EFFECT OF DRILLING PARAMETERS ON DIFFERENT FIBRE REINFORCED POLYMER MATERIALS WITH DIFFERENT THICKNESS

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Abstract: Due to the global developments and high strength low weight material requirement the FRP composite material have a huge demand in the industrial applications. Carbon fibre is highly demanded for automotive, lightweight combat equipment's, drones, and other. Also the GFRP has a great demand in the furniture as well as in the electrical industries, and Electronics industries. Drilling is the mostly required with good quality due to current demand in the specific application. For that it is required to optimize the parameters for GFRP & CFRP materials and to study the thrust force, torque and circularity for optimization of drilling parameters using Taguchi design and ANOVA analysis. This study will helpful in mass production of end product which contain a different thickness of FRP in industries. The results are analyzed by making use of L27 Orthogonal Array and signal to noise ratio (S/N ratio). From the results it has been observed that the circularity and thrust force is main significant responses and Speed, feed is the most significant factors in the study.

Key words: Drilling parameters, Machining, Circularity, ANOVA, Fibre reinforced polymer materials

1. Introduction:

Engineers and scientists have a lot of questions about drilling FRP composite materials. Drilling generated damage has been minimised through the adjustment of operating factors and conditions. [1] Drilling holes is a critical machining process in the construction of complex composite products. The twist drill used for cutting metallic materials was used to drill long fibre composite structures due to tool cost. The behaviour of fibres under the tool's action has a significant impact on the drilling process. Excessive tool wear and damage to the work piece (delamination, loosening of the fibres, matrix burning, and so on) limit these materials' cutting operations. This study is focused to optimize the parameters for the Two FRP material namely Glass fibre and carbon fibre. Due to the global demand with high quality, application and accuracy requirement it is necessary to optimize such parameters which are beneficial to the small as well as for the large industries. The basically spindle speed, feed rate is the mostly used parameters during the drilling and the drilling is the maximum used operation on the material to provide the joint with the other body. Different thickness of the material is the other most common parameter. Carbon fibre and glass fibre are the largely demanded FRP material in the recent scenario. Thrust force, torque, and the circularity are the parameters which are related to the output of the product with good quality and effective. Taguchi's design is simply used to minimize the time, cost with effective orthogonal array of L27 including repetitive parameters. ANOVA is useful to analyze the results or responses for finding out the optimum output.

2. Literature Review

One of the scope investigations is a literature review. It serves as a guidance for completing this analysis. It will play a role in obtaining information on FRP materials as well as providing guidance on how to conduct the test. Various literary investigations have been conducted since the beginning of the project. The principal sources in the project guides were research journals, books, and printed or online conference articles. This section will cover practically all of the operations, including the test, machining qualities, and outcomes. The literature review part serves as a reference, providing information and guidance based on journal articles and other media sources.

Vankanti V.K. et al. (2014) investigated various parameters in (GFRP) composites, such as cutting speed, feed, point angle, chisel edge width, thrust force, and torque analysis of variance (ANOVA), and found that feed rate is the most significant factor influencing thrust force, followed by speed, chisel edge width, and point angle. Cutting speed has the greatest influence on torque, speed, and hole circularity, followed by feed, chisel edge width, and point angle. Figure 1 shows the drilling experimental setup. [2]

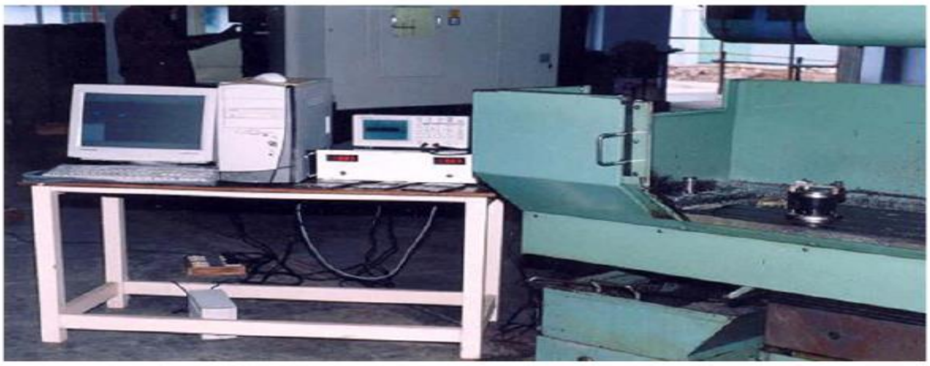

Figure 1 Experimental setup used for drilling (Vankanti V.K. 2014)

