Machinability Study on Milling Kenaf Fiber Reinforced Plastic Composite Materials using Design of Experiments

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Abstract. The surface roughness (Ra) and delamination factor (Fd) of a milled kenaf reinforced plastic composite materials are depending on the milling parameters (spindle speed, feed rate and depth of cut). Therefore, a study was carried out to investigate the relationship between the milling parameters and their effects on a kenaf reinforced plastic composite materials. The composite panels were fabricated using vacuum assisted resin transfer moulding (VARTM) method. A full factorial design of experiments was use as an initial step to screen the significance of the parameters on the defects using Analysis of Variance (ANOVA). If the curvature of the collected data shows significant, Response Surface Methodology (RSM) is then applied for obtaining a quadratic modelling equation that has more reliable in expressing the optimization. Thus, the objective of this research is obtaining an optimum setting of milling parameters and modelling equations to minimize the surface roughness (Ra) and delamination factor (Fd) of milled kenaf reinforced plastic composite materials. The spindle speed and feed rate contributed the most in affecting the surface roughness and the delamination factor of the kenaf composite materials.

1. Introduction

In historical records, the use of natural fiber composite materials had already been practiced in Egypt about 3000 years ago from now. Nowadays, in automotive field, the manufacturers are advised to take the environmental impact into account by considering renewable materials as alternative materials in their production especially European Union End of Life Vehicles (ELV) regulations had been introduced [1]. The fuel efficiency of a vehicle can be greatly increased due to reduction of its weight by using lightweight natural fiber reinforced plastic in the making of bumper and the door panel [2]. The East German car ‘Trabant’ was the first car that employed natural fiber composites in its production. The car’s body was made from a composite of cotton and polyester [3]. This had encouraged the rapid growth of implementation of natural fiber reinforced plastic into the manufacturing field.

Kenaf (Hibiscus Cannabinus) can found abundantly in Malaysia. Its potential usage should not be limited only in typical application such making rope or twine but should be concerned in manufacturing field by reinforcing with plastic. In this research, the epoxy was chosen as a matrix polymer because of the epoxy’s less hazardous nature and its ease of handling. Natural fiber composite
materials causes less damage to cutting tool and less hazard to health and environment due to its biodegradable properties. Besides, the cost of raw material of kenaf fiber is much lower than synthetic fiber since it is renewable source.

The milling was conducted by making slot on the kenaf composites. Slotting is one of the essential machining process which facilitates the assembly operations [4]. However, delamination and poor surface roughness can lead to a reduction in product quality if inappropriate milling parameters are used. Delamination can cause substantial reduction of load bearing capacity even the damages are not noticeable. Delamination is usually expressed by determining its factor. A rougher surface has a higher friction coefficient and wear off more quickly. The delamination factor (F_d) and surface roughness (R_a) are the two main criteria for predicting the mechanical performance and quality of a product. Hence, an optimum milling parameter and modelling equation for minimizing the milled kenaf composite are required.

Response surface methodology (RSM) is a set of statistical and mathematical modeling which helps in developing, enhancing and optimizing processes. The measured output is known as the response (surface roughness and delamination factor). The investigated parameters are known as the factors or variables (spindle speed, feed rate and depth of cut). In this research, RSM and analysis of variance (ANOVA) were used to investigate the relationships between measured responses and the input variables. The approach of Box-Behnken in RSM was selected to do the analysis on the response data. Before the RSM is applied to analyse the data, the full factorial design of experiments was used as an initial step to screen the significance of the parameters on the defects using Analysis of Variance (ANOVA). If the curvature of the collected data shows significant, Response Surface Methodology (RSM) is then applied for obtaining a quadratic modelling equation that has more reliable in expressing the optimization.

