STUDY ON CUTTING OF CFRP PLATE BY FIBER LASER

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1 Introduction

Application of CFRP to aircraft and other vehicle is being accelerated now. One of major problems is the reduction of cost and production time. On the other hand, new cutting methods, laser beam cutting shows big progress.
This study is focused to the feasibility of fiber laser beam cutting process to composite parts.
CFRP plates of 4 kind thicknesses were prepared, and proper cutting condition for each panel was examined, then effect of the heat affected zone by cutting on strength was examined by flexure test.
There are some reports to discuss the application of laser to cutting of FRP plate, however most of studies concerns about the application of CO_2 laser and YAG laser etc.1) 2) And there are very few data about the effect of laser cutting process on the mechanical properties.

2 Experimental Procedure

2.1 Material

Prepared CFRP plates were flat panels as follows.
Material: Resin-Epoxy#135, Fiber-UTS50 12K
Resin content: 35 %
Lay-up sequence pattern: （+45/0/-45/90）
Thickness: 1.5 mm (8 ply), 3.1 mm (16 ply), 4.6 mm (24 ply) , 9.2 mm (48 ply)

2.2 Cutting test method

Fiber laser equipment, YLR-5000C2 was applied. Its maxim power was 5kW. Wave length was 1.07 μ m. Beam was mainly focused at surface of panel, and beam diameter at surface was 0.24mm. Some cases were conducted to examine the effect of focal point position on cutting results.
Argon gas was used as assist gas. Gas flow rate was 30 l/min. Laser power and cutting speed were parametrically controlled. Appearance and section of cut area was examined to distinguish heat affected zone by laser.

2.3 Flexure Test Method

3 point flexure test was conducted for 4.6 mm thick specimens to consider the mechanically degraded area. Length between 2 fulcrums was 64mm.
Test specimen was 12mm wide 80 mm length. Three cutting conditions which caused different width of heat affected zone were selected. Both side of specimen was prepared as three cases, as cut, 2mm grinded from laser cut surface and 4mm grinded from laser cut surface as shown in Fig.1.

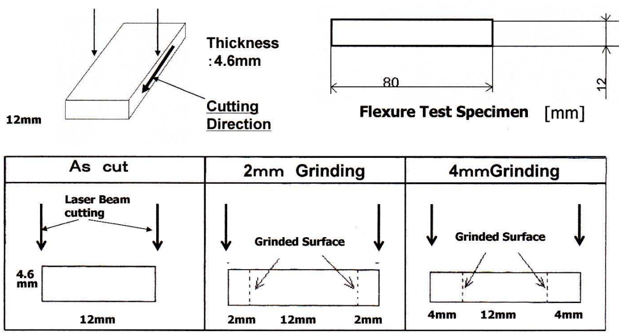
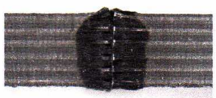
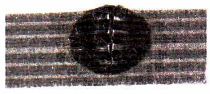


Fig .1 Preparation of flexural test specimen

3 Results and Discussion

3.1 Proper Cutting Condition for Each Thick Plate

Efficiency of fiber laser is high compared with that of CO_2 laser. Fig.2 shows the comparison of cutting results of 4.6mm thick CFRP plate between by fiber laser and CO2 laser at the same condition of laser power and cutting speed condition etc. as reference. Black color is the heat affected zone written later.

Parameter	Fiber Laser	CO_2 Laser
Laser Power : 1kw Cutting Speed : 1000mm/min Focal Point : Surface		

Thickness:4.6mm^t

Fig.2 Comparison of cutting ability between fiber laser and CO_2 Laser at same cutting parameter

Lower heat efficiency of CO2 laser caused fail to cut compared with the success results by fiber laser.
Fig.3 shows the cutting results of each thick CFRP plate by fiber laser. Vertical axis is laser power and horizontal axis is cutting speed, and open marks show success results to cut and solid marks show failed results to cut at each cutting condition.
When higher laser power and lower cutting speed was applied, cutting was successful and vice versa.
Cutting success area and failed area was divided by almost straight line for each thick plate.
When fiber laser power was 5kW, each thick plate could be cut by following cutting speed.