By using the compression moulding technique, Kulkarni G.S. et al. (2020) tested different factors such as pressure of 100 kgf, temperature of 50 °C, and time of 40 minutes. Cutting speed, feed rate, drill point angle, and tool material, as well as Taguchi design and ANOVA analysis, revealed that both materials with matrix weight ratios of 60:40 and 50:50 had very modest burr height (0.08 mm and 0.07 mm). [3] Wei Y. et al. (2016) investigated different parameters such as diamond-coated drills, multi-facet drills, and brad spur drills, drilling forces, drilling temperatures, chips, and delamination area with respect to cutting parameters and tool geometries and concluded that using a multi-facet drill could greatly reduce delamination and thus produce better surface integrity. Figure 3 shows a system for measuring cutting temperature and cutting force. [4] Michael G. (2017) looked into various factors such as cutting speed, feed, and drill bit type. Surface roughness and delamination factor were calculated, and it was found that the best process settings (7000 rpm spindle speed, 50 mm/min feed rate) resulted in the least amount of delamination. Figure 2 is displayed. Drilled holes picture & Delamination Measurement Scheme [5]

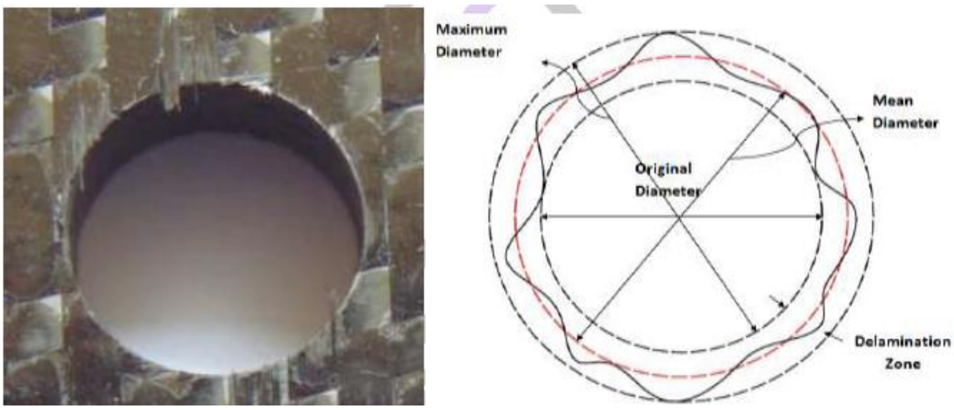

Figure 2 Drilled holed image & Scheme for measuring Delamination (Michael 2017)

Kilickap E. (2010) looked into a variety of variables, including tests that were conducted without the use of coolant. Cutting speed, feed rate, and point angle are all factors to consider. Delamination and surface roughness were studied, and it was discovered that delamination on drilled holes increased as cutting speed and feed rate rose. The optimum delamination outcomes come from cutting at a slower speed and feeding at a slower rate. Figure 3 depicts Photographs of delamination seen during GFRC drilling (point angle: 118): (a) at the entry and (b) at the exit. [6]

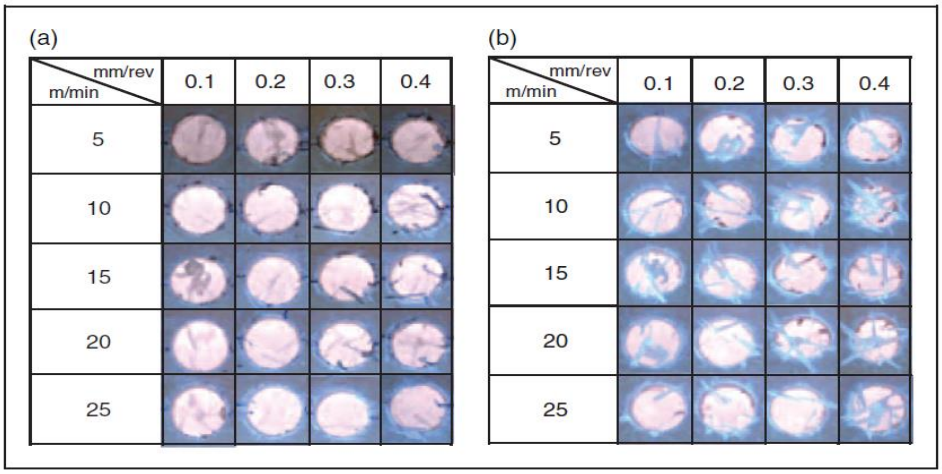

Figure 3 Photographs of the delamination observed in drilling GFRC (point angle: 118): (a) at entrance and (b) at exit (Kilickap 2010)

