Machinability study of JFRP composite using design of experiment

Mir Akmam Noor Rashid¹, Zakaria Mohd Zain¹, M K Nor Kairurusshima¹, Wazed Ibne Noor², Momin Mullah³, Shaheer Ahmed Khan⁴

¹Department of Materials & Manufacturing Engineering, International Islamic University Malaysia, Selangor, Gombak-53100, Malaysia
²Department of Mechatronics Engineering, International Islamic University Malaysia, Selangor, Gombak-53100, Malaysia
³Department of Electronics & Computer Engineering, International Islamic University Malaysia, Selangor, Gombak -53100, Malaysia
⁴Department of Mechanical Engineering, International Islamic University Malaysia, Selangor, Gombak -53100, Malaysia

Email: noorakmam@gmail.com

Abstract. Recently, the machining of composite materials has increased to a large extent to get the required shape and design during the assembly stage of Jute fiber reinforcement polymer (JFRP). The output performance of milled JFRP composite depends on the input machining parameter such as spindle speed, feed rate, and depth of cut. The output responses like tool wear, surface roughness (Ra), and delamination factor (Fd) affect the dimensional stability, structural integrity, and accuracy of the final product. The objective of this study to find out the most significant factor of the output performances on JFRP. In this machining study, the JFRP composite panels were fabricated according to the hand’s lay-up technique and the milling was done by using an uncoated carbide cutting tool. The DOE (Design of Experiment) tool was used to design the experimental table based on Response Surface Methodology (RSM). A Central Composite Design was used to analyze the data and the most significant factor that effect the output parameters. According to Analysis of variance (ANOVA), it was found that the feed rate has a significant influence on tool life, surface roughness, and delamination factor. The spindle speed has also an effect on output responses comparing to the depth of cut. Another objective of this research is to obtain an optimum setting of the input parameters and mathematical modeling equation to reduce the tool wear, surface roughness, and delamination factor. The optimum parameter of the input machining was found that the input parameter spindle speed 4293.88 rev/min, feed rate 150 mm/min, and depth of cut 1 mm in where the lowest surface roughness, delamination, and longer tool life would be achieved.

1. Introduction

Nowadays, there has been great interest in the use of Natural Fiber Reinforcement Polymer (NFRP) composite to replace synthetic fiber in composite applications [1]. Among different kinds of natural fibers, jute fiber is the most promising and satisfactory reinforcement for use in
composites in the view of cost-effective, eco-friendly, availability, lower energy prerequisite for preparing, high physical properties, and no wellbeing hazard [2]. A lot of research has been published regarding the reinforcement capacity of jute fiber on polymer composites. The properties of FRP composites are focused on numerous qualities like fiber properties, fiber orientation, staple length, matrix properties, and fiber-matrix interface strength [3]. Expanding the volume content of reinforcement can increase the load-bearing capacity, rigidity, and stiffness of a composite to a point. If the volume content of reinforcement is an excess of high there won't be a sufficient matrix to keep them discrete and they can get twisted. Likewise, the orientation or arrangement of the fibers relative to one another within the matrix can affect the performance of a composite [4].

Jute fibers are used to reinforce both thermoplastic and thermosetting matrices. Thermosetting resins such as epoxy, polyurethane, polyester, and phenolic, are usually used today in natural fiber composites, in which composites demanding higher performance applications [5]. Jute fiber reinforcement polymer (JFRP) composite provides sufficient mechanical properties, in particular strength and stiffness, at acceptably cost-effective [6]. Natural fiber composite is used in aerospace (cabin, chair), automotive, sports goods, and domestic upholstery [7]. Holbery & Houston [8] concluded that natural fibers are superior to synthetic fibers in terms of low price and better quality. Jute fiber reinforced polymer composite is now being applied to a surprising range in aircraft, automotive, sports goods, and domestic upholstery because of its dimensional constancy over a wide range of temperature, high strength, and high stiffness weight ratio with a low specific gravity [9].

1.1. Milling of Jute Fiber Composite

JFRP is generally fabricated in their net shape, however, to get the required shape, design, accuracy, dimensional stability, secondary machining operations must be done. These machining operations are such as drilling, milling, trimming, grinding, slotting. Machining of JFRP is difficult and quite different from metalworking because of the inhomogeneity, anisotropic structure, and abrasive nature. There also have different thermal properties of the fiber and matrix materials [10].

