Indian Journal of Pure & Applied Physics
Vol. 59, March 2021, pp. 258-262

Fabrication, Testing and Machining of Hybrid Basalt-Glass Fiber Reinforced Plastic composite

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Received 27 January 2021; accepted 17 February 2021

In modern industries, basalt and glass are the most commonly used fibers for the fabrication of various engineering components. Present work is focused on the fabrication of hybrid fiber reinforced plastic (FRP) composites, comprises of basalt and glass fibers. The aim of the work is to fabricate a composite justifying the current requirement of the era followed by the identification of the capabilities of fabricated composite by investigating its mechanical properties. Further, the machining of the fabricated composite has also been explored in order to limit the common problems in machining like fiber pull-out and delamination. From the results, it has been perceived that the fabricated composite can be machined flawlessly using laser beam machine subjected to the selection of input parameters. The proposed methodology seems helpful for researchers in fabricating the FRP composite and in identifying the range of input parameters suitable for machining.

Keywords: Fiber reinforced plastic composite; Response surface methodology; Laser beam machining; Box Behnken design; Hand layup method.

1 Introduction

Now a days, modern industries are focusing on cheap, durable as well as lightweight materials with excellent mechanical properties. This need gave rise to the hybridization of materials by which characteristics of two parent materials can be haul out in one.

A lot of researchers have used hybridization technique for the fabricating of composite[1]. The hybridization of materials is associated with the reinforcement. One of the most common fibers that are used in fiber reinforced plastic (FRP) composites is basalt[2-5]. Due to its significant characteristics researchers have used this material for many applications[6, 7]. Sim *et al.*[3] examined the strength of basalt fiber and used it with concrete. From the study, it was observed that basalt fibers can be used as an alternative of concrete in structures as it provides greater insulation and thus, one can use basalt fibers in electrical cables, underground ducts, printed circuit boards or/and for fire protection[8]. Fiore *et al.*[9] investigated that the mechanical properties of hybrid FRP can be improved if basalt laminates are placed at outer layers rather than glass. Further, studies has also indicated basalt as a possible alternative in marine applications such as construction of ship hull. Moreover, impressive characteristics of basalt fibers bridges the performance gap between glass and carbon fibers but later offers high resistance to bending than that of basalt fibers thus, hybridization of basalt and glass fibers may result in hybrid FRP composite that has better mechanical properties as it contains advantages of both parent fibers.

Composites for the above applications can be mold into any profile and at the same time they need to maintain high precision, which is hard to obtain through conventional cutting methods, as it may jeopardize tool and material because it requires high specific energy which may cause thermal expansion or frictional force at tool-material interface. These downsides may result in delamination around the cutting edges of fiber-matrix, formation of whiskers, poor machinability, loosing of fibers and subsequently in the tool wear, therefore, the conventional cutting methods hold-backs the cutting quality and thus, these methods are considered as inappropriate for machining of hybrid FRPs[10-15].

In concern to the applications of such composite materials, it has been found that such materials can be used at a wide range of areas including automobile industries, Automation industries, Contruction purposes, various light weight applications. Reseachers have also stated applications of such composited in high finish components with very complicated profiles for which

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suitable cutting of the material is essential. Studies found laser machining as a fashionable material processing method due to its numerous benefits such as better cut quality with high productivity at high speed, non-contact type processing results in no tool wear and in high accuracy. These qualities make it a perfect choice for the machining of advance materials. However, précise and accurate cut quality needs appropriate levels of cutting parameters and selection of favorable range, this motivated the present research.

2 Material fabrication, testing, and experimentation

In this work, woven basalt, and glass fibres of thickness 200 gsm each have been used to fabricate the hybrid FRP using hand layup method. Hardener CT/AH-60 with Epoxy resin CT/E-120 have been used as polymer matrix due to its favorable mechanical properties and adhesive structure. Since, volume fraction of fibers and their stacking sequence plays an equally important role in defining the mechanical characteristic of any hybrid FRPs, thus, in this study, basalt and glass laminates were symmetrically stacked (BBGGBB) with $[0^o/90^o/0^o/90^o/0^o/90]_6$ orientation.

The experiment begins with the fabrication of hybrid FRP, for which a mold of mild steel were prepared initially. A thin layer of wax was then evenly spread over the inner surface of mold which act as a releasing agent, following to which a laminate of basalt fiber is placed over the wax layer. A mixture of epoxy and hardener in an appropriate composition was prepared then uniformly poured over the basalt fiber laid earlier. A laminate of glass fiber was then spread over the earlier placed basalt fiber and then a roller was used to remove the air, which was likely to be trapped between the fibers and the process was repeated till the required stacking sequence is achieved. At the end the mold was tighten with the screw bolts and the specimen was left for curing for 24 hours. Dimension of fabricated hybrid composite equals to 200 mm × 250 mm × 2.15 mm. Fig. 1 represents the mold used in the fabrication process.

