

ANALYSIS OF DELAMINATION IN DRILLING OF BASALT FIBER REINFORCED POLYMER COMPOSITES

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Abstract. Fiber reinforced polymer composites are used in many engineering applications because of their low strength to weight ratio. Delamination is one of the major problems in manufacturing of the polymer composites. In this work, the delamination of acid treated basalt fiber reinforced composites was studied through drilling operation. Basalt fiber reinforced composites is prepared by using hand layup techniques with unsaturated polyester. Taguchi design of experiment was used to investigate the effects of drilling parameters such as spindle speed [2500, 2750, 3000 rpm], feed rate (0.2, 0.4, 0.6 mm/rev) and point angle (90°, 118°, 135°). A series of experiments based on L₉ orthogonal arrays are conducted using CNC machine and resulting delamination factor was determined. It was observed that speed and point angles are highly influencing parameters than feed rate for the delamination of the basalt fiber reinforced polymer composites.

1. Introduction

Usage of fiber reinforced polymer composites in automobiles, aerospace, sport goods play a major role. Basalt fibre is a material made from volcanic ingenious rock. Basalt fiber reinforced polymer composites nowadays replaces the application of the glass fiber. According to Manikandan et al. [1], it is found that acid treated basalt fiber composites showed better mechanical properties than combinations like untreated; base treated and acid treated glass fiber composites. Carbon fiber reinforced plastic (CFRP) composite has been manufactured through hand layup techniques and analyze the delamination in drilling of CFRP composites. Response surface methodology results indicated that the model can be effectively used to predict the delamination [2]. Erol [3] investigated on the influence of drilling parameters, such as cutting speed, feed, and point angle on delamination produced when drilling glass fiber reinforced plastics (GFRP) composite. The experiments are conducted based on Box–Behnken design. Empirical models are developed to correlate and predict the drilling parameters and delamination factor in drilling of GFRP. The developed models for delamination factor at entrance and exit are proposed that agree well with the experiment [4]. A fuzzy rule based model is developed to predict the delamination in drilling of GFRP composites by Latha and Senthilkumar. The drilling was carried out based on L₉ orthogonal array of GFRP composite specimens using carbide drill bits [5]. Basavarajappa et al. made an attempt to investigate that the effect of spindle speed and feed on machinability aspects likes thrust force, hole surface roughness, and specific cutting coefficient during drilling of glass epoxy composites. The response surface methodology based mathematical models were developed for analyzing the effects of cutting conditions on machinability characteristics [6]. Cutting force influenced the quality of the holes generated on the carbon fiber reinforced polymer composites that was studied Guo et al. [7] the model for the

prediction of the thrust force and torque generated in the drilling of composite materials using a twist drill. The cutting forces predicted by this model are in satisfactory agreement with experimental results and thus it is concluded that the proposed model can be used to optimize the cutting parameters and tool geometries in the drilling of composites [8]. Ozden and Elaheh [9] studied the growth of delamination of carbon fiber composites during drilling operation. The developed model with inclusion of the improved delamination model and real drill geometry is used to make comparison between the step drill of different stage ratio and twist drill. The model indicates that delamination and other workpiece defects can be controlled by selection of suitable step drill geometry. Delamination studies of drilled glass fiber reinforced polymer composites has been studied by Rajamurugan et al. [10] and developed the empirical relationships between the drilling parameters such as fiber orientation angle, tool feed rate, rotational speed and tool diameter with respect to delamination in drilling. It was revealed that the increase in feed rate and drill diameter increases the delamination size whereas there is no clear effect is observed for fiber orientation angle. Juan et al. [11] investigated the use of Taguchi's method in order to identify the best drilling setup of glass reinforced polyamide composites. The effect of tool geometry, spindle speed and feed rate factors on the thrust force, hole mean diameter and circularity error were analyzed. Influence of the process parameters on drilling operation of polymer composites studied by various researchers on the effect of process parameters on thrust force, torque, and tool wear in drilling of coir fiber reinforced composites. The optimal settings of the parameters were determined through experiments planned, conducted, and analyzed using the Box–Behnken design, Nelder – Mead, and genetic algorithm methods [12- 16].