Different parameters on aramid fibre reinforced plastic (AFRP) fibre deformation and material interface cracking were explored by Wang F.J. et al. (2020). The radial force and the thrust force. Twist drilling, candle core drilling, and three-point step drilling were studied, and it was discovered that the three-point step drill transformed standard cutting behaviour on drill-exit material into a compound process. Finally, the AFRP was actively sliced with a tiny thrust force using the innovative drill, and delamination and "burrs area" were minimised using various drilling parameters. [7] Khashaba U.A. et al. (2021) looked into drill diameters of 6 mm, point angles, feed rates, and drill spindle speeds. Thrust force in the heat-affected zone (HAZ) Through multi-variable regression analysis, Torque discovered that all machining parameters have a significant effect on the measured temperature, with the laminate thickness (33.14 percent) having the largest contribution, followed by speed and feed (29.00 percent and 15.10 percent, respectively), and the drill point angle having the smallest contribution (11.85 percent). Figure 4 shows an experimental setup employing a CNC milling machine and a Kistler dynamometer to measure thrust forces and torque in drilling GFRP composites. The temperature was measured using the following methods: (a) an instrumented drill with two thermocouples, and (b) an infrared camera. [8]

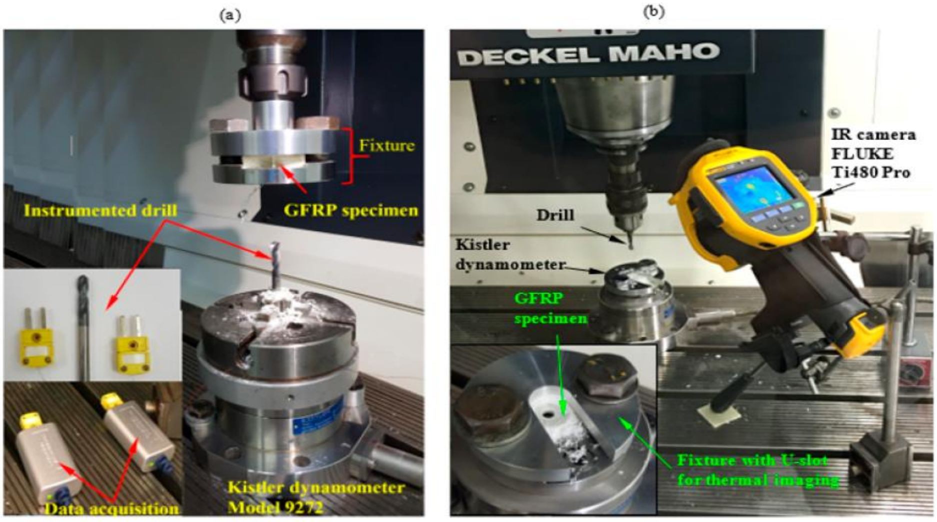

Figure 4 Experimental setup for measuring thrust forces and torque in drilling GFRP composites using CNC milling machine and Kistler dynamometer. The temperature was measured by: (a) instrumented drill with two thermocouples (b) IR camera (Khashaba U.A. 2021)

SEM and EDS analysis of two types of PCD drills (PCD standard twist drill and PCD special-geometric dagger drill) revealed that the PCD dagger drill seemed to provide a better tool-work configuration than the PCD twist drill for high-strength T800S/250F drilling, according to Jinyang Xu et al. (2014). The primary wear modes governing PCD wear advancement were abrasive and sticky wear. [9] LV Pinho et al. (2016) investigated different parameters such as the influence of machining parameters such as feed rate and spindle speed on delamination damage, as well as the influence of temperature at the tool's entrance, and concluded that the feed rate and tool, at the entrance and exit, respectively, are the most influential factors. The diamond-coated tools were the most effective at reducing delamination. [10] Anon. (2021) investigated various parameters such as carbon fiber-reinforced polymer (CFRP) cutting speeds and feed rates, variation of delamination, cold drill and heated drill, and the Fda in the hole entrance, and found that vc, f, cc, and the combination f x cc were in-fluent factors in the first hole for a 95 percent confidence interval. The cooled-air application helped to reduce delamination in the tenth hole, but the increase in vc had a detrimental impact. As a result, larger vc values can cause more delamination.[14] Karpat (2012) looked at a variety of variables including uncoated carbide and two diamond coated carbide drills, drill tip angles, force and torque measurements, and came to the conclusion that high feed rate drilling trials are beneficial in terms of drill wear. It has been discovered that feed is more essential than speed. During drilling of fabric woven CFRP laminates at high feeds, hole diameter tolerance is found to be more important than hole exit delamination. Figure 11 shown SEM images of the flank face of DCC-I cutting drills: (a) N = 15,000 rpm, f = 75 _m/rev, (b) N = 15,000 rpm, f = 225 _m/rev, (c) N = 5000 rpm, f = 225 _m/rev, (d) N = 5000 rpm, f = 75 _m/rev and (e) hole exits correspond to each experimental condition. [11]

