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Process optimization of CO_2 Laser Beam Cutting of Coir-Carbon Reinforced Hybrid Epoxy Composites

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ABSTRACT

Laser beam cutting process is actuated by thermal energy and is a non-contact advanced precision machining process which is currently in high use for wide range of applications in engineering, medical, communications and different other research areas etc. Lasers beam cutting consists of several controlling parameters to govern the effective functioning with desired accuracy and productivity etc. Coconut coir is highly used for fabrication of different varieties of polymer composites as it is light weight and has strong structure etc. Coir-carbon fibre reinforced hybrid epoxy composites are used in tremendous applications such as sport goods, helmet shells, roofing etc. In this paper, 120W CO_2 laser was used to machine coir-carbon fibre reinforced epoxy composites under different operating conditions using Taguchi technique. Analysis of experimental data was conducted using Minitab 19 software. Main effect and 3d contour plots showed that laser power has dominant effect on mean kerf width followed by stand-off distance and cutting speed, respectively.

***Keywords*:** CO_2 laser cutting, coir-carbon fibre reinforced hybrid epoxy composites, laser power, standoff distance, cutting speed, kerf width

Introduction and literature review

Laser is a device which is a good source of monochromatic coherent radiations. Nowadays, lasers have increased applications in industries for cutting and boring of different metals and non-materials etc, for medicinal surgery, in communications, scientific research, and holography [1, 2]. As this a contact less process so no cutting forces acting at the machining interface with minimal tool wear, machine vibration and reduced material loss etc. Natural fibres are nowadays useful to serve various industrial and societal needs due to their unique properties such as light weight, non-toxic nature, biodegradability etc. These fibers are less expensive, flexible, renewable source and have good insulating properties etc.

Lots of research is going on globally considering various issues of laser cutting (LC) of different domain of materials. Caiazzo et al. [3] studied LC of different types of plastics. The cutting speed (CS) has major influence on the cut edge quality. Choudhury and Shirley [4] conducted the CO_2 LC of three polymeric materials. Surface roughness (SR) decreases with increase in laser power (LP), CS and air pressure, respectively. Davim et al. [5] conducted CO_2 LC of PMMA. The HAZ increases with increase in LP and decreases with CS. SR increases with decrease in LP and an increase in CS. Kurt et al. [6] investigated the CO_2 LC of different engineering plastics. CS and LP have found significant effect on the edge dimensions and SR. Bahr et al. [7] performed the good quality LC of thick plastic scintillator and other materials etc.

Davim et al. [8] conducted LC of polymer materials. The HAZ increases with the LP and decreases with the CS. Berrir and Birkett [9] conducted LC and drilling of Perspex. Depth of cut increases with LP and decreases with CS. Tagliaferri et al. [12] studied thermal behavior of fibre composites during LC. It was found that the thermal properties have significant effect on SR. Groke and Emmelmann [13] explored the LC of CFRP composites. The HAZ and the KW decrease with increase in CS and decrease in LP. Riveiro et al. [14]

investigated the effect of control settings on the quality of the cut edge. High quality cuts can be achieved at optimum parameter settings.

Voisey et al. [16] conducted Nd:YAG laser drilling of various materials. LP has found major influence on MRR. Lau et al. observed that the MRR increases with LP and CS, respectively. Ghany et al. [17] conducted Nd:YAG LC of austenitic SS. It was found that by increasing the pulse frequency, the KW decreases. Karatas et al. [18] conducted CO_2 LC of steel. The KW is found to be dependent on focal length. Thawari et al. [19] conducted Nd:YAG LC of Ni alloy. It was found that on increasing the spot overlap, the KW increases. KW increases with increase in laser pulse duration. Borki et al. [20] investigated the laser surface transformation hardening of spur gears made of 4340 grade steel. Laser power has found major influence on SR as compared to other control parameters. Anghel et al. [21] conducted CO_2 LC of gears made of 304 SS material. Focal position was found to be the most significant parameter. Nieszporek et al. [22] explored the unique features and functions of CNC laser techniques for machining of different configuration of gears. Bhaskar et al. [23] conducted a review study on LC of glass fiber epoxy composites. They explored the effect of HAZ, taper angle and KW on SR. Trzepiecinski et al. [24] studied the pros and cons of various cutting techniques for processing of different types of composite materials. In the present paper, CO_2 LC of coir-carbon fibre reinforced hybrid epoxy composites was studied experimentally in terms of mean KW. Experiments were performed based on Taguchi design using L_9 orthogonal array. This work will be prove to develop a guiding mechanism for cost effective CO_2 laser cutting of high quality coir-carbon fibre reinforced hybrid epoxy composites at high production rate.

