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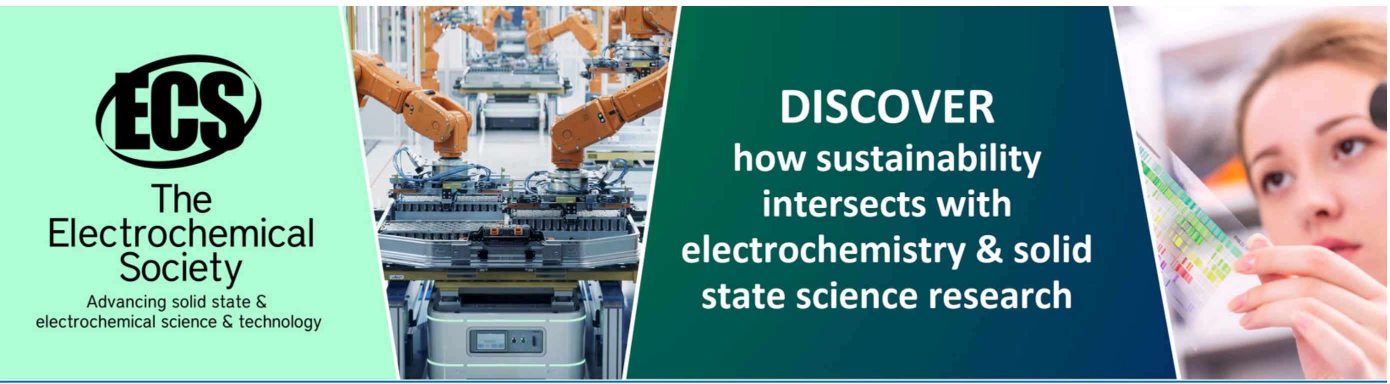


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# Analysis and modelling of surface roughness in milling of JFRP composite using central composite design

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**Abstract.** Nowadays, the JFRP composite is known as an eco-friendly, cost-effective, lightweight, higher stiffness product, and demand for this composite is increasing tremendously in various applications like automotive, aerospace, marine, and domestic upholstery. In order to achieve the required shape and design of this composite, machining is essential during the assembly stage. Thus, machining arises some difficulties in where surface roughness is one of the major drawbacks during machining of the milling process. The cutting parameter of machining influences the output performance of the product. The main purpose of this study is to find out the effect of milling parameters such as feed rate, spindle speed, depth of cut on the output responses like surface roughness, which generates during milling on JFRP composite. The machining was done by using a solid carbide cutting tool of 8 mm width and the experiments were conducted according to the Central Composite Design (CCD). It was found that whenever the spindle speed increases from 671.57 to 6328.43 rev/min then the Surface roughness decreases 18.58%. On the contrary, Surface roughness increased by 31.22% due to the increase in feed rate from 108.58 to 391.42 mm/min. A mathematical model was also developed in this study to correlate the milling parameters with the output parameter of the Surface roughness. It was found that the feed rate is the most significant factor to affects the Surface roughness. Based on the RSM, the predicted optimized input parameter were spindle speed 4293.8 rev/min, feed rate 1.50 mm/min, and depth of cut 1 mm in where Surface roughness would be lower (1.188 μm).

## 1. Introduction
There are momentous importance and request for natural composite materials such as Jute Fibre Reinforced Polymer (JFRP) in the industrial field. Nowadays, the application of this composite is being used in aerospace, automotive, marine, domestic upholstery, and sports [1]. The mechanical properties of JFRP are high comparing to Hemp fibre reinforcement polymer (HFRP), Banana fibre reinforcement

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polymer (BFRP), Kenaf fibre reinforcement polymer (KFRP) [2]. The high impact of properties has made JFRP an auxiliary for conventional material. JFRP parts are formed as near net shape and machining operation can remove the fibre [3]. However, machining processes such as milling, drilling, slotting, are needed to give the desired shape of JFRP panels.

Composite is known as the mix of two or additional parts that are physically bonded together. Thus, a material having two or more phases and properties are improved that may be considered a composite material [3-4]. Jute fibre reinforcement polymer (JFRP) Structure is one of the examples of composite material. Jute fibre reinforced polymer is used in where the eco-friendly product is needed even though the production can be expensive but commonly used in a specific place wherever high strength to weight ratio and rigidity is required such as automotive, civil engineering, sports, and other technical applications [5].

Jute fibre has some natural benefits like higher strength, higher modulus silky, fire resistance, low extensibility. Mohanty and Misra [6] have studied the jute-glass sandwich composite to measure the flexural strength and moisture absorption. The findings indicated that the moisture absorption is reduced in jute fiber due to the hybrid composite.