3.1 mm thick panel: 8500 mm/min
4.6 mm thick panel: 5000 mm/min.
9.2 mm thick panel: 2000 mm/min

Cutting speed of 1.5mm thickness panel was up to 10,000mm/min by 3kW. These cutting speed are over one order high compared with mechanical cutting. Each slope of line increased with increase of thickness.
Energy input per unit length might be considered as criteria between success to cut or not. Minimum energy input per unit length (E/v: E = laser power, v = cutting speed) to success cutting of each thickness was examined.
Fig.4 shows the relation between minimum energy input per unit length and laser power of each CFRP thick plate.
Value of E/v increased with increase of thickness, and it was almost constant regardless of laser power value under 4.6 mm thick plate cases. However, minimum E/v decreased with increase of E for 9.6 mm thick plate case. This means that another effect

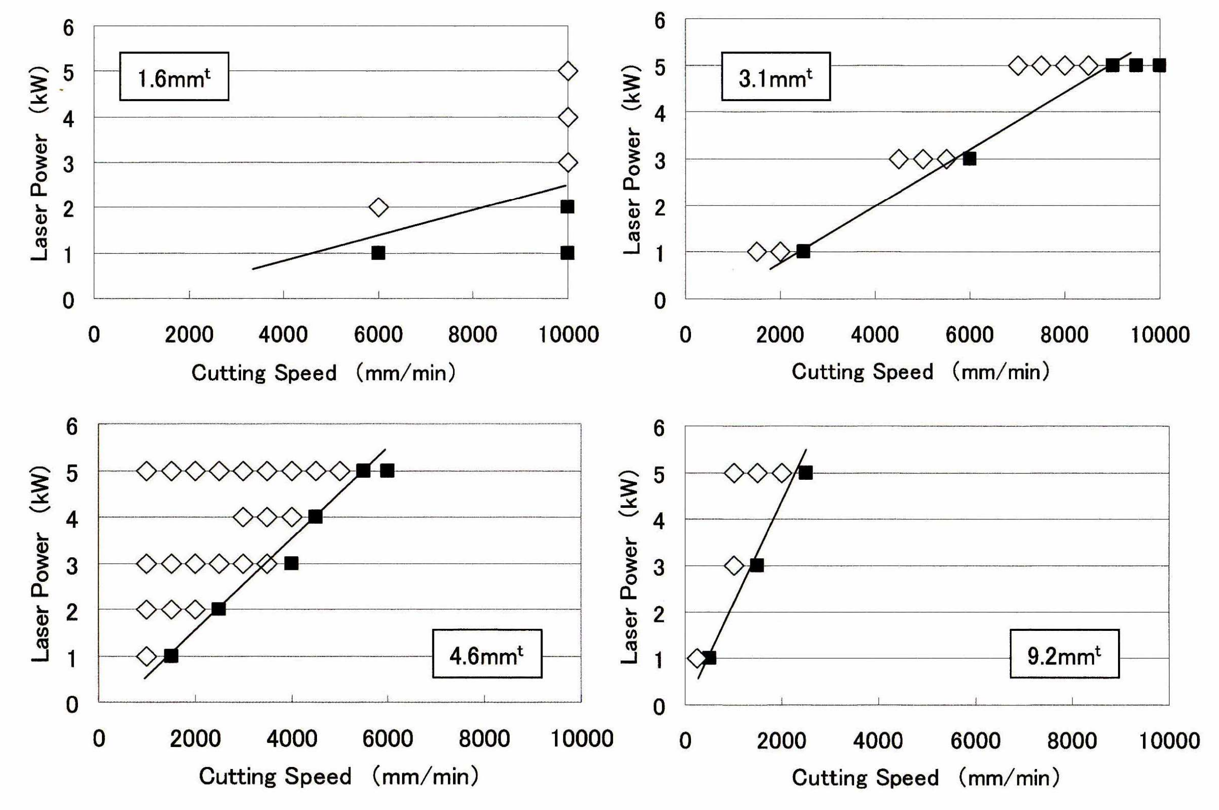


Fig.3 Effect of laser cutting parameters on the cutting results of each thick CFRP plate
(Success area to cut and failed area was divided by line.)

