Micro-manufacturing of fibre reinforced polymers (FRP) parts with picoseconds pulsed laser machining.

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Abstract

The study of FRP manufacturing with picoseconds pulsed laser machining has been developed to optimize process parameters to maximize material removal rate (MRR) and final part quality. The experiment was conducted on three kinds of composites, glass fibre, carbon fibre and natural fibre from jute using a home-made machine equipped by a picosecond pulsed laser (Hyper Rapid, Lumera) with three different wavelengths, 1064 nm (IR), 355 nm (UV) and visible green 532 nm. This work involves two different studies. The first one was related with a fundamental study of laser micro-machining, analysing the quality of parts against MRR. Secondly, the drilling strategy was studied based on previous results, in order to overcome the limitations imposed by the conventional machining techniques of FRP materials [1,2]. The results have shown that by choosing appropriate process parameters and drilling strategy, 3 mm thick composite sheets can be machined in less than 30 s.

1 Introduction

Composites exhibit very remarkable properties in high strength and weight saving application. Manufacturing of the parts and their union becomes a critical process for structural safety. In these cases, conventional cutting machining is limited by usual fibre delamination (Figure 1), a failure which could become catastrophic at the same way than the cracks in metal parts. For these reasons, new manufacturing processes are in continuous development to try reducing these defects while keeping or improving the productivity of classical processes.

This work presents an experimental analysis of several FRP materials manufacturing with an ultra-short pulsed laser source, where reduced thermal affected zone (HAZ) allows achieving high quality cutting performances. Two applications are considered in the present study: milling and holes drilling. The first one oriented to parts manufacturing and the second one to parts union through typical rivets used in aeronautical sector.

Figure 1: Typical problems of FRP material machining by cutting.

2 Laser Micro-manufacturing Equipment and Experimental set up

The equipment employed is a solid state Nd-YAG laser (Hyper rapid, Lumera) that can operate at three different wavelengths (1064, 532 and 355 nm). These laser sources delivers 10 ps pulses with repetition rates up to 1 MHz and average powers up to 40 W, (Figure 2). The laser beam is focused perpendicularly on the sample surface with a spherical lens, obtaining a spot between 10-25 μm. Self-developed micro laser ablation machine has following main features: high stiffness and stable granite-made structure, 3 ultraprecision axes CNC controlled with speeds up to 120 m/min and a maximum acceleration of 1g. The precision of machine is in the range of +/-1 μm.

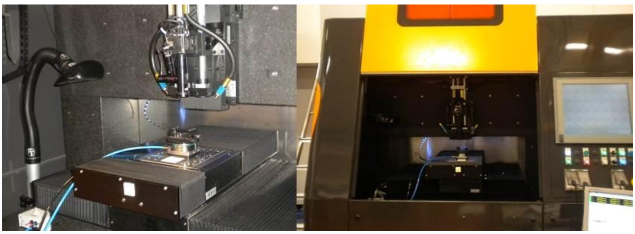
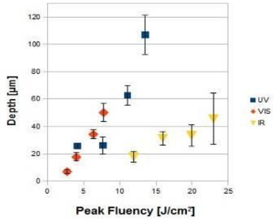


Figure 2: Picoseconds pulsed laser machining centre developed at IK4-IDEKO.

3 Experimental Results: Process parameters and Drilling strategies

In the first phase, the study has been oriented to optimize process parameters to maximize MRR, analysing the quality using the laser milling operation. The experimental results were measured in terms of material removal rate and peak fluency for each wavelength, Figure 3, 4 and 5. It was obtained that the UV wavelength is the one offering the best results in terms of productivity (MRR) and final part quality in carbon fibre reinforced polymer.



Glass fibre reinforced polymer (GFRP):

- UV: most efficient wavelength
- UV: less aggressive wavelength

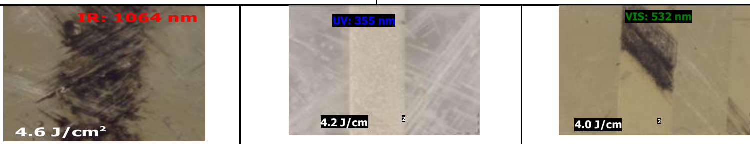
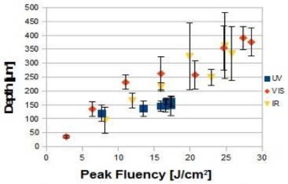


Figure 3: Milling results in parameters optimization trials for Glass FRP.