Even though the fibers can endure higher temperatures, the temperature generates during FRP machining should not over the curing temperature in order to avoid material deterioration. In the time of machining FRP composite, the cutting tool faces high abrasive wear. Abrasive wear happens when a hard-rough surface slides across a softer surface. The friction between the cutting tool and workpiece produces cutting forces in the machining of FRP and it can damage the material permanently [11]. Machining is a word that is used to describe a variety of metal material removal processes. There are various types of machining processes to get the required shape and design such as milling, drilling, slotting, turning, etc. The milling process is defined as the most acceptable process to remove materials and create a high-quality surface [12]. During machining, the principal drawbacks are severe tool wear, surface delamination, and poor surface roughness. The surface roughness drawing attention for many years because it can affect product performance, dimensional precision, and production cost [13]. In conventional machining methods, has been proved that FRP composite material faces difficulties in achieving acceptable surface quality [14]. Fibre delamination occurs generally in drilling and milling and affects product quality. During machining, the heterogeneous FRP composite causes delamination and this reduces the bearing strength, structural integrity, durability, and tool wear. Therefore, researchers and manufacturers face greater pressure as they need to establish a better understanding of FRP cutting processes, concerning accuracy and efficiency [15].

The challenges of machining can be eliminated by improving the machining cycle, in this way giving the occasion to higher efficiency and more noteworthy completing quality at a lower machining cost. The machining of FRPs requires an alternate age of instruments with changes in their calculation and the abrasion resistance of hardware material. Carbide cutting tool has better hardness and commonly used during FRP composite machining. According to Lie et al. [16], carbide cutting tools are cost-effective and gives a better surface finish. Its wear resistivity is very high and machinability also good.
1.2. Tool wear Surface Roughness and Delamination Factor

The fundamental of wear mechanisms can vary under different conditions. In FRP machining, the significant effects on the composite are abrasion, surface damage, and adhesion. This wear mechanism is initially related to the mechanical and physical properties of the fiber and matrix materials. It is very important to achieve a high metal removal rate, low tool wear, and good surface finish [17]. According to Krishnaraj et al. [18], abrasive wear is visible in CFRP machining because carbon fiber is extremely abrasive. A similar opinion comes from Tsao & Chiu [19] which said in GFRP machining, tool wear is very clear due to the abrasive nature of glass fiber. The machining input parameters such as feed rate, cutting speed, depth of cut are the most significant factors affecting tool wear. The cutting speed influences tool wear because of the amount of thermal energy that is generated at the cutting edge. The heat distribution between the tool and the composite depends on the thermal conductivity of the composite material. Tool wear improves at a higher cutting speed which is reported by several researchers [20-21]. Teti [22] concluded that machining FRP at higher cutting speeds results in better tool life. Some of the researchers also stated that during machining of JFRP composite, tool wear is affected by the increasing and decreasing cutting speed. During machining of JFRP composite, tool wear become very fast with a higher depth of cut and feed rate [23].

A higher machining rate and better surface finish are desirable and many aspects have been studied to improve the machinability of FRP composites. In order to achieve a good surface finish end product, machining on composite should be continued based on reducing surface roughness and protecting the material characteristics. Rashid et al. [23] also stated that on milling JFRP composite material, many factors affect the surface quality such as feed rate, depth of cut, cutting speed and these are the most important parameter which influences the machine tool and workpiece set up. Aouici et al. [24] mentioned that cutting parameters have a greater influence on international dimensional precision and the surface in addition to machining force and specific cutting pressure. Bhushan et al. [25] agreed with this report that the machinability of FRP composites, the feed rate was found to be the most dominant parameter, which has the highest statistical and physical influence on surface roughness during machining. The feed rate is an important factor for the improvement of surface roughness when machining glass fiber reinforced polymer, as an increment in the feed rate reduced the surface quality [26]. Khairussimah et al. [27] explained that during the milling of CFRP composite, higher feed rate values produced greater surface roughness. Azmi et al. [28] stated that, during machining of natural fiber reinforced polymer (NFRP) composite, the surface quality of the machined composite materials is reduced due to an increase of feed rate, which led to a greater thrust force responsible for fracturing the composite material. Therefore, the scope of higher feed rate must be determined, to achieve acceptable surface roughness and it can decrease cutting time.

