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Analysis of the Influents of Cutting Parameters in Drilling GFRP Composites Using Taguchi Method

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ABSTRACT

Carbon Fiber Reinforced Plastic (CFRP) is widely employed today, mainly in industries, due to its required properties of high corrosion resistance, high strength, and lightweight, this work studies the influence of the cutting parameters on the surface roughness by drilling two types of carbon-fiber-reinforced polymer composite material (CFRP) Composites 0° angle and 90° angle, the investigated of the drilling of CFRP by using an experimental design based on the Taguchi L18 orthogonal array. Spindle speed, feed rate, and tool diameter were the input parameters, and surface roughness was the output. The cutting settings (410, 806, and 1003) rpm and two different HSS tools were employed in the drilling operation of the CFRP composite. The feed rates used were (0.1, 0.2, and 0.3) mm/rev (at 10 and 12 mm in diameter). The Taguchi approach, the cutting speed, feed rate, and tool diameter were optimized to be 1003 rpm spindle speed, 0.1 mm/rev feed rate, and 10 mm, respectively, at a 0° angle, the surface roughness was 2.74 µm, while at a 90° angle, 4.12 µm, surface roughness was created by the Taguchi optimization of the surface for the cutting variables. According to the ANOVA analysis of the surface roughness (Ra) for CFRP/0-angles, The P-value of the factor feed rate was 0.044 less than 0.05, while the p-values of the tool diameter and spindle speed were greater than 0.05. At the CFRP/90-angle, the p-values of the factors feed rate and spindle speed were both less than 0.05, while the p-value of the tool diameter was 0.208.

1. Introduction

Carbon fiber reinforced polymer (CFRP) composite materials are an excellent choice for engineering applications because of their high strength and low specific weight, as well as their resistance to oxidation, high fatigue, toughness, and high temperature wear. and has been employed in numerous current applications, including as automotive, aerospace, and, sports equipment manufacturing [1,2]. Applications for carbon fiber-reinforced polymer (CFRP) composite laminates and nano-polymer composite laminates are based on the potential use of materials with specific properties and ultimate qualities that are not available in any of the raw materials. [3]. The Taguchi method is a technique for designing and analyzing experiments that is systematic. It is an efficient method of producing high-quality products at a low cost. The performance parameters improve with tool life, but decrease with cutting force and surface roughness. [4]. When the feed rate is high, the tool enters the work more quickly, increasing the thrust force. The inner surface is damaged as a result of the rapid penetration. [5,6]. An increase in spindle speed that causes a decrease in surface roughness and an increase in

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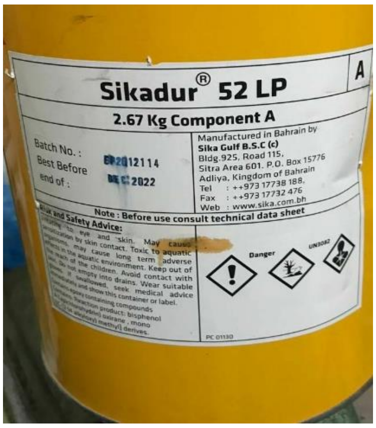
thrust force on a cutting tool. At higher spindle speeds the cutting tool rubs around the hole wall more frequently causing higher distortions that increase the circularity error [7, 8]. Selecting the right factor levels for machining is important as it helps manufacturers to choose the correct conditions for their products to be machined. [9]. Using the response surface methodology, R. M. Singari et al. [10] studied and examined surface roughness in drilling operations, depending on the RSM method, drill diameter, machining surface roughness, torque, and parameter thrust are all optimized. Drilling is guided by the sequence. It was finished using drill bits of various diameters made of HSS. RSM examines the outcome information to determine the ideal drilling conditions. High speed, low feed, and small diameter were found to be the best parameters for thesurface. abrasion, torque, and thrust. Surface roughness analysis was used by S. Shahabaz, N. et al. [11] in the drilling of carbon fiber/epoxy composites. Analysis of variance (ANOVA) was performed utilizing the data of the S/N ratio to identify the relevant cutting parameters on surface roughness. Surface roughness is significantly influenced by the feed rate, spindle speed, and drill diameter. It is clear from the study that the data used to create the main effect plots for S/N ratios for surface roughness in drilling with solid carbide drills show a significant correlation with the ANOVA results. The study "Optimization of milling carbon fiber reinforced plastic using RSM" was conducted by A. M. N. Khairusshima, et al. [12]. The most significant effects of feed rate were found to be on delamination and surface roughness. Higher cutting speed, lower feed rate, and a deeper cut produce lowered surface and decreased delamination factor on CFRP panels. It has been found that the feed rate is the main cutting parameter that significantly affects low surface roughness and the delamination factor. Ranganath, et al. [13] According to the study, the optimal values to reach the lowest value of surface roughness are, drilling parameters of 440 rpm, a tool diameter of 10 mm, and a feeding rate of 0.20 mm/rev. The TAGUCHI research found that feeding was the most important factor, followed by drilling speed and diameter. The current study's objective is to demonstrate the impact of various drill diameters with speed, feeding, and cutting depth variables on the surface roughness of the reinforced fiberglass with a polymer composite site. A fiber layer and a polymer layer are just two of the layers that make up composite materials. Once at an angle and once at a 90-degree angle, these fibers. Kumar et al. [14] observed that the most relevant factor for surface roughness is feed rate, followed by drill diameter, work piece thickness, and cutting speed. The work of Parida et al. [15] demonstrates that the GFRP drilling was done utilizing the response surface technique. The experimental approach and analysis, based on the Taguchi L27 orthogonal array, are developed taking into account the spindle speed, feed rate, and drill bit diameter. The ANOVA result shows that spindle speed is the most important factor. important factor influencing surface roughness, followed by drill bit diameter, with feed being determined to be an inconsequential factor in the study. Sivasankaran et al. [16] show that the surface roughness of the material was heavily influenced by the feed rate and cut depth. As the feed rate and depth of cut increased, the GFRP composite material's surface roughness increased. Ismail et al. [17] discovered that fiber aspect ratios significantly increased both delamination factors and surface roughness, whereas feed rate and cutting speed had the greatest impact on delamination and roughness. Senol and colleagues [18] show the surface roughness and cutting force of a CFRP material milled with many carbide end mills at a 45° fiber orientation angle were investigated. The results showed that as the feed rate was increased, an increase in both surface roughness and cutting forces were noted. Surface quality was improved and delamination was reduced using an uncoated carbide mill. Kilickap et al. [19] Surface roughness increased with higher feed rates and cutting speeds. By drilling GFRP composites with 0°/90° and 45° woven types, respectively, the lowest and maximum surface roughness were observed. Investigations and Taguchi analysis with drilling operations by Rajiv Chaudhary et al. [20] reveal that the cutting settings and tools should be carefully chosen to increase tool life and decrease surface roughness. In this study, experiments on cutting settings were created using the Taguchi method. The researchers altered the cutting parameters during the turning process in order to attain the lowest achievable surface roughness using a variety of mathematical models.

