High brightness laser cutting of CFRP

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1. Introduction

Carbon fiber reinforced plastic (CFRP) with high specific strength to weight ratio, outstanding fatigue resistance and no corrosion as one of composite materials has been widely applied in automobile, aerospace and electronics, where it is necessary to reduce energy consumption and CO_2 generation. However, CFRP is difficult to cut because of the high hardness of carbon fiber that made PITCH carbonized at high temperatures. The main cutting techniques of CFRP are abrasive water-jet machining and mechanical cutting operations by contact process between tool and material such as micro-cutter machining, milling machining. But they have several disadvantages such as moisture absorption, high tool wear because of mechanical loads and thermal loads, high costs and limited cutting speed. In recent years, laser cutting experiments with high power density heat source as one of non-contact process have been conducted to investigate cutting characteristics of CFRP using pulsed Nd:YAG laser, disk laser and CO_2 laser[1, 2]. During the laser cutting of CFRP with high laser beam absorptivity, however, a wider heat affected zone could be formed because of an increase in laser heat input at a range of lower speed and also was affected by material properties of CFRP and laser cutting parameters including the laser power, the cutting speed, the pressure of assist gas and the focal position. In this study, therefore, with the objective of obtaining the better cut quality and narrower HAZ width, laser cutting experiments were conducted to establish the proper laser cutting conditions for various CFRP sheets at ultra-high cutting speed using high brightness CW disk laser.

2. Experimental procedures

Table 1 shows material properties of CFRP sheets used in the experiments. Each CFRP was made by considering different material properties which include plastic type, volume of fiber (%), fiber type, manufacturing process and thickness of CFRP. A schematic experimental set-up for laser cutting of CFRP is given **Fig. 1**. The CW disk laser with a maximum power of 16 kW was utilized and the laser beam of 8 mm·mrad (BPP) was delivered by the optical fiber of 0.2 mm core diameter. The laser scanner head was employed in order to accomplish ultra-high cutting speed, and the laser beam was focused by the focal lens of 291.5 mm. The spot size of the laser beam was about 0.3 mm at the focal point.

Table 1 Material properties of CFRP used in experiments

No.	Plastic	Volume of fiber(%)	Fiber type	Manufacturing process	Thickness (mm)
1	Epoxy	50	Cross	RTM	1.2
2	PA6	50	One direction	Press	2.0
3	PA6	25	Random	Press	2.5
4	PA6	20	Long fiber pellet	Injection	3.0
5	PP	20	Long fiber pellet	Injection	3.0
6	ABS	20	Long fiber pellet	Injection	3.0
7	PPS	20	Short fiber pellet	Injection	3.0
8	PA6	20	Short fiber pellet	Injection	3.0

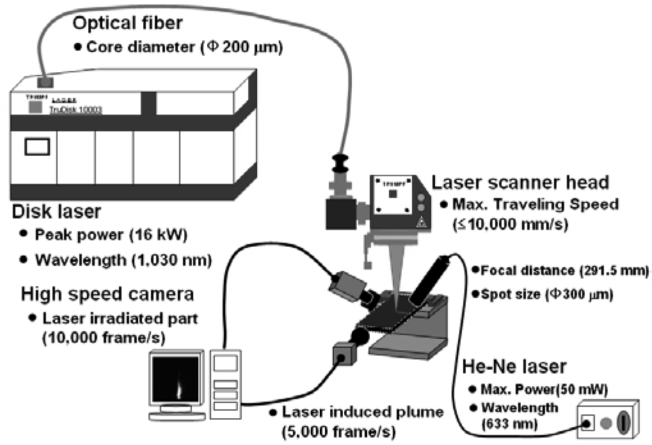

Fig. 1 Schematic experimental set-up for cutting of CFRP

Table 2 indicates laser cutting conditions used mainly for cutting of CFRP. Laser cutting parameters were the laser power of 1 kW, the cutting speed of 500 – 5000 mm/s, laser irradiated number of 1 – 80 passes, time interval after laser irradiated of 0 or 1 second, the focal position of ±0 mm. Cutting phenomena and behavior of the laser induced plume during the laser cutting were observed by using two

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high speed video cameras at 10,000 F/s and 5,000 F/s for laser irradiated part and laser induced plume, respectively. A He- Ne laser with the maximum power of 50 mW and the

Table 2 Laser cutting conditions used in experiments

Cutting parameters	Ranges
Laser power, P (kW)	1
Cutting speed, v (mm/s)	500 - 5000
Laser irradiated No., Pass	1, 10, 80
Time interval, D (sec)	0, 1
Focal position, f_d (mm)	± 0

wavelength of 633 nm was employed for illumination. In addition, HAZ widths and kerf widths for the cut surfaces and the cross sections of CFRP were evaluated using optical microscope and scanning electron microscope (SEM).

3. Results and discussions

In order to investigate the effect of the cutting speed on the cut quality of CFRP, laser cutting experiments were conducted by changing the cutting speed from 500 mm/s to 5,000 mm/s.