It has been found that fiber reinforced polymer milling shows delamination which is one of the surface quality related problem. Palanikumar [29] mentioned that delamination depends on fiber orientation and performance of cutting tools during milling GFRP. Delamination occurs in the form of fiber overhang and breakage of fiber at the cutting edge. Actually, delamination affects surface quality strongly and reduces the structural integrity and long-term performance of a part. Delamination factors decrease the structural integrity by lowering the bearing strength, leading to the poor assembly of tolerance, and potentially affect the long-term performance of parts [30]. The higher cutting speed reduces the delamination. It was explained by several researchers, Kilickap [31] recommended that low feed rate and high cutting speed reduces the delamination because higher speed results in the thermal condition of tool material, which burn the pull-out fiber and decrease the delamination.

The design of the experiment is the process of designing, planning, and analyzing the experiment. The objective, conclusion, and the valid result can be drawn efficiently and effectively through this design of experiment software. have been conducted to study the FRP machinability and analyzing the influencing factors. Response surface methodology (RSM) is an important technique for creating and
optimizing a statistical model. The performance of the advanced model is demonstrated by using scrutiny tests given by Analysis of Variance (ANOVA). Until now, no research has been conducted to find out the optimum input parameter of JFRP composite machining to get lower surface roughness and delamination factor with higher tool life. It is expected from this study, it would be possible to get the most significant input factor with optimum machining parameters.

| Nomenclature          | Description                          |
|-----------------------|--------------------------------------|
| CFRP                  | Carbon Fiber Reinforcement Polymer    |
| RSM                   | Response Surface Methodology          |
| CCD                   | Central Composite Design             |
| JFRP                  | Jute Fiber Reinforcement Polymer      |
| GFRP                  | Glass Fiber Reinforcement Polymer     |

2. Materials and Methods

2.1. Materials

The jute fabric (Tossa grade-1) was collected from Janata jute mill corporation, Bangladesh, and stored at room temperature. The tenacity of Tossa grade-1 jute fabric is 3.5-4.5 g/den. Its dimensional stability and thermal resistance are very good and moisture regains 13.5%. The staple length of Tossa grade-1 is 0.5-30 inches and a diameter of 18 microns respectively. Figure 1(a) shows the Tossa jute fabric grade-1. Epoxy resins are available in various quality and different coded forms like E205, E105, E101, BRT Epoxy resin, etc. The best quality coded (E101) epoxy resin was collected from Prantika Dsara Trading Company, Selangor. Similarly, there are various coded and commercially named hardener is available also like ALBAFIF-ECO, SUNFIX, MB-1, H10, H151, etc.

2.2. Fabrication of Jute Composite

Jute fabric was fabricated by following hands lay-up techniques in a different composition. The first composition was 60% jute fabric (reinforcement) with 40% matrix material (epoxy resin & hardener) and the second composition was 70% jute fabric with 30% matrix material. The fabric was cut according to the unidirectional way. The dimension of the composite was 200 mm × 200 mm × 5 mm (Fig. 1(b)). The resin was mixed with the hardener and the ratio was 2:1. The stirrer was used to mix these two materials uniformly. After making the solution, jute fabric was dipped with the solution one by one and placed it on mylar plastic. The plastic ruler was used to place the layer closely one after one and to distribute the resin hardener to all the corners of the fabric by moving the plastic ruler to and fro. After completion of five layers, another plastic was put on the top layer, and weight was applied according to the hands lay-up technique. All the panels were fabricated individually and prepared for the mechanical test according to ASTM standards and machining respectively. Figure 1(c) shows the machined JFRP panel.
Figure 1. Jute fabric composite panel machining in a Dekel Maho CNC machine

2.3. Design of machining Experiments
The lower and higher value of cutting parameters is shown in (Table 1). Response surface methodology is used to design the experiment by using DOE. 15 experiments were provided by Central Composite Design (CCD) by selecting a small type in the Design Expert 10 software.