3. Research Methodology

The area of selection and literature for the study were collected in the first session. For research objectives, the procedure should be identified and studied. Collect some essential programme expertise, such as MINITAB 17. Based on the literature, it has been determined that optimization is required for greater accuracy with the DOE approach for the same parameter. Collect a necessary distinct FRP material in the middle of the stage.

In the drilling of FRP sheets, the Taguchi Method was employed to reduce hole growth. Taguchi advocates analysing the mean response for each run in the inner array, as well as analysing variance with a carefully adjusted signal-to-noise ratio (S/N). Three of these S/N ratios are regarded standard and widely applicable, and they are derived from the quadratic loss function. These are the following:

i. Lower is best: Signal to Noise Ratio - Smaller is better Formula: -10×Log10(sum(Y^2)/n)

ii. Higher is best:

iii.Average is best

Our goal is to achieve the least amount of hole expansion possible, so we employed the lower is best rule, which states that a lower S/N ratio equals greater performance. As a result, the process parameter level with the lowest S/N value is the ideal level.

For the graphical analysis of the acquired data, Minitab 17 software was utilised. All of the experiments will be done in the lab. Thrust force, torque, and circularity will be measured.

Spindle speed 1000 – 1250 – 1500 rpm, feed rate 70 – 110 – 150 mm/min, thickness 4 – 6 – 8 mm for various sheets of CFRP, GFRP with solid carbide drill tool tip angle 90° were used in the experiment. Thrust force, torque, and circularity will be measured as outputs. The impact of cutting tool shape, material thickness, feed rate, and speed on thrust force, torque, and circularity produced when drilling a glass fibre reinforced composite will be investigated. A sample of data from the dynamometer will be compared and computed for carbide drill tools. Drilling will be done on each sheet of FRP (40 x 100 x 4 – 6 – 8 mm) using a vertical machining centre. The size of the hole will be determined using a 3D Measuring Microscope. The findings of drilling parameters for FRP composites in Minitab 17 will be optimised as a result of this study.

4. Experimental Setup

Experimental setup is a vertical machining center as soon in figure 5, I which the drill tool dynamometer was fixed on the bed and connected to data acquisition system to measure the Torque applied by the tool on the workpiece, and Thrust force generated during the drilling of the workpiece. Workpiece is required to prepare before it was fixed on to the dynamometer according to the space between fixtures in the dynamometer. The workpiece prepared for the drilling operation has a dimension of 40mm x 100 mm in which the distance between two fixtures was 52 mm. fixture is fix the workpiece on the dynamometer then the reference zero position has been taken for the machining and set the required program with different inputs as per Taguchi's Array.

Figure 5 Photograph of Experimental Setup

Taguchi design for GFRP & CFRP:

Taguchi Orthogonal Array Design is the common for both the cases of GFRP & CFRP

L27(3^3)

Factors: 3

Runs: 27

Columns of L27(3^13) Array 1 2 3

Factors and Their Uncoded Levels

Sr. No.	Factor Name	Levels
A	Spindle Speed (RPM) =	1000, 1250, 1500
B	Feed (mm/min) =	70, 110, 150
C	Thickness (mm) =	4, 6, 8

Signal to Noise Ratio: Smaller is better

Formula: - 10×Log10 (sum(Y^2)/n)

From the Taguchi's design orthogonal aray has been developed by the Minitab 17 software as follows;

Table 1 Taguchi's Orthogonal Array Design for CFRP & GFRP

Run	Spindle speed (rpm)	Feed rate (mm/min)	Thickness (mm)
1	1000	70	4
2	1000	70	4
3	1000	70	4
4	1000	110	6
5	1000	110	6
6	1000	110	6
7	1000	150	8
8	1000	150	8
9	1000	150	8
10	1250	70	6
11	1250	70	6
12	1250	70	6
13	1250	110	8
14	1250	110	8
15	1250	110	8
16	1250	150	4
17	1250	150	4
18	1250	150	4
19	1500	70	8
20	1500	70	8
21	1500	70	8
22	1500	110	4
23	1500	110	4
24	1500	110	4
25	1500	150	6
26	1500	150	6
27	1500	150	6