Some mechanical properties namely, tensile strength and flexural strength are determined using computerized universal testing machine which is working on hydraulic mechanism as shown in Fig. 2.

For determining the tensile strength, the specimen having dimensions as per ASTM D3039/D3039 M standards and gauge length equals to 75 mm is placed axially and crosshead having constant speed of 0.1 mm/s has been moved during the test. Total six specimens, three samples of each type been investigated and the corresponding tensile strength is measured from the mean value of observed data and the same is illustrated in Table 1.

For flexural strength, composites were tested under three-point bending and were prepared as per ASTM D790 standards having span length equals to 68.8 mm. Specimens were made to fix at both the ends by holders and a transverse load was applied at the mid span by the loading nose moving with a constant speed of 1mm/min. Fig. 3 represents the tested samples under point loading. The data evaluated from the experiment is illustrated in Table 1.

Results of the conducted experiment enlighten that, on hybridization of basalt and glass fibers, the hybrid FRP offers mechanical characteristics better than the individual fibers. Basalt fiber known for its high tensile strength but its use was restricted to certain applications due to its fewer flexural strength.

Fig. 1 — Setup used for Fabrication

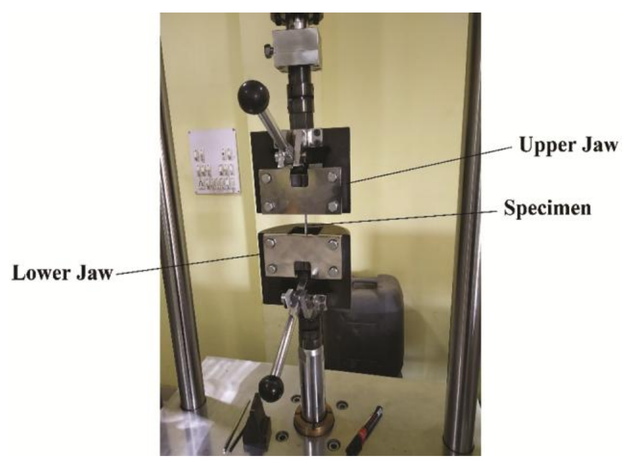

Fig. 2 — Universal testing machine

Table 1 — Properties of Composite

Properties	Basalt	E-Glass	Hybrid composite
Tensile Strength (MPa)	335	195	312.6
Flexural strength (MPa)	328	360	339.3

Now, when hybrid composite of basalt-glass combination has flexural strength higher than basalt fibers and at the same time it offers mechanical advantages of individual fibers as well, thus, the hybrid composite can be possible to use as an alternative of both basalt and glass fibers and equally replace some conventional composites in the applications where tensile strength required is higher than the glass fiber and flexural strength required is higher than the basalt fibers.

Fabricated composites have undergone cutting experiment and the system used for the corresponding experiment is pulsed based Nd: YAG laser machining system. Table 2 shows the input variables with their respective levels that helped in framing the design of experiments using the Box Behnken design (BBD)[16].

After experimentation, the top kerf deviation (TKD) and bottom kerf deviation (BKD) have been calculated. Some of the data has been shown in Table 3. The transformation of un-coded input variables into coded form has been done using the Equation.

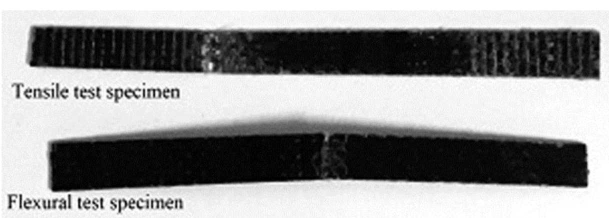

Fig. 3 — Tested Specimens under three-point bending

Table 2 — Laser machining factors and levels

Symbol	Factor	Unit	L1	L2	L3
A	Lamp Current	(Amp)	160	180	200
B	Pulse Frequency	(Hz)	20	25	30
C	Cutting Speed	(mm/min)	30	40	50
D	Pulse Width	(ms)	2	2.3	2.6
E	Air gas pressure	(bar)	8	9	10

$$X_A = \frac{A-180}{20}, X_B = \frac{B-25}{5}, X_C = \frac{C-40}{10}, \quad (1)$$
$$X_D = \frac{D-2.3}{0.3}, X_E = \frac{E-9}{1}$$

3 Modeling using response surface methodology (RSM)

This study involves development of RSM based model[17, 18]. This experimental study used Box Behnken Design with five-factor three levels. Total 46 experiments have been conducted and mathematical models for TKD and BKD have been generated.