| 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    |

2.4. Measurement of Tool wear, Surface Roughness, and Delamination
The Nikon Measuring Microscope model: MM-400/L used to measure tool wear of the uncoated carbide cutting tool and delamination factor. Figure 2 shows the delamination measurement area of the machined JFRP panel. The microscope is connected to the CPU and the data is analyzed using NIS-Element F3.0 software. Figure 3. shows the Nikon Measuring Microscope. The surface roughness of the milled JFRP is used to measure by using Veeco Wyco Optical Profiling System Measuring: model NT 1100. The microscope collects the surface data by scanning the machined surface. FOV and objectives lens options were selected to display the magnification and field view. The user controls the length, infra-red back scan, and the percentage modulation of the threshold.
3. Results and Discussion

Tool wear, surface roughness, and delamination factors are the greatest significant defects for the refutation of the industrially made constituents, which appeal serious consideration to the engineers for machining JFRP. It is very essential to measure the tool wear, surface roughness, and delamination factor for the acceptance of the produced goods. In this study, the surface roughness was measured by using the Veeco Wyco (1100) Optical Profiling System microscope and the tool wear and delamination factor of the JFRP panel was measured by using Nikon Measuring Microscope. The delamination factor was determined by measuring the maximum width of damage suffered by the material after machining. According to the small CCD design, fifteen experiments were run and (Table 2) shows that the result of the delamination factor for all cutting parameters.

| Run | Spindle Speed (rev/min) | Feed Rate (mm/min) | Depth of Cut (mm) | Tool life (min) | Ra (µm) | Fd |
|-----|-------------------------|--------------------|------------------|----------------|---------|----|
| 1   | 3500.00                 | 250.00             | 1.50             | 21.6           | 2.19    | 1.37 |
| 2   | 6328.43                 | 250.00             | 1.50             | 14.4           | 1.56    | 1.27 |
| 3   | 3500.00                 | 250.00             | 1.50             | 21.6           | 2.22    | 1.51 |
| 4   | 3500.00                 | 250.00             | 1.50             | 21.6           | 2.19    | 1.46 |
| 5   | 3500.00                 | 391.42             | 1.50             | 13.5           | 2.69    | 1.54 |
| 6   | 3500.00                 | 250.00             | 0.79             | 22.08          | 2.39    | 1.12 |
| 7   | 5500.00                 | 150.00             | 2.00             | 30.66          | 2.15    | 1.32 |
| 8   | 3500.00                 | 250.00             | 1.50             | 21.6           | 2.2     | 1.40 |
| 9   | 3500.00                 | 250.00             | 2.21             | 18.9           | 2.15    | 1.703 |
| 10  | 3500.00                 | 108.58             | 1.50             | 41.6           | 1.85    | 1.09 |
| 11  | 1500.00                 | 350.00             | 2.00             | 17.55          | 2.11    | 1.52 |
| 12  | 1500.00                 | 150.00             | 1.00             | 39.84          | 1.96    | 1.34 |
| 13  | 3500.00                 | 250.00             | 1.50             | 19.8           | 2.02    | 1.57 |
| 14  | 5500.00                 | 350.00             | 1.00             | 11.31          | 2.43    | 1.21 |
| 15  | 671.57                  | 250.00             | 1.50             | 35.88          | 2.69    | 1.58 |
3.1. Mathematical Model of Tool Life

Table 3 shows the ANOVA model for the tool life (Response 1). The Model F-value of 185.64 suggests that the model is significant with the Values of "Prob > F" under 0.05. There is essentially a 0.01% possibility that a "Model F-value" this large could happen because of noise. In this situation, the significant model terms are the fundamental effect of spindle speed (A), the primary impact of feed rate (B), the main effect of depth of cut (C), two-level interaction of feed rate and depth of cut (BC), the second-order impact of spindle speed (A^2) and feed rate (B^2). Table 3 likewise shows that the factor with the main impact on the tool life was the feed rate with an F-value that was equivalent to 827.83. This was expected and reported by a large portion of scientists that the feed rate is the essential factor that impacts the tool life of the cutting tool [25].