The aim of this study is to determine optimal drilling parameters that result in the lowest possible surface roughness.

2. Experiment

2.1 Materials and procedure

The carbon fiber reinforced polymer (CFRP) was employed in the testing in this study. As indicated in Figure 1, the polymer was made up of two parts: A (epoxy) and B (hardener). Tables 1 and 2 exhibit the polymer's technical and application information.



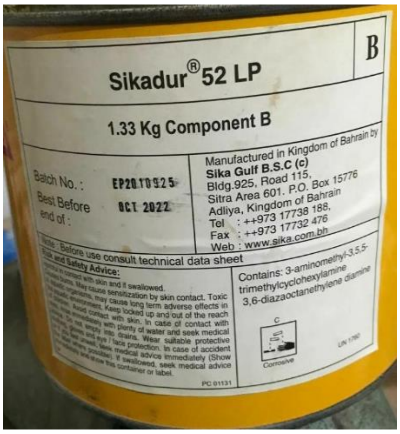


Figure 1. Parts A (Epoxy) and B (hardener)

Table 1: The Mechanical Properties of polymer

Tensile strength	27N/mm^2
Compressive stress	70 N/mm^2

Table 2: Application information of polymer

Application Information	
Mixing Ratio	A: B = weight and volume ratio of 2:1
Consumption	1 kg of sikadur- 52 LP is equal to 1 liter of injection resin consumption
Substrate Temperature	40°C maximum/25°C minimum
Substrate Moisture Content	Dry or damp (dry SSD-saturated surface: No standing water

2.2 Carbon fiber

Carbon fiber weave plain (200g/m^2), as shown in Table 3 and Figure 2.

Table 3: The properties Carbon fiber weave plain (200g/m^2)

Fiber family	HTA40
Filament diameter	$7\mu m$
Tensile strength	4100 Mpa
Tensile modulus	240 Gpa
Elongation	1,7%
Number of Filament	1K

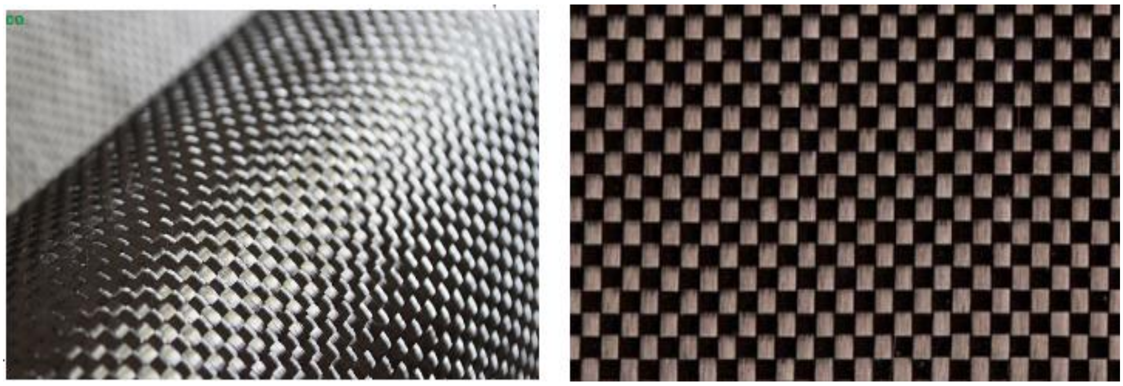


Figure 2. Sample of carbon fiber - weave plain (200g/m^2)

2.2. Specimens preparation

To prepare the specimens in a suitable, clean, and dry container, combine both components: Part A epoxy mixed with Part B hardener in a ratio of 2:1 to get the correct ratio. At least three minutes should be spent slowly mixing with a hand mixer and avoid sucking in air, the carbon fiber-reinforced polymer composite of laminate specimens (CFRP), which was used as a work piece of materials placed in 5 layers, perpendicular to each other (Figures 3 and 4) and cut into rectangular shapes with a dimension of (200×150 ×15) mm; the symbols were manufactured by the layout method. Then repeat the process by adding [5] pieces of carbon fiber to a mold with dimensions of [200*150 mm]. Then add a small amount of the mixture of polymer over the carbon piece and distribute it along the area of the carbon fibers. The samples consist of 42% epoxy and 58% long carbon fibers.