Figure 6 Software and Data Acquisition system for recording the Force & Torque

The dynamometer was fixed on the bed of VMC machine and attached with Siemens controller data acquisition hardware and software as shown in Figure 6. The GFRP & CFRP sheets with thickness of 4, 6 and 8 mm were drilled with the Taguchi's orthogonal array L27 design parameters as shown in the Figure 7 respectively with the 90º 5mm solid carbide drill bit.

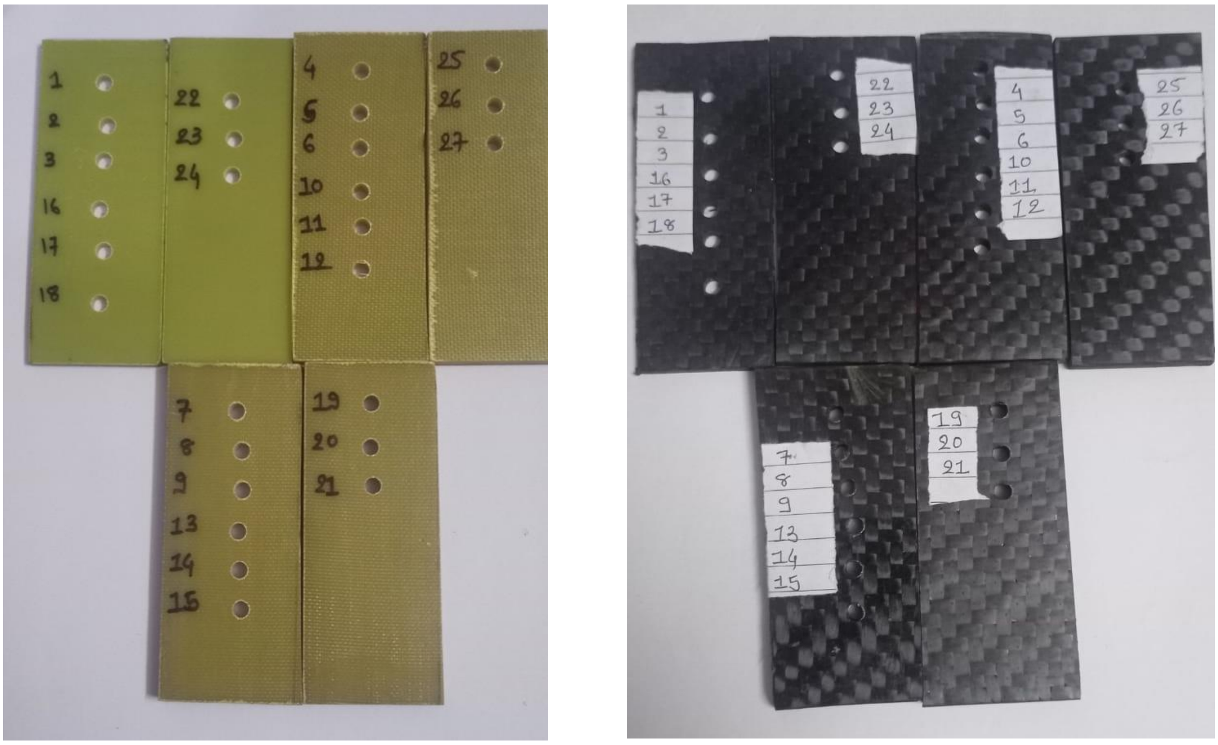

Figure 7 Photograph of GFRP & CFRP sheet drilled with 5mm bit in L27 Taguchi's Array respectively.