The model is acceptable on the grounds that the Lack of Fit is not significant with 21.42% comparative with the pure error. The R^2 is 0.993 which is high and close to 1, the R^2 predicted of 0.912, and the R^2 adjacent of 0.987.

Table 3. ANOVA model for tool life

| Source          | Sum of Squares | df | Mean Square | F Value | p-value Prob > F |
|-----------------|---------------|----|-------------|---------|-----------------|
| Model           | 1208.55       | 6  | 201.42      | 185.64  | < 0.0001        |
| A - Spindle speed | 230.70       | 1  | 230.70      | 212.62  | < 0.0001        |
| B - Feed Rate   | 827.83        | 1  | 827.83      | 762.95  | < 0.0001        |
| C - Depth of cut| 6.91          | 1  | 6.91        | 6.37    | 0.0356          |
| BC              | 27.97         | 1  | 27.97       | 25.77   | 0.0010          |
| A^2             | 21.82         | 1  | 21.82       | 20.11   | 0.0020          |
| B^2             | 64.33         | 1  | 64.33       | 59.29   | < 0.0001        |
| Residual        | 8.68          | 8  | 1.09        |         |                 |
| Lack of Fit     | 6.09          | 4  | 1.52        | 2.35    | 0.2142          |
| Pure Error      | 2.59          | 4  | 0.65        |         |                 |
| Cor Total       | 1217.23       | 14 |             |         |                 |

R^2 = 0.993  Adj. R^2 = 0.987  Pred.R^2 = 0.912  Adeq.Precision = 40.434

Equation 3.1 describes the tool wear final equation in terms of actual factors.

\[
Tool\ Life = 57.67541 - 0.00673873 * A - 0.13384 * B + 16.83733 * C - 0.074787 * BC + 0.000000420223 * A^2 + 0.000288589 * B^2
\]

(3.1)

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

3.2. ANOVA analysis for Ra

Table 4 shows the ANOVA model for surface roughness (Response 2). The Model F-estimation of 28.14 suggests that the model is significant with the Values of "Prob > F" under 0.05. There is only a 0.01% possibility that a "Model F-value" this large could happen because of noise. For this situation, the significant model terms are the principle impact of spindle speed (A) and feed rate (B) and the two-level interaction of spindle speed and depth of cut (AC), a two-level association of feed rate with a depth of cut (BC). Table 4 likewise shows that the feed rate is the most significant factor in surface
unpleasantness with an F-value that was equivalent to 43.92. This is valid, as it has been reported by Palanikumar [32] that during machining composite GFRP, the feed rate has been recognized as the main factor that impacts the surface roughness of GFRP.

The model is acceptable as the Lack of Fit is not significant with 38.85% comparative with the pure error. The $R^2$ is 0.939 which is high and close to 1. The $R^2$ predicted of 0.803 is in reasonable concurrence with the $R^2$ adjacent to 0.906. A proportion greater than 4 is desirable. In this model, the ratio is 19.936 which shows a satisfactory signal.

**Table 4. ANOVA model for Ra**

| 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  |           |
| AC                | 0.072          | 1  | 0.072       | 8.94    | 0.0152  |           |
| BC                | 0.56           | 1  | 0.56        | 69.16   | < 0.0001|           |
| Residual          | 0.072          | 9  | 8.032E003   |         |         |           |
| Lack of Fit       | 0.046          | 5  | 9.154E-003  | 1.38    | 0.3885  | Not Significant |
| Pure Error        | 0.027          | 4  | 6.630E-003  |         |         |           |
| Cor Total         | 1.20           | 14 |             |         |         |           |

$R^2 = 0.939$  Adj. $R^2 = 0.906$  Pred.$R^2 = 0.803$  Adeq. Precision=19.936

Equation 3.2 describes the surface roughness final equation in terms of actual factors

Surface Roughness

\[
\begin{align*}
Surface\ Roughness & = -0.63843 - 0.000483985 \times A + 0.018780B + 1.85453 \times C + 0.000189485 \times AC - \\
& 0.010540 \times BC
\end{align*}
\]

(3.2)

