Educational Administration: Theory and Practice
2024, 30(1), 3122-3127
ISSN: 2148-2403
https://kuey.net/
Research Article

Investigations On Drilling Characteristics Of Glass-Bamboo Reinforced Hybrid Composites

Dr. Ketul Brahmbhatt[1*], Dr. Kundan Patel[2], Dr. Hitesh Bhargav[3],

[1*]Assistant Professor, Birla Vishvakarma Mahavidyalaya Engineering College, Vallabh Vidyanagar, Gujarat
[2]Assistant Professor, Charotar University of Science and Technology, CHARUSAT Campus, Gujarat
[3]Assistant Professor, Birla Vishvakarma Mahavidyalaya Engineering College, Vallabh Vidyanagar,Gujarat

Citation: Dr. Ketul Brahmbhatt et.al. (2024), Investigations On Drilling Characteristics Of Glass-Bamboo Reinforced Hybrid Composites *Educational Administration: Theory And Practice*, *30*(5), 3122-3127
Doi: 10.53555/kuey.v30i1.7035

ARTICLE INFO
Submitted: December 07 2023
Reviewed: December 20 2023
Accepted: January 03 2023
Published: January 22 2023

ABSTRACT
Polymer matrix composites possess better properties like great strength-to-weight ratio, stiffness-to-weight ratio, and noble corrosive resistance and consequently, are chosen for high-performance applications like in the aerospace, defense, and sport goods industries. Drilling is one of the vital methods for structure products with composite panels. By adjusting the cutting speed, feed rate, and tool geometry, this work aims to highlight the machining properties of the hybrid composites. The hand lay-up approach was used to create the hybrid composite specimens. Using MATLAB's image analysis technique, the damage caused by drilling is investigated. Regression analysis and ANOVA are used to analyze the data in order to reach the ideal condition. For drilling hybrid composites, it was found that the center drill, higher spindle speed (5500 rpm), and lower feed value (0.18 mm/rev) provide the least amount of delamination. For thrust force, it was discovered that the feed rate mattered more than the spindle speed and drill geometry.

Keywords: Hybrid composites, Design of Experiments, Delamination Factor, Image Analysis, ANOVA, Regression.

1. Introduction

Lightweight materials in structural design are a major source of worry for engineers and designers in the automotive industry. [1]. These goals can be met by hybridizing two different kinds of fiber-reinforced plastic (FRP) to create a composite with unique mechanical or physical characteristics, such carbon-glass hybrid FRP. In addition to having good corrosion resistance, high specific strength, and modulus, it may save a substantial amount of weight. But most importantly, it has a cheap material cost, which is difficult to achieve with the same metal alloys and fiber reinforcement composites [2]. Composite components are created almost entirely, but in order to meet the tolerance requirements for the last stages of product manufacture, secondary machining, such as drilling, is necessary. These involve drilling holes for bolts, rivets, and screws to assemble various composite parts. Because hybrid FRP composites are inhomogeneous, anisotropic, and highly abrasive, machining them is a crucial task. Therefore, the flaws that arise when drilling fiber-reinforced polymers (FRP) composites, like delamination, fiber pullout, matrix-cracking, and tool wear, differ from those that arise when drilling metals [3].

Numerous methods have been used to measure delamination like scanning electron microscope [4], C-Scan [5] and shop microscope [6, 7]. In general a measureable assessment is required in order to assess the effect of the cutting parameters and the geometry of drill tool [8, 9].

The drilling behavior of composites made of synthetic fibers has been extensively studied [10, 11], while natural fiber and hybrid fiber composites have received very little attention. The drilling behavior of hybrid epoxy composites made of glass fiber and bamboo is the main focus of this work.

2. Experimental Procedure

2.1 Material

The composite specimen was made from glass fiber and bamboo fiber using hand layup technique with polyester resin. Figure 1 shows bamboo yarn. Figure 2 shows glass fiber used for the reinforcement. Figure 3 shows the prepared composite specimen. The fiber weight fraction, tensile strength and flexural strength detail is shown in table I.

Figure 1 Bamboo yarn.

Figure 2 Glass fibers.

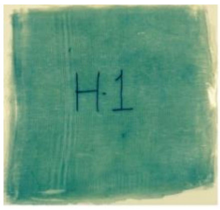

Figure 3 Hybrid Composite.

Table I Details of weight fraction, tensile strength and flexural strength.