Figure 3. Sample of carbon fiber with angle 0

Figure 4. Sample of carbon fiber with angle 90

The cutting material in this study was an HSS tool (DIN 338) with 10- and 12-mm diameters and a 30° helix angle. The cutting tools had a point angle of 140o and a hardness rating of 65 HRC.

2.3 CNC Drilling machine

The CNC drilling machine Model SSB 40 XN was used, and the spindle speed, power, and feed rate were 1/min 75-2.020, 1.5 (kW), and 0.4 mm/rev, respectively. the work table's highest feed rate settings on the X, Y, and Z axes as illustrated in Fig. 5.

Figure 5. Drilling machine (Model SSB 40)

The carbon fiber reinforced plastic (CFRP) samples were drilled at 0° and 90° angles using an HSS tool with 10mm and 12mm diameters and 18 holes per sample. The drilling procedure was used, for the first three holes, a 410-rpm spindle speed was used, with feeds of 0.1, 0.2, and 0.3. The second of three holes, which rotate at a speed of 806 rpm, receives a feed of 0.1, 0.2, and 0.3. Drill the third three holes with feeds of 0.1, 0.2, and 0.3 and a speed of up to 1003 rpm, with a spacing of 15 (mm) between the axes of each hole on the sample, as shown in Figs. 6 and 7.

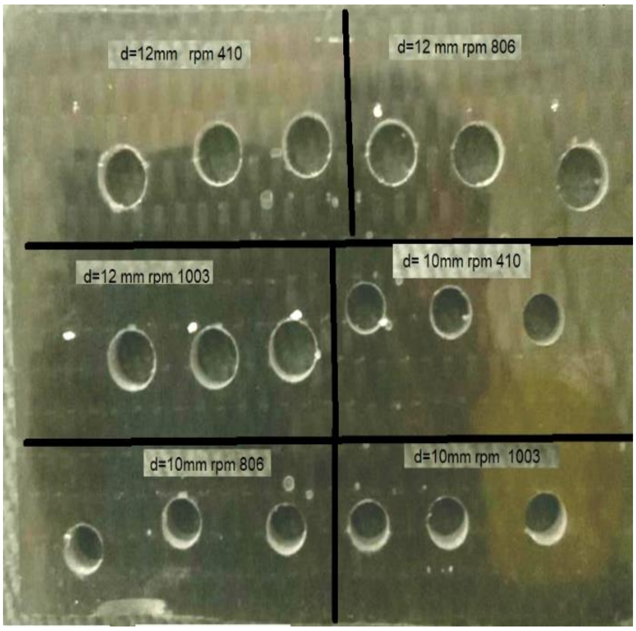


Figure 6. Carbon fiber-reinforced polymer (CFRP) with 0 angle

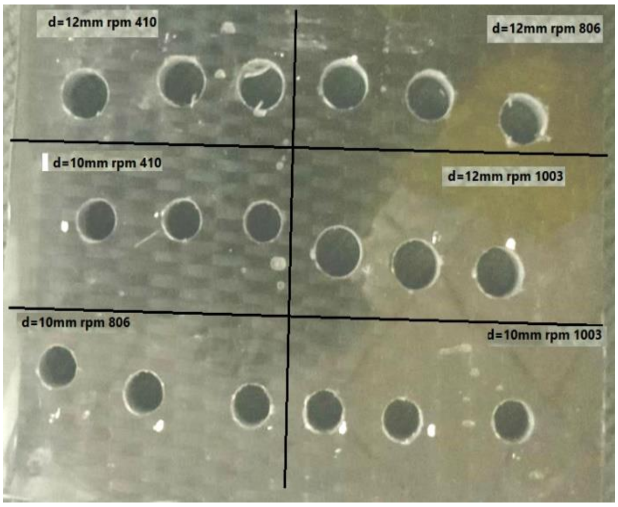


Figure 7. Carbon fiber-reinforced polymer (CFRP) with 90 angle

2.4 The surface roughness

The surface finish was tested by using the measurement device (Mahr federal pocket surf), as illustrated in Figure 8, is typically based on a sensory measurement principle. The surface is measured by moving a stylus across it; as the stylus moves up and down, a transducer converts the movements into a signal, which is then transformed into a roughness number and, in most cases, a visually displayed profile.

Figure 8. Surface device

2.5 Experimental study

2.5.1 Design of experiments

In the Taguchi method, a special design of orthogonal arrays was used to investigate the entire parameter space with a limited number of experiments. The experimental data is then converted into signal-to-noise ratios (S/N), which represent the experimental results. The desired value was referred to as the signal, while the undesirable value was referred to as the noise. The S/N ratio was created as a performance measure for developing noise-resistant products and processes. [15] S/N values were calculated with the smaller-the-better Equation 1. [21] as follows Minitab 14 was calculated using the assumption that the smaller number, the better. because the stresses due to the parameters affecting the cutting force and surface roughness were desired at the lowest level. The best quality features are always created with the least amount of variation when the process parameter with the highest S/N ratio is used.

$$S/_{N} = -10\ Log\ (\tfrac{1}{n}\sum y_i^2\ ) \qquad 1$$

Y = the performance-characteristic value,
n = the number of Y values

The L18 Taguchi orthogonal array was chosen based on Taguchi's design of experiments for parameters and levels.as shown in table 4.

