

Research Article

Investigation of Drilling Process Parameters of Palmyra Based Composite

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The drilling process is the most essential in the final assembly of the mechanical parts. Natural fiber based composites replace traditional materials due to their advantages, such as strength to weight ratio, availability, and environmental hazards. In this work, an attempt has been made to find the minimum thrust force produced by the drill tool at specified drilling process parameters. The drilling process parameters used for the investigation are rotational speed, tool feed, and resins. The spindle speed and feed rate are selected with three levels. Three resin materials were used, namely, epoxy, polyester, and vinyl ester. Taguchi's L₂₇ orthogonal array was implemented. The result shows that the candlestick drill bit generated lesser thrust force at the specified drilling process parameters, followed by the twist and step cone drill bits.

1. Introduction

Environmental protection is the main focus towards the use of cellulose fiber as reinforcement in the polymer matrix. Natural fibers having many advantages compared to synthetic fibers are lightweight, available in plenty, biodegradable, and no hazards to the environment. Hence, they are used as load transfer material in composite material. However, they have few drawbacks compared to synthetic materials, such as poor resistance to water, lesser modulus, and lower strength. Few authors reported the different studies in the natural fiber based composites, namely, hemp, abaca, sisal, banana, oil palm, and wood pulp [1–3]. The strength and stiffness characteristics of the natural fiber based composite can be improved by increasing interfacial bonding of the fibers and matrixes [4].

The machining of the fiber based composite is complicated due to the property difference and the fiber orientation nature of the natural fibers reinforcement [5]. Hence, it is required special attention to analyze fiber based composite compared to homogeneous machining. During drilling of the fiber strengthened composite, the effect of the mechanical and thermal properties is more. Hence, the selection of the process factors of the drilling process and the experimental conditions is more essential to produce quality machining. During fiber based composite machining process, the manufacturing defects produced are cracks, voids, fiber pullouts, delamination, and thermal defects. The following factors are considered to determine the machinability of the fiber-reinforced composite: tool materials, tool geometry, cutting condition, and type of

machining process [6–8]. The other factors, namely, surface roughness, roundness, and residual stress, are considered less critical.

Drilling is an essential machining process in the final assembly process of the manufacturing industry [9–13]. Different methods are used to make a hole on the fiber based composite. However, the most common traditional method has been employed. According to the forces generated during drilling, drilling is more complicated than another machining process. Few other factors affect the hole quality, namely, delamination fiber pullouts and surface roughness. To overcome the defects generated during the drilling process, it is required to develop proper experimental procedures, machining conditions, and cutting conditions [5, 14, 15].

The composites are inclined towards delamination and fiber pullouts due to their unidirectional properties. The hole quality is checked by visual inspection that is a standard assessment method. The delamination defects may be present, namely, peel-up and push-down delamination in the drilled hole. The measurement of the delamination in the natural fiber based composite is either direct or indirect. Indirect measurement measures delamination factors such as chip produced, damage width, surface unevenness, and delamination factor. The indirect measurement includes assessment of axial force, torque, and power generation during the drilling process.

In most of the direct assessment methods of delamination, the essential parameter considered is the delamination factor. The delamination is majorly classified into two types, namely, push-down and peel-up delamination. The following parameters are considered appropriate to avoid defects during the drilling process: drill rate, cutting speed, tool shape, and experimental conditions [16]. Feito et al. [17] found the lesser axial force and delamination factor during drilling at a low drill rate using stepped drill geometry. In addition, the backplate can be used to diminish delamination factor and axial force and obtain quality holes. They stated that the best contract is obtained between the experimental results and the mathematical model. The investigation was carried out with flax-based composite and found that the defacing factor reduces with drill rate.