Jute epoxy composite is consisting of high structural stability, high stiffness, good toughness, and corrosion resistance [7]. Jute fiber has more cellulose percentage comparing to kenaf, hemp, ramie, sisal due to this reason the composite strength is also higher, and a combination of other properties is a large number [8].

Currently, the manufacturing process of JFRP has not required too many finishing operations. The composite is formed like near net shape assembly. However, some of the machining operations are used such as drilling is used to make a hole perfectly, milling is used to remove material from the surface, trimming is used to finalize the parts, slotting is to make pieces in perfect shape [9]. The final operation is critical due to the product quality depend on it and any defects may consequence in the whole part. To avoid surface roughness, surface damage, delamination several aspects of machining performance should be considered.

The machining process of JFRP depends on the cutting factors such as spindle speed, feed rate, depth of cut in order to escape machining defects like delamination and surface roughness. Both of these machining problems may be the cause of product rejection. During machining, the higher cutting speed generates higher temperatures surrounding the cutting tool which affects the quality of finished products [10]. Therefore, numerous investigations and experimental designs need to be accompanied to find out the suitable cutting parameters in the milling process of JFRP. In machining certain cutting parameters should be considered to run the machine. Actually, the surface finish is affected by a large number of factors but spindle speed, feed rate, depth of cut has a pronounced effect. To achieve less surface roughness with a higher standard, perfect machining parameters for machining must have to be chosen. It is expected from this research that an optimized solution will come out to adopt JFRP machining for better performance.

**Nomenclature**

| | |
|---|---|
| BFRP | Banana Fiber Reinforcement Polymer |
| RSM | Response Surface Methodology |
| CCD | Central Composite Design |
| HFRP | Hemp Fiber Reinforcement Polymer |
| KFRP | Kenaf Fiber Reinforcement Polymer |
| JFRP | Jute Fiber Reinforcement Polymer |

## 2. Materials and Methods

The JFRP panel of different compositions was used to conduct the machining process. The composite panel was made according to the hand's lay-up technique and the reinforcement percentage was 60%

and the matrix material 40%. The composite panel was organized into five-layer to form 5 mm thickness and the dimension of the panel was 5mm x 200 mm x 200 (Figure 1). The milling process was continued by using an uncoated carbide cutting tool (8.0 mm diameter). The cutting tool has an OAL (overall length) of 60 mm and a helix angle of 30º with two sharp flutes (Figure 2). A very sophisticated CNC machine was used whose brand name is DECKEL MAHO-DMU 35M and the machine is consisting of 7.5 KW spindle power with a high spindle speed of 12000 rpm. The machining was continued until the tool wear reaches 0.3 mm according to ISO:1989 standard. During machining, the mechanical force was imposed that's why the composite panel was tightened enough on an Aluminium plate with different shapes of screws and supporting tools. The method is known as the clamping method (Figure 3). Surface roughness was measured from the cutting line under the Veeco Wyko optical profiling machine (Figure 4).