Observation Tables

Table 5.1 Observation table for the GFRP Orthogonal array L27

Run	Spindle Speed	Feed	Thickness	Torque	Force	Circularity
	RPM	mm/min	mm			mm
1	1000	70	4	0.41609	77.7059	0.8047
2	1000	70	4	0.41609	77.7059	0.0641
3	1000	70	4	0.41609	74.6537	0.0381
4	1000	110	6	0.41609	111.281	0.0302
5	1000	110	6	0.72126	105.1762	0.0509
6	1000	110	6	0.4161	111.281	0.0093
7	1000	150	8	0.41609	126.542	0.0222
8	1000	150	8	0.41609	123.49	0.0237
9	1000	150	8	0.72127	123.49	0.0311
10	1250	70	6	0.41609	71.6014	0.0344
11	1250	70	6	0.72126	71.6014	0.0318
12	1250	70	6	0.41609	71.6014	0.0749
13	1250	110	8	0.41609	83.81	0.0397
14	1250	110	8	0.72127	77.706	0.0419
15	1250	110	8	0.72127	83.8124	0.0016
16	1250	150	4	0.72126	111.2807	0.0513
17	1250	150	4	0.41609	108.2285	0.0539
18	1250	150	4	0.41609	105.1762	0.0648

19	1500	70	8	0.72127	59.3924	0.0581
20	1500	70	8	0.72127	56.3401	0.0419
21	1500	70	8	0.72127	59.3924	0.0146
22	1500	110	4	0.72126	80.7558	0.0631
23	1500	110	4	0.72126	74.6537	0.0502
24	1500	110	4	0.72126	80.7582	0.05
25	1500	150	6	0.41609	99.0717	0.0567
26	1500	150	6	0.72126	92.967	0.0535
27	1500	150	6	0.41609	92.961	0.016

Table 5.2 Observation table for the CFRP Orthogonal array L27

Run	Spindle Speed	Feed	Thickness	Torque	Force	Circularity
	RPM	mm/min	mm	N.m	N	mm
1	1000	70	4	0.41609	83.8104	0.012
2	1000	70	4	0.41609	80.7582	0.0145
3	1000	70	4	0.41609	80.7582	0.112
4	1000	110	6	0.41609	86.8627	0.389
5	1000	110	6	0.41609	77.7059	0.0374
6	1000	110	6	0.41609	92.9672	0.0276
7	1000	150	8	0.41609	96.0195	0.0485
8	1000	150	8	0.41609	99.0717	0.0471
9	1000	150	8	0.41609	111.281	0.0456
10	1250	70	6	0.41609	111.385	0.018
11	1250	70	6	0.41609	83.8104	0.0216
12	1250	70	6	0.7212616	89.9149	0.0149
13	1250	110	8	0.41609	105.176	0.0873
14	1250	110	8	0.41609	111.281	0.0783
15	1250	110	8	0.41609	99.0717	0.0738
16	1250	150	4	0.41609	83.8104	0.0413
17	1250	150	4	0.41609	89.9149	0.048
18	1250	150	4	0.41609	80.7582	0.0437
19	1500	70	8	0.72126	147.908	0.0398
20	1500	70	8	0.72126	114.333	0.0371
21	1500	70	8	0.72126	126.542	0.0348
22	1500	110	4	0.72126	83.8104	0.026
23	1500	110	4	0.41609	89.9149	0.0117
24	1500	110	4	0.72126	71.6014	0.01766
25	1500	150	6	0.41609	96.0194	0.0155
26	1500	150	6	0.41609	111.281	0.0163
27	1500	150	6	0.41609	102.124	0.0212

Table 5.1 & Table 5.2 show the observation table for GFRP & CFRP drilling output with the Taguchi's orthogonal array parameter as an input. The output of the FRP drilling was analyzed by Taguchi analysis with ANOVA in the Minitab 17.

Observation of circularity in 3D Microscope:

Figure 8 shows the photographic view of different circularity (delamination) results for the experiment R2, R17, & R27 for the carbon fibre drilling and R1, R5 & R6 for Glass fibre drilling. From the all observation it has been noticed that higher cutting angle gives the better results in circularity.