Table 4: Input Levels and parameters

Input parameters	**Levels**		
	Level 1	**Level 2**	**Level 3**
Speed of cutting (rpm)	410	806	1003
Feeding rate (mm/rev)	0.1	0,2	0,3
Drill diameter (mm)	10	12	--------

As shown in table 4, three drilling parameters were used as control factors in this study. The L18 Taguchi orthogonal array was chosen for three parameters, cutting speed and feed rate at three levels, and drill diameters at two levels, based on Taguchi's design of experiments, as shown in Figures 7 and 8.

3. Result and discussion

3.1 Influence of the drilling parameters on surface roughness

The Taguchi experimental design was used to determine the effect of (cutting speed, feed rate, and tool diameter) on surface roughness. using two plates of carbon fiber reinforced polymer workpiece (CFRP) (90o and 0o angles) with three factors (two factors: cutting speed and feed with 3 levels: 410, 806, 1003 (r,p.m.) and 0.1, 0.2, 0.3 f (mm/rev) respectively and one factor with tool diameter with 2 levels, 10 (mm), 12 (mm) at L18.

Table 5 and Figures (9 -10) indicate the impacts of cutting parameters on surface roughness (CFRP) at 0 - angles of means, and S/N ratio, with the results of the 3D response plots as shown in the figure 11. Surface roughness increases with feed rate while cutting speed decreases with the surface roughened. The Taguchi optimization for the surface roughness for the cutting parameters was obtained at 2.74 (µm) surface roughness, which was found with 0° angle, 1003 rpm, feed rate of 0.1 (mm/rev), and 10 mm, diameter. It was assumed that the highest S/N ratio of each parameter showed the optimum level of that parameter.

Table 5: Cutting parameters with surface roughness for CFRP / 0º- angles w. p.

Runs/ 0 angle	Diameter (mm)	r.p.m	Feed (mm/rev)	Ra (μm)	SNRA	MEAN
1	10	410	0.1	6.92	-14.5508	5.34
2	10	410	0.2	4.42	-15.5775	6.01
3	10	410	0.3	4.94	-15.8198	6.18
4	10	806	0.1	4.91	-14.7120	5.44
5	10	806	0.2	5.05	-15.2084	5.76
6	10	806	0.3	6.92	-13.2552	4.60
7	10	1003	0.1	2.74	-12.1491	4.05
8	10	1003	0.2	3.01	-12.2979	4.12
9	10	1003	0.3	3.67	-15.2386	5.78
10	12	410	0.1	5.78	-15.6781	6.08
11	12	410	0.2	5.79	-14.5671	5.35
12	12	410	0.3	5.92	-16.0828	6.37
13	12	806	0.1	5.14	-14.5671	5.35
14	12	806	0.2	6.24	-16.0828	6.37
15	12	806	0.3	5.76	-15.4317	5.91
16	12	1003	0.1	3.01	-12.6694	4.30
17	12	1003	0.2	4.27	-13.2363	4.59
18	12	1003	0.3	6.19	-15.6781	6.08

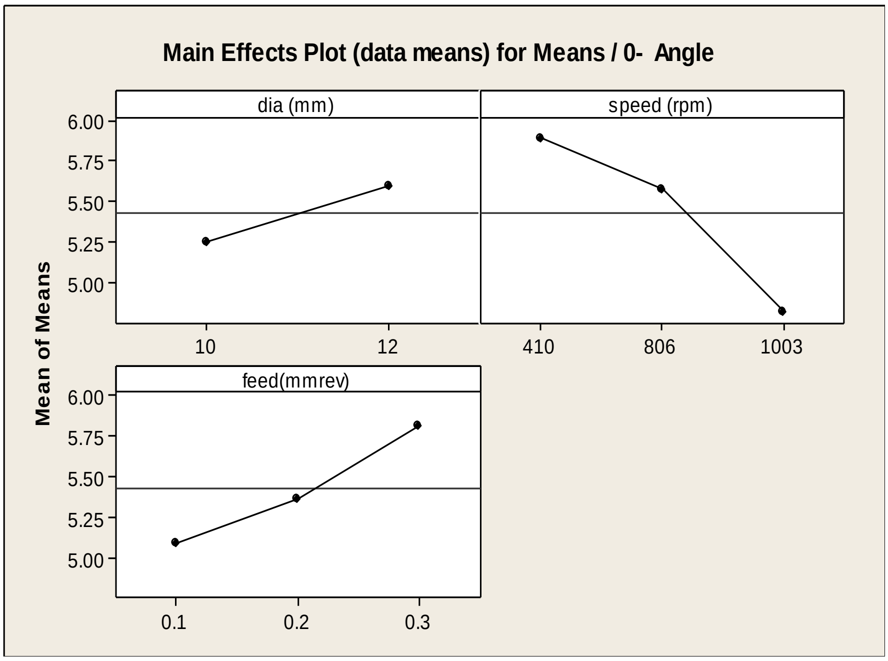


Figure 9. Main cutting parameter influence on surface roughness for CFRP / 0º- angles w. p.