Carbon fibre reinforced polymer GFRP),

- Vis and IR: most efficient wavelengths
- UV: less aggressive wavelength
- Optimised parameters: 355 nm, 200 kHz, 2.73 W (= 17.4 J/cm^2)

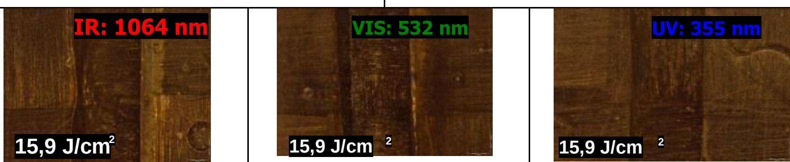
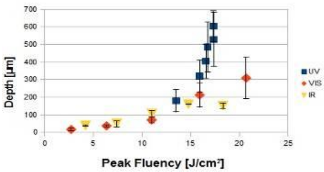


Figure 4: Milling results in parameters optimization trials for Carbon FRP.



Natural fibre reinforced polymer (GFRP)

- UV: most efficient wavelength
- UV: less aggressive wavelength
- Optimised parameters: 355 nm, 200 kHz, 2.6W (= 16.5-17.4 J/ cm^2)

Figure 5: Milling results in parameters optimization trials for Natural FRP.

In the second phase, experiments were based on the preliminary result obtained from the first phase. The purpose of this phase was to optimize and study drilling strategy, achieving an averaged ablation feed rate used in drilling. Pulse frequency was studied from 200 to 500 kHz, and peak fluency from 17.4 J/cm^2 to 47.1 J/cm^2. At these conditions, machining feed rate goes from 90 µm per cycle to 257 µm per cycle, cutting a composite sheet 3 mm thick in less than twelve repeats (Figure 6), around 30 seconds in time.

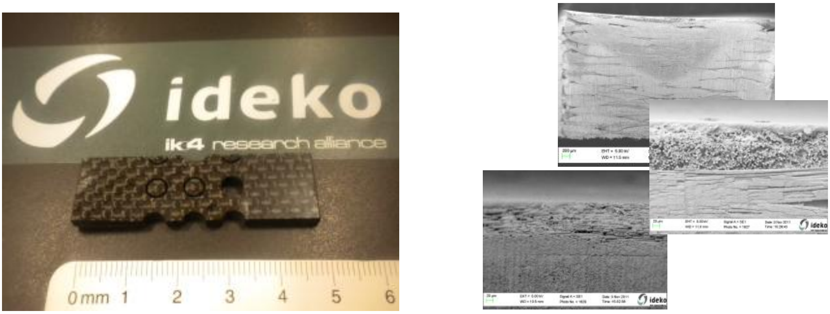


Figure 6: Drilling results in Carbon FRP, including micro sized HAZ and good edge quality.

5 Conclusions

Picoseconds pulsed laser micro-machining conditions for three FRP materials have been studied. In the first phase was obtained that the 355 nm wavelengths (UV) is the one offering the best results in terms of productivity (MRR) and final part quality.

In the second phase using the appropriate parameters and drilling strategy can be machined successfully a composite sheet 3 mm thick in less than twelve repeats, with peak fluency of 33.4 J/ cm^2 and pulse frequency of 400 Hz. At these conditions, machining feed rate goes from 90 µm per cycle to 257 µm per cycle, cutting a composite sheet 3 mm thick in less than twelve repeats.

References:

[1] Machining Composite Materials, J. Paulo Davim, Wiley, London (2010).

[2] A. Wolynski, T. Herrman, P. Mucha, H. Haloui, J. L'huillier, Laser ablation of CFRP using picosecond laser pulses at different wavelengths from UV to IR, Physics Procedia 12 (2011) 292-301.