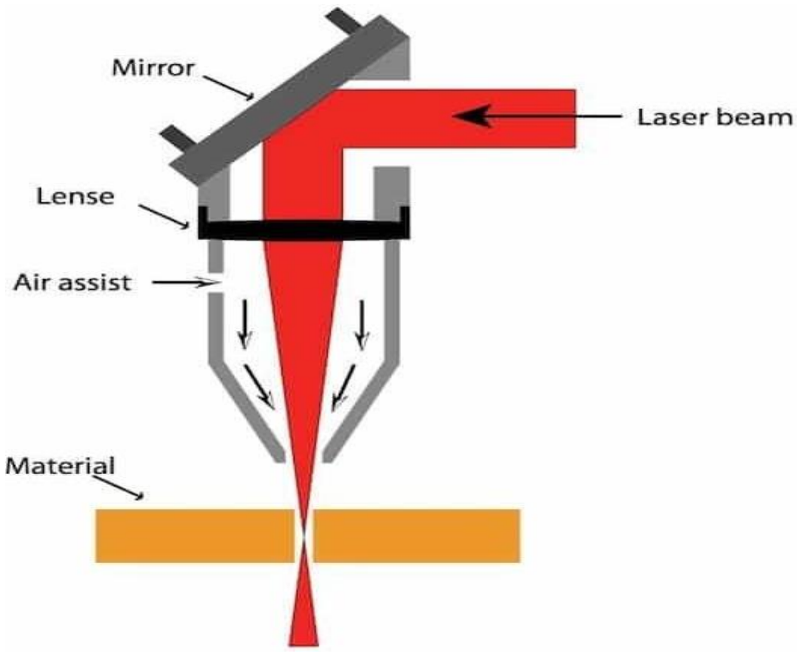


Figure 1. Schematic diagram of Laser beam cutting process [1]

Sample preparation

Carbon fibre woven fabric sheet (400GSM) and natural coir fibres have been purchased from suppliers of Indiamart as per our requirements. As coir straightening is a challenging issue and it creates problems during composite's fabrication. Therefore, treatment of coir fibres is urgently required. To serve this purpose, NaOH and acetic acid solutions in different proportions are utilized. Initially coir fibres were processed in 10 percent NaOH solution for 30 minutes. After carefully washing using hand gloves, it was again processed in 2 percent acetic acid solution for some time for neutralization, followed by washing. Now treated coir fibres are ready to use with woven carbon fibre after proper drying process (Figure 3).

In the next stage, carbon woven fabric sheet was cut in size as per dimensions of wooden mould as shown in Figure 4(a). Treated coir fibres were added in different proportions (30, 20 and 10%, respectively) for preparation of final samples of coir-carbon fibre hybrid reinforced epoxy composites (Figure 4b). Hand lay-up process was utilized for fabrication of hybrid polymer composites using epoxy resin (LY-556) and hardener (HY-951) purchased from CF Composites, New Delhi. For efficient lay-up purpose during fabrication, the resin and hardener were added in ratio of 10:1. The SEM images of fabricated coir carbon fibre reinforced hybrid epoxy composites are shown in Figure 5.