Additionally, different factor accounts in the numerical model have been validated with experimental results [18]. Vinayagamoorthy et al. analyzed the hole-making characteristics of the vetiver-based composite. The drill's drilling rate and point angle mainly influence the push-out defacing, but the effect of the spindle speed is very minimal. They also found that the spindle speed, drill rate, and point angle majorly influence the peel-up defacing [19]. Rezghi Maleki et al. found that the feed rate has influenced the axial force generation during drilling jute-based fibers for all drill tools. They concluded that the high-speed steel drill and CoroDrill 856 contribute more to the generation of axial force and surface unevenness during drilling compared to CoroDrill 854, feed rate 0.15 mm/rev, and rotational speed 1250 rpm that are very much suitable for drilling of jute-based composite with minimum drilling defects [20]. Rezghi Maleki et al. repeated the same investigation to the flax-

based fibers and found that the high-speed drill influences the thrust force generated more than the CoroDrill 856 and CoroDrill 854 drill bits. They also reported that the hole quality and delamination factor influence the different geometrical drill bits more than the spindle speed and drill rate [21]. Patel et al. investigated the drilling characteristics of the hybrid composite, namely, basalt/glass, the tool geometry, and the lamination sequences effects of peel-up and push-down delamination. The parabolic geometry of the drill bit with high feed shows lesser delamination at exit. They concluded that the low spindle speed, low feed, and parabolic geometry drill bit are very much suitable for drilling hybrid composites to produce high quality holes [22]. Pradeep and Rajasekaran [23] analyzed the drilling behavior in chopped jute-based fiber, and three different drill tool materials are used, namely, high-speed steel, cobalt steel, and tungsten carbide. The axial force required to make the hole is lesser for the tungsten drill bit than other drill bits. Bajpai and Singh [24] found the drilling characteristics of the sisal fiber based composite, and two different geometrical drill bits have been used, namely, twist and trepanning tools. The thrust force generated by the trepanning tool is much lower compared to the twist tool. They concluded that the hollow drill bit might be suitable to drill natural fiber-reinforced composites. The drilling process parameters, namely, spindle speed, drill rate, and the drill geometries, are influenced much more by the defacing factor and drilling forces (axial force and torque) during drilling of sisal/optiva natural fiber based composites. Among the process parameters, the drill bit geometry contributes more to the defacing factor [25]. Roy Choudhury et al. [26] examined drilling-induced delamination, forces, and induced temperature produced during the drilling process experimentally. The five different geometric drill bits have been used for the investigation. Turki et al. [27] inspected the influence of fiber alignment on the delamination damage and thrust force. The friction-induced between the tool and the composite surfaces is examined by the temperature developed during the carbon fiber-reinforced epoxy composite specimen. The assessment between the thrust force and the defacing factor of two dissimilar geometrical drill bits on the flax-based composites has been carried out. They also found that the feed rate affects more the induced damage during drilling in the composite specimen [28].

The delamination defect, namely, peel-up occurred at the tool entrance of the composite specimen. When the tool starts to pierce the surface of the specimen, it generates peel-up force in the axial direction, and it separates the laminates. The delamination degree will depend on the rotational speed and point angle. The push-down delamination happens at the exit of the drilled hole. This is because the resistive force offered by the exit laminae is lesser than the axial force of the tool. Hence, it generates exit delamination [29]. Belaadi et al. [30] investigated the drilling process parameters with four different geometrical drill bits, and response surface methodology and artificial neural networks are used to authenticate the experimental values. The two techniques obtained from the artificial neural network are closer to the experimental value than the response surface methodology.

Rajaraman et al. [31] examined the process parameters of drilling on the kenaf and banana-based composite. The high-speed steel of three different diameters and the L9 factorial method has been used for the experimental study. They concluded that the spindle speed of 3000 rpm and 150 mm/min has been suitable for defect-free holes. Panneerselvam et al. [32] investigated the drilling on the sisal/glass hybrid composite and found that the drilling rate influences the exit defacing more. They used a profile projector, and image processing software was used to examine the defects in the holes. Abilash and Sivapragash [33] evaluated the effect of the induced force during drilling of bamboo-based composites and developed the regression modelling to reduce exit delamination. Ramesh et al. [34] investigated the drilling defects in hybrid composites, which consist of the sisal/glass, also found that the axial force is enhanced with drill rate, and obtained the maximum value for high-speed steel tool.