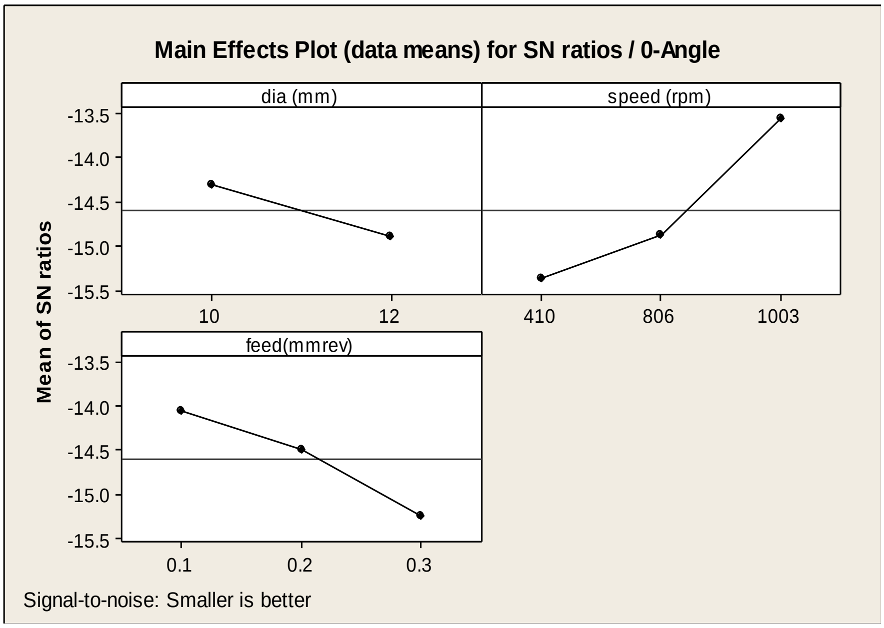


Figure 10. S/N ratio cutting parameter influence on surface roughness for CFRP / 0^o- angles w. p.

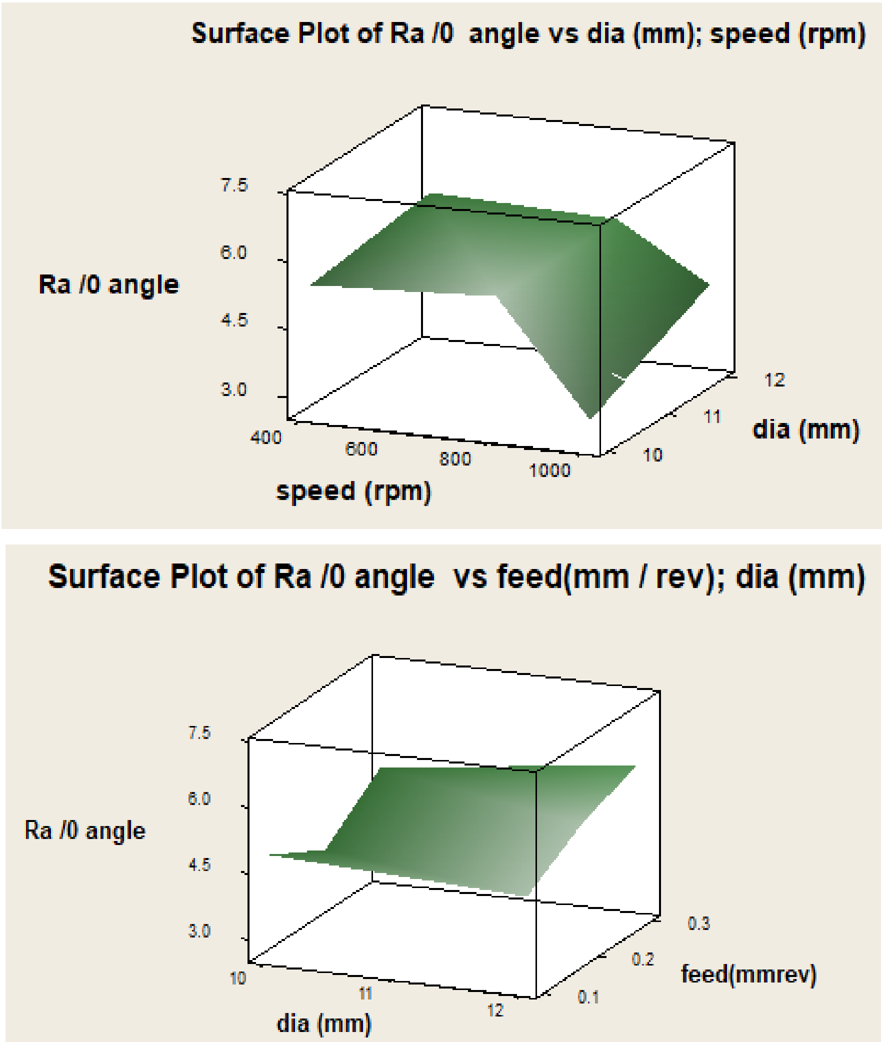


Figure 11. Effect of cutting parameter on surface roughness for CFRP / 0^o- angles w. p.