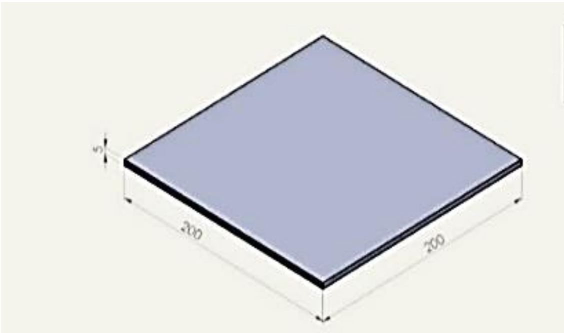



**Figure 1.** Dimension of JFRP panel

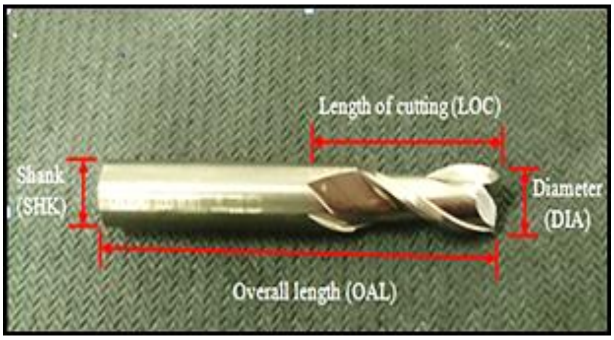



**Figure 2.** Uncoated carbide cutting tool

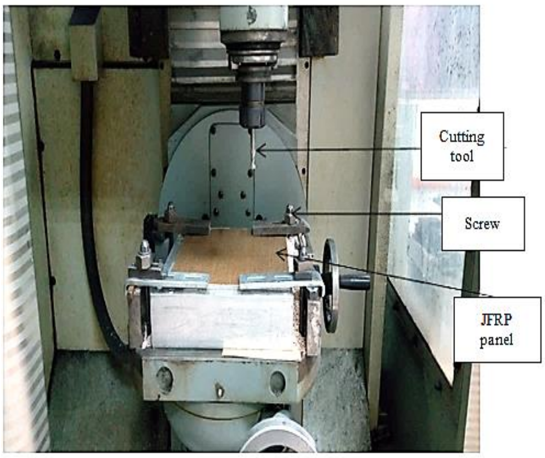



**Figure 3.** Machining set up

**Figure 4.** Optical Profiling Microscope

*2.1. Design of machining Experiments*

The lower and higher value of cutting parameters is shown in (Table 1). Response surface methodology is applied to analyze the dataset which is produced by DOE (Design of experiment). 15 experiments were provided by CCD by selecting a small type in the Design Expert 10 software.

**Table 1.** Range of cutting parameters [3]

| Input parameter | Lowest | Highest |
|---|---|---|
| A. Cutting Tool speed, rpm | 1500 | 5500 |
| B. Machining Feed rate (mm/min) | 150 | 350 |
| C. Depth of cut in composite panel (mm) | 1.0 | 2.0 |

## 3. Results and Discussion

### *3.1. Effect of input parameter on Surface Roughness*

A pertinent parameter of machining JFRP is Surface roughness. Table 2 tabulates values of surface roughness for the respective cutting parameters. It is of paramount importance to measure surface roughness for the produced goods to be accepted. It varies with the changes of input parameters and from the central composite design, it can be explained the most significant cutting factors which can be optimized through optimization of the input and output responses.

**Table 2.** Output responses of Surface roughness (Ra)

| Run | Input Variables | | | Response |
|---|---|---|---|---|
| | Spindle Speed (rev/min) | Feed Rate (mm/min) | Depth of Cut (mm) | (Ra) |
| 1 | 3500.00 | 250.00 | 1.50 | 2.19 |
| 2 | 6328.43 | 250.00 | 1.50 | 1.56 |
| 3 | 3500.00 | 250.00 | 1.50 | 2.22 |
| 4 | 3500.00 | 250.00 | 1.50 | 2.19 |
| 5 | 3500.00 | 391.42 | 1.50 | 2.69 |
| 6 | 3500.00 | 250.00 | 0.79 | 2.39 |
| 7 | 5500.00 | 150.00 | 2.00 | 2.15 |
| 8 | 3500.00 | 250.00 | 1.50 | 2.2 |
| 9 | 3500.00 | 250.00 | 2.21 | 2.15 |
| 10 | 3500.00 | 108.58 | 1.50 | 1.85 |
| 11 | 1500.00 | 350.00 | 2.00 | 2.11 |
| 12 | 1500.00 | 150.00 | 1.00 | 1.96 |
| 13 | 3500.00 | 250.00 | 1.50 | 2.02 |
| 14 | 5500.00 | 350.00 | 1.00 | 2.43 |
| 15 | 671.57 | 250.00 | 1.50 | 2.69 |

### *3.2. Spindle speed effect on Ra*

The histogram in (Figure 5) shows the data for Surface roughness at a spindle speed of 671.57, 3500, and 6328.43 rev/min with a depth of cut 1.50 mm and feed rate 250 mm/min. It could be observed that surface roughness was decreasing whenever the spindle speed increased from 671.57 to 6328.43 rev/min. It also can be observed that the spindle speed 671.57 and 6328.43 rev/min gives the surface roughness 2.69 and 1.57 µm. It exhibits the decline of surface roughness by 18.58% for the increment of spindle speed from 671.57 to 3500 rev/min and as the spindle speed increased from 3500 to 6328.43 rev/min then the surface roughness decreased by 28.3%. This phenomenon is due to high spindle speed generates high temperatures surrounding the cutting tool and burn the small fiber and matrix which creates a smooth surface [11].