The availability of Palmyra fiber is plenty in south zone of India especially in Tamilnadu. It made interesting investigation on optimization of drilling parameters during drilling of Palmyra based composite. Only few papers are available on characteristic study of Palmyra based composite. However, there are no research papers available for drilling parameters optimization of Palmyra based composites. Hence, in this investigation, an attempt has been made to find the most appropriate drilling process parameters to reduce drilling defects. One appropriate drill bit has been suggested with optimum drilling process parameters among the two different geometrical drill bits used for this investigation. As per Taguchi's design of the experiment L_{27} model has been used for investigation. Table 1 shows the methodology of investigation on drilling process parameters of Palmyra based composite.

2. Materials and Methods

The three matrices have been used for the investigation, namely, epoxy, polyester, and vinyl ester. The density and viscosity of epoxy at 25°C are 1.16 gm/cm³ and 900 cps, respectively. The hardener used is 3 diacid anhydride. The density and viscosity of vinyl ester at 25°C are 1.052 gm/cm³ and 325 cps, respectively. For polyester, the density and viscosity at 25°C are 1.12 gm/cm³ and 500 cps, respectively. These are purchased from the Aypols private limited Coimbatore. Methyl ethyl ketone peroxide and cobalt activator are used as curing system for vinyl ester and polyester resin, respectively. The Palmyra sprout fiber extracted from the Palmyra sprout fruit (*Borassus flabellifer*) is shown in Figure 1. Sipcon vertical profile projector has been used to view outer periphery of the drilled hole. The resolution of the profile projector is up to 0.5 micrometer.

2.1. Experimental Setup. The investigation has been carried out in Computer Numerical Control (CNC) vertical machining center. The maximum spindle speed, power, and machine axis are 40,000 rpm, 5 kW, and 3. The drill tool dynamometer is of 50 Hz frequency, with the axial measuring range 0–50000 N fixed in the CNC platform as shown

in Figure 2. The drilling tool is 6 mm carbide, and different geometries were used, namely, standard twist, candlestick, and step cone drill bits, as shown in Figure 3. Three levels of rotational speed and drill rate have feed considered for investigation. Three levels of rotational speed are 1000, 1500, and 2000 rpm. Three levels of feed are 0.1, 0.15, and 0.2 mm/rev.

2.2. Composite Fabrication. The Palmyra sprout fiber is cleaned and chopped with 5 to 10 cm length. The range of diameter is 0.05 to 2 cm. The fibers are dried under vacuum for 3 hours at the temperature of 60°C [35]. The palmyra sprout fiber-reinforced polyester, vinyl ester, and epoxy are made up of hand layup process and compression moulding techniques. The fibers are randomly oriented, and steel rollers have been used to form an even surface of the specimen. The uniform thickness of the specimen has been obtained by the hydraulic press for 4 hours. The curing reagent of 1 Vol.% has been used for fast curing. The composite specimen has been allowed to cool for 24 hours at atmospheric temperature. The required dimension of 30 cm * 3 cm * 0.3 cm was obtained as shown in Figure 4.

2.3. Taguchi Method. The Taguchi method of optimization has been selected for this study due to the three process parameters, three levels, and one response parameters, and L_{27} full factorial method has been implemented. The output influencing parameters are listed in the orthogonal array Table 1. The L_{27} orthogonal array test can be conducted to minimize a large number of experiments. The maximum signal to noise ratio value is considered the best value to minimize the thrust force value. A loss function has been characterized to determine the difference between the experimental value and the standard value. The process behavior is characteristic of three types: the smaller the better, the nominal the better, and the higher the better .

$$\text{Lower - the - better} = -10 \log \left(\frac{1}{n} \sum_{i=1}^n y_t^2 \right), \quad (1)$$

where n = number of replications and y_t = tensile strength for the i^{th} trial.