1.1. Kenaf Fiber Composite
The main constituents of kenaf are cellulose (45–57 wt. %), hemicelluloses (21.5 wt. %), lignin (8–13 wt. %) and pectin (3–5 wt. %) [3]. Wambua et al. claimed that poor mechanical properties may be resulted due to insufficient firm between the polymers (hydrophobic) and the natural fiber (hydrophilic) [5]. Kenaf fiber offers a better interfacial adhesion to matrix polymer than other natural fibers [6]. Matrix polymer can support the fibers, transfer the stresses to them to bear the most of the load, prevent direct physical damage to fibers and improve the ductility and toughness of the whole composite [7]. Epoxy gives no toxic gases and offers high temperature resistance which enables it performs at a high temperature [8]. Hafizah et al. studied tensile behavior of kenaf fiber reinforced several polymer composites and concluded that kenaf reinforced epoxy composite had the highest ultimate tensile strength and the Young’s modulus [9]. There were various researches had been conducted and proved that machining parameters possess significant effects to performance and quality of natural fiber composite[4], [10].

1.2. Milling Kenaf Fiber Composite
Erkan et al. claimed that increased spindle speed worsen the damage factor and increase the plastic deformation rate on an end milled fiber reinforced plastic composite [11]. Davim et al. claimed that feed rate was expected to affect delamination rather than cutting speed on the machining of fiber reinforced plastic [12]. Ramulu et al. studied the machining of polymer composite. They stated that a better surface finish can be obtained with higher cutting speed [13]. The impact of depth of cut is not as important as cutting speed and feed rate in composite machining, however, it still gives a significant effect on machining process [14]. Besides, the milled surface is getting smoother as the flute of the cutting tool increases [11]. The end mill cutter can be made of either high speed steel or carbide insert and usually has a straight shank or tapered shank. Normally, the cutter rotates on a workpiece in a perpendicular axis but it still can be tilted in order to match the need of producing a machine tapered or curve surface. However, milled composites always tend to have the surface roughness and delamination problem which much depends on cutting parameter and the composite’s characteristic [19]. Thus, an optimum setting of these parameters is needed to find out in order to control the quality
of a workpiece. The advantages of High Speed Steel (HSS) cutting tool over carbide cutting tool are higher strength to withstand cutting forces and lower cost. However, Carbide insert cutting tool is taking over HSS in metal cutting due to its great abrasion resistance and high temperature resistance which allows it to serve a machining process at a high speed without considering of over-heat situation. For machining of natural fiber composites, HSS cutting tool is sufficient to meet this research’s purpose.

1.3. Surface Roughness and Delamination Factor
Surface roughness is one of the criteria in determining the quality of workpiece based on surface texture. If the deviation of actual surface is large from the ideal surface, the actual surface is considered as a rough surface. The smaller the deviation, the smoother the actual surface. \( R_a \) is the value of the Roughness Average of surface measured microscopic peaks and valleys. Sorrentino and Turchetta claimed that a reduction of surface roughness \( (R_a) \) can be obtained by increasing the feed rate [15]. The other researchers also expressed that feed rate contributes the highest statistical and physical influence on surface roughness in end milling [16]. Rao et al. investigated the effect of cutting parameters on the surface roughness of multi-walled carbon nanotubes (MWCNT) reinforced epoxy composite using CNC end milling and claimed that depth of cut affected the most on the surface roughness, followed by feed rate and spindle speed [17].

Delamination of a natural fiber composite can be described as the loss of adhesion between the layers that can leads critical damage of the reinforcement layers (separation). Hocheng et al. believed the delamination can be worsened by increasing the feed rate on milling parameter [18]. The damage of the composite is greater if operated with high cutting speed and high feed rate [19]. Delamination of a natural fiber composite can be described as the loss of adhesion between the layers that can leads critical damage of the reinforcement layers (separation). Hocheng et al. believed the delamination can be worsened by increasing the feed rate and tool life can be shortened by increasing the cutting speed which causes higher torque [18]. Davim et al. studied the effects of cutting speed and feed rate on delamination of glass fiber reinforced plastic during machining it with two different matrices [26]. The damage of the composite is greater if operated with high cutting speed and high feed rate [19].

