

**A COMPARATIVE STUDY OF CONTINUOUS WAVE AND PULSED WAVE Coz  
LASER CUTTING OF A POLYMER MATRIX COMPOSITE MATERIAL**

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Paper Presented at the Conference On Advanced Materials, ATCi2005, 6<sup>th</sup> - 8<sup>th</sup> December, 2005  
Putrajaya, Malaysia

**UNIVERSITI TEKNIKAL MALAYSIA MELAKA**

## A COMPARATIVE STUDY OF CONTINUOUS WAVE AND PULSED WAVE CO<sub>2</sub> LASER CUTTING OF A POLYMER MATRIX COMPOSITE MATERIAL

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### Abstract

Heat affected zone (HAZ) is always produced when laser cutting is used to cut any material. In this paper, a comparative study of the effects of continuous wave (CW) and pulsed wave (PW) CO<sub>2</sub> laser cutting on generation of HAZ is presented. The material used in the cutting experiment is Kevlar which is a widely used polymer matrix composite (PMC). The thickness of the Kevlar sheet considered in the present study is 2 mm. The effects of two main laser cutting parameters i.e. the laser power output and the cutting speed on the generation of HAZ are investigated in the study. The results showed that PW laser gives a smaller area of HAZ as compared to the CW laser.

### Introduction

LASER is an acronym for Light Amplification by Stimulated Emission of Radiation that was initiated by the work of Dr. Albert Einstein which was later followed-up by Dr. Theodore Maiman who had developed the first working ruby laser [1]. Currently CO<sub>2</sub> lasers have become a mainstream in a wide variety of industrial, medical, and scientific applications. These lasers are often integrated into assembly lines, on movable gantries or on robot arms, with applications ranging from metal cutting and welding, cutting dieboard or complex acrylic signage, to textile processing, package marking for date codes on cheese, fruit, or other food products [2].

Although the CO<sub>2</sub> is generally accepted in the industrial application, most of the applications involve the metallic materials application [3]. Generally when cutting polymer matrix composite (PMC) materials, the material removal is a consequence of the high energy density on the material surfaces resulting in either melting, evaporation or chemical degradation [4, 5]. Among the three cutting mechanisms, the dominant mechanism is influenced by the type of the PMC being cut. For Kevlar which falls under the category of PMC that does not melt, the most influential cutting mechanism is the chemical degradation [4, 5, 6].

Laser materials processing is a method to be considered for processing PMC because it is non-contacting, non-abrasive nature eliminates tool wear, reduce machine tools deflections, vibrations and cutting forces [7]. However there is a possibility that the laser light due its high energy intensity will have an effect towards the structures of

## Laser Machine Configuration

All the trial cut sets were performed with the LVD Helius 2513 CO<sub>2</sub> laser machine. The maximum capacity of the output power is 3 kilowatt (kW) with the capability of cutting speed up to 15 m/min. For pulse mode, the pulses can be set up to 2 kilohertz (kHz). The laser machine is a horizontal type machine with a moving table that has a work area of 3.0 meters x 1.5 meters in x-axis and y-axis directions respectively. Machining in z-axis direction is obtained by the movement of the laser head. Figure 2 below shows the laser machine configuration which consist of a CNC controller with Cadman-L software as the interface, the laser head, the horizontal moving table with the material clamping mechanism and the fume extraction system to extract gaseous generated during the laser cutting process. The schematic diagram of the laser cutting process is shown in Figure 3.

