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A Study on Drilling Behavior of Banana-Glass Fibre Reinforced Epoxy Composite

KEYWORDS: Hybrid composite, Drilling, Banana fibre, Glass fibre, Delamination, Machine Vision, ANOVA

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ABSTRACT *Composite materials are used in many engineering applications due to their superior properties. Hybrid fibre composites are developed to provide the advantage of both natural fibre and synthetic fibre. Drilling is an inevitable task for component assembly. Studies on drilling performance of Banana-Glass fibre hybrid composite is reported in this article. Banana-Glass fibre reinforced Epoxy composites were prepared by using hand layup method. Drilling experiments were conducted on chopped fibre and laminated woven fibre composites using standard twist drill. Experiments were conducted by varying the feed rate and speed. The Effect of fibre volume fraction in chopped fibre and stacking sequence in woven fibre composite on the drilled hole quality was found. Optimum drilling parameters were determined for selected samples each from chopped fibre and woven fibre composite. Machine vision technology was used to measure quality of the drilled Hole. ANOVA technique was used to analyse the experimental data and it was found that the feed rate has major influence than drilling speed on the hole quality.*

INTRODUCTION

In many engineering applications composite materials are widely used because of their high strength to weight ratio, low thermal expansion and high performance. Properties of composite materials can be tailored according to the necessacity of application. Synthetic materials like glass fibre and carbon fibre are widely used in composites due to their high strength[1]. However, in recent years the search for natural fibres as a suitable replacement for synthetic fibre was necessitated due to environmental concerns. Studies have shown that natural fibres like coconut, bamboo, sisal, jute and banana fibre can be used as reinforcement for polymer composite[2-4]. Natural fibres are lighter and cheaper, but their mechanical properties are inferior to synthetic fibres. The use of hybrid fibre composites can solve this problem. Research is being carried out in the development of hybrid fibre composites. Hybridization of natural fibre with synthetic fibre drastically improves the properties like tensile strength, flexural strength, moisture absorption rate and toughness. Studies have shown that hybridization of sisal fibre with glass fibre improved the mechanical properties[5,6]. Mishra[7] *et al.* improved the mechanical properties of bio-fibres by mixing them with glass fibre. The work done by Uma devi[8] *et al.* have shown that water absorption of palf fibre composite is reduced by adding glass fibre. Since India is one of the largest producer of banana cultivation. The extraction of banana fibre and studies on banana fiber composites can lead to better utilization of agricultural products. Venkateshwaran[9] *et al.* reported prospective applications of banana fiber for automotive industries and other engineering applications.

Drilling is the most common machining process during the assembly of fibre reinforced plastic (FRP) composites. Drilling of metallic materials is different from composites. Metals are homogeneous and isotropic in nature. Hence, the drilling behaviour will be same throughout the drilling operation. But, composites are heterogeneous and anisotropic in nature. The drilling tool has to cut through the soft polymer matrix and cut the hard reinforcing fibres during the drilling operation. This leads to defects like delamination and fibre pull out in drilled holes. Studies on drilling behaviour of composites were widely reported by several researchers. Wong TL[10] *et al.* reported that 60% of rejections of FRP composites in aircraft industry happen due to delamination defects in drilled holes. To increase the quality of drilled holes and to minimize the damages and rejection, it is imperative to characterize the drilling behavior of composites by conducting number of drilling experiments. The type of drill tool geometry on the effect of delamination and other defects was reported widely. Delamination in layered composite is initiated by two mechanisms as shown in figure 1. The delamination at the entry of the tool is known as peel up delamination, this is due to the upward force on the top layer at the entry of the tool. Push out delamination is caused, when the thrust force acting on the bottom layer exceeds the bonding strength between the matrix and fibre layer. In this case, the bottom layer de-bonds from the adjacent layer due to the thrust force.