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

### 3.3. ANOVA analysis for Fd

The delamination factor (Fd) assumes a significant role that impacts the quality of the end product. In this investigation, a developed model has been predicted to observe the significant factor which influences the delamination factor. Table 5 shows that the ANOVA model shows the delamination factor (Response 1). The model gives the F-value 16.28 which recommends that the model is significant with Values of "Prob > F" under 0.05. For this situation, the significant model terms are the key impact of spindle speed (A), the fundamental effect of feed rate (B), the principal effect of depth of cut (C), two-level interaction of spindle speed and depth of cut (AC) and second-order impact of feed rate (B²). The model shows that the effect of feed rate has the main effect on the delamination factor with an F value of 62.89. This outcome chooses with the report of [33], which determined that feed rate, gives the highest contribution to the delamination factor.
The model has a Lack of Fit that is not significant with 75.71% comparative with the pure error. The $R^2$ is 0.9482 which is high and close to 1. The $R^2$ predicted of 0.7303 is in reasonable concurrence with the $R^2$ adjusted of 0.9094. Then, the value of satisfactory accuracy 19.98 which is desirable as the proportion is more noteworthy than 4.

**Table 5. ANOVA model for Fd**

| Source           | Sum of Squares | df | Mean Square | F Value | p-value Prob > F | p-value Prob > F |
|------------------|----------------|----|-------------|---------|-----------------|-----------------|
| Model            | 0.71           | 6  | 0.12        | 24.42   | < 0.0001        | significant     |
| A - Spindle speed| 0.074          | 1  | 0.074       | 15.26   | 0.0045          |                 |
| B - Feed Rate    | 0.30           | 1  | 0.30        | 62.89   | < 0.0001        |                 |
| C - Depth of cut | 0.17           | 1  | 0.17        | 35.13   | 0.0004          |                 |
| AB               | 0.036          | 1  | 0.036       | 7.38    | 0.0264          |                 |
| AC               | 0.13           | 1  | 0.13        | 27.58   | 0.0008          |                 |
| $B^2$            | 0.14           | 1  | 0.14        | 28.67   | 0.0007          |                 |
| Residual         | 0.039          | 8  | 4.837E-003  |         |                 |                 |
| Lack of Fit      | 0.012          | 4  | 3.105E-003  | 0.47    | 0.7571          | not significant |

$R^2 = 0.9482$ Adj. $R^2 = 0.9094$ Pred.$R^2 = 0.7303$ Adeq. Precision = 19.98

Equation 3.3 describes the delamination factor final equation in terms of actual factors

$$Delamination \ factor = 1.41348 - 0.000602460 \times A + 0.00711503 \times B - 0.49171 \times C + 0.000000668108 \times AB + 0.000258272 \times AC - 0.0000133914 \times B^2$$

$$3.3$$

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

**3.4. Optimization of all input parameter**

In this study, the relationship of three input parameters which are spindle speed, feed rate, depth of cut, and three responses which are tool life, surface roughness, and delamination factor is observed. It is necessary to adopt the process of optimization to achieve the optimum values of the responses simultaneously.

The optimization is obtained using software of Design Expert 10.0.3 which corresponded to the responses criteria of maximized tool life, minimized delamination factor, and surface roughness. The range of the responses is selected based on the data acquired during machining.

a) Tool life: $11.31 < Tl < 41.6$ minutes
b) Surface roughness: $1.56 < Ra < 2.69 \mu m$

The optimum solutions are tabulated in Table 6 as the best desirability index obtained which is 96.8%. It has been indicated that the optimum values of the machining parameters can be obtained at a spindle speed 4293.56 rev/min, feed rate 150 mm/min, and depth of cut 1.0 mm. These conditions yield optimum value of surface roughness, tool life, and delamination factor of 28.525 min, 0.760 mm, and 1.188 $\mu$m respectively.
Table 6. Optimized solutions for machining JFRP

| No. | Spindle Speed (rev/min) | Feed Rate (mm/min) | Depth of Cut (mm) | Tool Life (minutes) | Surface Roughness (µm) | Delamination Factor | Desirability |
|-----|------------------------|--------------------|------------------|--------------------|------------------------|--------------------|--------------|
| 1   | 4293.788               | 150.000            | 1.000            | 28.525             | 1.188                  | 0.760              | 0.968 (selected) |
| 2   | 4271.672               | 150.000            | 1.000            | 28.594             | 1.194                  | 0.764              | 0.963         |
| 3   | 4318.524               | 150.000            | 1.009            | 28.498             | 1.190                  | 0.760              | 0.963         |
| 4   | 4329.215               | 150.000            | 1.013            | 28.486             | 1.191                  | 0.760              | 0.963         |
| 5   | 4278.443               | 150.000            | 1.004            | 28.597             | 1.197                  | 0.765              | 0.963         |
| 6   | 4247.296               | 150.000            | 1.001            | 28.675             | 1.202                  | 0.769              | 0.963         |