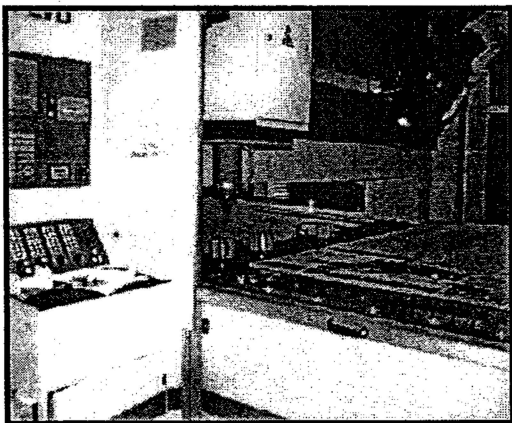


Fig. 2: LVD Laser Machine Configuration

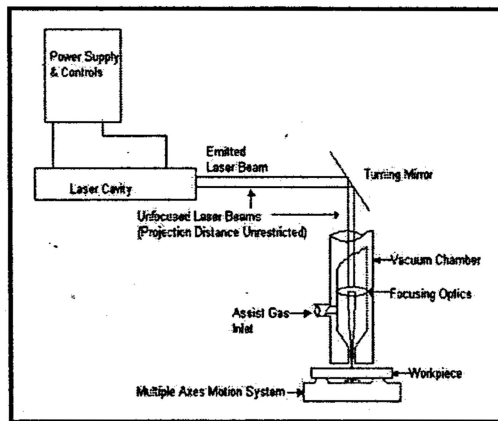


Fig. 3: Schematic of Laser Experiment Set-Up

## Experimental Method

For the cutting trials, the Kevlar plate is secured using a clamping mechanism on the moving table. A straight-line cutting was used to evaluate the variable laser parameters for full through cutting. All trial cuts were carried out for a length of 30 mm to ensure constant cutting condition and that was enough to measure the heat affected zone of the cut Kevlar [9]. Separation between each cutting condition of 20 mm was used, which had been proved sufficient to avoid interference of the preceding and subsequent cutting because the spreading of the localised heat input by the laser processing is very minimum [9, 10].

Only two laser processing parameters were varied while other parameters such as laser stand of distance, shielding gas pressure, nozzle diameter and focal length were kept constant so that the cutting condition for the material may be optimised. The parameters selected to be varied were the laser output power and laser light movement which is the laser cutting speed. The experimental parameters used for the cutting trials for the comparison study to evaluate the effect of CW and PW laser mode is shown in Table 2, where both laser modes utilised the same parameters. A total of



thirty set of trial cuts conducted for the experiment, where fifteen trial cuts were for the CW laser mode and another fifteen set of trial cuts were for the PW laser mode.

SPEED		20 mm/s	40 mm/s	60 mm/s
POWER	250 watt	Exp. 1	Exp. 6	Exp. 11
	400 watt	Exp. 2	Exp. 7	Exp. 12
	600 watt	Exp. 3	Exp. 8	Exp. 13
	800 watt	Exp. 4	Exp. 9	Exp. 14
	1000 watt	Exp. 5	Exp. 10	Exp. 15

Note: Exp. # denotes number of experiment

Table 2: Experimental Parameters for CW and PW LaserCut Trial

All cuts were repeated three times to reduce systematic error that might occur during the experiment. The power output was regulated using a CNC programming and the cutting speed was achieved via the movement of the horizontal moving table. An initial test program was carried out to ascertain the processing envelope for Kevlar and the results of the initial cutting trials indicated that the range selected for the laser parameters produced a through cut. All the cuts produced during the experiment were sectioned transversely and examined using optical microscope.

### Results and Discussion

Based on the visual inspection of the cut Kevlar as shown in Figure 4 and 5, a layer of carbon deposit due to the charring effect of the PMC material could be seen on the surface of the cut Kevlar that is perpendicular to the laser cutting entry.

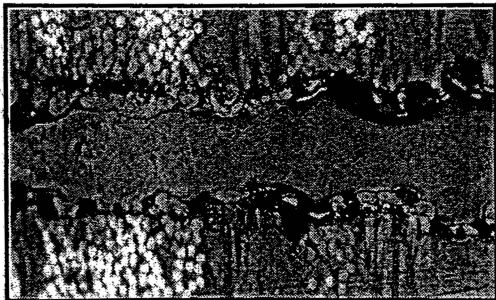


Fig. 4: Feature of a Cut Section Using CW Laser Display the Charring & Slight "Step Effect"

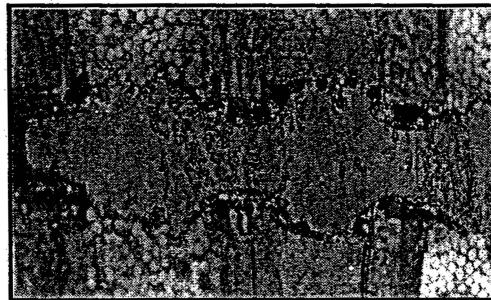


Fig. 5: Feature of a Cut Section Using PW Laser Display the Charring & Substantial "Step Effect"

An occurrence of "step effect" was detected when the cut image was subjected to a higher magnification. The fibres that were parallel to the cut surface have been stripped off their resin coating and those fibres which were perpendicular to the cut surface were less affected. This phenomenon was due to the orientation of the woven Kevlar fibres. The heat energy was fully absorbed by the parallel orientation fibres that promote cutting efficiency, whereas the perpendicular fibres conducted the heat away from the cutting region. It seems that the "step effect" was more apparent for the PW laser cut than the CW laser cut. The periodic heat input of the PW laser and

continuous heat input the CW laser was assumed for the outcome of the mixed “step effect” occurrence.