Tsao[11,12] *et al.* reported the effect of drill geometry, feed rate and speed on the thrust force and torque developed during drilling operation. K.palanikumar[13] optimized the drilling speed and feed rate by considering drilling parameters such as delamination, surface roughness and thrust force. Velayudham[14] *et al.* evaluated the optimum drilling parameters for high volume glass fibre composites. T.V.Rajamurugan[15] *et al* studied the effect of drill diameter and feed rate on the delamination of Glass fibre reinforced composites. Venkateswaran[16] *et al* studied the drilling performance of banana sisal hybrid composites. He used the machine vision technology to study the delamination of the drilled holes. Abilash[17] *et al.* optimized the feed rate and cutting speed for bamboo reinforced polyester composites. Veerapuram sreedharan[18] *et al.* studied the effect of alkali treatment on the drilling behaviour of jute reinforced polyester composites. He reported that the alkali treatment had lesser effect on drilling quality of the jute / polyester composite. JP Davim[19] *et al* used digital analysis method successfully to analyze the delamination of FRP composites. While most of the studies are concentrated on

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delamination woven fibre composites, very less has been reported on chopped random oriented fibre composites. Even though delamination in chopped fibre is very less reported, the hole quality must be analysed due to two different phases present in the composite. Fibre pull out from the matrix during cutting operation by drill tool can result in excessive roughness on the side walls which affects the hole quality. Circularity is another factor affecting the hole quality.

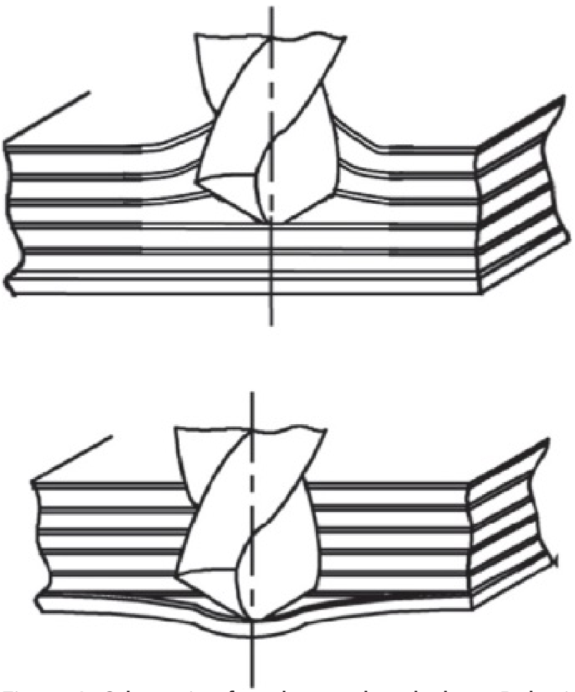

Figure 1: Schematic of peel up and push down Delamination in composites

It was observed from the literature that extensive research has been reported on the drilling behaviour of synthetic fibre composites[20,21], but very less was reported on natural fibre and hybrid fibre composites. This paper concentrates on the drilling behavior of banana/glass fibre hybrid epoxy composites. Experiments were conducted on chopped fibre composites with different fibre volume fraction and woven fibre composite with different stacking sequence.

MATERIALS AND METHODS

Banana fibre was obtained from ROPE international Ltd. Chennai, India. It has a tensile strength of around 600Mpa, tensile modulus of 17.85GPa and density of 1.35gm/cm^3. Banana fibre contents are cellulose - 65.3%, Lignin-5%and extractive-19%. It has better mechanical strength than many other natural fibres[9]. Proper extraction and processing methods ensure the removal of moisture from the fibre. E-Glass fibre was obtained from Sakthi fibres, Chennai, India. It has a tensile strength of 2400Mpa and density of 2.55 gm/cm^3. The glass fibre was mixed with banana fibre at equal ratio. Epoxy resin was used as matrix to prepare the composite specimens. Composites were prepared using hand layup method. Two sets of specimens were prepared for the study. One set of specimen having different volume proportion of chopped, random oriented fibre was fabricated. The fibre volume content was varied as 5%, 10%, 15% and 20%. Another set of composites were prepared with woven fibre, with three different stacking arrangements.

Initially the fibres were cut to a length of 15mm each and they were mixed at equal volume proportion. A mould of 300mm x 300mm x 6mm was used to prepare the specimens. Initially the chopped fibres were mixed in the epoxy resin then the mixture was poured into the mould. Care was taken to avoid the formation of void and pressure was applied on top of the mould. The specimens were removed from the mould after 48Hrs. Similarly woven fibre composite specimens were prepared by changing the stacking sequence. The details of fibre volume fraction in chopped fibre composite and stacking sequence of woven fibre composite are given in table I. Figure 2 shows the sample composite specimens.