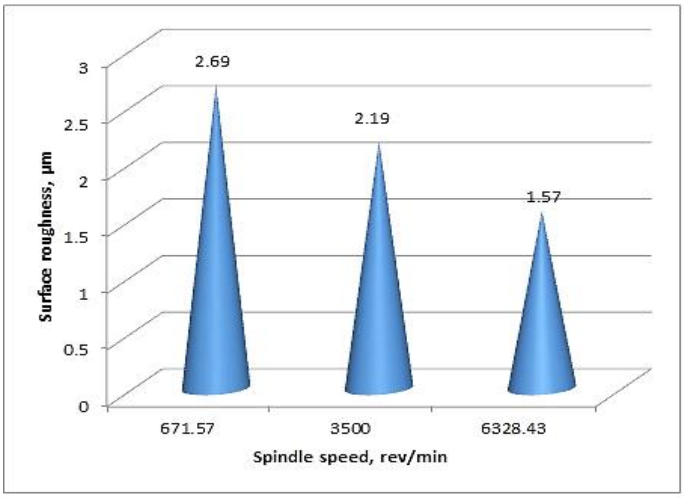
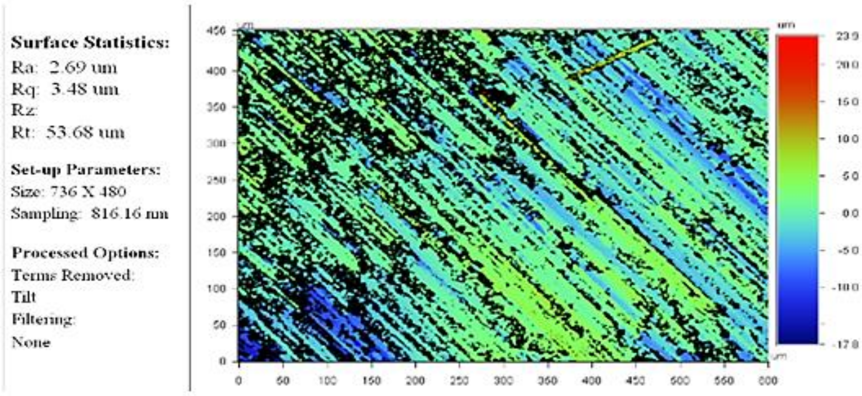
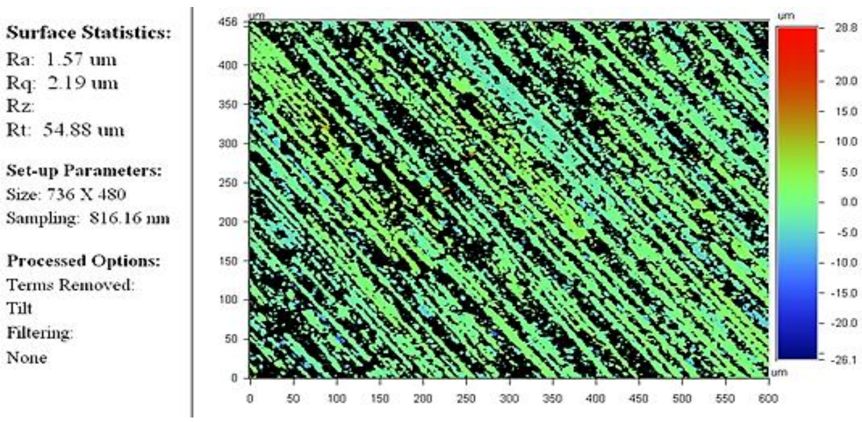



**Figure 5.** Surface roughness of JFRP at different spindle speeds (FR = 250 mm/min and DoC = 1.50mm)




(a) Surface roughness at lower spindle speed (671.57 rev/min)




(b) Surface roughness at higher spindle speed (6328.43 rev/min)

**Figure 6.** Surface roughness at various spindle speed

Figure 6 (a) (b) shows the topography of JFRP under Veeco Wyco Optical Profiling System Microscope for various spindle speeds with a feed rate of 150 mm/min and depth of cut 1.50 mm. Figure 6 (a) illustrates, at a spindle speed of 671.57 rev/min, the wavelength of the green region to the blue region is higher (2.69 µm) which indicates high surface roughness. As the spindle speed increased from 671.57 to 6328.43 rev/min (Figure 6 (b)) then the wavelength of the green region to blue region is lower (1.57 µm) compare to (Figure 6 (a)), which means the surface roughness has become smoother. According to Davim [12] due to the heat generated, the surface of the composite became softened as the spindle speed increased. As a result, the less deformed and uncut fibre could rapidly and easily leave the material, thus leading to a good surface finish. could rapidly and easily leave the material, thus leading to a good surface finish.

### *3.3. Feed rate effect on Ra*

Figure 7 illustrates that the feed rate changes from 108.58 mm/min to 391.42 mm/min with a constant spindle and depth of cut. It can be concluded that the surface roughness was increasing whenever the feed rate increased from 108.58 to 391.42 mm/min. Moreover, the surface roughness increased by 31.22% as the feed rate is raised from 108.58 to 250 mm/min. Furthermore, for a rise from 250 to 391.42 mm/min the surface roughness also increased by 18.58%. It also can be observed that the growth of feed rate from 108.58 to 391.42 mm/min results in the raising of surface roughness was 1.85 and 2.69 µm. The surface roughness rose as much as 31.22% because of the rise in feed rate from 108.58 to 391.42 mm/min. This phenomenon is due to the increased feed rate resulting in high levels of chatter, thus producing unfinished machining with an accelerated traverse of the cutting tool, leading to a higher surface roughness [13].