The graphical optimization or overlay contour plot was developed by overlapping the contours for each of the responses. Figure 4 shows the overlay plot for JFRP machining. The shaded portion on the overlay plot defines the permissible value of the dependent variable.

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 was surface roughness. From the result, it can be decided as follows:

- It was found that the machining feed rate is the most significant factor that affects the output responses of the tool wear, surface roughness, and delamination factor.
- 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 fiber reinforced polymer) composite to get better machining performance.
Acknowledgment
The experimental work was continued in the tool and die lab, composite lab, and metrology lab of University Islam Antarabangsa. The authors are highly grateful for the lab facility and the assistance of lab staff.

References

[1] Lau, K. T., Hung, P. Y., Zhu, M. H., & Hui, D. (2018). Properties of natural fibre composites for structural engineering applications. Composites Part B: Engineering, 136, 222-233.
[2] Ahmad, F., et al. (2015). A review: Natural fiber composites selection in view of mechanical, lightweight, and economic properties. Macromolecular Materials and Engineering, 300(1), 10-24.
[3] Mohammed, L., et al. (2015). A review on natural fiber reinforced polymer composite and its applications. International Journal of Polymer Science, 2015.
[4] Patel, P., Chaudhary, V., Patel, K., & Gohil, P. (2018). Milling of polymer matrix composites: a review. International Journal of Applied Engineering Research, 13(10), 7455-7465.
[5] Khan, J. A., & Khan, M. A. (2015). The use of jute fibers as reinforcements in composites. In Biofiber Reinforcements in composite materials (pp. 3-34). Woodhead Publishing.
[6] Bongarde, U., & Shinde, V. (2014). Review on natural fiber reinforcement polymer composites. International Journal of Engineering Science and Innovative Technology, 3(2), 431-436.
[7] Mohammed, L., Ansari, M. N., Pua, G., Jawaid, M., & Islam, M. S. (2015). A review on natural fiber reinforced polymer composite and its applications. International Journal of Polymer Science, 2015.
[8] Holbery, J., & Houston, D. (2006). Natural-fiber-reinforced polymer composites in automotive applications. JOM Journal of the Minerals, Metals and Materials Society, 58(11), 80-86.
[9] Babu, G. D., Babu, K. S., & Gowd, B. U. M. (2018). Effect of machining parameters on milled natural fiber-reinforced plastic composites. Journal of Advanced Mechanical Engineering, 1, 1-12.
[10] Çelik, Y. H., Kilickap, E., & Kilickap, A. İ. (2019). An experimental study on milling of natural fiber (jute)-reinforced polymer composites. Journal of Composite Materials, 53(22), 3127-3137..
[11] John, R., Lin, R., Jayaraman, K., & Bhattacharyya, D. (2020). Effects of machining parameters on surface quality of composites reinforced with natural fibers. Materials and Manufacturing Processes, 1-11..
[12] Çelik, Y. H., & Alp, M. S. (2020). Determination of Milling Performance of Jute and Flax Fiber Reinforced Composites. Journal of Natural Fibers, 1-15..
[13] Palanikumar, K. (2010). Modeling and analysis of delamination factor and surface roughness in drilling GFRP composites. Journal of Materials and Manufacturing Processes, 25(10), 1059-1067.
[14] Yashiro, T., et al. (2013). Temperature measurement of cutting tool and machined surface layer in milling of CFRP. International Journal of Machine Tools and Manufacture, 70, 63-69.
[15] John, R., Lin, R., Jayaraman, K., & Bhattacharyya, D. (2020). Effects of machining parameters on surface quality of composites reinforced with natural fibers. Materials and Manufacturing Processes, 1-11..
[16] Liu, D., et al. (2012). A review of mechanical drilling for composite laminates. Composite Structures, 94(4), 1265-1279.
[17] Rashid, M. A. N., Mullah, M. & Zain, Z. M. (2020). Study on Tool Wear Mechanism during Milling of JFRP Composite. International Journal of Science and Engineering Investigations (IJSIE), 9(98), 20-26.http://www.ijsei.com/papers/ijsei-99820-05.pdf.
[18] Krishnaraj, V., et al. (2012). Optimization of machining parameters at high speed drilling of carbon fiber reinforced plastic (CFRP) laminates. Composites Part B: Engineering, 43(4), 1791-1799.
[19] Tsao, C., & Chiu, Y. (2011). Evaluation of drilling parameters on thrust force in drilling carbon fiber reinforced plastic (CFRP) composite laminates using compound core-special drills. International Journal of Machine Tools and Manufacture, 51(9), 740-744.