Table I
Details of composite samples.

Type of composite	Sample ID	Fibre volume fraction / stacking sequence
Chopped fibre composite	A	5% (Banana + Glass)
	B	10% (Banana + Glass)
	C	15% (Banana + Glass)
	D	20% (Banana + Glass)
Woven fibre composite	WO-A	G-B-G-B (4 Layers)
	WO-B	G-B-B-G (4 Layers)
	WO-C	B-G-G-B (4 Layers)

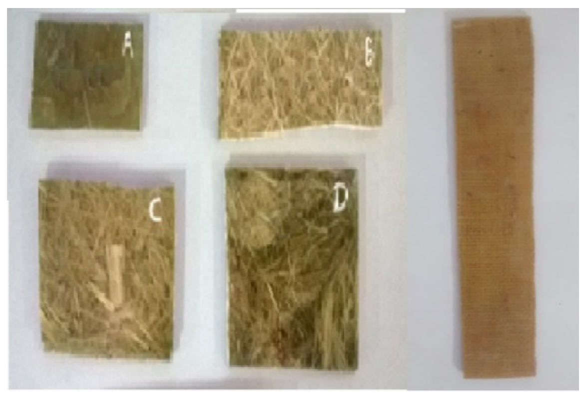

Figure 2: Composite specimens with chopped fibre and woven fibre compositions

Experimental

MTAB-DENFORD CNC machine was used for drilling the composites specimens. A standard twist drill of 8mm dia is used for drilling the holes. The speed was varied as 700 rpm, 1400rpm and 2100 rpm. Since 8mm diameter tool was used in the drilling operation the cutting speed (peripheral) was kept in between 20m/min up to 60m/min. Most of the conventional machines operate in this range of cutting speed. Also if higher cutting speed is used, the matrix material which is soft may get softened due to the heat generated. The feed rate was also widely reported as less than 0.3mm/rev. Hence the feed rate was varied as 0.05mm/rev, 0.12mm/rev and 0.20mm/rev in this experiment. The tool material used in this experiment was single point HSS twist drill.

Delamination factor was used to assess the quality of the drilled holes. The hole quality for chopped fibre composites are measured by the machine vision technology. The machine vision facility available at Rajalakshmi Engineering College-TIFAC-CORE, Chennai was used. The machined samples are shown in Figure 3. The delamination of woven fibre composites were measured scanning the samples through the flat-bed scanner. This method was success-

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fully reported by Kashaba[22] *et al* and Mohan[23] N S *et al*. In this method the drilled samples were placed in the flatbed scanner with a resolution of 4800 dpi then the image was processed for the pixel density to obtain the delaminated zone. Study of hole quality by machine vision technology is given in figure 4. The digital image processing is performed by Labview software. A sample image is given in figure 5.

The ratio between the nominal diameter (D) of the hole to the largest diameter (D_{max}) of the delamination zone will give delamination factor (F_d).

$$F_d = (D_{max}/D) \quad \text{--------------------------------} \quad (1)$$

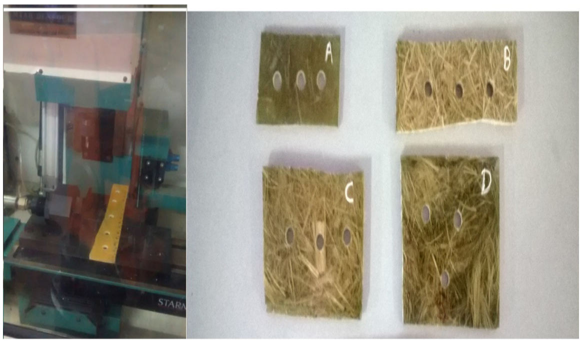

Figure 3: Composite samples with drilled holes.