This paper focus to optimize the drilling parameters of the basalt fiber reinforced polymer composites in delamination. Drilling parameters are optimized for improving the quality of the drilled hole.

2. Experimental description

2.1. Materials. Basalt fibre (Plain weave) was imported from by ASA.TECH, Austria and Unsaturated polyester resin, methyl ethyl ketone peroxide (MEKP) and co-naphthenate were purchased from GVR traders, Madurai, India. Sulphuric acid were purchased from the United Scientific Company, Madurai, India.

2.2. Treatment of fibres. The basalt woven fabrics were cut into an approximate size of 350 x 350 mm. The fiber was treated by soaking in solutions with 1N H₂SO₄ for 24 hours at room temperature. After this, the fibres were washed with distilled water to remove the H₂SO₄ from the surface of the fibres. Finally, the fibres were dried at room temperature for about 24 hours before the composites were prepared.

2.3. Fabrication of composites. Basalt fibre reinforced polymer matrix composites were fabricated using the hand layup method, and unsaturated polyester resin was used for the matrix. For a proper chemical reaction, cobalt naphthenate and methyl ethyl ketone peroxide were used as an accelerator and a catalyst, respectively. Twelve layers of basalt fibre mats were cut into size of 350 X 350 mm. These were weighed to determine the corresponding 1:1 amount of unsaturated polyester resin. The polyester resin was cured by incorporating one volume per cent of the methyl ethyl ketone peroxide (MEKP) catalyst. One volume per cent cobalt naphthenate (accelerator) was also added. A stirrer was used to homogenise the mixture. Then, the resin mixture was used to fabricate four layers of basalt fibres with the hand layup technique using a roller. The samples were cured for approximately 24 hours at room temperature. The fabricated composite specimen is presented in Fig. 1 and the mechanical property of the composites is presented in the Table 1.

2.4. Drilling of composites. Computer Numeric Control drilling machine is used for drilling. The carbide coated drill is fixed to the drill bit holder. Three carbide coated drill Bits

each with a diameter of 8 mm, but with different point angles such as 90°, 118°, 135° were purchased from S.S. Solutions Pvt Ltd, Chennai. The drill tool is shown in Fig. 2.



Fig. 1. Fabrication of composites.

Table 1. Properties of the composites.

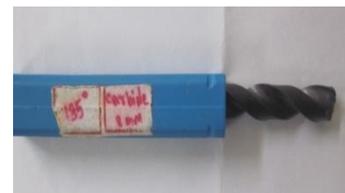
Tensile strength	246 MPa
Flexural strength	128.65 MPa
Impact strength	2.855 J/mm



a)



b)



c)

Fig. 2. Drill bits with angles a) 90°, b) 118°, and c) 135°.

2.5. Analysis of delamination. The typical drilled composite is presented in Fig. 3 and the measurement of data is shown in Fig. 4. The delamination of the drilled holes is measured by the optical microscope.

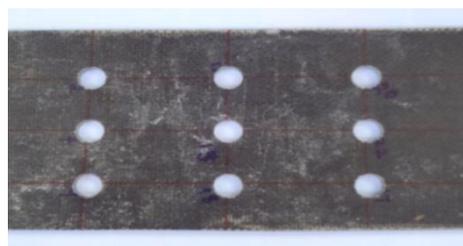


Fig. 3. Holes being laid over the finished sample.

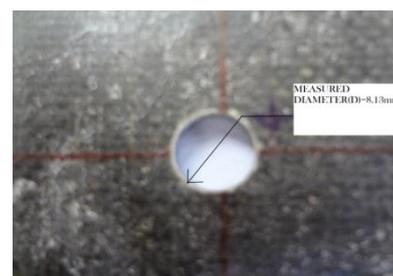
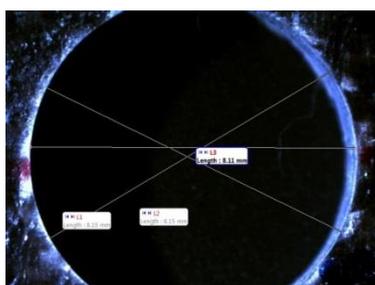


Fig. 4. Measured diameter of a drilled hole.