3. Results and Discussion

Many researches prove that the defects produced during drilling of the fiber based composites depend on the thrust force produced during drilling [8, 15, 34]. The axial force was determined using different geometrical drill bits to drill the palmyra fiber-reinforced epoxy, polyester, and vinyl ester composites. The three drill bits used for the analysis are the candlestick, twist, and step one. The axial force generated during drilling of Palmyra fiber based composite is listed in the Table 1. The L_{27} orthogonal array is used with three drilling process factors: resin, rotational speed, and drill rate. Three levels of spindle speed are 1000, 1500, and 2000 rpm. Three levels of feed are 0.1, 0.15, and 0.2 mm/rev. The axial force generated by the three drill tools shown in Table 2

TABLE 1: Methodology of investigation on drilling process parameters of Palmyra based composite.

Materials	Fibers	Palmyra sprout fruit
	Resins	Epoxy Polyester Vinyl ester
Drilling process parameters	Speed (rpm)	1000, 1500, 2000
	Feed (mm/rev)	0.10, 0.15, 0.20
	Drill bit geometry	Candlestick, standard twist, and Stepcone drill
	Response parameter	Thrust force (N)
Experimental setup	Fabrication method	Hand layup process
	Machine	CNC vertical machining center
Optimization of process parameters	Taguchi's method	L ₂₇ orthogonal array



(a)



(b)

FIGURE 1: (a) Palmyra sprout fruit. (b) Palmyra sprout fiber.

varies from 7.39 N to 12.83 N. The axial force generated by the candlestick drill bit is lesser than that of other drill bits. At 1000 rpm and 0.2 mm/rev, the axial force generated by the candlestick is minimum. The smaller it is, the better option has been considered for the S/N ratio to find the deviation from the desired value as shown in Figure 5. Since lesser thrust force is required, the smaller, the better S/N ratio selected for the study.

At 1000 rpm rotational speed, and 0.2 mm/rev axial feed, the drilled hole of the Palmyra reinforced epoxy specimen by candlestick drill bit has been viewed using profile projector as shown in Figure 6. The specimen has been cut laterally and viewed using profile projector; it is clear that the defects on the specimen at specified speed, feed, and drill bit are lower compared with the drilled hole at different speeds and feeds.

Figure 5 shows the Signal to Noise (S/N) ratio during drilling of Palmyra based composite. Figure 5(a) shows the S/N ratio of thrust force generated by the candlestick

drill bit. The lower S/N ratio value is shown at 1000 rpm and 0.2 mm/rev. Similarly, at 1000 rpm and 0.2 mm/rev, the S/N ratio of thrust force produced by the twist drill has a minimum, as shown in Figure 5(b). At 2000 rpm and 0.2 mm/rev, the S/N ratio of thrust force produced by the step cone drill bit has a minimum, as shown in Figure 5(c).

The signal to noise ratio of spindle speed is increased to 18.5% and 92.59% for 1500 rpm and 2000 rpm, respectively, compared to 1000 rpm for the candlestick drill bit during the drilling process Figure 5(a). It implies that the spindle speed increases with the increase in the thrust force value. For candlestick drills, the thrust force value is significantly influenced by the spindle speed. Similarly, the signal to noise ratio during drilling of the composite by standard twist drill is increased to 59.09% and 50% for the spindle speed of 1500 rpm and 2000 rpm, respectively, compared to 1000 rpm as shown in the Figure 5(b). In contrast, the signal to noise ratio decreases to 32.2% and 12.9% for the step cone drill bit

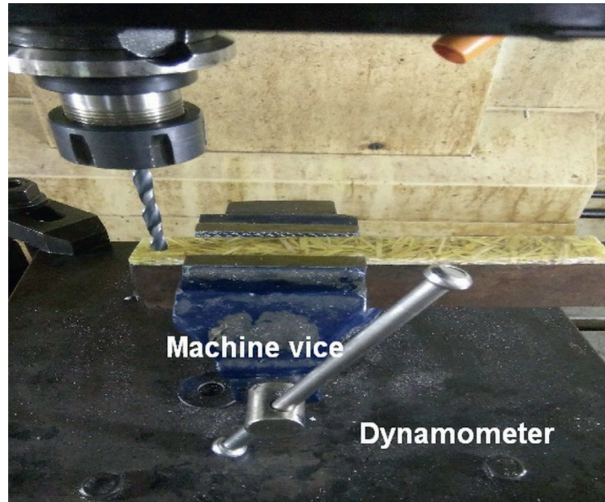


FIGURE 2: Drilling experimental setup.