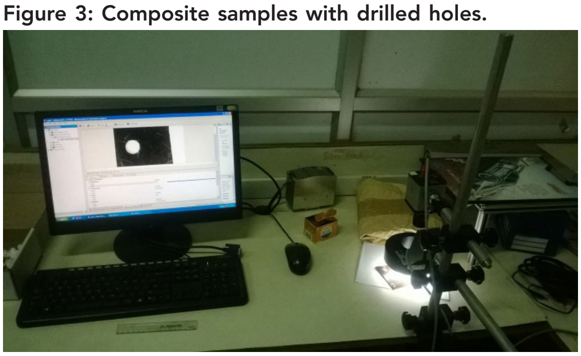

Figure 4: Machine Vision setup

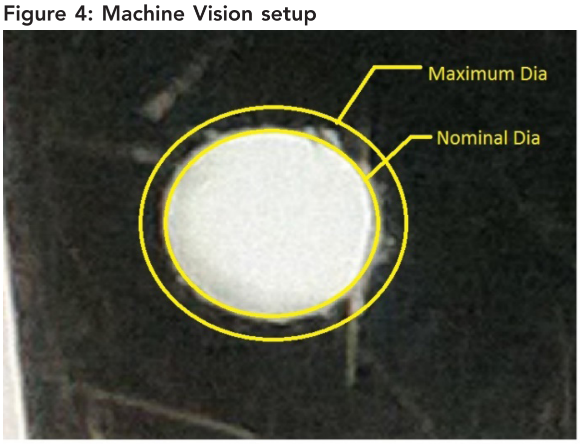

Figure 5: Digital Image processing of the hole.

RESULTS AND DISCUSSION

Initially the chopped fibre composites with 5%, 10%, 15% and 20% volume fraction were drilled with an intermediate value of speed and feed rate. i.e at 1400rpm and 0.12mm/rev respectively. From this, the composite sample with better hole quality was chosen for further study by varying the drill speed and feed rate. Thus the numbers of repeated experiments were minimized for all the samples. After initial drilling it was observed that the samples exhibited a decrease in hole quality with increase in fibre content. The values of delamination factor for random, chopped fibre composite samples are given in Table 2. From the results it was observed that the hole quality is adversely affected by the fibre volume fraction in random, chopped fibre composites. Even though the value of delamination factor marginally increases with the fibre volume fraction, the effect can be neglected as the deviation is smaller. The difference of the delamination factor between 5%-vol fraction and 20%-vol fraction composites is less than 5%. Since the difference between the values is small, the sample with 20% volume fraction was considered to get optimum drilling speed and feed rate. Also it was found from the literature that the hybrid composite with 20%-vol fraction has better mechanical properties[24]. Hence selection of sample D for further study will be appropriate.

The delamination factor for various values of speed and feed for sample D is tabulated in table 3. The inspection of chopped random fibre composites clearly exhibited that the quality of hole was mainly affected by fibre pullout from the matrix and matrix deformation due to voids. Delamination like defect was not observed from the random chopped fibre composites.

Table 2
Delamination for samples with different volume fraction

Sample ID	Speed	Feed rate	Delamination factor	
			Peel up	Push out
A	1400	0.12	1.28	1.28
B	1400	0.12	1.30	1.29
C	1400	0.12	1.29	1.30
D	1400	0.12	1.31	1.33

In the case of woven fibre composites it was observed that the stacking of fibre layer drastically affected the hole quality. The value of delamination factor at the entry and exit of the tool were tabulated in table 4, 5 and 6 respectively for WO-A, WO-B and WO-C specimens. All the specimens exhibited an increasing delamination factor with an increase in feed rate. But it was observed that the specimens with glass fibre at the top layer had smaller values of entry delamination compared with banana fibre at the top layer. This could be due to the fact that it is hard to peelup the glass layer.

Table 3
Delamination for samples with 20% volume fraction (chopped fibre)

Sample ID	Speed	Feed rate	Delamination factor	
			Entry	Exit
D	700	0.05	1.11	1.21
D	700	0.12	1.28	1.39
D	700	0.20	1.44	1.61
D	1400	0.05	1.10	1.18
D	1400	0.12	1.31	1.33
D	1400	0.20	1.42	1.51
D	2100	0.05	1.09	1.17

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D	2100	0.12	1.22	1.29
D	2100	0.20	1.43	1.49

Table 4
Delamination of woven fibre composite (GBGB)

Sample ID	Speed	Feed rate	Delamination factor	
			Entry	Exit
WO-A	700	0.05	1.11	1.26
WO-A	700	0.12	1.24	1.42
WO-A	700	0.20	1.39	1.57
WO-A	1400	0.05	1.07	1.24
WO-A	1400	0.12	1.26	1.41
WO-A	1400	0.20	1.38	1.51
WO-A	2100	0.05	1.09	1.22
WO-A	2100	0.12	1.29	1.38
WO-A	2100	0.20	1.37	1.48