1.4. Response Surface Methodology (RSM)
Response Surface Methodology (RSM) is used to solve the industrial problems such as mapping a response surface over a particular region of interest, optimization of the response and selection of operating conditions to achieve specifications or customer requirements [20]. The sequential nature of the Response Surface Methodology is as follows [20]:

Phase 0 - In this phase, amount of variables is reduced to minimum in order to reduce the number of experiments and make the experiments more efficient. This is called as screening experiment and identification of independent variables is carried out in this phase.

Phase 1 - In this phase, method of steepest ascent (descent) is used as optimization technique with considering the use of the first-order model.

Phase 2 - In this phase, the true response surface exhibits curvature near the optimum and a second-order or higher-order model should be implemented. The model can be analyzed later for determining the optimum conditions once an approximately accurate model has been made.

Palanikumar analyzed about the surface roughness in machining glass fiber reinforced plastic using response surface methodology. A second-order model is used in his research and he concluded that the surface roughness decreases with the increase of cutting speed and depth of cut but increases with the increase of feed rate [14]. Hussain et al. studied the optimization of surface roughness of glass fiber reinforced plastic composite in turning process had been evaluated using RSM. They suggested that RSM model can be interfaced with an effective genetic algorithm in determining optimum process parameters and this helps in enhancing the quality of the surface finish of workpiece [21]. Sorrentino
and Turchetta analyzed the milling cutting force and surface roughness of carbon fiber reinforced plastics composite and used ANOVA to determine that the cutting force is depending on three parameters which is feed rate, radial and axial depth of cut [22].

2. Methodology

2.1 Materials Preparation

The kenaf reinforced epoxy composites materials were prepared using Vacuum Assisted Resin Transfer molding (VARTM). VARTM was used to transfer the resin to the natural fiber in vacuum condition for molding with assistance of vacuum pump. Type of kenaf fiber is mat form were cut in dimension of 300 mm x 300 mm x 5 mm (thickness). Two layer of kenaf fiber mat that used and mix with epoxy resin. The resin was prepared in ratio 4 (800g epoxy): 1 (200g hardener). VARTM manufacturer recommended this ratio for fabricating the kenaf fiber reinforce plastic composite materials. The VARTM is gaining the interest of manufacturer due to its ease of handling and low cost of preparation. Figure 2 shows the actual set up of VARTM. The composite panels were then cut into small workpiece which about in dimension 75 mm X 30 mm X (8 mm – 10 mm) for milling process.

Figure 1. VARTM process for kenaf fiber reinforce plastic composite workpiece. (a) VARTM process, (b) actual composite materials, (c) small workpiece for milling process.

2.2 Milling Parameter

The milling parameters of this research were based on Babu et al. research since they studied machining of natural fiber composite. The parameter setting in this research base on previous parameters used in research by Babu et al. [4]. Table 1 shows the parameters used in this research which all the units are converted to suit the use of computer numerical control (CNC) milling machine. There were 3 parameters used in this research spindle speed (rpm), feed rate (mm/min) and depth of cut (mm) with low and high level for each parameter. Thus, a 2-level factorial design of experiments was selected with 8 experiment run and aid of Design Expert 7.0 software. 4 center points were added to seek for the significance of the curvature and error testing. If the curvature of the results show not significant, a linear modeling equation is sufficient to express the optimization. If it shows significant, there is a chance for applying RSM. In RSM, the Box-Behnken Design approach was used to get the quadratic modeling equation for parameter optimization. RSM is used to develop a second order modeling equation which is better in accuracy of expressing the optimization. In Box-Behnken design approach, 12 experiment run was selected with 3 level of factor were low, middle and high. 5 center points were added in this design approach to get more accurate on quadratic modeling equation.
Table 1. Parameter setting for milling process.

| Milling parameters | Low  | High | Center point |
|--------------------|------|------|--------------|
| Spindle speed (rpm)| 500  | 1000 | 700          |
| Feed rate (mm/min)| 200  | 1200 | 750          |
| Depth of cut (mm)  | 1    | 3    | 2            |

Table 2 shows the runs of the 2-level factorial design (2^3) of experiment for screening process based on parameter setting shown in Table 1. These parameters setting also used for Box-Behnken Design in RSM. If the results from 2-level factorial design shown, the curvature is significant, the Box-Behnken Design approach was chosen to estimate a quadratic equation that satisfies the optimization of the parameters (Table 3). For maximum efficiency, the axial points should be placed over the original factor range. For example, the low level and high level of spindle speed are 500 rpm and 1000 rpm respectively, thus, the axial point should be extended to 326 rpm and 1174 rpm.