Cutting speed and feed rate are important factors in determining the surface of roughness (CFRP) at 90o- angles with means and S/N ratio. Table 6 and Figures 12 and 13 with the results of the 3D response plots as shown in the figure 14 illustrate the influences of these parameters on the Surface of Roughness (SOR) for a robust design by Taguchi et al. The results show that cutting speed decreases surface roughness, while feed rate increases surface roughness. The Taguchi optimization for the surface roughness for the cutting parameters was obtained at 4.12 Ra (µm) surface roughness, which was found with a 90° angle, 1003 rpm, feed rate 0.1 (mm/rev), with 10 mm diameter. It was assumed that the highest S/N ratio of each parameter showed the optimum level of that parameter, also according to the observation of the 3D response plots in figure 14, the minimum surface roughness may be obtained with the smallest drill diameter.

Table 6. Cutting parameters with surface roughness for CFRP / 90º- angles w. p

Runs/ 90 angle	Diameter (mm)	r.p.m	Feed (mm/min)	Ra (µm)	SNRA1	MEAN1
19	10	410	0.1	5.34	-14.5508-	5.34
20	10	410	0.2	6.01	-15.5775	6.01
21	10	410	0.3	6.18	-15.8198	6.18
22	10	806	0.1	5.44	-14.7120	5.44
23	10	806	0.2	5.76	-15.2084	5.76
24	10	806	0.3	4.60	-13.2552	4.60
25	10	1003	0.1	4.05	-12.1491	4.05
26	10	1003	0.2	4.12	-12.2979	4.12
27	10	1003	0.3	5.78	-15.2386	5.78
28	12	410	0.1	6.08	-15.6781	6.08
29	12	410	0.2	5.35	-14.5671	5.35
30	12	410	0.3	6.37	-16.0828	6.37
31	12	806	0.1	5.35	-14.5671	5.35
32	12	806	0.2	6.37	-16.0828	6.37
33	12	806	0.3	5.91	-15.4317	5.91
34	12	1003	0.1	4.30	-12.6694	4.30
35	12	1003	0.2	4.59	-13.2363	4.59
36	10	1500	0.3	6.08	-15.6781	6.08

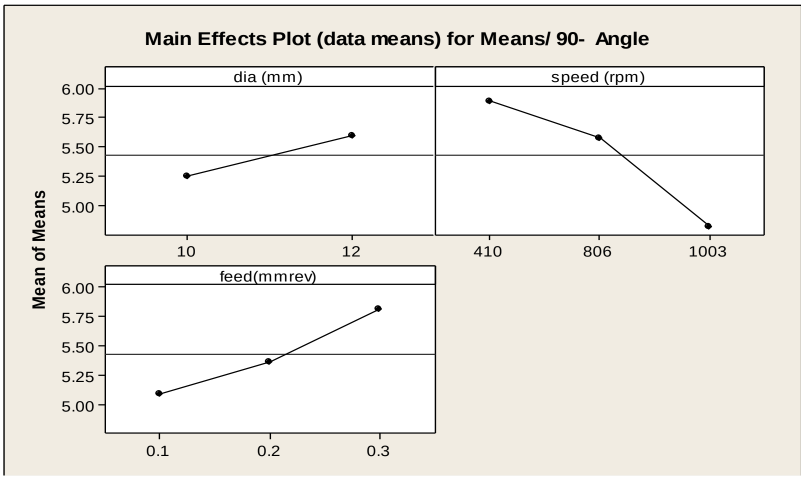


Figure 12. Main cutting parameter influence on surface roughness for CFRP / 90º- angles w. p.

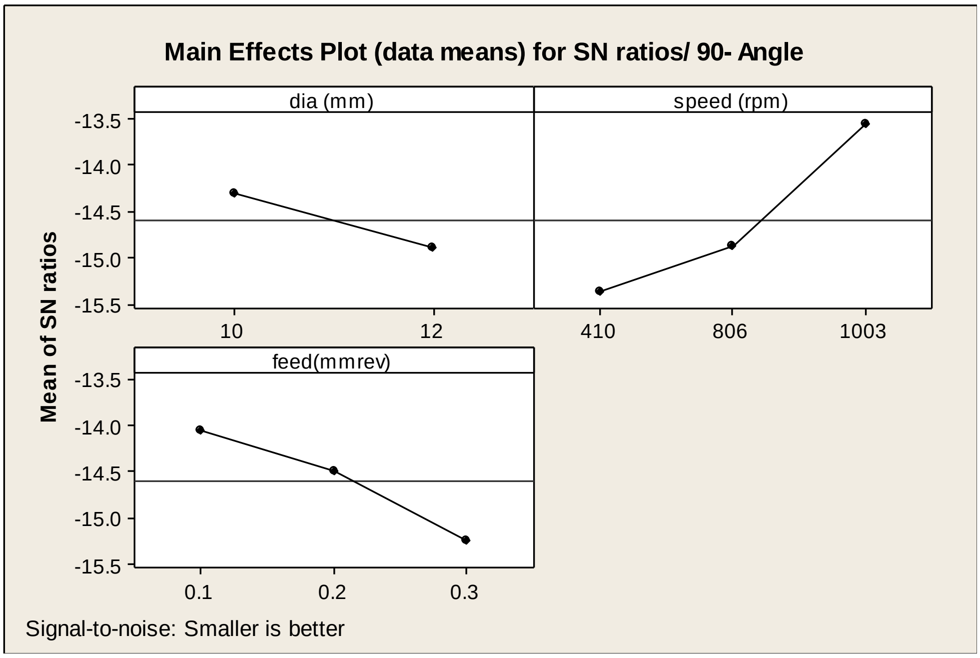


Figure 13. S/N ratio cutting parameter influence on surface roughness for CFRP / 90°- angles w. p.