2(a) 2(b)

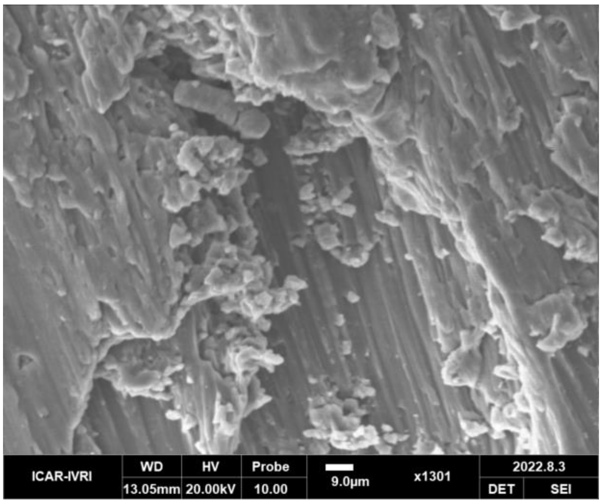
Figure 2. Coir treatment process with (a) 10% NaOH solution (b) Acetic acid

3(a) 3(b)

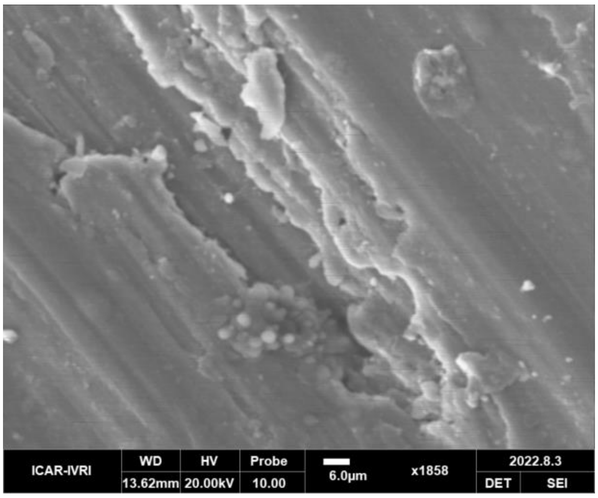
Figure 3. Coir fibre (a) before treatment (b) after treatment

4(a) 4(b)

Figure 4. (a) Wooden mold used for hand lay-up process (b) Coir-carbon hybrid epoxy composite



5(a)



5(b)

Figure 5. SEM of Coir-carbon fibre hybrid composites (a) with untreated coir fibres (b) with 10% NaOH treated coir fibres

2-Experimentation

Cutting Experiments using CO_2 laser were performed under different operating conditions on coir-carbon reinforced hybrid epoxy composites sheets of thickness 2.0-5.0 mm. The operating parameters and their ranges are decided based on the literature review as shown in Table 1. The KW is measured by a digital vernier caliper with an accuracy of 0.01 mm. To reduce error of measurement, three different measurement points were taken and the average was considered as the mean KW. The CO_2 process of coir-carbon reinforced hybrid epoxy composites is shown in Figure 5.

Table 1: Process parameter and their range

Parameters	Levels		
	1	2	3
Laser power (W)	30	60	90
Cutting speed (mm/s)	10	15	20
Standoff distance (mm)	4	8	12

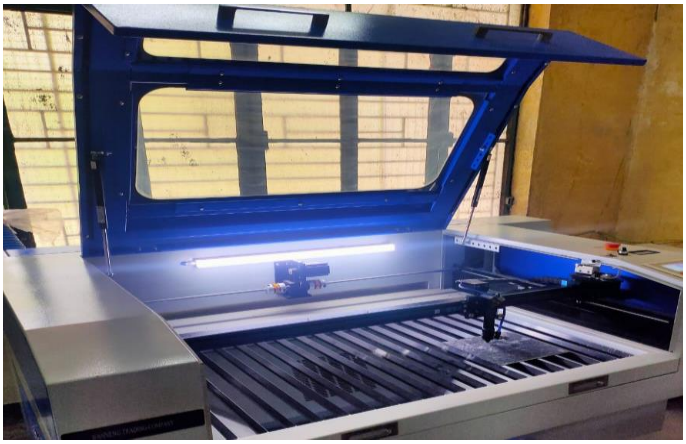


Figure 6. CO_2 laser cutting of hybrid natural fibre coir-carbon epoxy composites

3-Results and discussion

The S/N ratio for "lower the better" response (KW) is computed as below:

$$\eta p = -10 \log10 (Y_q^2) \qquad \text{(I)}$$

where Y_q is the value of the *p*th experimental response for *q*th quality characteristics.

Based on the S/N ratios, analysis was conducted and main effect and 3d contour plots were drawn between mean KW for three operating parameters as LP, CS and standoff distance (SOD) using Minitab 19.0 software.