$$\begin{aligned} TKD = {} & 0.062+0.01375*A-0.00325*B + 0.00275*C - 0.00675*D - 0.02025*E - \\ & 0.004*A*B+ 0.00725*A*C - 0.00125*A*D -0.00975*A*E+0.0035*B \\ & *C+0.0035*B*D-0.00975*B*E+0.0025*C*D-0.00375*C*E+0.01575* \\ & D*E-0.0208333*A*A-0.021*B*B+0.00325*C*C-0.0160833*D*D+ \\ & 0.00691667*E*E+0.00025*A*A*B+0.0005*A*A*C+0.004*A*A*D- \\ & 0.0035*A*A*E-0.00575*A*B*B-0.0115*A*C*C -0.0005*A*D*D+ \\ & 0.00375*B*B*C+0.00525*B*B*D-0.0025*B*B*E+0.00425*B*C*C+ \\ & 0.00675*B*D*D+0.00225*C*C*D-0.008*C*C*E-0.00225*C*D*D \end{aligned} \quad \ldots (2)$$

$$\begin{aligned} BKD = {} & 0.0541667+0.005*A+1.09996e^{-19}*B+0.00675*C+0.01775*D-0.01825*E+ \\ & 0.05025*A*B-0.00375*A*C-0.01225*A*D-0.04*A*E-0.0035*B*C+0.0255 \\ & *B*D+0.0315*B*E+0.00625*C*D-0.00025*C*E+0.01475*D*E+0.0516667 \\ & *A*A+0.0135*B*B+0.001*C*C- 0.0005*D*D+0.0279167*E*E-0.00175*A* \\ & A*B-0.0015*A*A*C+3.63858e^{-18}*A*A*D*0.00175*A*A*E-0.00075*A*B*B+ \\ & 0.00125*A*C*C+0.00125*A*D*D-0.00175*B*B*C+0.00325*B*B*D+0.00025* \\ & B*B*E+9.69026e^{-18}*B*C*C-0.003*B*D*D-0.0005*C*C*D+0.0015*C*C*E- \\ & 0.0025*C*D*D \end{aligned} \quad \ldots (3).$$

The accuracy of RSM model has been checked by identifying the error.

An error between experimental and predicted values been calculated using Eq. 4. The calculated

Table 3 — Obtained TKD and BKD

Lamp current amp	Pulse frequency (B) Hz	Cutting Speed (C) mm/min	Pulse Width (D) Ms	Air pressure (E) bar	TKD mm	BKD mm
-1	-1	0	0	0	0.012	0.168
1	-1	0	0	0	0.036	0.076
-1	1	0	0	0	0.015	0.064
1	1	0	0	0	0.022	0.171
0	0	-1	-1	0	0.059	0.043
0	0	1	-1	0	0.055	0.039
0	0	-1	1	0	0.045	0.065
0	0	1	1	0	0.049	0.086
0	-1	0	0	-1	0.069	0.144
0	1	0	0	-1	0.082	0.084
0	-1	0	0	1	0.043	0.049
0	1	0	0	1	0.017	0.111

error estimates the suitability of developed models and the corresponding equation as is follows,

$$e_{ai} = \frac{V_E - V_P}{V_P} \quad \ldots (4)$$

Here *eai* is the average individual error and V_E is experimental values and V_P is predicted values. The percentage errors derived from both models has been calculated. For TKD, the average percentage error value equals to 7.01% while for BKD, the value is 3.17%.

4 Results and Discussion

In the laser machining process, cut quality is a function of TKD and BKD. Lower the value of these deviation would result in better cut quality, thus, for achieve better cut quality, an optimal range of cutting parameters should be decided. For which multi-objective genetic algorithm has been used. The bounds for the parameters selected is 160≤A≤200; 20≤B≤30; 30≤C≤50; 2≤D≤2.6; 8≤E≤10. Some measurable characteristic viz. population size of 250, double vector, population type, number of iterations equals to 600, cross over probability of size 0.8, and mutation probability 0.8 grouped into a set of optimization parameters. Single optimal solution is not possible to accomplish through optimization.

From the execution 50 optimal solutions has been generation. The aim of the present multi-objective optimization is to minimize the TKD and BKD. The obtained optimal parameters have been plotted in order to decide the range of optimal cutting parameters resulting in better quality cut with high dimensional precision and accuracy. Two sample contour plots for TKD and BKD have been shown in Figs 4(a-b). Similarly, the plots for other combinations have been generated.All these combination of contour plots have been merged to ascertain the optimal parameters for TKD and BKD as shown in Table 4 and 5, respectively.

The optimal range of cutting parameters for TKD and BKD as shown in Tables 4 and 5 have been combined together to obtained the optimal range. Table 6 shows the combined range.