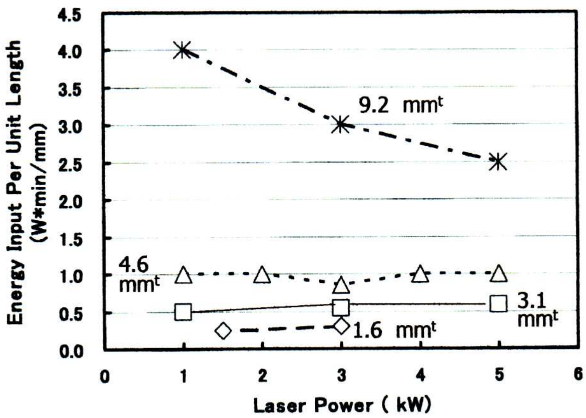


Fig.4 Relation between minimum energy input to cut successfully per unit length and laser power of each thick CFRP plate

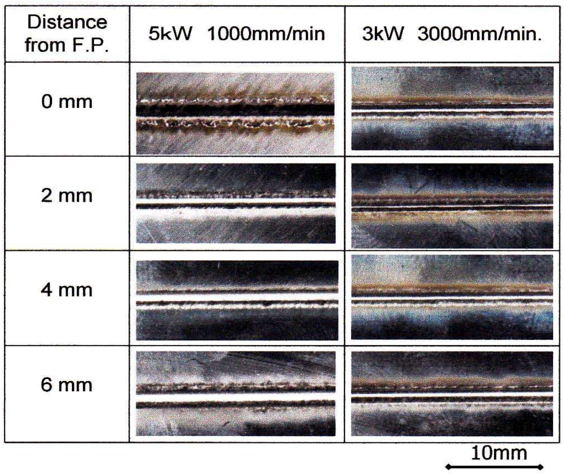


Fig.5 Effect of work position on the cutting results of 1.6 mm thick plate (F.P.: Focal Point)

of cutting process might be occurred.
In those experiments, focal point were fixed to the surface, and energy concentration was the highest at the focal point. Energy concentration decreased with increase of the distance from focal point because the increase of beam diameter.
If CFRP plate is not thick energy concentration level through thickness is sufficient to cut. However plate becomes thick, beam concentration level may be not proper for the lower side of plate
Fig.5 shows the effect of CFRP plate position from focal point of laser on the cutting appearance by two typical cutting parameters shown in the figure. 1.6 mm thick plate settled at focal point and at written distance under the focal point.
Width of material lost area increased with increase of the distance from focal point, increment was small until 4mm, and it became very large at 6mm distance.

3.2 Heat Affected Zone by Cutting

Heat of laser beam cutting caused heat affected zone (HAZ) at the cutting area. Thermal decomposion of resin was occurred to cause the change of volume fraction of resin and to cause porosity etc..
HAZ was easily distinguished by change of color and porosity when section was examined.
Fig.6 shows the section of the cut area of 4.6 mm CFRP plate at each cutting condition.
Width of HAZ depended mainly on cutting speed, width decreases with increase of cutting speed. Increase of laser power caused to increase width, but relatively small effect. This result means that high power and high speed cutting is desired to get narrow HAZ.

