Experiments for cutting glass fiber epoxy plates with CO_2 laser

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Abstract: *This paper deals with cutting glass reinforced epoxy composites using a CO_2 laser. An analytical model for different material thickness is proposed, which allows finding optimal conditions for cutting process. The model allows us to describe the cutting process showing the influence of cutting speed and laser power.*

Key words: *laser cutting, glass fibre epoxy, full factorial design, Pareto chart, cutting speed.*

INTRODUCTION

In last years the requirement has arisen for technologies that offer best performance regarding cutting composite materials with plastic matrices, many technological and scientifically investigations were made.

Previous papers were made to understand the cutting mechanism [1, 2] of glass and carbon fibre reinforced plastics, taking in consideration also the amount and the orientation of reinforced elements.

Other papers deals with cutting of aramid fibre reinforced plastic (AFRP) having a comparison between mechanical cutting and laser cutting. Mechanical strength is increased by 4-25% for laser cutting, for a certain thickness (2mm) different cut width is observed at top and bottom surfaces. It is indicated that the laser cutting of composites is possible even at 6mm thickness. Also the heat affected zone (HAZ) was under analysis [3], for CO_2 laser cutting having 380W, cutting speed 2000-4000mm/min, cutting gas is nitrogen 4 bar pressure.

This paper deals with the influence of laser power and cutting speed over cutting characteristics, also the influence of other important factors is analyzed.

EXPERIMENTS

The industrial equipment used for cutting glass fibre reinforced epoxy (GFRE) plates is a Rofin SCx20, CO_2 laser continuous wave (cw). During experiments laser power P[W] and cutting speed [mm/s] were changed, also different focal position were used depending of piece thickness s [mm]. The spot diameter of laser beam used is Ø0.32mm, the focal length 100[mm]. Air was used by the gas-assisted system 5bar pressure.

GFRE contains glass fibre type “E” maximum 5mm length, random oriented, material is considered heterogeneous. Two thicknesses of fibres were used 0.1mm and 0.2mm, the fibre percentage used is 75%.

Several channels were performed on a length of 60mm (figure 1), the cross section can be observed in figure 2 (schematic). The cut width was measured at top (Bf) and bottom (B_v) plate surface three times, at 15mm, 30mm and 45mm distance from the start point of laser cut. Having those values measured an average width was calculated.

Several factors were considered in order to analyze the cut:

$B_m = \frac{B_f + B_m}{2}$ [J/mm] –average cut width (1)

$E_v = \frac{2P}{(B_f + B_v)\, s\, v}$ [J/mm^3] - energy necessary to remove a unit of material volume (2)

$Pr = \frac{B_f + B_v}{2} \cdot s \cdot v$ [mm^3/s] - removed material rate-volume (3)

$U = arctg \frac{2s}{B_f - B_v}$ [°] - angle of cut walls (4)

For the 2mm plates the focal position was on top surface, for the 4.3mm plates the focal position was 2mm under the top surface.

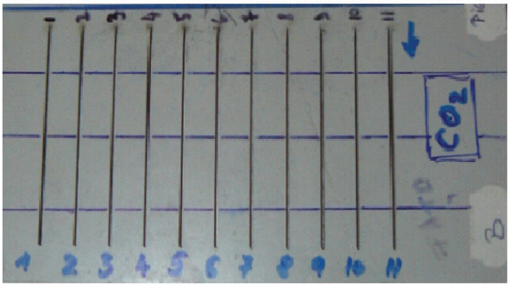

Figure 1. Image of glass fiber epoxy plate

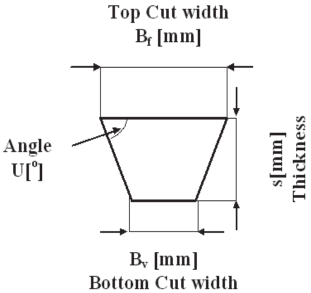

Figure 2. Cut cross section

Theoretical model was 3^2, statistical calculation was made using Statgraphics. On "Pareto" chart the effects of significant factors is shown. Statistical calculation considers that laser power and cutting speed are dimensionless factors. Following relations were considered for calculation:

$A = 1.2v - 3$ [-] (5)

$B = 0.0347P - 6.333$ [-] (6)

Laser power and cutting speed values are indicated on table 1.

