cutting process, and to facilitate the investigation of the physical mechanisms involved in the process, we demonstrate a piercing process with a similar set of parameters.

## 2. Experimental

The samples, supplied by Toray Industries, were 1.6 mm-thick CFRPs used for aircraft, consisting of 8 layers of prepregs. The prepreg layers were unidirectionally aligned. The laser utilized in the experiment has the wavelength of 258 nm, and is the fourth harmonic generated from a home-build 1030 nm-wavelength laser. The average laser power, pulse duration and repetition rate of the 258 nm laser pulses were 1 W, 7 ns and 10 kHz respectively. The linearly-polarized laser pulses were focused onto the surface of CFRP with a diameter 20 μm. We used mechanical shutters to gate these pulses. The samples were irradiated for several different gate-times, and later, both surfaces of the samples were observed by a conventional optical microscope. The sample with the shortest gate-time that had a pierced hole on the back side was sent to an X-ray CT (Yamato Scientific, TDM1000H-Sμ) for further analysis.

## 3. Results

In Figure 1, observed images from the sample with the irradiation gate-time of 0.125 second (nominal) is shown. Fig 1(a) and (b) are the optical microscope images of the laser-incident and the laser-exit side, respectively. The observed hole diameters on the input and output surfaces were about 30 μm and 5 μm, respectively (the sample with a nominal gate-time of 0.12 seconds did not have the pierced hole on the back side). On the input side, some of the resin is evaporated with a diameter of 50 μm. Fig. 1(c) shows the cross-section of the pierced hold, acquired by X-ray CT. It shows that, except for the evaporated resin at the entrance of the hole, inner walls of the holes were free from HAZ. Upto the resolution of the X-ray CT, the HAZ-free characteristic of the inner wall is in parallel with the single-scanned cutting mentioned above.

Given the average laser power of 1 W, the piercing time of 0.125 seconds is considered to be fast, compared to conventional laser piercing with IR lasers for other materials by about an order of magnitude. It suggests an efficient energy use, or an efficient light-matter interaction, in the process of material removal.

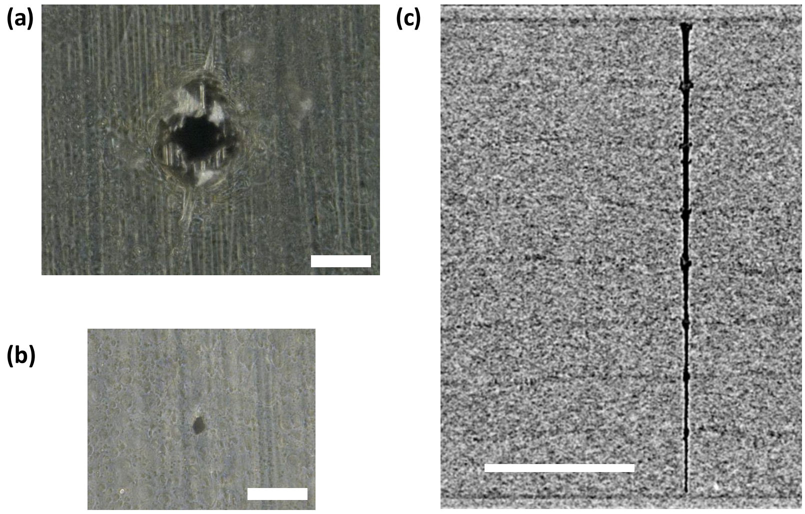

Fig. 1. Microscope image of the pierced hole at (a) the laser-incident-side surface, and (b) laser-exit-side surface; white bar is 50 μm wide. (c) X-ray CT cross-section of the pierced hole; white bar is 500 μm wide.

## 4. Conclusion

A high-speed laser piercing of 1.6 mm-thick CFRP is demonstrated using a 1W-average-power nanosecond UV laser pulses. The volume-removal rate of CFRP for piercing is on the same order of that for cutting with similar processing parameters. The efficient light-matter interaction in the process of material removal is shown to be also valid for piercing process, and not only the cutting process, and will be studied in the future works.

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