SHORT PULSE Nd:YAG LASER CUTTING OF CFRP SHEET

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Introduction

In the last years fibre reinforced plastic have increase their use in structural application due to their high specific strength. Although in many application composites are cured to final shape, cutting and drilling can still be required. However machining of CFRP composites with conventional cutting methods produce tool wear, damage such as delamination and fibre pull out [1-2]. Laser cutting is a possible alternative that not involve mechanical cutting forces or tool wear, and allow to obtain complex shape too. However, laser cutting is based on the thermal interaction between laser beam and the materials, that produce heat affected zone (HAZ). During the beam-material interaction, the time that elapses before the vaporisation condition for carbon fibres is larger than that for the resin, so, a great amount of heat is absorbed by the matrix thanks to the good conductivity of the fibres. It results in thermal degradation of both fibres and matrix, in matrix burning, in fibres debonded from the matrix and delamination [3]. It results that the kerf and the HAZ dimensions depend on the interaction time and then on the cutting speed [4-5]. The use of pulsed Nd:YAG laser in cutting operation of CFRP was investigated in [6]. It was found that, the high beam intensity and the better focusing behaviour of this lasers, give a narrow kerf and a smaller HAZ compared to CO_2 ones, if the right parameter combinations are adopted. Since the HAZ and the kerf width depend on the energy release-time dependence, a strategy to decrease the HAZ and the kerf width could be the use of high pulse energy released in very short time, like in the case of short or ultra-short Nd:YAG laser pulsed source. For this laser source, the high peak power released in short time, rapidly heats the material and directly leads to the evaporation and/or plasma [7], reducing the heat absorbed by the matrix and then the kerf dimension and the HAZ extension.
Aim of the work is to study the features and the performances of a 100 W short pulse Nd:YAG laser in cutting 1 mm CFRP laminates.

Experimental

A multimode pulsed lamp pumped Nd:YAG (Starcut 150 from ROFIN), working at the wavelength of 1064 nm, with a maximum average power of 150 W was used in the experiments. The laser allows the selection of the pulse duration (D), the pulse frequency (F) and the lamp voltage (V). Cutting tests were carried out on a 1 mm in thickness CFRP plate obtained by autoclave cure. The lay-up was: 2 external plies of T400 carbon fibre fabric 193 gr/mm^3 for each side and eight internal unidirectional plies of T400 carbon fibre 145 g/mm^3 in $(45_2/-45_2)_s$ sequence. The matrix was HMF 934 epoxy resin. During the tests, pulse durations were selected at the values of 1, 0.5 and 0.25 ms, while different values of mean power (P_m) were used changing F and V. For each process condition, different beam speeds were tested and the maximum cutting speed was determined. The kerf sections of all the samples were examined by microscopic analysis measuring the top (W_t) and bottom (W_b) kerf width, the taper angle (T_a) and the HAZ extension, as reported in figure 1. At the end, the kerf geometry and the HAZ were related to the process condition. (W_b)

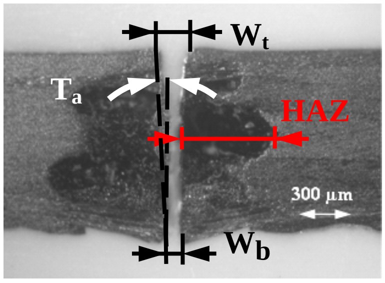

Fig. 1: Kerf section and analysed parameters.

Risults and discussion

In figure 2, the maximum cutting speed is reported as a function of the mean power for the different pulse duration values. The dashed lines represent the best fitting ones and they represent a limit between the “no-cutting” and the “cut region”. The figure reveals that CFRP cutting is possible over a large processing window enveloping a wide mean power-speed range. The maximum cutting speed linearly depends on the mean power and it is in agreement whit what observed by Caprino et alt. [5] using a CO_2 laser source. At last, the maximum cutting speed of 11 mm/s was founded with a P_m of about 95 W.
In figure 3, the mean values of fifteen measurements of the top (open dots) and the bottom (closed dots) kerf width are plotted against the cutting speed. The vertical bars denote the standard deviations of ten samples. From figure, both the kerf widths decrease at the increase of the cutting speed following a power law. However, the data distribution and the presence of data scattering do not allow any particular observation about the influence of the different values of pulse duration. Besides, the top kerf width appears always larger than the declared beam spot

(min. 198, μm against the 170 μm of the declared beam spot), while the bottom kerf width appears always lower then the top one, with minimum values, 68 μm, smaller than the beam spot diameters. Using the data of figure 3, the taper angle was calculated and plotted against the spot overlap in figure 4. From the figure, the taper angle is very small, with values in the range of 1÷6 degree, furthermore the taper angle tends to increase at the increase of the cutting speed.