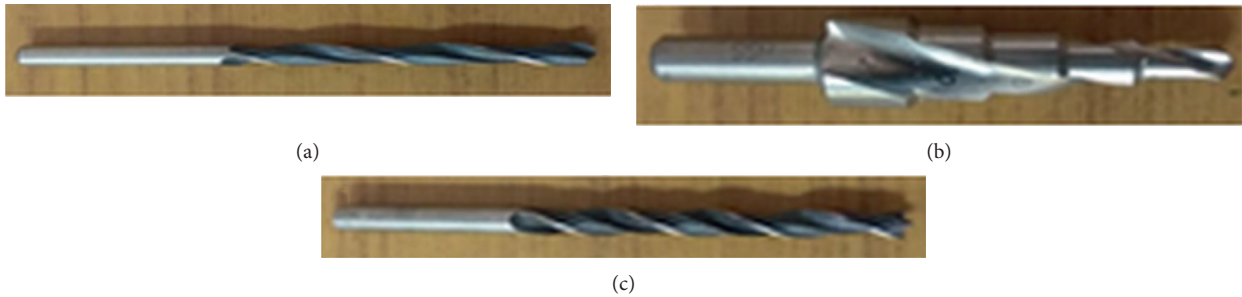


FIGURE 3: (a) Standard twist drill, (b) step cone drill, and (c) candlestick drill tools.

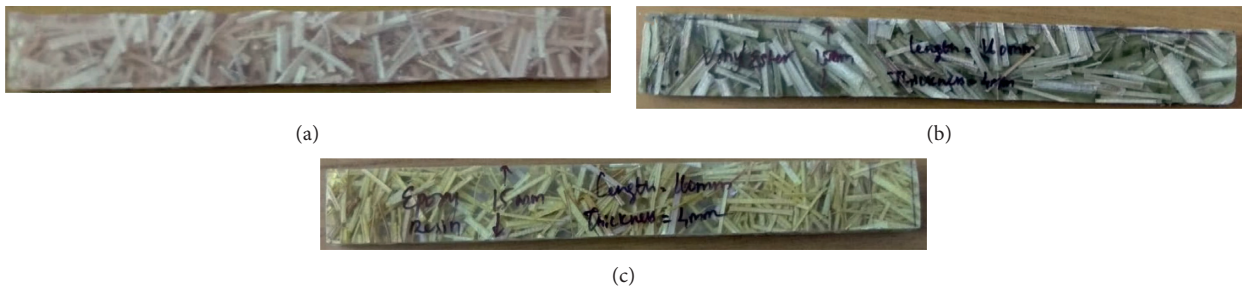


FIGURE 4: Palmyra sprout fiber-reinforced (a) polyester, (b) vinyl ester, and (c) epoxy composites specimen.

for spindle speed 2000 rpm and 1500 rpm, respectively, compared to the 1000 rpm as shown in Figure 5(c). The signal to noise ratio increases with the increase in the spindle speed for the candlestick and twist drill bit. In contrast, the signal to noise ratio decreases with spindle speed for the step cone drill bit. The statistical significance of the spindle on the thrust force generated by the candlestick drill bit is very high compared to the other drill bits. The thrust force values greatly reduced at 1000 rpm spindle speed due to the forces generated, as drill bit A has been transferred to the outer periphery compared to the other drill bits.