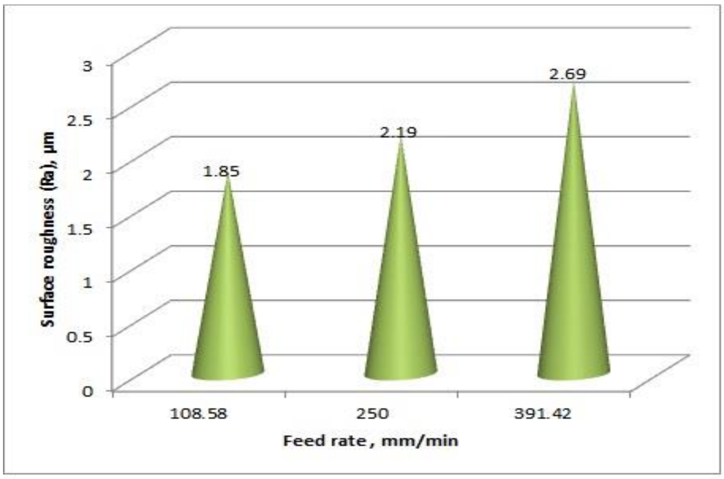
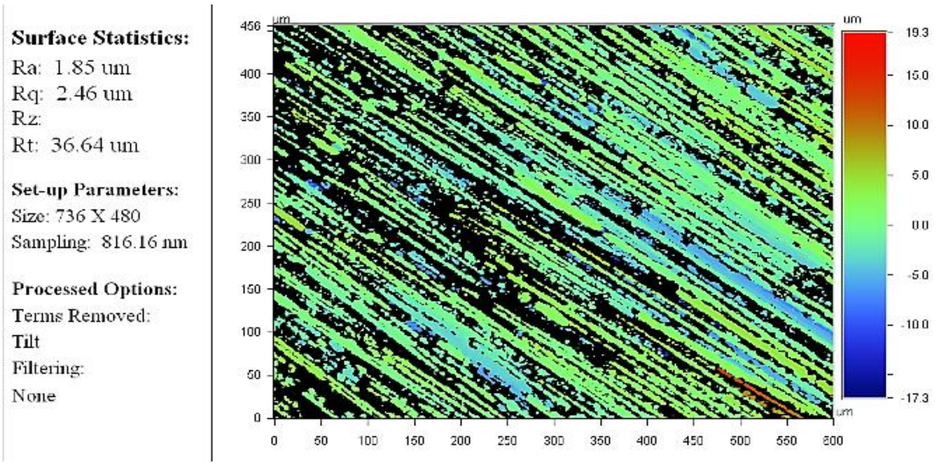
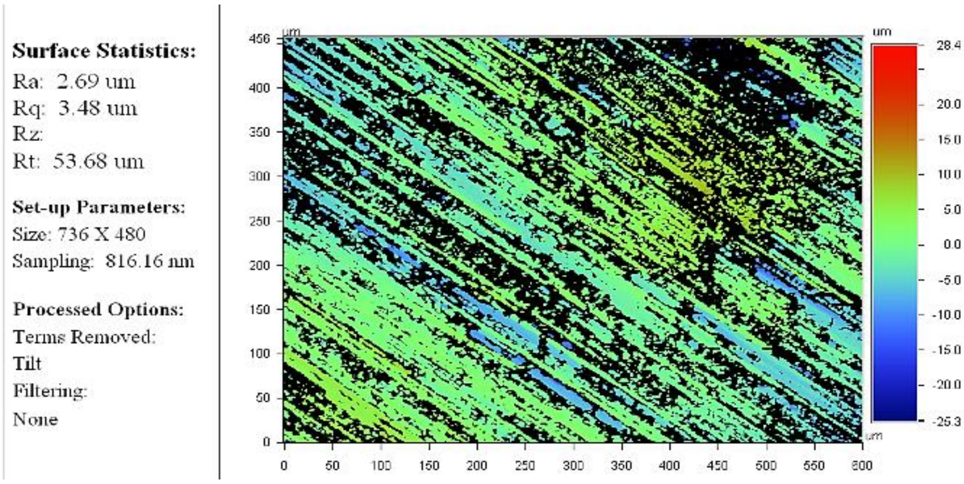



**Figure 7.** Surface roughness of JFRP at various feed rate (SS = 3500 rev/min and DoC = 1.50 mm)

Figure 8 (a) (b) illustrates the surface topography of JFRP under the same Microscope for various feed rates with spindle speed 3500 rev/min and depth of cut 1.50 mm. Figure 8 (a) shows that at feed rate 108.58 mm/min that the wavelength of the green region to the blue region is 1.85 µm. With the feed rate raised from 108.58 to 391.42 mm/min (Figure 8 (b)) then the wavelength of the green region to blue region is higher (2.69 µm) red which means that the surface has become rougher. It was expected that at high feed rates, the machining process would be unstable, which caused higher chatter during machining and thus leading to poor surface finish [14].