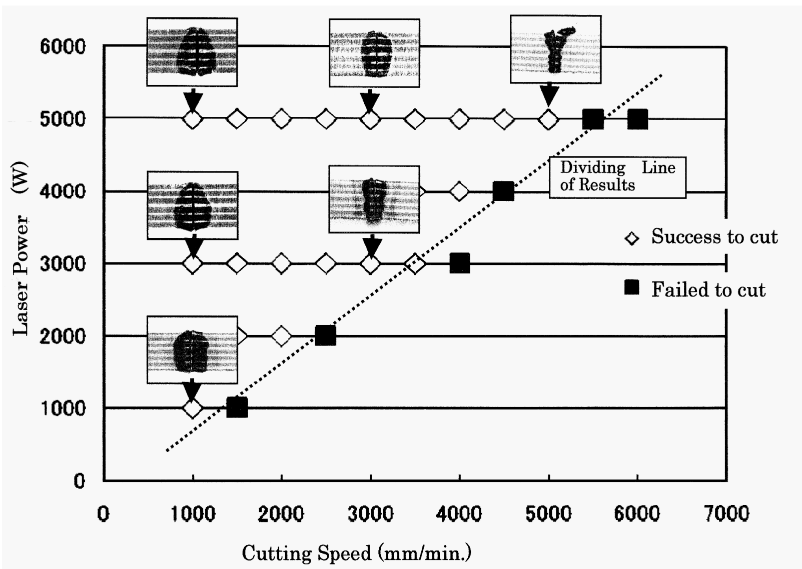


Fig.6 Effect of the laser power and cutting speed on the shape of heat affected zone of 4.6mm thick CFRP plate

3.3 Flexure Test Results

Flexure test specimens were cut by following cutting conditions.

Case A: 1000 mm/min. 1 kW (Wide HAZ)
Case B: 3000 mm/min. 3 kW (Medium HAZ)
Case C: 5000 mm/min. 5 kW (Narrow HAZ)

Flexural strength of as received plate is 902 MPa. Results of the laser beam cut specimen are shown in Fig.7. Strength of as cut test specimen was low. Strength of Case A(Wide HAZ) was especially low, so flexural strength was degraded by heat of laser. Grinding to remove HAZ improved flexural strength, and strength of Case B and Case C reached the strength of as received plate if 4mm thick area was grinded from the laser cutting edge. This means the remove of HAZ.

4 Conclusions

(1) Very high speed cutting of thick CFRP plate could be conducted by fiber laser. Its speed was over one order higher than that of mechanical cutting.
(2) Width of heat affected zone mainly depended on cutting speed and decreased with increase of cutting speed.
(3) Flexural strength was recovered to as received condition if heat affected zone was sufficiently removed.

Acknowledgement

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Reference

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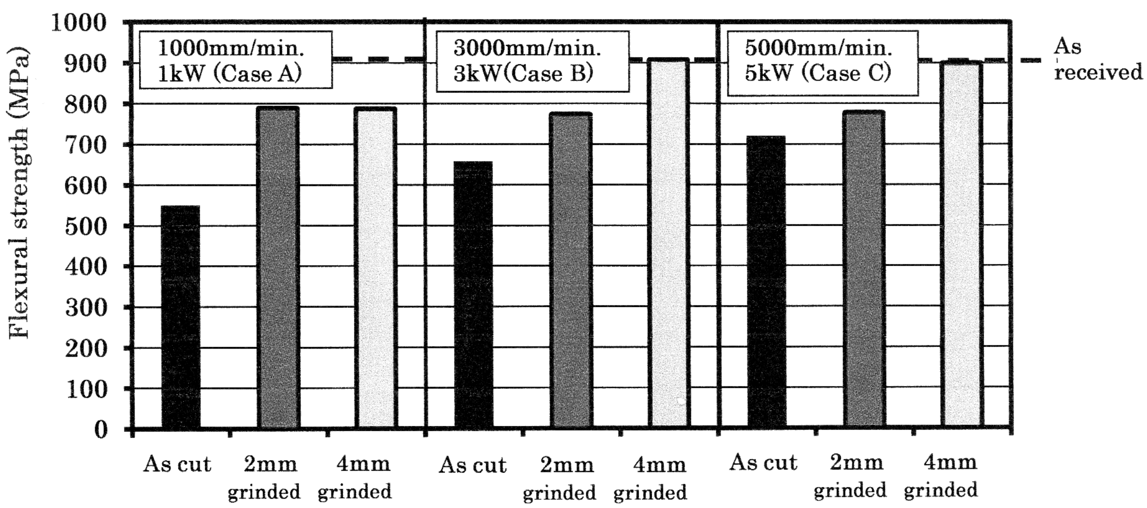

Fig.7 Effect of the heat affected zone by laser cutting and grinding on the flexural strength of 4.6mm thick CFRP plate