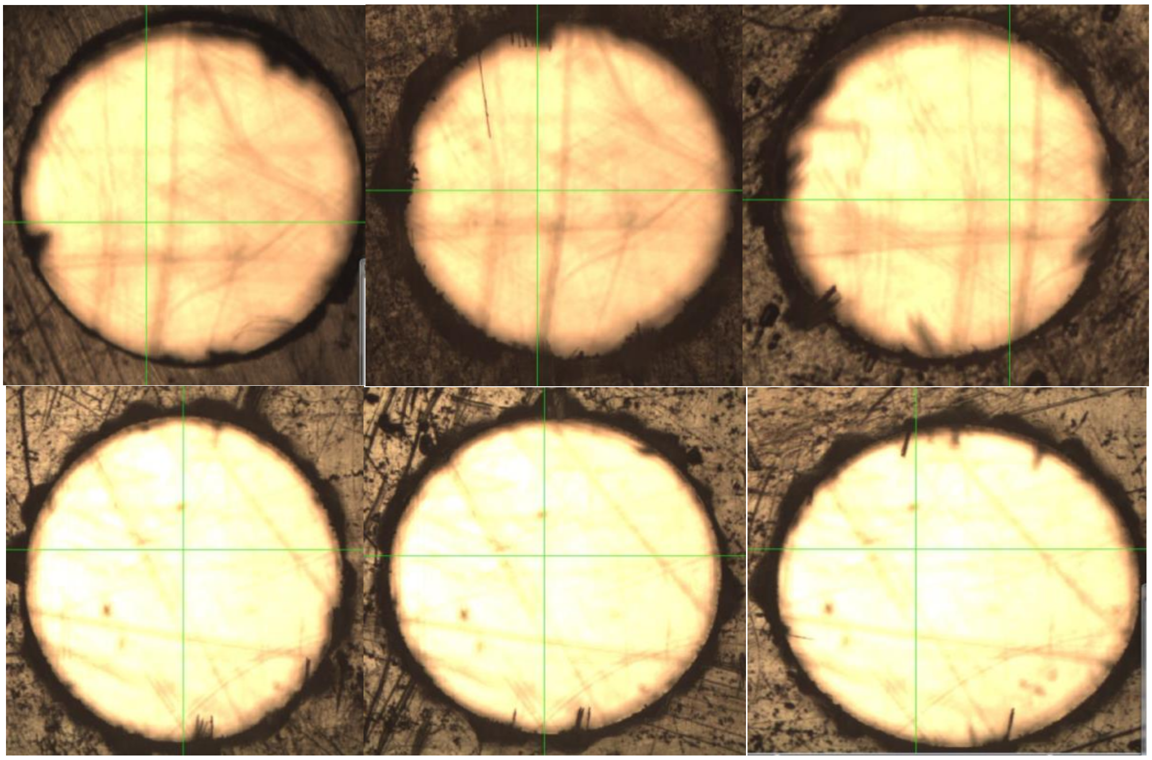

Figure 8 Photograph of circularity observation in CFRP (R2, R17, & R27) & GFRP (R1, R5, & R6) drilling.

5. Result Discussion for GFRP drilling

From the foregoing observations, the value of R-Sq is 98.8% and R-Sq (Adj.) is 95.3 percent on the SN Ratios chart Vs Thickness, Feed, and Speed. This was an acceptable parameter outcome that was quite close.

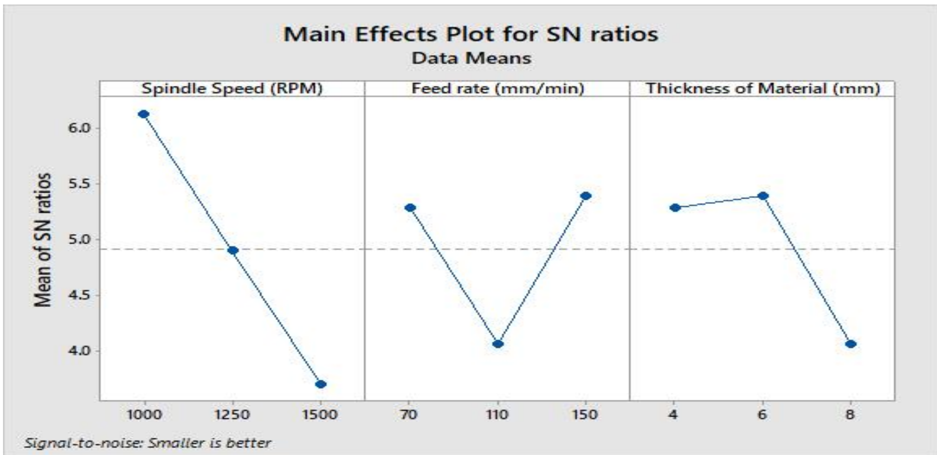

Figure 9 Main effect plot for SN Ratio vs Spindle Speed, Feed, Thickness for Torque of GFRP