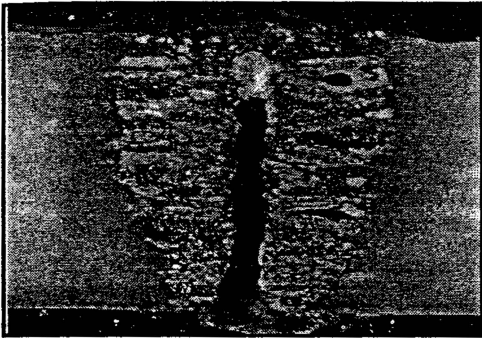


Fig. 6: Image of a Transverse Section exhibit a Large HAZ Area for CW Laser Cut

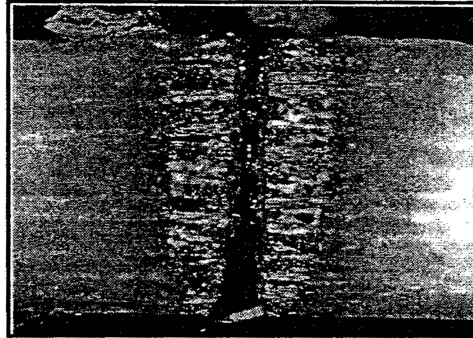


Fig. 7: Image of a Transverse Section Exhibit a Reduce HAZ Area for PW Laser Cut

A discrete heat affected zone (HAZ) was observed adjacent to the cut area as pointed out in Figure 6 and 7. For both CW and PW laser cutting experiment, all cutting condition correspond to a similar pattern. The highest HAZ width was observed at the entry point of the cutting zone. The minimum HAZ width was seen at the cutting exit region. The HAZ adjacent to one side of the cut as per indicated in Figure 7, was measured using the Image Analysis System.

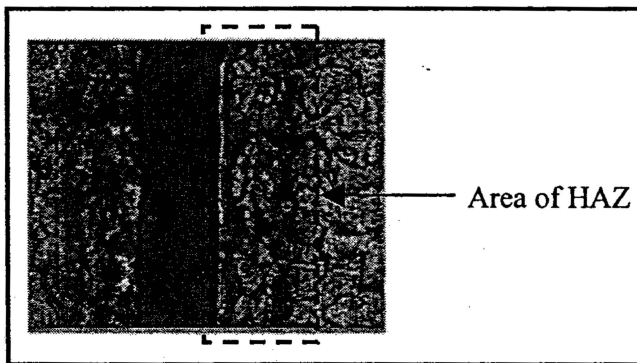


Fig. 7: Area of HAZ that is measured using the Image Analysis System

The amount of HAZ varied accordingly to the laser cutting parameters used to cut the Kevlar. An average being calculated from three individual readings and different cutting parameters were evaluated. The results obtained from the analysis are given in the following Table 4, 5 and 6.

POWER (watt)	250	400	600	800	1000
HAZ CW (mm <sup>2</sup> )	0.270	0.350	0.220	0.200	0.260
HAZ PW (mm <sup>2</sup> )	0.052	0.114	0.061	0.066	0.107