Table 5
Delamination of woven fibre Composite (GBBG)

Sample ID	Speed	Feed rate	Delamination factor	
			Entry	Exit
WO-B	700	0.05	1.10	1.32
WO-B	700	0.12	1.24	1.45
WO-B	700	0.20	1.39	1.68
WO-B	1400	0.05	1.06	1.29
WO-B	1400	0.12	1.28	1.44
WO-B	1400	0.20	1.31	1.59
WO-B	2100	0.05	1.09	1.29
WO-B	2100	0.12	1.26	1.44
WO-B	2100	0.20	1.44	1.49

Table 6.
Delamination of woven fibre composite (BGGB)

Sample ID	Speed	Feed rate	Delamination factor	
			Entry	Exit
WO-C	700	0.05	1.12	1.29
WO-C	700	0.12	1.25	1.41
WO-C	700	0.20	1.41	1.59
WO-C	1400	0.05	1.08	1.23
WO-C	1400	0.12	1.29	1.41
WO-C	1400	0.20	1.33	1.49
WO-C	2100	0.05	1.11	1.21
WO-C	2100	0.12	1.29	1.37
WO-C	2100	0.20	1.45	1.44

It was also noticed that, the specimens with glass layer at the bottom exhibited larger delamination factor than banana fibre as the bottom layer. It was due to the thrust force acting on the banana layer could easily cut through without damaging the epoxy matrix. Whereas, the tensile strength of glass fibre layer is more than that of strength of the epoxy matrix. Hence the delamination between layers occurs, before cutting through the hard glass fibre layer. Even though the delamination factor at low feed rate and high speed was less, the surface roughness was slightly higher during visual inspection. It was due to the heat generated due to low feed rate. Hence a medium feed rate can be preferred for better quality holes. Hence a 1400 rpm and feed rate of 0.05 can give better hole quality both for chopped fiber and woven fiber composites.

Analysis of variance
ANOVA analysis was performed from the experimental results to determine the most influencing machining variable in the drilling process. Two factors (speed and feed rate) with three levels each was considered to plot the variables. The experimental values of Sample D (chopped random oriented fibre) composite and sample WO-A (woven GBGB composite) is presented in this article. Delamination factor was the response factor in this analysis.

Significance of a parameter on the effect of delamination is statistically given by p-value from the ANOVA table. A p-value of less than 0.05 (95% confidence level) indicates the factor is significant. The P-Value from table 7 of 0.965 for speed (rpm) indicates that the effect of speed on the entry delamination for chopped fibre composites is not significant. The P-Value of 0.000 for feed rate indicates that it has significant effect on the quality of drilled holes. Similarly the exit delamination for random chopped fibre composites also exhibited similar trend in the P-Values. The regression equations for entry delamination and exit delamination for sample D and WO-A is given in the equations 2 and 3 respectively.

Regresion equations (Sample D)

Entry delamination = 1.0049 + 0.000002 Speed(rpm) + 2.185 Feed rate(mm/rev) -------(2)

Exit delamination = 1.1517 - 0.000062 Speed(rpm) + 2.337 Feed rate(mm/rev) ----------(3)

Regression Equations (Sample WO-A)

Entry delamination = 1.0041 + 0.000002 Speed (rpm) + 1.922 Feed Rate (mm/rev)-----(4)

Exit Delamination = 1.2154 - 0.000040 Speed (rpm) + 1.857 Feed Rate (mm/rev)-------(5)

Table 7
ANOVA for entry delamination for Chopped fibre composite(Sample D)

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Speed(rpm)	2	0.000022	0.000011	0.04	0.965
Feed rate(mm/rev)	2	0.166289	0.083144	267.25	0.000
Error	4	0.001244	0.000311		
Total	8	0.167556			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
0.0176383	99.26%	98.51%	96.24%

Table 8
ANOVA for exit delamination for Chopped fibre com-

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posite (Sample D)