Table 2. The 2-level factorial design of experiment (2^3)

| Run | A (Spindle speed, rpm) | B (Feed rate, mm/min) | C (Depth of cut, mm) |
|-----|------------------------|-----------------------|----------------------|
| 1   | 500                    | 200                   | 3                    |
| 2   | 1000                   | 1200                  | 1                    |
| 3   | 700                    | 750                   | 2                    |
| 4   | 1000                   | 200                   | 1                    |
| 5   | 700                    | 750                   | 2                    |
| 6   | 500                    | 1200                  | 3                    |
| 7   | 1000                   | 1200                  | 3                    |
| 8   | 500                    | 200                   | 1                    |
| 9   | 1000                   | 200                   | 3                    |
| 10  | 700                    | 750                   | 2                    |
| 11  | 700                    | 750                   | 2                    |
| 12  | 500                    | 1200                  | 1                    |

Table 3. The Box-Behnken Design for RSM

| Run | A (Spindle speed, rpm) | B (Feed rate, mm/min) | C (Depth of cut, mm) |
|-----|------------------------|-----------------------|----------------------|
| 1   | 750                    | 700                   | 2                    |
| 2   | 500                    | 700                   | 3                    |
| 3   | 1000                   | 700                   | 3                    |
| 4   | 750                    | 1200                  | 3                    |
| 5   | 750                    | 700                   | 2                    |
| 6   | 750                    | 700                   | 2                    |
| 7   | 750                    | 700                   | 2                    |
| 8   | 500                    | 700                   | 1                    |
2.3 Measurement of Surface Roughness and Delamination

The results of surface roughness and factor of delamination were obtained after milling processes. The surface roughness of milled kenaf composites was measure using a surface roughness tester (Mitutoyo CS-3000 525-780E-1). For workpiece with dimension 75 mm X 30 mm X (8 mm – 10 mm), 4 area were measured on slotted kenaf composite (see figure 2) for surface roughness. Every area the measured area was divide into 4 points and average of them ($R_a$) were recorded in Table 4. The delamination factor ($F_d$) can be determined using (1).

\[ F_d = \frac{W_{\text{max}}}{W} \]  

Where,

- $F_d$ = Factor of delamination
- $W_{\text{max}}$ = maximum width of the delamination area
- $W$ = width of original cut

![Figure 2. Schematic diagram for measurement of surface roughness ($R_a$).](image-url)
3. Results and Discussion

Table 4. Result for surface roughness (Ra) and delamination factor (F_d) using screening parameter setting.

| Run | A (Spindle speed, rpm) | B (Feed rate, mm/min) | C (Depth of cut, mm) | Ra   | F_d  |
|-----|------------------------|-----------------------|----------------------|------|------|
| 1   | 1000                   | 1200                  | 1                    | 3.47 | 1.113|
| 2   | 500                    | 200                   | 1                    | 3.073| 1.039|
| 3   | 500                    | 1200                  | 1                    | 6.725| 1.077|
| 4   | 750                    | 700                   | 2                    | 3.28 | 1.042|
| 5   | 750                    | 700                   | 2                    | 2.952| 1.067|
| 6   | 1000                   | 1200                  | 3                    | 4.743| 1.016|
| 7   | 750                    | 700                   | 2                    | 4.02 | 1.062|
| 8   | 1000                   | 200                   | 3                    | 2.539| 1.134|
| 9   | 1000                   | 200                   | 1                    | 2.248| 1.124|
| 10  | 750                    | 700                   | 2                    | 4.133| 1.034|
| 11  | 500                    | 1200                  | 3                    | 6.012| 1.075|
| 12  | 500                    | 200                   | 3                    | 1.7  | 1.035|