Laser power and cutting speed values Table 1

No.	Cutting speed		Laser power	
	v [mm/s]	A[-]	P [W]	B[-]
1	3.33	+1	153.6	-1
2	3.33	+1	182.4	0
3	3.33	+1	211.2	+1
4	2.50	0	211.2	+1
5	2.50	0	182.4	0
6	2.50	0	153.6	-1
7	1.67	-1	153.6	-1
8	1.67	-1	182.4	0
9	1.67	-1	211.2	+1
10	2.50	0	182.4	0
11	2.50	0	182.4	0

From table 1 three replications are identified in experiment centre-point, very useful for statistical calculation and for analysis of variance (ANOVA).

EXPERIMENTAL RESULTS

The effect of relevant factors over the cutting width on cut's top surface for 2mm plate is presented on figure 3. It can be observed that laser power has the highest influence. As can be notice the width at top cut surface is proportional with laser power and decrease if the cutting speed is reduced. The effect of laser power is more important than the decrease of cutting speed. For 4.3mm plate the influence over cut width are presented in figure 4. Laser power and cutting speed are proportional with cut width-top surface. This behaviour can be explained by the thermal degradation of epoxy.

Figure 5 represents Pareto charts related to factor's effect over cut width bottom surface. The cutting speed has the highest influence over cut width. Cut width is proportional with laser power and is decreasing once the cutting speed is increasing. Same behaviour is notice for 2mm and for 4.3mm plates, figure 6. For the thicker plate (4.3mm) the effect of laser power is less significant than cutting speed.

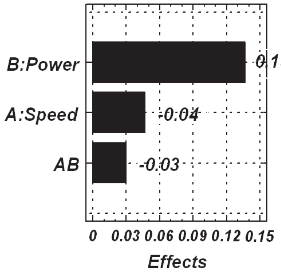

Figure 3. Pareto chart for top cut width at 2mm thickness

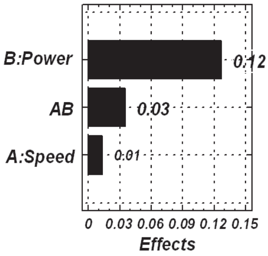

Figure 4. Pareto chart for top cut width at 4.3mm thickness

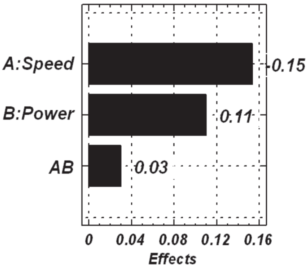

Figure 5. Pareto chart for bottom cut width at 2mm thickness

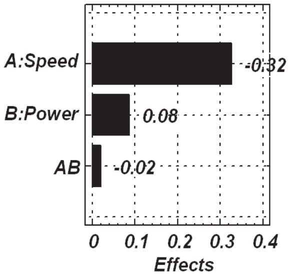

Figure 6. Pareto chart for bottom cut width at 4.3mm thickness

On figures 7 and 8 Pareto charts are presented for average cut width. Cut width is proportional with laser power and is decreasing once the cutting speed is increasing. Laser power and cutting speed have the highest influence over cut width, the interaction between those two factors is less significant.

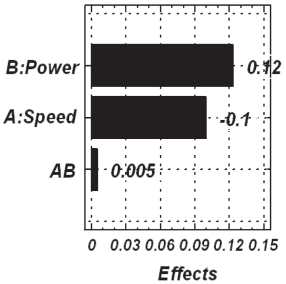

Figure 7. Pareto chart for average cut width at 2mm thickness

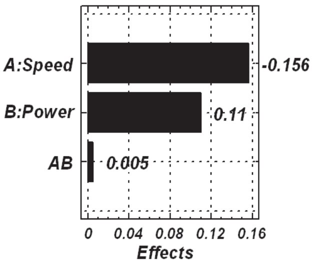

Figure 8. Pareto chart for average cut width at 4.3 mm thickness

For the main objective function E_v under analysis, Pareto charts (figure 9 and 10) are showing that the cutting speed has the highest influence. To decrease E_v is necessary to increase the efficiency of laser power during cutting process, so optimal conditions can be reached in this way. It is possible to decrease E_v by increasing the cutting speed without changing the laser power. For the thicker plate (4.3mm) the differences between laser power and cutting speed effect is smaller. For thicker materials the laser power is most significant and domain of cutting speed variation is smaller.