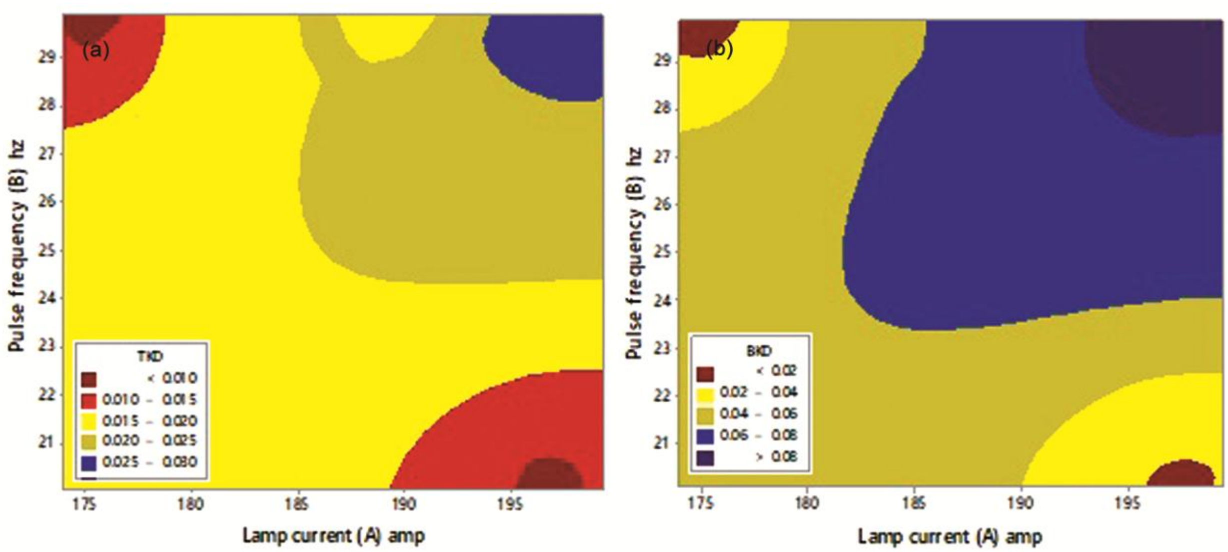

Fig. 4 — Stable cutting zone for (a)TKD and (b) BKD, when C, D and E are fixed

Table 4 — Optimal cutting parameters for TKD

	Parameters range					Optimal Range
	A (amp)	B (hz)	C (mm/min)	D (ms)	E (bar)	
A	-	174-195	174-190	174-190	174-184	174-184
B	20-30	-	20-30	20-30	20-29	20-29
C	38-48	38-48	-	38-48	38-47	38-47
D	2	2	2	-	2	2
E	9.25-10	9.25-10	9.25-10	9.25-9.90	-	9.25-9.90

Table 5 — Optimal cutting parameters for BKD

	Parameters range					Optimal Range
	A (amp)	B (Hz)	C (mm/min)	D (ms)	E (bar)	
A	-	174-182	174-184	174-184	174-182	174-182
B	20-30	-	20-25	20-22	20-24	20-22
C	38-48	38.-48	-	38.-48	38-42	38-42
D	2	2	2	-	2	2
E	9.25-10	9.25-10	9.25-10	9.25-9.50	-	9.25-9.50

Table 6 — Optimal cutting parameters for TKD and BKD

Parameters	units	Optimal range
A	ampere	174-182
B	hertz	20-22
C	mm/min	38-42
D	m/s	2
E	bar	9.25-9.50

Ideally, for the perfect cut, TKD and BKD should be zero but in the real case, it is not possible to achieve. However, it is expected if experiments are performed at this range of optimal parameters resulting TKD and BKD will be in the favorable range of 0-0.025 mm and 0-0.060 mm, respectively.

Conclusion

This study focusses on the fabrication of hybrid FRP and investigation of its mechanical properties.

1 The mechanical testing results revelas that the hybrid FRP offers mechanical characteristics better than the individual fibers.
2 Basalt fiber known for its high tensile strength but its use was restricted to certain applications due to its fewer flexural strength. Now, when hybrid composite of basalt-glass combination has flexural strength higher than basalt fibers
3 The obtained average percentage deviation for the cut qualities (TKD & BKD) is 7.01 % and 3.17 %, respectively. Which shows that the models are significant.
4 The results also shows that by setting the lamp current in the range of 174-182 amp, pulse frequency in the range of 20-22 Hz, cutting speed in the range of 38-42 mm/min, pulse width at 2 ms and air pressure in the range of 9.25-9.50 bar, minimum value of TKD and BKD can be obtained, simultaneously.

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