2.6. Optimization of drilling parameter using Taguchi method. The two major tools used in Taguchi's method are the orthogonal array (OA) and the signal to noise ratio (S/N ratio). OA is a matrix of numbers arranged in rows and columns. Each row represents the level of factors in each row and each column represents a specific level for a factor that can be changed for each row (Table 2). S/N ratio is indicative of quality and the purpose of the Taguchi experiment is to find the best level for each operating parameter so as to maximize S/N ratio.

Table 2. Drilling optimization parameters.

S. No	Speed, rpm	Feed rate, mm/rev	Drill bit angle, °
1	2500	0.2	90
2	2750	0.4	118
3	3000	0.6	135

In the Taguchi method, the term signal represents the desirable value (mean) for the output characteristic and the term noise represents the undesirable value (deviation, SD) for the output characteristic. Therefore the S/N ratio is the ratio of the mean to the SD. Taguchi uses the S/N ratio to measure the quality characteristic deviating from the desired value. There are several S/N ratios available, depending on the type of the characteristic; lower the better, nominal is best and higher the better. The lower the better characteristic Eq. (1) is used for determination of delamination factor, and to achieve better hole quality.

$$S/N = -10 \log \sum_{i=1}^m 1/n [y_{ij}^2], \quad (1)$$

i =experiment number; y_{ij} =output response for i^{th} experiment for j^{th} response; n = number of replications.

The Analysis of Variance (ANOVA) technique is used to predict the relative significance of the process factors and estimate the experimental errors. It gives the percentage contribution for each factor and proves the better for the relative effect of the different factor on experimental responses.

3. Result and discussion

Delamination factor is calculated as measured diameter (D)/actual diameter (d). Delamination factor = $8.136/8 = 1.0170$ mm.

In machining operation, minimizing the delamination factor is an important criterion. The delamination factor in drilling primarily depends upon the tool geometry, cutting speed, and workpiece material. When the material tends to elongate to some extent during delamination factor. However if the material is quite brittle, catastrophic factors occurs as the feed rate and cutting speed increases resulting in regular delamination.

A series of drilling test was conducted to assess the influence of drilling parameters on delamination factor in drilling Basalt fibre. The S/N ratios for each experiment of L9 were also calculated by applying an equation (Table 3). The objective of using the S/N ratio as a performance measurement is to develop products and process insensitive to noise factor.

From the Figure 5 it shows when increased the speed, the delamination was reduced and it was found that the delamination of composites minimized at the feed rate of 0.2 mm/rev. When increasing the drill bit angle to 135 ° the delamination of the composites is reduced. According to S/N ratio plot the delamination of composites was optimized. The optimized paramters are speed (3000 rpm), feed rate (0.2 mm/rev) and drill bit angle (135 deg) (Fig. 6 and Fig. 7). At higher speed lower feed rate shows the less delamination (Table 4).

Table 3. Drilling parameters with response.

S. No	Speed, rpm	Feed rate, mm/rev	Drill bit angle, °	Delamination factor, mm	S/N ratio
1	2500	0.2	90	1.017	-0.14641
2	2500	0.4	118	1.0143	-0.12332
3	2500	0.6	135	1.0152	-0.13103
4	2750	0.2	118	1.0168	-0.14471
5	2750	0.4	135	1.0175	-0.15068
6	2750	0.6	90	1.017	-0.14641
7	3000	0.2	135	1.0112	-0.09674
8	3000	0.4	90	1.0158	-0.13616
9	3000	0.6	118	1.0154	-0.13274

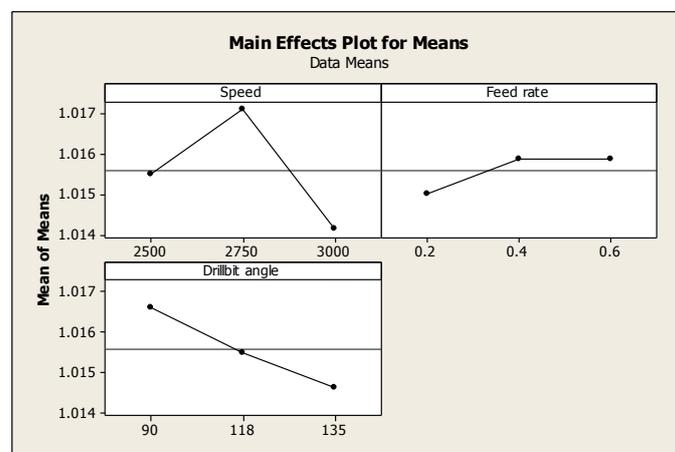


Fig. 5. Main effects plot for means.