Stacking sequence	**Weight of bamboo (gm)**	**Weight of Glass (gm)**	**Weight of Polyester (gm)**	**Tensile strength (MPa)**	**Flexural strength (MPa)**
GBGBGBGB	60	220	280	122	661

2.2 Machining

Using a 3-axis CNC machining center JYOTI PX10 with a customized configuration, the composite behavior during machining was investigated, and the impact of process parameters on the thrust force and delamination factor was assessed (Figure 1). The drilling that is being done in-process A piezoelectric dynamometer (KISTLER, 9272) equipped with a charge amplifier (Type 5070) was used to measure thrust forces. Figure 4: The experimental configuration. Using the LabVIEW software and a continuous data acquisition system (NI 9221 DAQ), signals were recorded on a desktop computer.

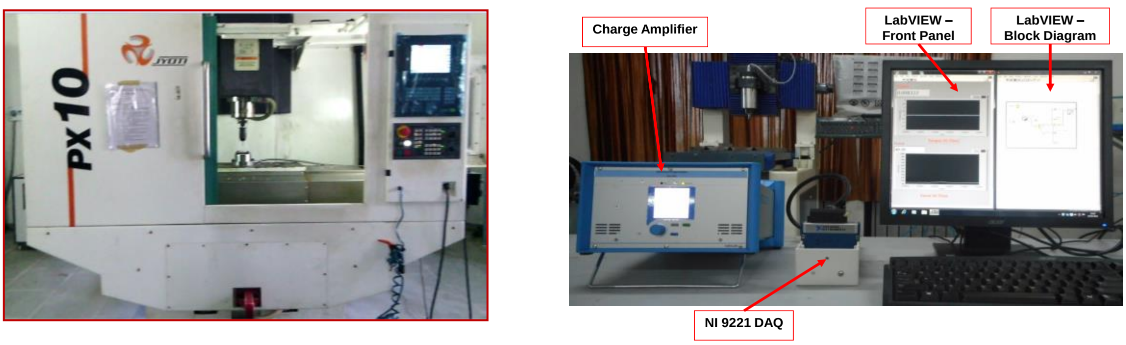

Figure 4 Experimental Set up.

2.3 Plan of Experiments

Using the setup described above, a full factorial test plan was followed to study three cutting speeds, three feed rates expressed as feed per revolution and three different drill geometries (Spur, Twist and center).
The traditional HSS drill tools used in this study are as indicated in figure 5. A drill diameter of 5 mm was kept in comparable with composite plate thickness. The parameters selected, the units and their levels are given in Table II.

Table II Process parameters and their levels

Parameters/Factors	**Symbol**	**Units**	**Levels**
Speed	s	(rpm)	2500, 4000, 5500
Feed	f	(mm/rev)	0.18, 0.25, 0.32
Drill Geometry	-	-	Spur, Twist, Centre

The values of responses for drilling of Hybrid PMCs workpieces as per full factorial design are summarized in table III.

Table III Results of experimental runs for drilling Hybrid PMCs

Sr No.	Speed (rpm)	Feed (mm/rev)	Drill Geometry	Thrust Force (N)	Delamination Factor
1	2500	0.18	Twist	143.849	1.07476
2	2500	0.18	Centre	105.379	1.05734
3	2500	0.18	Spur	197.493	1.07509
4	2500	0.25	Twist	154.003	1.08413
5	2500	0.25	Centre	115.640	1.07800
6	2500	0.25	Spur	275.325	1.08805
7	2500	0.32	Twist	159.577	1.09200
8	2500	0.32	Centre	127.532	1.07870
9	2500	0.32	Spur	290.628	1.10261
10	4000	0.18	Twist	106.902	1.06880
11	4000	0.18	Centre	86.905	1.04829
12	4000	0.18	Spur	257.124	1.07590
13	4000	0.25	Twist	133.111	1.08850
14	4000	0.25	Centre	95.588	1.05978
15	4000	0.25	Spur	274.524	1.07210
16	4000	0.32	Twist	139.794	1.09011
17	4000	0.32	Centre	107.689	1.07608
18	4000	0.32	Spur	242.475	1.07700
19	5500	0.18	Twist	99.320	1.06035
20	5500	0.18	Centre	71.166	1.04260
21	5500	0.18	Spur	205.848	1.05778
22	5500	0.25	Twist	121.954	1.06950
23	5500	0.25	Centre	85.689	1.05302
24	5500	0.25	Spur	213.479	1.06140
25	5500	0.32	Twist	128.894	1.08966
26	5500	0.32	Centre	86.637	1.06598
27	5500	0.32	Spur	299.545	1.08183

3. Results and Discussion

MINITAB software was used to statistically evaluate the main effects and the outcomes of the ANOVA. To measure the impact of process parameters on hybrid composite drilling, an ANOVA was run. The process parameters' significance rate is expressed as "% Contribution." The model's ability to accurately predict answers for new observations is indicated by the updated coefficient of determination (R2) values, which indicate the degree of variation in the response figures it represents [12].