For the candlestick drill bit, the tool feed’s signal to noise ratio increases to 0.15 mm/rev and then decreases, as shown

in Figure 5(a). The percentage of the signal to noise ratio of tool feed increases to 32.35% and then decreases to 67.85%, corresponding to 0.15 mm/rev and 0.20 mm/rev, respectively. The same trend has been followed for the other drill bit also; for a standard twist drill, the signal to noise ratio of tool feed increases to 10.34% and then decreases to 18.5%, corresponding to the 0.15 mm/rev and 0.2 mm/rev, respectively. Likewise, the signal to noise ratio of tool feed increases to 1.38% and then decreases to 12.12%, corresponding to the 0.15 mm/rev and 0.2 mm/rev, respectively. The statistical importance of the tool feed on the thrust force generated by the candlestick drill bit is very high compared to other drill bits. The thrust force values greatly reduced at

TABLE 2: Thrust force generated by the candlestick, standard twist, and step cone drill bits during the drilling process.

S. no	Resin	Speed (rpm)	Feed (mm/rev)	Thrust force by candlestick (N)	Thrust force by a twist drill	Thrust force by step cone drill
1	Epoxy	1000	0.10	08.153	10.371	11.232
2	Epoxy	1000	0.15	09.292	10.674	11.331
3	Epoxy	1000	0.20	07.392	10.998	10.459
4	Epoxy	1500	0.10	10.169	10.370	12.981
5	Epoxy	1500	0.15	09.125	10.458	10.600
6	Epoxy	1500	0.20	10.023	10.566	10.968
7	Epoxy	2000	0.10	09.674	10.234	12.259
8	Epoxy	2000	0.15	10.359	10.356	12.657
9	Epoxy	2000	0.20	09.129	10.554	11.227
10	Polyester	1000	0.1	09.627	10.369	11.599
11	Polyester	1000	0.15	10.522	10.273	11.451
12	Polyester	1000	0.20	08.439	10.123	11.348
13	Polyester	1500	0.10	10.438	10.262	11.117
14	Polyester	1500	0.15	10.566	10.178	10.573
15	Polyester	1500	0.20	10.635	10.019	11.896
16	Polyester	2000	0.10	09.534	10.198	10.693
17	Polyester	2000	0.15	08.356	09.956	13.893
18	Polyester	2000	0.20	09.259	09.897	11.354
19	Vinyl ester	1000	0.10	08.933	10.595	11.400
20	Vinyl ester	1000	0.15	09.875	10.097	11.366
21	Vinyl ester	1000	0.20	08.996	09.899	10.289
22	Vinyl ester	1500	0.10	10.544	10.480	11.090
23	Vinyl ester	1500	0.15	09.153	10.569	11.199
24	Vinyl ester	1500	0.20	09.756	10.668	13.288
25	Vinyl ester	2000	0.10	09.432	10.393	12.639
26	Vinyl ester	2000	0.15	09.356	10.456	12.156
27	Vinyl ester	2000	0.20	08.289	09.754	10.887