Figure 3. Example measurement of delamination factor (F_d)

Figure 4. Example SEM for surface roughness
3.1 ANOVA analysis for screening process of surface roughness ($R_a$)

Table 5. ANOVA result of surface roughness ($R_a$)

| Source   | Sum of squares | Degree of freedom | Mean square | F-value | p-value Prob>F |
|----------|---------------|------------------|-------------|---------|----------------|
| Model    | 23.03         | 5                | 4.61        | 17.28   | 0.0036 significant |
| A-Spindle speed | 2.54         | 1                | 2.54        | 9.54    | 0.0272 |
| B-Feed rate  | 16.22       | 1                | 16.22       | 60.84   | 0.0006 |
| C-Depth of cut | 0.034      | 1                | 0.034       | 0.13    | 0.7353 |
| AB       | 2.57          | 1                | 2.57        | 9.66    | 0.0266 |
| AC       | 1.67          | 1                | 1.67        | 6.25    | 0.0545 |
| Curvature | 0.13         | 1                | 0.13        | 0.47    | 0.5221 Not significant |
| Residual | 1.33          | 5                | 0.27        | -       | - |
| Lack of fit | 0.35        | 2                | 0.17        | 0.53    | 0.6332 Not significant |
| Pure of error | 0.98      | 3                | 0.33        | -       | - |

According to Table 5, the feed rate was determined that made the largest contribution in affecting surface roughness ($p$-value 0.0006<0.05), followed by spindle speed ($p$-value 0.0272<0.05) whereas the depth of cut contributed the least ($p$-value 0.7353 > 0.05). The value of alpha $\alpha$ is 0.05. The depth of cut cannot be ignored since it was the main factor for interaction of AC (spindle speed and depth of cut). The interaction of AB and AC were determined as significant factors since the p-value is between 0.05 and 0.1. However, the curvature and ‘lack of fit’ show no significant, which means a linear equation is sufficient for optimizing the surface roughness using these factors. So, for surface roughness results, the analysis cannot be used in Box-Behnken Design analysis. For surface roughness, the mathematical modelling and the optimum parameter just used the ANOVA result in screening process.
Figure 6 shows the effect of AB interaction on surface roughness with low level (black line) and high level (red line) of feed rate (depth of cut remains 1.5 mm). The surface roughness decreases with a high spindle speed and low feed rate. To get a good surface roughness, the every milled segment of workpiece have to be milled repeatedly and evenly. With a high feed rate, the workpiece fail to do so and caused a rough surface. These findings were found similar to the research of Babu et al. which claimed that surface roughness decreases as the spindle speed increases whereas a low feed rate contributes the most in obtaining a good surface finish [4]. Although the depth of cut shows least significant, it still plays an essential role in affecting surface roughness but not in critical way. Palanikumar believed that high depth of cut leads to a total removal of fiber which results in having a good surface finish [14].

3.1.1 Optimum Parameters and modeling equation for Optimization of Surface Roughness

Design Expert software was used to predict the optimum milling parameters and to estimate the coefficient for the modelling equation. The suggested optimum parameters were 500 rpm spindle speed, 200 mm/min feed rate and 2 mm depth of cut. The prediction of surface roughness was 1.865 µm with the range between 0.13µm and 3.60 µm. This means the optimum parameters are valid if the response ($R_a$) is located at the range. The linear modelling equation for optimization of milling parameters on minimizing surface roughness is shown in (3).

$$R_a = 5.42561 + 4.46324 \times 10^{-3} A + 6.13008 \times 10^{-3} B - 2.86442 C - 4.36606 \times 10^{-6} A + 3.57843 \times 10^{-3} AC$$

Where $A$ is spindle speed (rpm), $B$ feed rate (mm/min), and $C$ depth of cut (mm) in actual value.