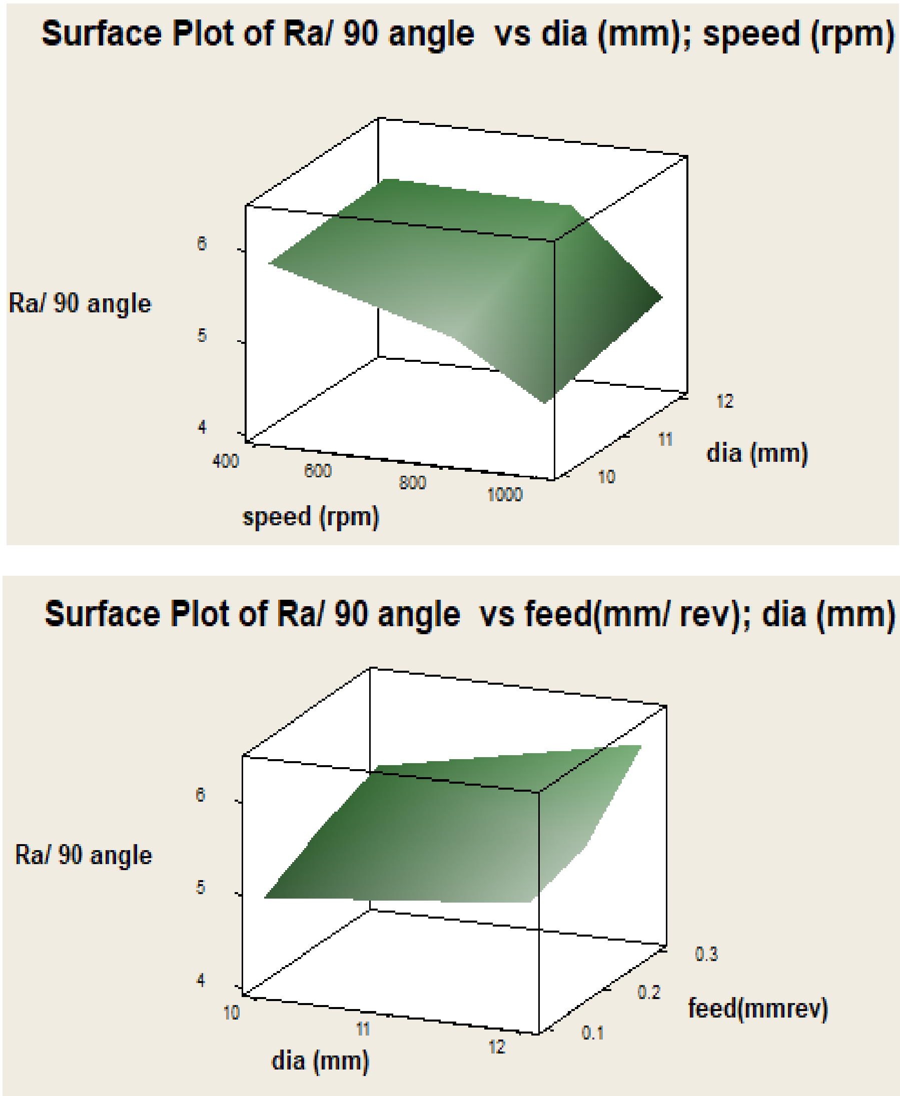


Figure 14. Effect of cutting parameter on surface roughness for CFRP / 90°- angles w. p.

3.2 Analysis of ANOVA

The ANOVA analysis of surface roughness (Ra) for CFRP / 0o- and 90 angles w. p. is shown in Tables 7 and 8, respectively. At CFRP / 0-angles ANOVA analysis it was shown that the R-Sq is 90.64%. and the feed rate is more significant than spindle speed and tool diameter, with the P-value of the factor feed rate being 0.044 less than 0.05, while the p-values of the tool diameter and spindle speed being 0.485 and 0. 624 respectively more than 0.05. At CFRP / 90- angle, the R-Sq is 89.19 %. and the p-values of the factors feed rate and spindle speed are 0.007 and 0.022, respectively, less than 0.05, while the p-value of the tool diameter is 0.208 greater than 0.05, indicating that feed rate was more significant than spindle speed and tool diameter. According to the F- value for feed rate for CFRP/90o, feed rate has a larger impact on surface roughness than CFRP/0o, the normal probability plot is used to confirm the assumption of normality. Figures 15 and 16 display the normal probabilities of residuals at 0° and 90° angles, respectively. This information is used to validate the assumption of normality. The data are approximately distributed in a straight line. It can be inferred that the data are regularly distributed as a result.

Table 7. ANOVA results of surface roughness /0^0 angle

	Cutting parameters(mm)	Degree of freedom	The sequential sum of squares	Means of squares	F-Value	P-value	R-Sq
1	Tool diameter	1	2.9363	2.9363	0.72	0.485	90.64%
2	Spindle speed (rpm)	2	4.8878	2.4439	0.60	0.624	
3	feed (mm/rev)	2	4.2907	2.1454	5.51	0.044	

Table 8: ANOVA results of surface roughness /90^0 angle

	Cutting parameters	Degree of freedom	The sequential sum of squares	Means of squares	F- value	P-value	R-Sq
1	Tool diameter	1	0.1250	0.1250	3.37	0.208	89.19%
2	Spindle speed	2	3.2452	1.6226	43.78	0.022	
3	Feed rate	2	4.4581	2.2290	12.43	0.007	