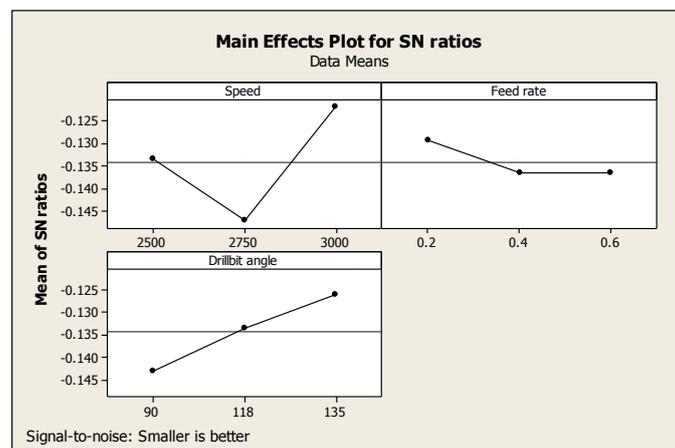


Fig. 6. Main effects plot for S/N ratios.

Table 4. Response table.

Factors / Avg. at factor level	Speed	Feed rate	Drill bit angle	Error
L1	-0.1279	-0.1236	-0.1370	-0.13673
L2	-0.1473	-0.1364	-0.1222	-0.12216
L3	-0.1207	-0.1359	-0.1370	-0.13702
Max - Min	0.0265	0.0129	0.0149	-0.01457

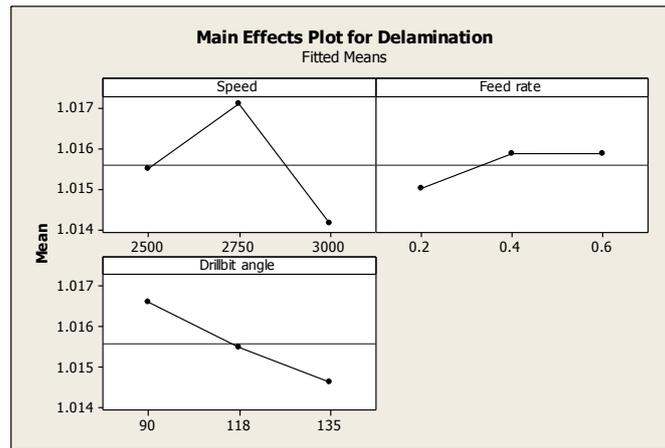


Fig. 7. Main effects plot for delamination.

From the ANOVA Table 5 indicated that the drilling speed and drill bit angle are the significantly influencing parameters for the drilling of basalt fiber composites. At lowest feed rate and highest speed the composite shows the lowest delamination. When increasing the spindle speed which reduces the delamination and with increasing of feed rate, the delamination also increased [17]. The contribution for the error value places significant parameters. The error value may be due to orientation of the fiber and depth of cut.

Table 5. Scheme for ANOVA.

	DOF	Sum of sq.	Mean sq.	Contribution	Contribution, %
Speed	2	0.0011306	0.00056528	0.487072745	48.71
Feed rate	2	0.0003164	0.00015820	0.136309886	13.63
Angle	2	0.0004413	0.00022064	0.190114158	19.01
Error	2	0.0004329	0.00021645	0.186503211	18.65
Total	8	0.0023211			

4. Effect of process parameters on the delamination

The effect of feed rate on the delamination with respect to different speeds is shown in Fig. 8. At higher speed and lower feed rate, the delamination of the composite was decreased. At spindle speed of 2500 and 2750 rpm the delamination was observed higher. The spindle speed was most dominating factor for the delamination of the composites which is presented in the ANOVA Table 5 [18, 19].