| Spindle speed (rpm) | Feed rate (mm/min) | Depth of cut (mm) | Calculated $R_a$ | Measured $R_a$ | Percentage error (%) |
|---------------------|--------------------|-------------------|------------------|----------------|---------------------|
| 500                 | 200                | 2                 | 2.267            | 2.287          | 0.88                |
Table 6 shows the percentage error between calculated ($R_a$) using the equation (3) and the measured $R_a$. The measured $R_a$ was located at the prediction range (0.13µm-3.60 µm) and the percentage error was only 0.88%. These proved the both suggested optimum milling parameters and modelling equations were valid.

3.2 ANOVA analysis for screening process of delamination factor ($F_d$)

Table 7. ANOVA result of delamination factor ($F_d$)

| Source        | Sum of squares | Degree of freedom | Mean square | F-value | p-value | Prob>F |
|---------------|---------------|-------------------|-------------|---------|---------|--------|
| Model         | 0.012         | 4                 | 2.957E-003  | 20.75   | 0.0012  | significant |
| A-spindle speed | 2.319E-003   | 1                 | 2.319E-003  | 16.27   | 0.0068  |
| B-feed rate   | 2.622E-004   | 1                 | 2.622E-004  | 1.84    | 0.2237  |
| C-depth of cut| 1.157E-003   | 1                 | 1.157E-003  | 8.12    | 0.0292  |
| AB            | 8.090E-003   | 1                 | 8.090E-003  | 56.78   | 0.0003  |
| Curvature     | 3.456E-003   | 1                 | 3.456E-003  | 24.26   | 0.0026  |
| Residual      | 8.549E-004   | 6                 | 1.425E-004  | -       | -       |
| Lack of Fit   | 4.073E-004   | 3                 | 1.358E-004  | 0.91    | 0.5300  |
| Pure Error    | 4.476E-004   | 3                 | 1.492E-004  | -       | Not significant |

The curvature shows significant (see Table 7) and this indicates there is a chance for developing quadratic modeling equation using RSM with Box-Behnken approach. From the ANOVA analysis for delamination factor ($F_d$), the spindle speed was the most significant factor (p-value 0.0068) affecting the delamination. The depth of the cut was the second significant factor (p-value 0.0292) whereas the feed rate contributed the least (0.2237). In order to apply RSM, the Box-Behnken Design (see Table X) was added to further investigation of the parameters on the delamination by constructing a three order modeling equation.

3.3 Results of delamination factor ($F_d$) using Box-behnken Design

Table 8. Results of delamination factor ($F_d$) using Box-Behnken Design

| Run | A (Spindle speed, rpm) | B (Feed rate, mm/min) | C (Depth of cut, mm) | $F_d$  |
|-----|------------------------|-----------------------|----------------------|--------|
| 1   | 750                    | 700                   | 2                    | 1.045  |
| 2   | 500                    | 700                   | 3                    | 1.054  |
| 3   | 1000                   | 700                   | 3                    | 1.052  |
| 4   | 750                    | 1200                  | 3                    | 1.042  |
| 5   | 750                    | 700                   | 2                    | 1.047  |
| 6   | 750                    | 700                   | 2                    | 1.038  |
| 7   | 750                    | 700                   | 2                    | 1.05   |
| 8   | 500                    | 700                   | 1                    | 1.042  |
After obtaining the experimental result from Box-Behnken Design of experiments, a ANOVA had been constructed again to seek the significance of the three order factors and the significance of ‘Lack of Fit’ of the quadratic modeling equation as shown in Table 9. From Table 9, the main factor that significant to delamination factor (F_d) is Feed rate with F-value 5.97 (0.6%), interaction AB with F-value 9.14 (1.16%) and interaction BC with F-value 13.73 (0.3%). BC (feed rate and depth of cut) interaction made the largest contribution in affecting kenaf composite to laminate. Followed by AB (spindle speed and feed rate) and B (feed rate). The main factors (A and C) show non-significance values. However, these 2 factors cannot be eliminated due to the existence of AB and BC which include the factor A and C. The graph of delamination factor versus BC and AB interaction had been plotted in figure 5 and figure 6.
Figure 7. Effect of BC interaction for delamination factor

In figure 7, the spindle speed maintains at 750 rpm whereas the red line indicates the high level of depth of cut (3 mm) and the black line indicates the low level of depth of cut (1 mm). It can be clearly observed that the higher the feed rate (1200 min/mm), the worse the delamination. For BC interaction, the worse delamination factor (\(F_d\)) will course with high level of feed rate and low level of depth of cut.