(a) Feed rate at 108.58 mm/min




(b) Feed rates 391.42 mm/min

**Figure 8.** Illustration of the impact of feed rate on surface roughness

### *3.4. Depth of cut effect on Ra*

Figure 9 shows that various depth of cut has a significant effect on surface roughness. The collected data suggest that the surface roughness decreased rapidly whenever the depth of cut increased from 0.79 mm to 2.21 mm. It was seen from the experiment that, the depth of cut increased from 0.79 mm to 1.50 mm then the Ra decreased 7.1% (2.39 to 2.22 µm). Similarly, Ra decreased from 2.22 µm to 2.15 µm whenever the depth of cut became 1.50 mm to 2.21 mm. This phenomenon is because, at a lower depth of cut, the material matrix is removed less, at a higher depth of cut the removal of fibre is higher and leads to a good surface finish [15].

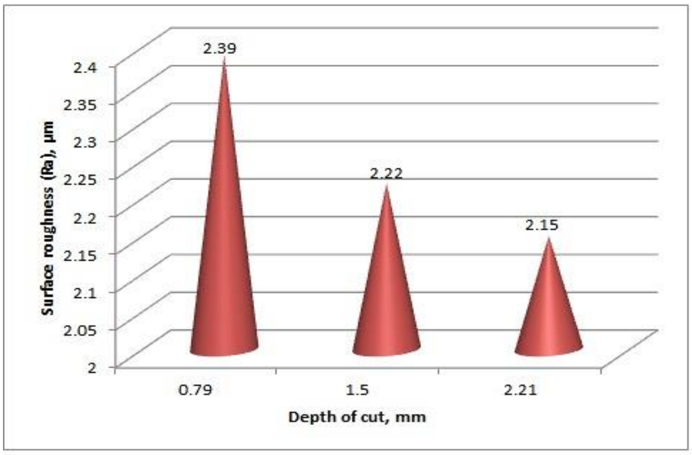
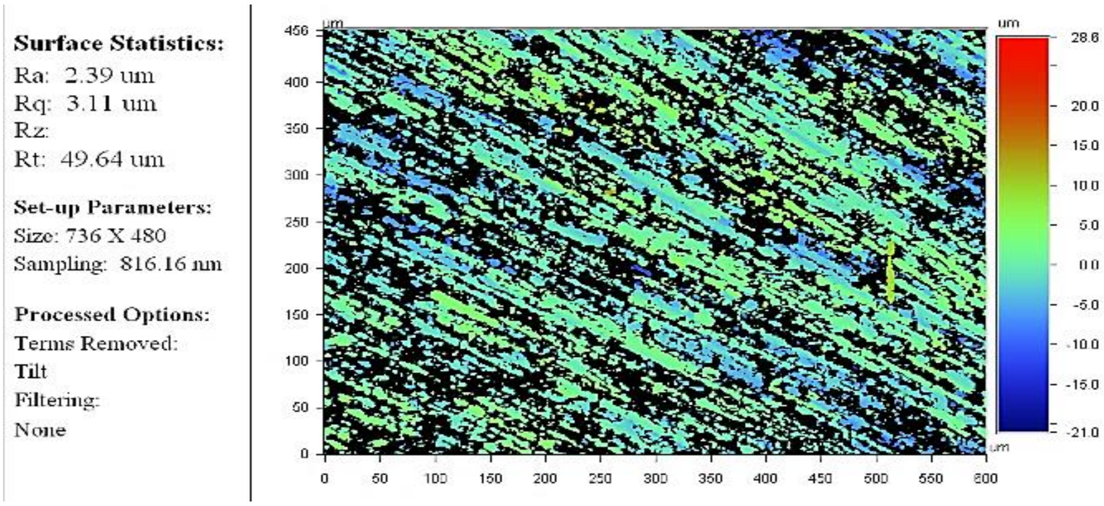
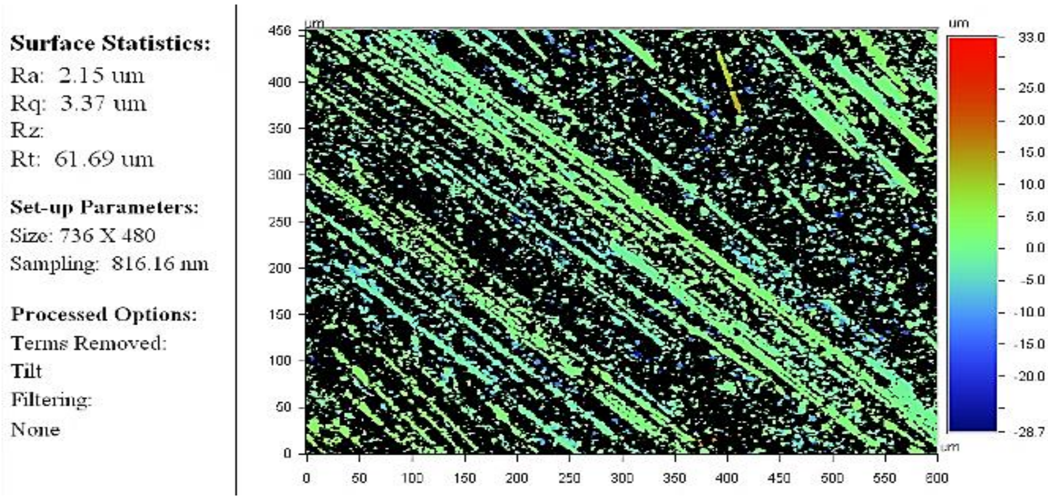