The thrust force is considerably influenced by the speed, feed, and drill geometry, as indicated by the p-value found in Table IV's ANOVA results. The thrust force is dependent on drill geometry, speed, and feed by 92.91%, 4.31%, and 2.91%, respectively. Trust force's adjusted R2 value of 92.06% indicates that the model fits the data reasonably well.

Table IV ANOVA results for thrust force

Source	DF	Seq SS	Adj SS	Adj MS	F	P	% Contribution
S	2	3667	3667	1834	4.52	0.024	2.91
F	2	5421	5421	2711	6.68	0.006	4.31
Drill Geometry	2	115720	115720	57860	142.52	0	92.11

Error	20	8119	8119	406			
Total	26	132928		62811			
S = 20.1488		R-Sq = 93.89%		R-Sq(adj) = 92.06%			

The main impact graphs (figure 6) show that there is a direct relationship between the feed and the TF. It was also noted that the lowest thrust force is produced by a center drill bit and a higher spindle speed. The delamination factor is significantly impacted by the spindle speeds, feed, and drill geometry, as indicated by the p-value from the ANOVA findings displayed in Table V. The delamination factor is impacted by the spindle speed, feed, and drill geometry by 24.73%, 41.78%, and 32.17%, respectively. The torque adjusted R2 value of 84.90% indicates that the model fits the data satisfactorily.

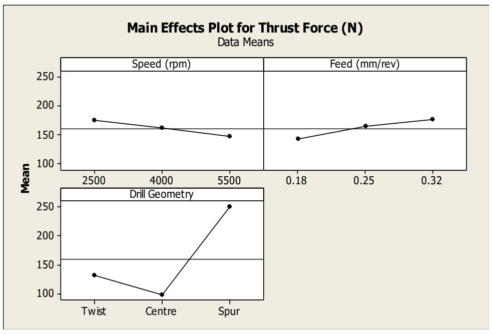

Figure 6 Main effect plots for thrust force.

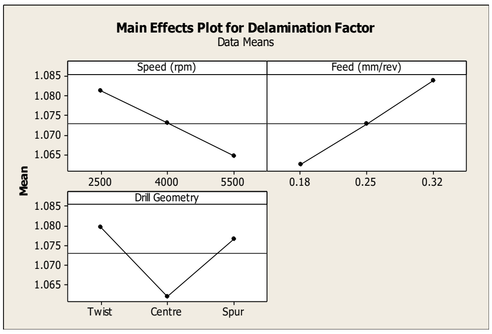

Figure 7 Main effect plots for Delamination factor.

Table V ANOVA results for delamination factor

Source	**DF**	**Seq SS**	**Adj SS**	**Adj MS**	**F**	**P**	**% Contribution**
s	2	0.00123	0.00123	0.00061	19.06	0	24.73
f	2	0.00207	0.00207	0.00104	32.21	0	41.78
Drill Geometry	2	0.0016	0.0016	0.0008	24.8	0	32.17
Error	20	0.00064	0.00064	3.2E-05			
Total	26	0.00554		0.00248			
S = 0.00567066		R-Sq = 88.38%		R-Sq(adj) = 84.90%			

In figure 7, the primary effects plot is displayed. It demonstrates that feed and delamination factor are directly correlated. It was also noted that the lowest delamination factor is correlated with increased spindle speed and a center drill bit.