In figure 8, the interaction of AB, the depth of cut remain at 2 mm. The red line indicates the high level of feed rate (1200 mm/min) and the black line indicates the low level of feed rate (200 mm/min). From the AB graph, the worse delamination factor (\(F_d\)) will accrue with high spindle speed and low
feed rate. For both BC and AB graph, the factor B (feed rate) is most contributed to the delamination factor (Fd). Davim et al. had the same viewpoint that high cutting (spindle) speed caused great damage on glass fiber reinforced plastic composites during machining [19]. The non-linear relationship between the feed rate and the delamination might be caused by opposite milling to orientation of kenaf fiber. The obtained results might be less accurate if not all the specimens are milled in direction of orientation of fiber. In addition, there were previous researchers concluded that low feed rate favors small damage on composites [4], [19].

3.3.2 Optimum parameter and modeling equation for optimization of delamination factor

The three order modelling equation for optimization of milling parameters on minimizing delamination factor (Fd) is shown in (4).

\[
Fd = 0.97903 + 4.390 \times 10^{-5} A + 9.375 \times 10^{-5} B + 0.01455 C - 6.2 \times 10^{-8} AB + 1.9 \times 10^{-5} BC
\]  

Where

- \(A\): spindle speed (rpm)
- \(B\): feed rate (mm/min)
- \(C\): depth of cut (mm) in terms of actual value.

Table 10. Optimum parameter and conformation test for delamination factor (Fd)

| Spindle speed (rpm) | Feed rate (mm/min) | Depth of cut (mm) | Calculated Fd | Measured Fd | Percentage error (%) |
|---------------------|---------------------|-------------------|---------------|-------------|----------------------|
| 500                 | 200                 | 2                 | 1.027         | 1.032       | 0.48                 |

Table 10 shows the percentage error between calculated (Fd) using the equation (4) and the measured Fd. The measured (Fd) was located at the prediction range (0.01 - 0.04) and the percentage error was only 0.48% which proved the modelling equation and the suggested optimum parameters can be accepted.

4. Conclusion

Both suggested optimum milling parameters in this research for minimization of surface roughness (\(R_a\)) and delamination factor (Fd) were the same. 500 rpm spindle speed, 200 mm/min feed rate and 2 mm depth of cut gave the minimum surface roughness (\(R_a\)) and delamination factor (Fd).

For optimization of surface roughness, the ANOVA of the data showed no significance of curvature. This indicated a linear modelling equation was fit enough to express the optimization. RSM requires a significant curvature to prove the possibility of developing a second order equation to improve the reliability of the optimization. In this study, the feed rate affected the surface roughness the most. A low feed rate promised a minimum surface roughness. The spindle speed did not affect the surface roughness significantly. However, a high spindle speed tended to favor a good surface finishing. The effect of depth of cut on surface roughness was not displayed clearly. This might due to a larger range of depth of cut is required in order to amplify its impact on surface roughness. Nevertheless, a greater depth of cut is believed in producing product with a good surface finish.

For the optimization of delamination, the curvature shown in ANOVA after the 2^3 factorial design of experiments was significant. This enabled the proceeding of RSM with Box-Behnken Design approach that requires more experiment runs to collect data for constructing a second order modelling.
equation. A central composite design was selected and 8 more runs of experiments were added. A low spindle speed and a low feed rate caused less delamination on milled kenaf composites. In addition, with a deeper depth of cut, the possibility of delamination can be reduced.

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