S = 0.623908 R-Sq = 90.64% R-Sq(adj) = 73.49%

S = 0.423471 R-Sq = 89.19% R-Sq(adj) = 69.38%

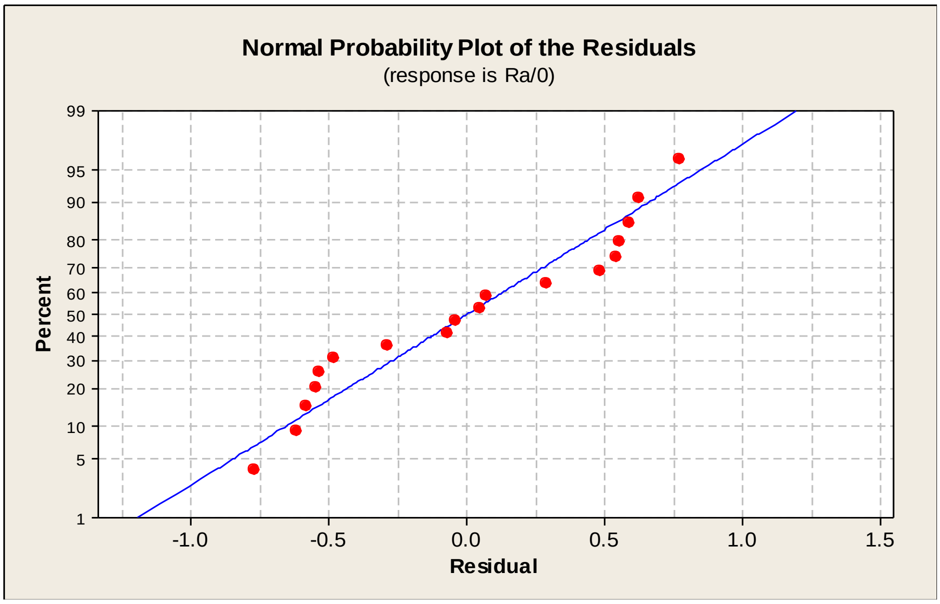


Figure 15. The Normal Probability plot of residuals at 0° angle

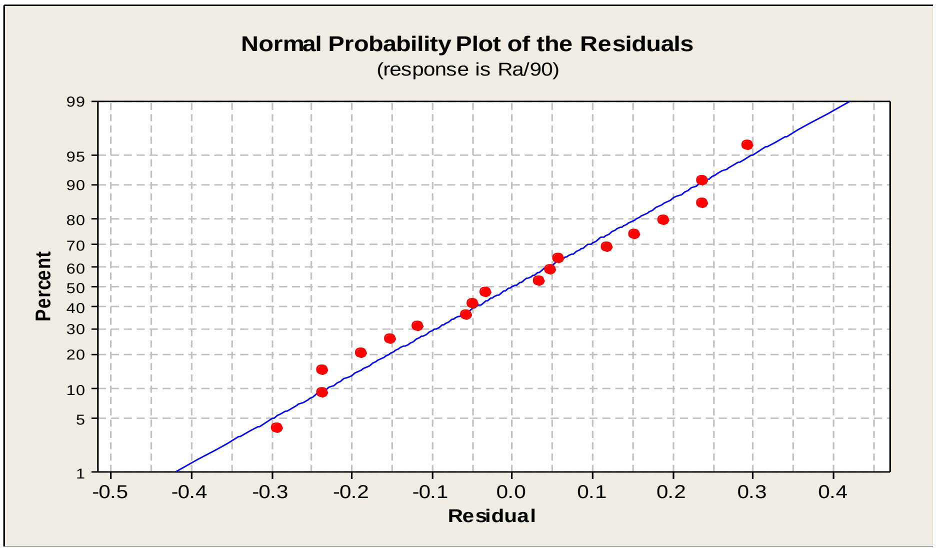


Figure 16. The Normal Probability plot of residuals at 90° angle

4. Conclusion

The Taguchi robust design L18 orthogonal array was applied to evaluate the effects of tool diameter, feed rate and cutting speed, on surface roughness of CFRP / 90 and 0 angles w. p, and the following conclusion can be got from the current work.

- The spindle speed, feed rate, and tool diameter were optimized using the Taguchi method to be 1003 rpm spindle speed, 0.1 mm/rev feed rate, and 10 mm, respectively.
- As a result of Taguchi optimization for the cutting parameters, the surface roughness was 2.74 µm at a 0° angle and 4.12 µm at a 90° angle.
- Surface roughness increased with increasing feed rate and then tool diameter for two types of CFRP.
- Surface roughness increased as spindle speed decreased.
- The ANOVA analysis of surface roughness (Ra) for CFRP/0°-angles, the R-Sq is 90.64%. The P-value of the factor feed rate was 0.044 less than 0.05, while the p-values of the tool diameter and spindle speed were greater than 0.05.
- The R-Sq at CFRP/90^{ol}-angle was 89.19%. Similarly, the p-values of the factors feed

rate and spindle speed were both less than 0.05, while the p-value of the tool diameter was 0.208, greater than 0.05

- The feed rate is more significant than the spindle speed and tool diameter.
- • The F-value for the feed rate at the CFRP/90o was higher than the F-value at the CFRP/0o, showing that the feed rate had the largest impact on surface roughness.
- The main effect plots and interaction effects between parameters were analyzed using the MINITAB 14 data and conclusions were drawn.

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