Figure 2 shows cut quality and plume behavior observation results of No. 4 CFRP at the laser power of 1 kW, the laser irradiated number of 1 pass and the focal position of ±0 mm. The results showed that the cut depth and HAZ width of surface appearances and cross section at 500 mm/s were deeper and wider in comparison with those of 5,000 mm/s. In addition, it was observed that the plume at 500 mm/s was ejected violently on the cut surface and to the back direction and became lower the height of the plume than that of 5,000 mm/s. Based on these results, by increasing the laser heat input because of the long interaction period between laser and material at the lower speed, it was noted that HAZ width was considerably wider.

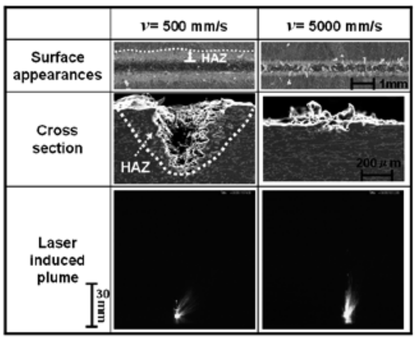

Fig. 2 Cut quality and plume behavior observation results of No.4 CFRP at different speed

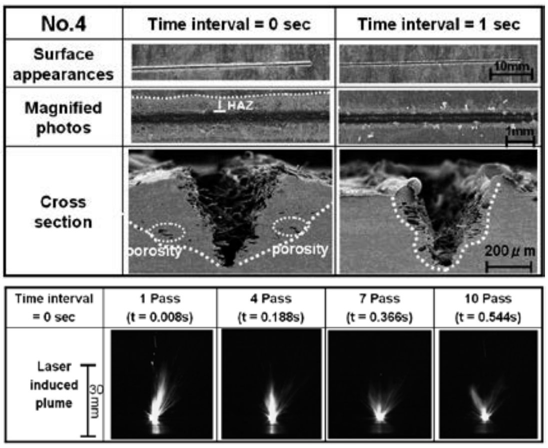

Fig. 3 Cut quality and laser induced plume behavior observation results for cutting of No.4 CFRP considering the effect of time interval

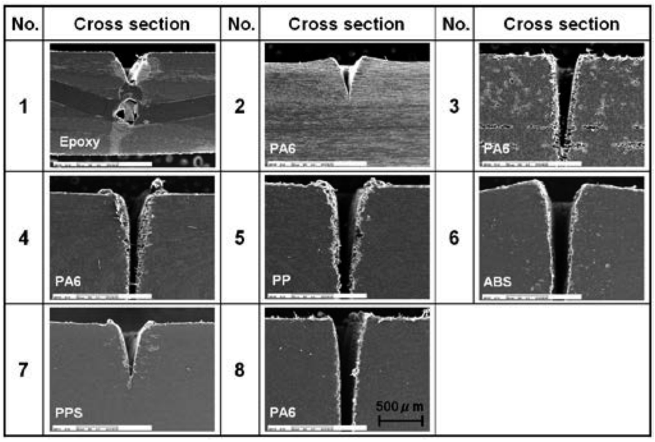

Fig. 4 SEM photos of cross section of various CFRP with 1kW laser power, 5,000 mm/s cutting speed, 80 pass laser irradiated number and 1 sec time interval

Figure 3 shows cut quality and plume behavior observation results of No. 4 CFRP, considering the effects of time interval on HAZ width for the laser power of 1 kW, the cutting speed of 5,000 mm/s, the laser irradiated number of 10 passes. In the case of time interval of 0 sec, wider HAZ was generated compared with that of 1 sec. These results can be explained by several causes as follows. First, the deep-black high temperature stream during the observation of laser irradiated parts was observed continuously to remain to stay on the cut surface. Second, in the case of plume observation results for time interval of 0 sec, as the laser was irradiated continuously, the height of the plume was going down. From the results, the laser heat input came to increase. Wider HAZ was attributed to the phenomena that the heat inside CFRP sheet was increasingly accumulated in the case of the continuous laser irradiation.

In order to evaluate cut quality and cutting possibility for various CFRP sheets, laser cutting experiments were performed. The results are shown in **Fig. 4**. Cutting of No.1 and No. 7 CFRP was significantly difficult in comparison with other CFRP sheets. The reason is attributed to the base plastic of Epoxy and PPS, respectively. No. 2 CFRP with 50 % volume of fiber and one-directional fiber type was also difficult in cutting. Cutting of No. 4, No. 5, No. 6 and No. 8 CFRP with lower volume of fiber was easier than that of the other CFRP, and narrower HAZ was obtained. In addition, as compared with No. 4 and No. 8 CFRP with long fiber pellet and short fiber pellet, respectively, No. 8 CFRP with short fiber pellet had narrower HAZ width due to the effect of heat conduction by the different length of fibers.

4. Conclusions

Laser cutting experiments of various CFRP sheets were performed using a high brightness CW disk laser. At the ultra-high cutting speed of 5,000 mm/s, narrower HAZ and kerf widths were obtained due to the decrease in laser heat input for short interaction period. During the multi-passes laser irradiation, time interval was effective to produce narrower kerf widths and HAZ on the cut surface and the cross section than no time interval. Moreover, cut quality and cutting possibility are known to highly depend on plastic type, the volume of fibers, fiber laminated type of CFRP sheets.

References

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