**Figure 9.** The Surface roughness of JFRP at various depth of cut (spindle speed =3500 rev/min and depth of cut = 1.50 mm

Figure 10 (a) (b) illustrates the surface topography of JFRP under Veeco Wyco Optical Profiling System Microscope for the various depth of cut with spindle speed 3500 rev/min and feed rate 250 mm/min. Figure 10 (a) shows that at depth of cut 0.79 mm the wavelength of the green region to the blue region is 2.39 µm. With the increment of the depth of cut from 0.79 to 2.21 mm (Figure 10 (b)) then the wavelength of the green region to the blue region is nearer (2.15 µm) compare to (Figure 10 (a)) which means the surface roughness has become smoother. It can be concluded that with the increment of the depth of cut from 0.79 to 2.21 mm, the surface roughness becomes smoother due to the increasing trends of the depth of cut. Researcher also reported that it could be happened during machining of GFRP because higher depth of cut remove more amterials and make the surface smooth [13].




(a) Depth of cut 0.79 mm




(b) Depth of cut 2.21 mm

**Figure 10.** Surface roughness's at various depth of cut

*3.5. ANOVA analysis of Surface roughness*

The realization gathered from (Table 3) is that the model is significant, and the F value of this model is 28.14. Three factors of cutting parameters are defined as A. Spindle speed, B. feed rate, and C. depth of cut. Table 3 also reveals the most impactful parameter is feed rate (F value 43.92) comparing to other values like spindle speed and depth of cut. This result is agreed by the researcher Taso and Hocheng [14] that the most impactful parameter is feed rate during machining of CFRP.

**Table 3.** ANOVA analysis of Surface roughness

Response 3 Surface Roughness
ANOVA for Response Surface Quadratic Model
Analysis of variance table [Partial sum of squares - Type III]

| Source | Sum of Squares | df | Mean Square | F Value | p-value Prob > F | |
|---|---|---|---|---|---|---|
| Model | 1.13 | 5 | 0.23 | 28.14 | < 0.0001 | Significant |
| A-Spindle speed | 0.64 | 1 | 0.64 | 39.49 | < 0.0001 | |
| B-Feed Rate | 0.35 | 1 | 0.35 | 43.92 | < 0.0001 | |
| C-Depth of cut | 0.028 | 1 | 0.028 | 3.43 | 0.0971 | |

*3.6. Mathematical model developed of Ra*

Figure 11 illustrates the normal probabilities plot of the standardized residuals that is utilized to verify the normality of residuals. Plotting the points show that they are situated relatively closer to the straight line, proving that the errors exhibited a normal distribution.