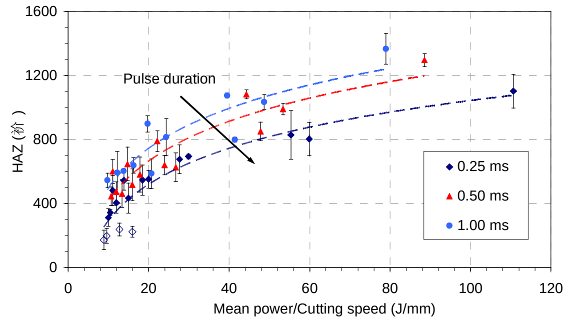

Fig. 2: Influence of the mean power and beam speed on the cutting regions map.

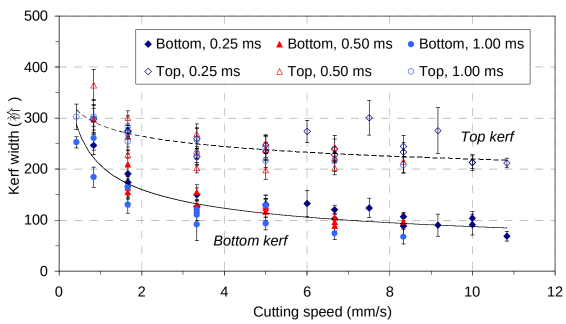

Fig. 3: Bottom kerf width as a function of cutting speed.

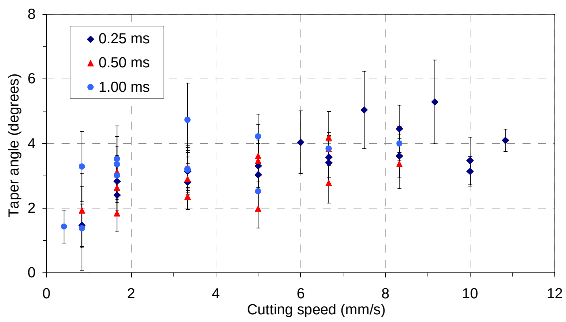

Fig. 4: Taper angle as a function of cutting speed.

The optical microscopy analysis showed the presence fibres debonding and matrix thermal degradation, while no delamination was observed. Despite the limited kerf dimension, a larger HAZ extension occurs at the centre of the thickness, in correspondence of unidirectional lamina, as matrix burning. In figure 5, the HAZ extension was reported as a function of the cutting speed: the HAZ extensions depend on the cutting speed by the way of an exponential law. This can be explained considering that at the decrease of the cutting speed the interaction time increases, so more material is removed or burned, consequently larger and regular kerf is obtained but, in this case, also HAZ increases. This effect increases if a long pulse duration is used. However, there is a singularity for the data obtained at the minimum duration and the maximum power (open dots interpolate by the dashed line). In this condition a linear dependence and a sensible HAZ extension reduction was observed.

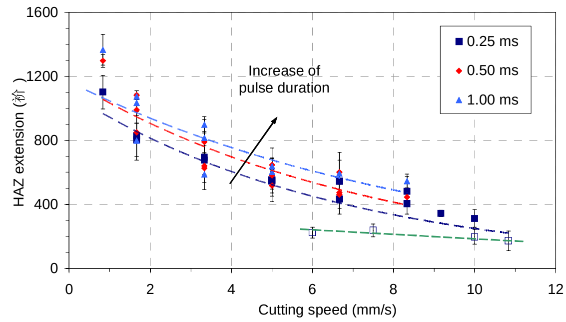

Fig. 5: HAZ extension as a function of cutting speed.

4. Conclusions

In conclusion it is possible to assert that a 100 W pulsed Nd:YAG can be satisfactory used to cut CFRP plate 1 mm in thickness, at the maximum cutting speed of about 11 mm/s. The maximum cutting speed depends on the released mean power. Narrow kerf could be obtained increasing the cutting speed up to its limits. Thermal damages consist of fibres debonding and matrix degradation while no delamination was observed. The maximum HAZ extension occurs at the centre of the laminate in correspondence of the unidirectional lamina. The HAZ extension strictly depends on the cutting speed through an exponential law and it decreases at the decrease of the pulse duration .

References

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