It is observed that the mean KW increases with laser power as shown in Figure 6. This is due to increase in heat input to the substrate. The KW decreases with increase in CS and it has negligible effect on mean KW. As SOD increases, this may lead to divergence of laser beam and results in decrease in mean KW. The significance of each operating parameters was calculated using ANOVA. According to ANOVA results shown in Table 2, LP has significant effect followed by SOD and CS. The 3d contour plots for KW were also drawn between these three operating parameters (Figures 7(A), (B)). As sample fabrication was done in an efficient manner after few initial trials, therefore negligible amount of delamination is observed in all samples.

Table 2: Factor response table for KW used to determine the rank

Levels	S/N response data (dB)		
	Laser power (W)	Cutting speed (mm/s)	Standoff distance (mm)
1	8.64	7.14	7.75
2	6.83	6.35	6.60
3	6.82	7.25	6.65
Delta	1.82	0.90	1.15
Rank	1	3	2

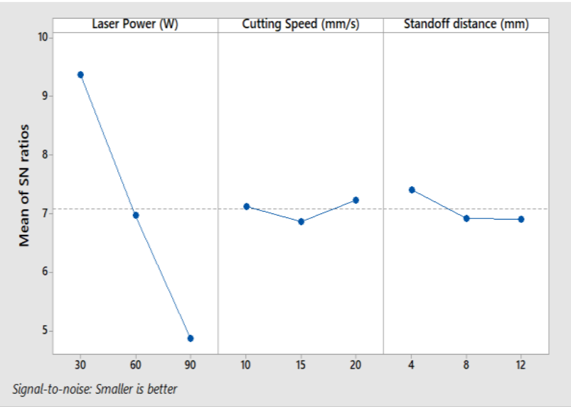
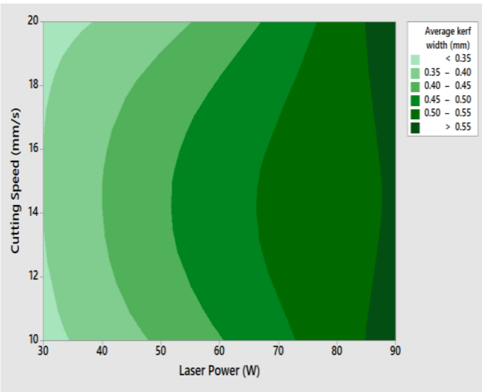
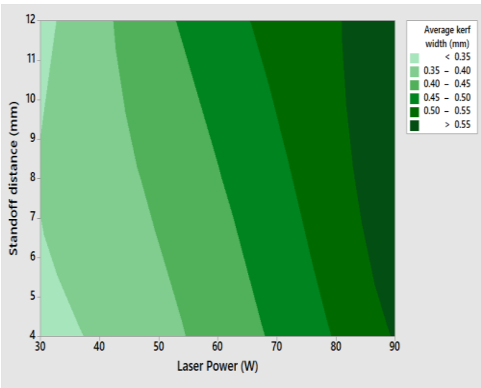


Figure 7: Main effect plot for kerf width



8(a)



8(b)

Figure 8 (a) Contour plot of mean KW (A) for laser power and cutting speed (b) for laser power and standoff

4-Conclusions

Following conclusions have been drawn from the present work of CO_2 laser cutting of coir-carbon fibre reinforced hybrid epoxy composites under different operating conditions.

1. KW decreases with increase in laser power.
2. Initially KW decreases with increase in cutting speed and then starts increases with further increase in cutting speed.
3. KW decreases with increase in standoff distance.
4. From delta statistics, laser power is kept at rank 1 (most important) followed by standoff distance at rank

2 while cutting speed is kept at rank 3 (least important).

5. Optimum combination for minimum KW is at higher laser power (90 W), medium cutting speed (15 mm/s) and higher standoff distance (12 mm).
6. This work is very useful for cost effective CO_2 laser cutting of high quality coir-carbon fibre reinforced hybrid epoxy composites under optimum parameter settings.
7. These fabricated natural fibre composites are eco-friendly and biodegradable in nature and therefore help in reduction of environmental pollution at the shop floor etc.

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