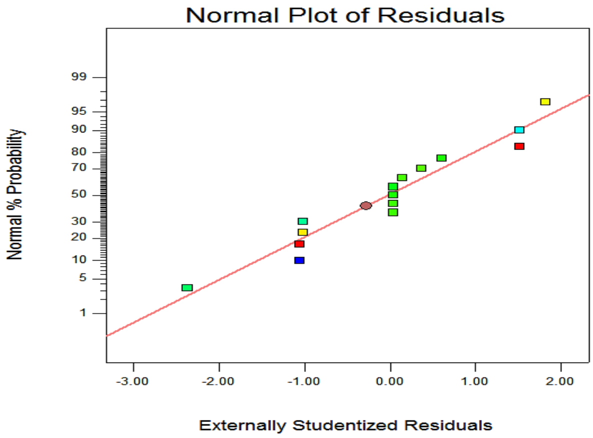



**Figure 11.** Normal probabilities of residuals for surface roughness

### *3.7. Effect of cutting parameters on Ra*

Figure 12 exhibits the three-dimensional graph of contour for the surface roughness. It can be observed that with the increment of the depth of cut from 1 to 2 mm, surface roughness is decreasing (smoother). The same trend is observed on the spindle speed, with the acceleration of spindle speed from 1500 to 5500 rev/min, surface roughness is decreasing (smoother). This phenomenon is due to high spindle speed which generates high temperature surrounding the cutting tool and burns the small fiber and matrix which creates a smooth surface [15].

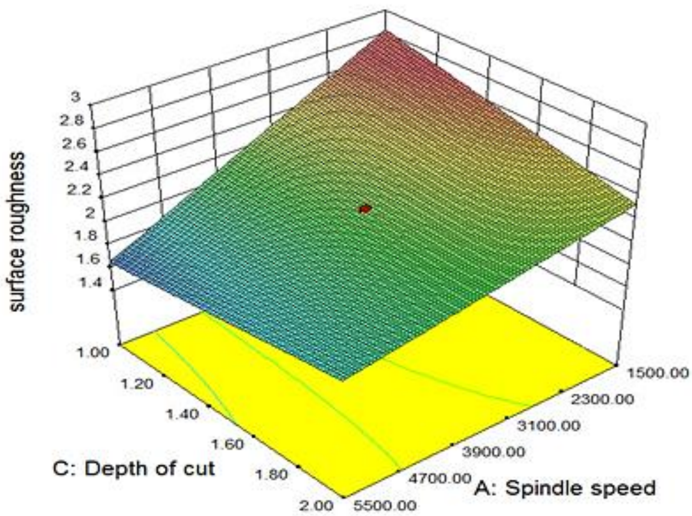



**Figure 12.** Three-dimensional graph of surface roughness

Equation 3.1 describes the final equation in terms of actual factors

$$Surface\ Roughness = -0.63843 - 0.000483985*A + 0.018780*B + 1.85453*C + 0.000189485*AC - 0.010540*BC \quad (3.1)$$

Where, A = Spindle speed (rev/min), B = Feed rate (mm/min), and C = Depth of cut (mm)

### *3.8. Optimization*

This analysis outlines the relationship of three input parameters which are feed rate, spindle speed, depth of cut, and one response which is surface roughness were observed. It is necessary to adopt the process of optimization to achieve the optimum values of the responses simultaneously. The optimization is obtained using the software of Design Expert 10.0.3 which corresponded to the responses to decrease the surface roughness. The highest and lowest values of responses is selected according to the measurement acquired during machining.

The optimum solutions are tabulated in (Table 4) as the best desirability index obtained which is 96.8%. It has been indicated that the peak values of the machining parameters can be attained at a cutting speed of 4293.56 rpm, the feed rate of 150 mm/min, and depth of cut 1.0 mm. The optimum value of the surface roughness is 1.18 µm.

**Table 4.** Optimization of Ra

| No. | Spindle Speed (rev/min) | Feed Rate (mm/min) | Depth of Cut (mm) | Surface Roughness (µm) | Desirability |
|---|---|---|---|---|---|
| 1 | 4293.788 | 150.000 | 1.000 | 1.188 | 0.968 (selected) |
| 2 | 4271.672 | 150.000 | 1.000 | 1.194 | 0.963 |
| 3 | 4318.524 | 150.000 | 1.009 | 1.190 | 0.963 |
| 4 | 4329.215 | 150.000 | 1.013 | 1.191 | 0.963 |
| 5 | 4278.443 | 150.000 | 1.004 | 1.197 | 0.963 |
| 6 | 4247.296 | 150.000 | 1.001 | 1.202 | 0.963 |

## 4. Conclusion

In this study, the experimental table was designed following the central composite design, and the analysis was done by using ANOVA. The cutting parameters were feed rate, spindle speed, depth of cut and responses were surface roughness. From the result, it can be decided as follows:

- It was found that the machining feed rate is the most impactful parameter that affects the out responses of Surface roughness.
- The best outcomes of the optimization solution were found that the cutting speed, feed rate, depth of cut are 4293.56 revs/min, 150 mm/min, and 1.0 mm. optimum value of the surface roughness was 1.18 µm.

This optimum parameter can be used for the machining of NFRP (Natural Fibre Reinforced Polymer) composite to get better machining performance. It is highly recommended for the Finite Element Model Analysis for the further experimentation and modelling as well.

## Acknowledgment

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