Table 4: Variation of HAZ at Cutting Speed 20 mm/s



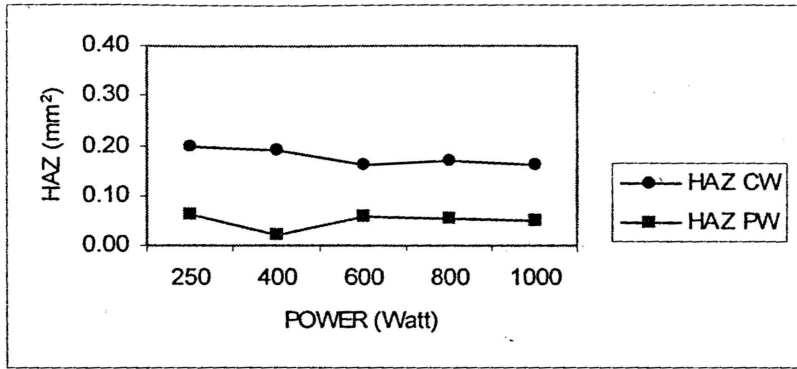


Fig. 9: Graph of HAZ at Cutting Speed 40mm/s

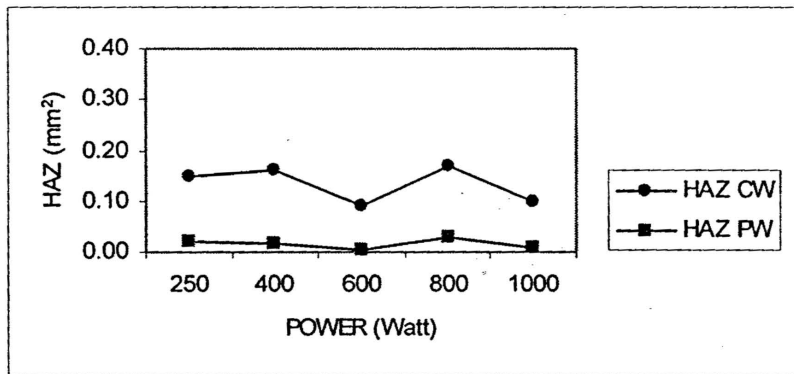


Fig. 10: Graph of HAZ at Cutting Speed 60mm/s

The trend of the graphs from Figure 8, 9 and 10 implies that the HAZ area was lower for the PW laser compared to the CW laser. It also reveals that the decrease of cutting speed has increased the HAZ for both PW and CW laser. However the increase of laser power give a minimum effect towards the HAZ area of the cut Kevlar, as per graphs represented in Figure 10 and 11. An investigation on the roughness of the laser cut surfaces need to be conducted to verify the cut surface integrity, hence allowing further comparative study between CW mode CO<sub>2</sub> laser and PW mode CO<sub>2</sub> laser.

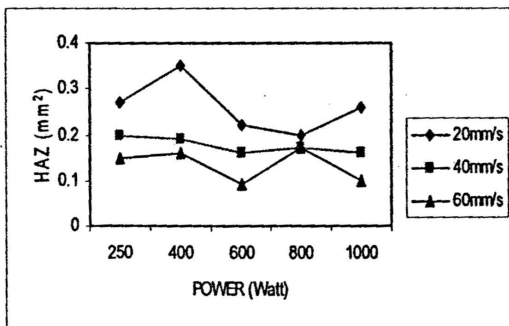


Fig. 11: Graph of CW HAZ at Different Cutting Speed and Power Level

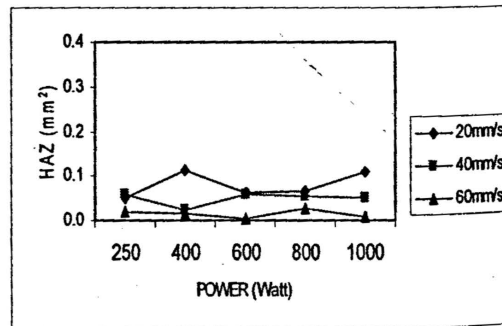


Fig. 12: Graph of PW HAZ at Different Cutting Speed and Power Level

## Conclusion

This comparative study of the effect of the CW laser mode and the PW laser mode was investigated experimentally based on the generation of HAZ area on a PMC material i.e. Kevlar. The study showed that all cut trials by PW laser produces low HAZ area compared to the CW laser. Both laser modes exhibit a greater HAZ area upon the laser cut entry than the exit cutting point. Scrutinizing the data collection of the experimental results also reveals that, the increased of cutting speed has an inverse proportional effect towards the HAZ area. Nevertheless the increased of cutting power although was found trivial, it has a foremost consequence when compared against the different cutting power level within the same laser cutting speed parameters. This study also demonstrated that the anticipated HAZ and charring effect when cutting PMC using CW laser can be overcome by utilising the capability of PW laser. With reference to all the findings and results gathered from the laser cutting experiment, there is an obvious relationship between the various laser cutting parameters which involves during the cutting process of the PMC material that need to be further investigated.

## Acknowledgement

The authors acknowledge the research grant (#6035068) provided by Universiti Sains Malaysia, Penang which has resulted in the article. We are indebted to the Faculty of Manufacturing Engineering KUTKM for providing the laser cutting trials as well as the assistance of Ms. Izati from CTRM for the analysis work.

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