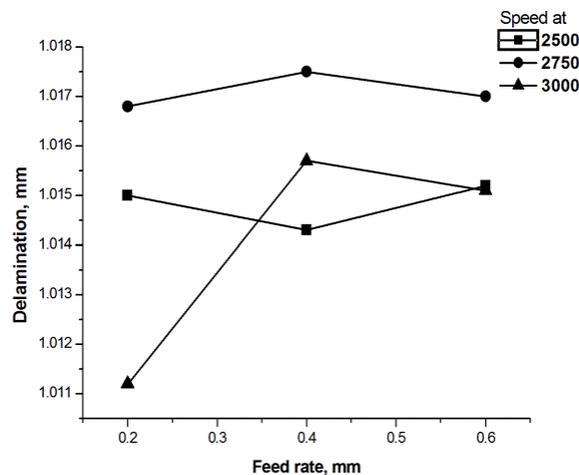


Fig. 8. Effect of feed rate on delamination with different speed.

From Fig. 9 it was observed that at lower feed rate and higher drill bit angle has lowest delamination of the composites. Caprino and Tagliaferri [21] stated that damage induced in the composite during drilling operation was strongly depends on the feed rate. At higher feed rate the failure mode shows the impact damages like delamination [20].

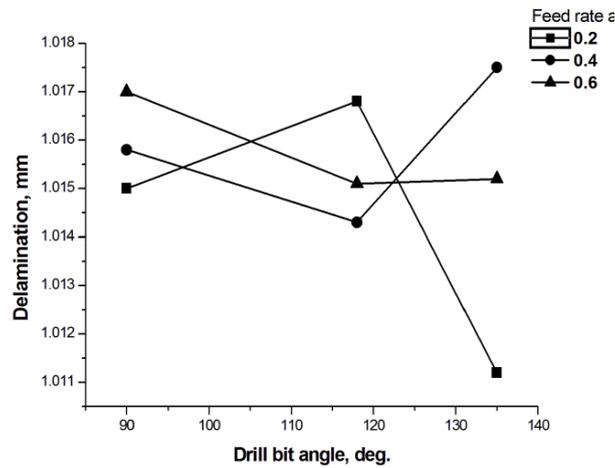


Fig. 9. Effect of Drill bit angle on delamination with different feed rate.

The delamination is significantly affected by the drill bit angle shown in Fig. 10. The point angle increases the delamination of the composites also increased for increasing of the spindle speed. At higher drill bit angle 135 degree and 3000 rpm, the delamination of the composites was observed higher.

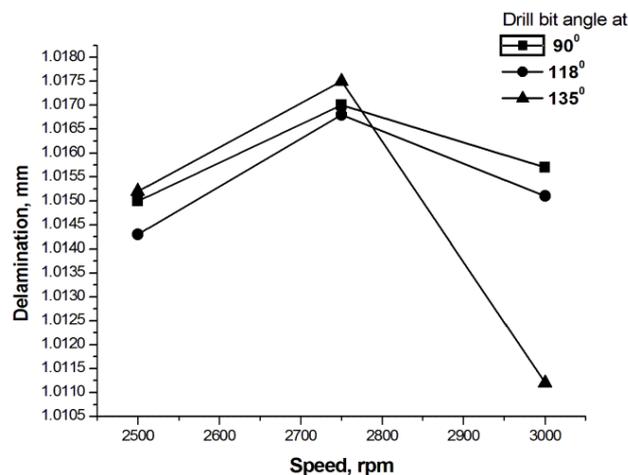


Fig. 10. Effect of speed on delamination with different drill bit angle.

5. Conclusion

The polymer composite with basalt fiber is prepared successfully by hand layup technique and the following conclusion can be drawn:

1. The Taguchi method successfully verified the optimum drilling parameters on the delamination of the composite using ANOVA.

2. The results of ANOVA revealed that speed was most significant drilling parameter which has greater influence on the delamination factors. The optimum parameter were cutting speed (3000 rpm), feed rate (0.2 mm/rev) and drill bit angle (135°). For achieving minimal delamination factor in the Basalt fiber always higher cutting speed, and higher drill bit angle to be preferred.

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