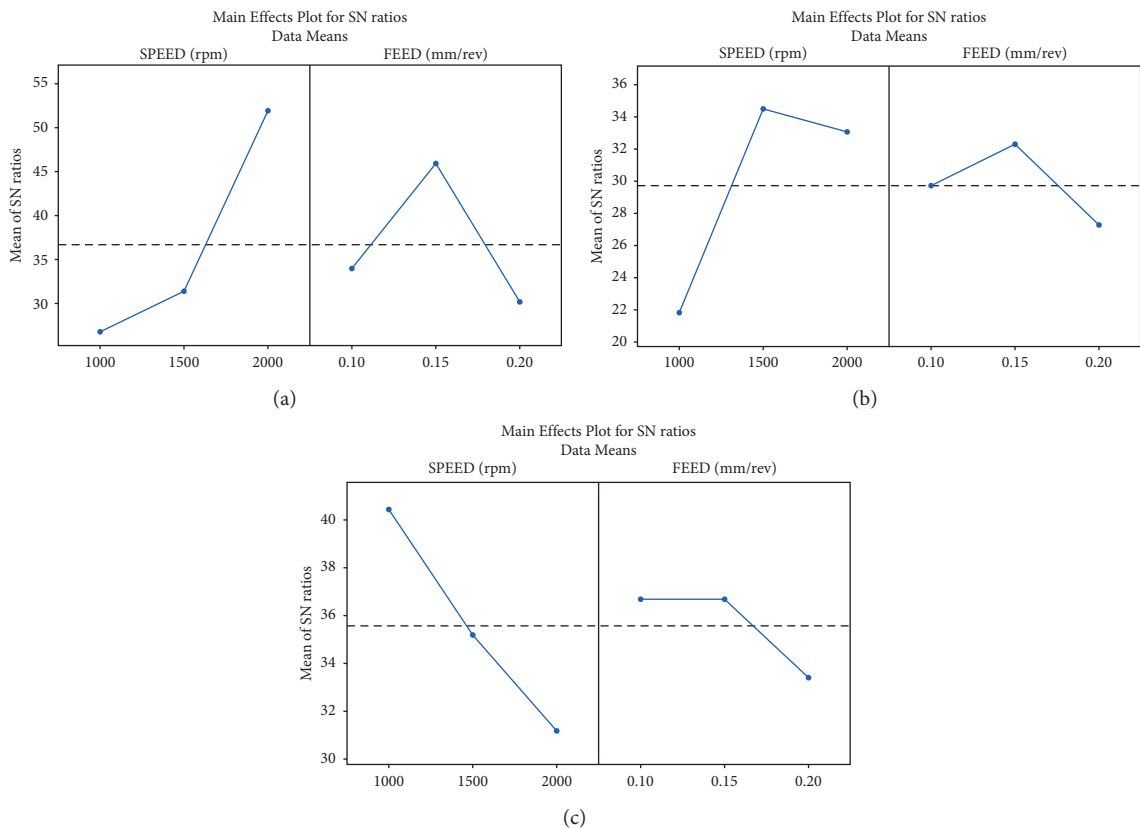


FIGURE 5: Signal-noise ratio of (a) candlestick, (b) twist, and (c) step cone drill bits during the drilling process.



FIGURE 6: Periphery of the drilled hole is viewed using profile projector.

0.2 mm/rev feed rate, because the forces generated during drill bit A have been transferred to the outer periphery compared to the other drill bits. The suitable spindle speed and feed rate are 1000 rpm and 0.2 mm/rev, respectively, to drill Palmyra reinforced epoxy composites.

The defects generated during drilling of Palmyra reinforced epoxy resin depend on the thrust force generated during drilling [8, 15, 34]. In previous studies, it is evident that the peel-up and push-down defects at the entry and exit, respectively, are formed during drilling. Hence, this work aims to reduce thrust force and achieve defect-free hole. Among the three different geometrical drill bits, the candlestick drill bit distributes the axial force into the outer circumferential of the hole. This may be the reason for the lower thrust force. The twist and step cone drill bit transmit thrust force in the axial direction; hence, the thrust force generated at the end of the composite specimen is higher due to the tool's axial force exceeding the adhesive force of uncut thickness the composite specimen [36, 37].

4. Conclusion

The drilling analysis has been carried out on the Palmyra based composites. Three process parameters have been

selected for the investigation: resin, rotational speed, and drill rate. The three levels of rotational speed and drill rate have been chosen for the study. The result shows that the axial force generated by the candlestick drill bit during the drilling process has a minimum. It is followed by the twist and step cone drill bits. At lower rotational speed and higher drill rate, the thrust force generated by the candlestick and the twist drill has a minimum. Likewise, at the maximum rotational speed and higher drill rate, the axial force produced by the step cone drill bit is minimum. The minimum axial force produced by the candlestick drill tool is distributed to the tool's outer periphery. The thrust force of the drill tool exceeds the adhesive force of uncut thickness of the composite specimen, and it may be the cause for the higher axial force of twist and step cone drill bits.

Data Availability

The data used to support the findings of this study are included in the article.

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this article.

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