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Speed(rpm)	2	0.012067	0.006033	11.31	0.023
Feed rate(mm/rev)	2	0.185000	0.092500	173.44	0.000
Error	4	0.002133	0.000533		
Total	8	0.199200			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
0.0230940	98.93%	97.86%	94.58%

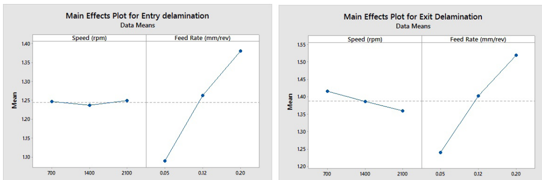

Figure 6. Main Effects plot for entry and exit delamination (sample D)

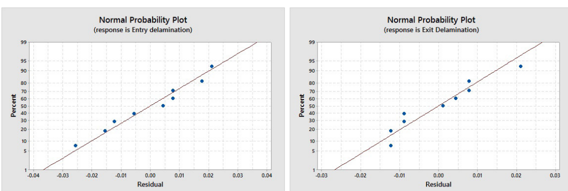

Figure 7. Normal probability plot for entry and exit delamination (sample D)

Table 9
ANOVA for entry delamination for woven fibre composite (Sample WO-A)

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Speed(rpm)	2	0.000289	0.000144	0.29	0.761
Feed rate(mm/rev)	2	0.127756	0.063878	129.19	0.000
Error	4	0.001978	0.000494		
Total	8	0.130022			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
0.0222361	98.48%	96.96%	92.30%

Table 10
ANOVA for exit delamination for woven fibre composite (Sample WO-A)

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Speed(rpm)	2	0.004822	0.002411	9.23	0.032
Feed rate(mm/rev)	2	0.118689	0.059344	227.28	0.000
Error	4	0.001044	0.000261		
Total	8	0.124556			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
0.0161589	99.16%	98.32%	95.75%

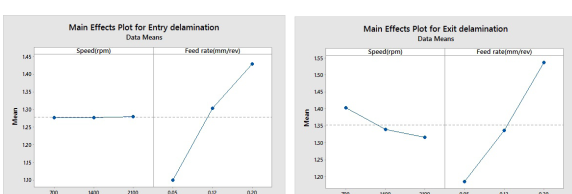

Figure 8. Main Effects plot for entry and exit delamination (sample WO-A)

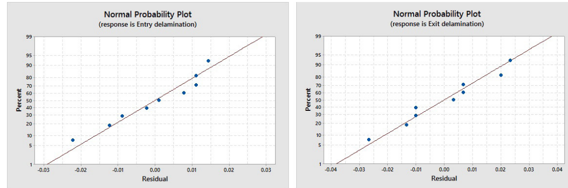

Figure 9. Normal probability plot for entry and exit delamination (sample WO-A)

The main effects plot for entry delamination and exit delamination of both samples D and WO-A is shown in Figure 6 and Figure 8 respectively. It can be inferred from the plots that the speed has lesser effect on the change of delamination factor. But the feed rate has an increasing trend on the values of delamination factor. The normal probability plot shown in figure 7 and figure 9 has established the validity of the experimental observations. Tables 8,9 and 10 give the details of ANOVA analysis of experimental details for sample D and sample WO-A.. The regression equations (2 – 5) were also developed for the model to predict the delamination factor for intermediate values of speed and feed rate.

CONCLUSION

The drilling experiment was conducted on chopped banana/glass fibre hybrid composite and woven banana/glass fibre composite. The effect of fibre volume fraction on the drilled hole quality was identified in chopped random fibre composites. Similarly the effect of layering sequence was studied in woven fibre composites. The drilling parameters also changed for both configurations. It was found that the fibre volume fraction had minor effect on hole quality in random chopped fibre composites. But a value of optimum drilling speed and feed rate of 2100rpm and 0.05mm/rev was observed for composite with 20% vol fraction of fibre content. Also the difference between delamination is less than 10% between 0.05mm and 0.12mm feed rate. In this view, 0.12mm/rev can be used for better production rate. In case of woven fibre composites the glass fibre at the top and banana fibre at the bottom had low delamination factor. The optimum speed and feed rate was found as 2100rpm and 0.05mm/rev respectively. Further research can be done on the effect of thrust force and torque on the delamination. Also the effect of tool geometry on the hole quality can be studied.

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