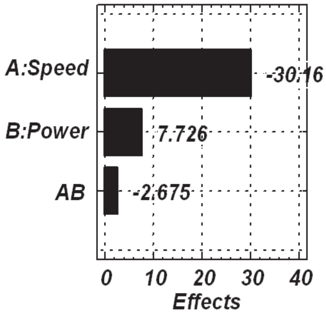

Figure 9. Pareto chart for E_v function at 2mm thickness

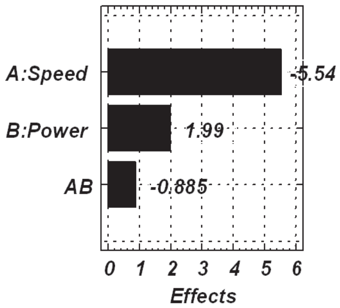

Figure 10. Pareto chart for E_v function at 4.3mm thickness

In figure 11 and 12 the Pareto charts are presented for function P_r , showing the material removed volume on a time period. In order to obtain a better efficiency of laser power consumption it is necessary to have highest values of P_r. It can be notice that most significant effect over the process is the cutting speed, so certainly we can optimize the cutting process by increasing cutting speed.

Figure 13 and 14 represent the Pareto charts for angle of cut walls, it can be notice that for both thicknesses the most significant factor is cutting speed.

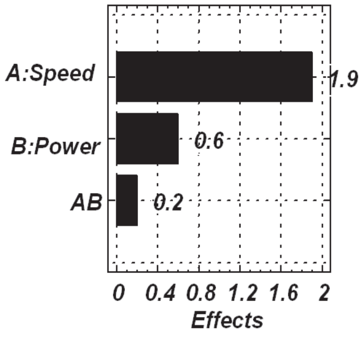

Figure 11. Pareto chart for P_r function at 2mm thickness

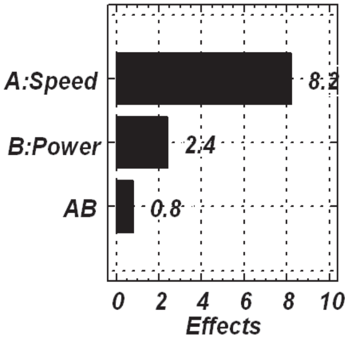

Figure 12. Pareto chart for P_r function at 4.3mm thickness

For thicker plate the difference between cutting speed and laser power is even higher. The objective function under analysis is measuring the U angle related to a reference of 90°. Negative values indicate that the U angle is decreasing.

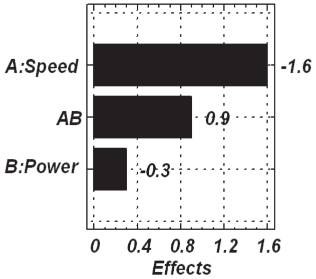

Figure 13. Pareto chart for U angle at 2mm thickness

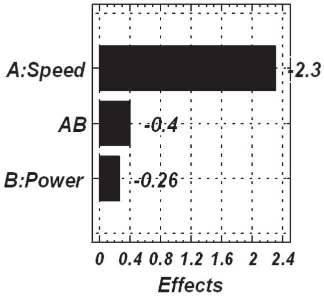

Figure 14. Pareto chart for U angle at 4.3mm thickness

CONCLUSIONS AND FUTURE WORK

The analysis over laser cutting process was made using a factorial experiment. Manny objective functions were proposed as cut width at top and bottom surface (measurable values). Average width and wall's angle U are calculated objective functions that are describing the cut quality. Functions E_v and P_r are characteristics for laser cutting process. The analysis shows following conclusions:

- Cut width increase if laser power is also increase and is decreasing if the cutting speed is increased
- If the material thickness and cutting speed are increased the U angle is decreasing (no parallel walls)
- Since the cutting speed has more significant effect over objective functions E_v and P_r, it is possible to optimize the cutting process by modifying the cutting speed

Experimental results are useful for controlling and optimization of laser cutting process of composite material under study and also for other materials with similar structure. For next research studies it is important to take into consideration the request from industry also for curved cutting contour.

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Докладът е рецензиран