[20] Chegdani, F., Mezghani, S., & El Mansori, M. (2015). Experimental study of coated tools effects in dry cutting of natural fiber-reinforced plastics. Surface and Coatings Technology, 284, 264-272.

[21] Rashid, M. A. N., Khan, S. A., Khairusshima, M. N., & Sarifuddin, N. (2018). Study on Tool Wear and Tool Life During Milling JFRP Using Uncoated Carbide Cutting Tool. ARPN Journal of Engineering and Applied Sciences (JEAS), VOL. 13, NO. 8 (2930-2934).

[22] Teti, R. (2002). Machining of composite materials. CIRP Annals-Manufacturing Technology, 51(2), 611-634.

[23] Rashid, M. A. N., Zain, Z. M., Noor, W. I., & Mullah, M (2020). Machinability Effect During Milling on Different Composition of JFPRP using Uncoated Carbide Cutting Tool. International Journal of Engineering Research & Technology, 9 (03), 283-287.

[24] Aouici, H., et al. (2012). Analysis of surface roughness and cutting force components in hard turning with CBN tool: Prediction model and cutting conditions optimization. Measurement, 45(3), 344-353.

[25] Bhushan, R. K., et al. (2010). Effect of machining parameters on surface roughness and tool wear for 7075 Al alloy SiC composite. The International Journal of Advanced Manufacturing Technology, 50(5-8), 459-469.

[26] Rajasekaran, T., et al. (2011). Application of fuzzy logic for modeling surface roughness in turning CFRP composites using CBN tool. Production Engineering, 5(2), 191-199.

[27] Khairusshima, M. N., Zakwan, B. M. H., Suhaily, M., Sharifah, I. S. S., Shaffiar, N. M., & Rashid, M. A. N. (2018). The optimization study on the tool wear of carbide cutting tool during milling Carbon Fibre Reinforced (CFRP) using Response Surface Methodology (RSM). IOP Conference Series: Materials Science and Engineering, 290 (6).

[28] Azmi, H., et al. (2016). Study on machinability effect of surface roughness in milling kenaf fiber reinforced plastic composite (unidirectional) using response surface methodology. ARPN Journal of Engineering and Applied Sciences, 11(7), 4761-4766.

[29] Palanikumar, K. (2010). Modeling and analysis of delamination factor and surface roughness in drilling GFRP composites. Materials and Manufacturing Processes, 25(10), 1059-1067.

[30] Srinivasan, T., Palanikumar, K., Rajagopal, K., & Latha, B. (2017). Optimization of delamination factor in drilling GFR–polypropylene composites. Materials and Manufacturing Processes, 32(2), 226-233.

[31] Killickap, E. (2010). Optimization of cutting parameters on delamination based on Taguchi method during drilling of GFRP composite. Expert Systems with Applications, 37(8), 6116-6122.

[32] Palanikumar, K. (2008). Application of Taguchi and response surface methodologies for surface roughness in machining glass fiber reinforced plastics by PCD tooling. The International Journal of Advanced Manufacturing Technology, 36(1), 19-27.

[33] Karnik, S., et al. (2008). Delamination analysis in high speed drilling of carbon fiber reinforced plastics (CFRP) using artificial neural network model. Materials & Design, 29(9), 1768-1776.