Regression analysis uses a function to represent observational data that have been fitted using a series of consecutive approximations. The goal was to use general regression to create mathematical representations of the thrust force and delamination factor that would closely match the actual data. Using MINITAB software, multivariable regression analysis was used to determine the relationships between the drilling process parameters and the machining characteristics (responses). The following are the empirical models that were produced using multiple regression analysis (MRA) to predict the delamination factor and thrust force in N:

Twist $TF = 108.725 - 0.00951465s + 245.068f$ **Center** $TF = 74.8167 - 0.00951465s + 245.068f$ **Spur** $TF = 227.507 - 0.00951465s + 245.068f$	$R^2 = 93.80\%$ S = 19.3583
Twist $DF = 1.06346 - 5.50222e - 6\ s + 0.153222f$ ***Center*** $DF = 1.0459 - 5.50222e - 6\ s + 0.153222f$ ***Spur*** $DF = 1.06057 - 5.50222e - 6\ s + 0.153222f$	$R^2 = 88.37\%$ S = 0.00540950

ANOVA was used to test the model's adequacy at a 95% confidence level. The suggested process parameters and machinability parameters exhibit a strong correlation between their expected and experimental values, as demonstrated by the R2 value of the mathematical models. Figure 8 presents a comparison between the experimental and anticipated values, demonstrating the strong correlation between the two.

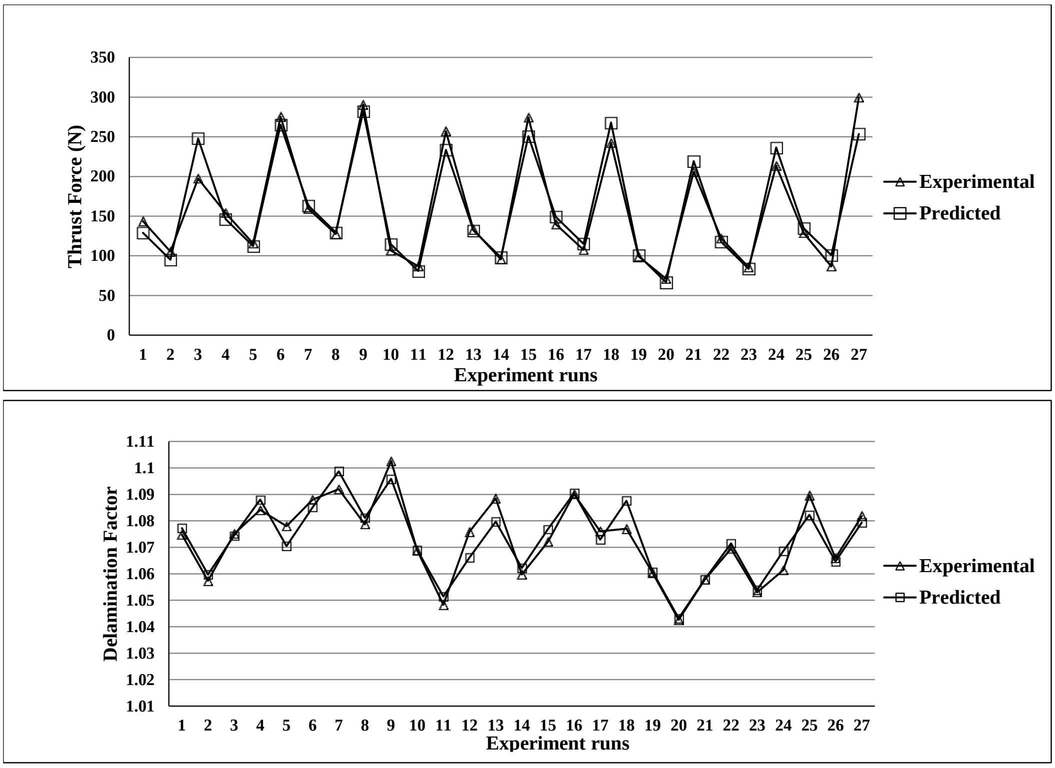

Figure 8 Comparison of predicted values and experimental values of thrust force and delamination factor.

4. Conclusions

The following are the main findings from research on glass-bamboo reinforced hybrid composites that were drilled:

- The primary factor that determines the TF is the drill geometry. Drilling Glass-Bamboo hybrid composites requires a central drill and a high spindle speed (5500 rpm) in order to minimize TF lower feed (0.18 mm/rev).
- Feed exerts a stronger effect on the delamination factor. Reduced feed (0.18 mm/rev), a central drill, and a high spindle speed (5500 rpm) are crucial for drilling Glass-Bamboo hybrid composites to get the lowest possible DF.
- Within the precincts, the empirical models derived from multiple regression analysis results are remarkably accurate in predicting the factors under investigation. These models can result in a noticeable reduction of time and costs.

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