Figure 9 depicts the effect of varying thickness, feed, and spindle speed on the SN Ratio for Torque, with a smaller SN Ratio indicating a better result. The signal-to-noise (S/N) ratio for the responses of the three distinct machining parameters is shown in Figure 9. Figure 9 shows how the criteria of a Torque with a higher S/N ratio can be utilised to identify the cutting settings that generate the least torque. Similarly, the S/N ratio findings show that a spindle speed of 1000 rpm, a feed rate of 150 mm/min, and a thickness of 6 mm are the best combinations for achieving the lowest torque. Figure 9 shows that lowering the spindle speed, increasing the feed rate, and lowering the drilling average torque can all help to minimise drilling average torque. Similarly, the S/N ratio findings show that a spindle speed of 1500 rpm, a feed rate of 70 mm/min, and a thickness of 8 mm are the best combinations for achieving the least thrust force. The drilling average force can be reduced by raising the spindle speed, thickness, and decreasing the feed rate, according to the results. Similarly, the S/N ratio findings suggest that the spindle speed of 1500 rpm, feed rate of 150 mm/min, and thickness of 8 mm are the best combinations for achieving the smallest circularity.

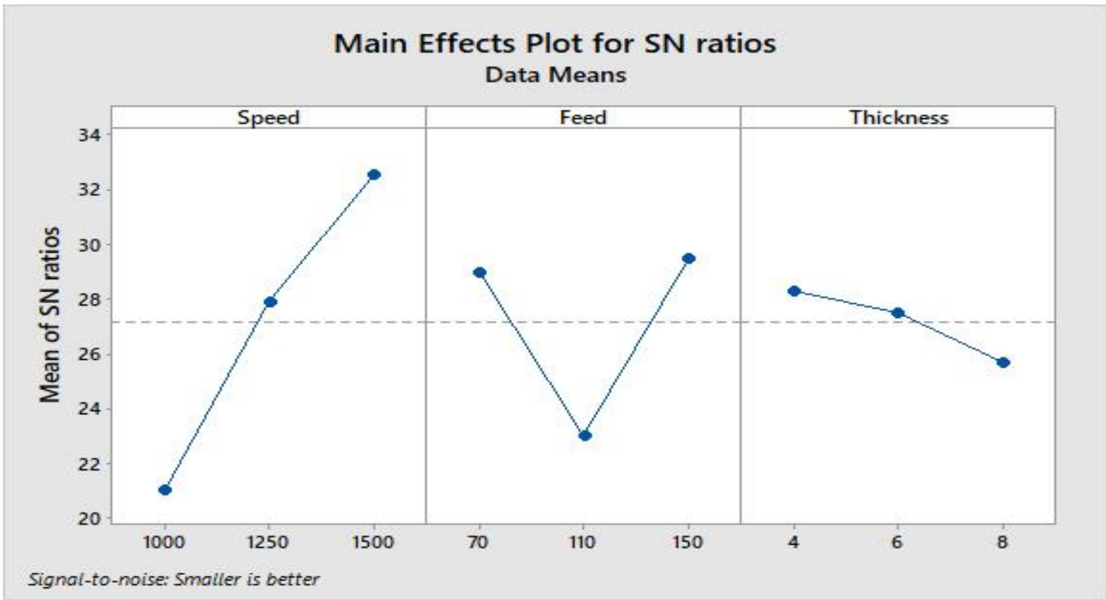

Figure 10 Main effect plot for SN ratios of Circularity

Figure 10 shows how the criteria of circularity with a higher S/N ratio can be utilised to identify the drilling parameters that produce the least amount of circularity. The S/N ratio data also demonstrate that the spindle speed of 1500 rpm, feed rate of 150 mm/min, and thickness of 4 mm were the best combinations for achieving the least circularity. Similarly, the S/N ratio findings show that the spindle speed of 1000 rpm, feed rate of 150 mm/min, and thickness of 6 mm were used to obtain the minimum thrust force. The S/N ratio data also demonstrate that the spindle speed of 1000 rpm, feed rate of 150 mm/min, and thickness of 6 mm were used to generate the least torque.

6. Conclusion

The goal of this research was to find the best drilling settings for CFRP and GFRP materials. Both materials have a wide range of industrial uses. DOE Taguchi's Analysis was used to conduct a comparative evaluation for both materials. The circularity and thrust force are the most significant reactions, while speed and feed are the most significant components in the study, according to the findings. Low speed and high feed are used to increase torque, high speed and low feed are used to increase force, and high speed and high feed are used to increase circularity in GFRP sheet drilling. Similarly, in CFRP sheet drilling, low speed and low feed enhance torque, low speed and moderate feed improve force, and high speed and high feed improve circularity. The rising thickness of the GFRP material has also been noted. The torque is increased, and the force and circularity are minimised; increasing the thickness of CFRP material increases the thrust force and circularity, which results in the bed impact, and moderate thickness results in the average torque.

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