A Study on Parameter Optimization of the Delamination Factor (F_d) in Milling Kenaf Fiber Reinforced Plastics Composite Materials Using DOE Method

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ABSTRACT

Kenaf is known by its scientific name, Hibiscus cannabinus, which is similar to jute and cotton, and is also a warm-season annual fibrous crop. In the past, it was used to make sackcloth, and its twine was used to manufacture rope. Kenaf is also used as a cordage crop. A machine's surface quality normally depends for its reliability in the service application. The machining process changes the mechanical and chemical properties of individual constituents used for the composite. The objectives of this research are to study the effects of milling parameters and to determine the optimum conditions for a range of milling parameters to minimize the delamination factor (F_d) in milling kenaf fiber-reinforced plastic composite using the Taguchi Method. The Taguchi Method L_8 (2^3) design was used to conduct a non-sequential experiment. The experimental results were analyzed using the Minitab 16 software. A study was carried out to investigate the relationship between the milling parameters, and their effects on the kenaf reinforced plastic. The composite panels were fabricated using the vacuum assisted resin transfer molding (VARTM) method. This study determined that the optimum parameters for the minimum

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delamination factor were a cutting speed of 16 Vm/min, a feed rate of 0.1 mm/tooth, and a depth of cut of 2.0 mm. The feed rate and cutting speed made the biggest contributions to the delamination factor (F_d). The use at high spindle speeds and low feed rates led to minimized delamination factor (F_d) during the milling of kenaf reinforced plastic composite materials.

Keywords: *Kenaf Fiber, Taguchi Method, Delamination, Optimization*

Introduction

Natural fiber (kenaf fiber) is sustainable as well as eco-efficient; therefore, it has been used to replace glass fiber as well as other synthetic polymer fibers that have various kinds of a caption in the engineering field [1]. Kenaf is known by its scientific name, *Hibiscus cannabinus,* which is similar to jute and cotton, and is also a warm season annual fibrous crop. In the past, it was used to make sackcloth and its twine was used to manufacture rope; kenaf is also used as a cordage crop [2]. Nowadays, kenaf is widely used in various industries due to an increasing demand for green and clean industrial products. Additionally, kenaf plant fiber can be processed to produce paper pulp, building materials, construction materials, automotive materials, and bio fuels due to its properties of low weight, high specific properties, and renewability. This indicates that kenaf acts as a good potential natural fiber to be used in the automotive and construction industries (door trim in the vehicle and flooring for building).

Dr. Genichi Taguchi from Japan was the developer of the Taguchi method, which is a method based on orthogonal array (OA) experiments. The Taguchi Method uses a signal-to-noise (S/N) ratio as a statistical measure of performance. The S/N ratio considers both variability and mean. The ratio of the mean (signal) to the standard deviation (noise) is the S/N ratio [3]. The ratio depends on the quality characteristics of the process or product to be optimized. The standard S/N ratios used were as follows: higher is better (HB), smaller is better (SB), and nominal is best (NB) [3]. Hence, the S/N ratio is expressed as the mean (signal) to the noise, which is the deviation from the target; maximizing the S/N ratio would give a minimum deviation and, therefore, the S/N ratio is maximized [4].

The machine's surface quality normally depends on the machine components' reliability in the service application [5]. The performance of a composite material is minimally dependent on the surface condition produced from machining. This research focuses on the parameter settings such as spindle speed, feed rate, and depth of cut, which affects the delamination factor (F_d) in milling natural fiber reinforced plastic composite materials [5]. Kenaf fiber composite can be machined through the computer numerical control (CNC) milling operation.

Experimental Set Up

Design Parameter

The number of arrays, factors, and levels for the Taguchi Method were determined first before carrying out the experiment. The levels and process parameter's selections of the experiment were important because it would affect the results obtained during the experiments. The factors which were chosen for this experiment was spindle speed (rpm), feed rate (mm/min), and depth of cut (mm). The ranges of these factors for kenaf fiber reinforced plastic are selected based on the research paper by other researchers in milling natural fiber composite materials [5]. The three main factors that were selected were examined at two levels, which are shown in Table 1.

Table 1: Levels of the parameter used in the experiment

Process Parameter	Low (1)	High (2)
A - Spindle speed, Vm/min	16	32
B - Feed rate, mm/tooth	0.1	0.3
C – Depth of cut, mm	1.0	2.0

For this research, orthogonal arrays (OA) were used to complete the design of the experiment. The OA L_8 were selected for the experiment due to its composition of three factors and two levels; it can also be written in the form of L_8 (2^3). Table 2 shows the experimental form of OA L_8 (2^3).

Table 2: Orthogonal array L_8 (2^3) in experiment form

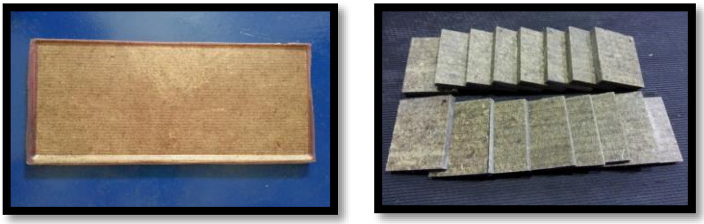
L_8 (2^3) Test	A – Spindle speed, (Vm/min)	B – Feed rate, (mm/tooth)	C – Depth of cut, (mm)
1	16	0.1	1.0
2	16	0.1	2.0
3	16	0.3	1.0
4	16	0.3	2.0
5	32	0.1	1.0
6	32	0.1	2.0
7	32	0.3	1.0
8	32	0.3	2.0

Experimental Procedure

The material kenaf fiber-reinforced plastic composites was used in this study. Table 3 shows the comparison properties between natural fiber including kenaf fibers. Figure 2(a) is the kenaf fiber reinforced plastic composite board. The kenaf fiber reinforced plastic was then cut into sample size of 70 mm in length, 52 mm in width, and 10 mm in height or thickness, as shown in Figure 2(b). The mixtures of the kenaf fiber reinforced plastic consists of unsaturated polyester, methyl ethylketone, and cobalt naphthalene in the ratio of 98:1:1. This sample was slotted at the middle using a CNC milling machine with the HSS uncoated end mill Ø10 mm 4 flutes cutting tool. The HSS end mill cutting tool was chosen because of its ability to machine parts to the closest tolerance [6]. Figure 3 illustrates the milling operation on the kenaf fiber reinforced plastic composite. The milling operation was performed under two conditions: (1) horizontal; sample condition was parallel with the cutting path direction (Figure 3); and (2) vertical; sample condition will be rotated 90° from the horizontal position (Figure 4).

Table 3: Comparison properties of natural fiber [13,14]

Properties	Hemp	Flax	Jute	Ramie	Coir	Cotton	Kenaf	Sial
Tensile Strength (MPa)	550-900	800-1500	400-800	500	220	400	283-800	600-700
E-Modulus (GPa)	70	60-80	10-30	44	6	12	21-60	38
Specific, E/d	47	26-46	7-21	29	5	8	-	29
Density (g/cm^3)	1.48	1.4	1.46	1.5	1.25	1.51	1.4	1.33
Elongation at Failure (%)	1.6	1.2-1.6	1.8	2	15-25	3-10	1.6	2-3
Moisture Absorption (%)	8	7	12	12-17	10	8-25	-	11



(a) (b)

Figure 2: (a) Kenaf fiber reinforced plastic board, (b) sample for experiment

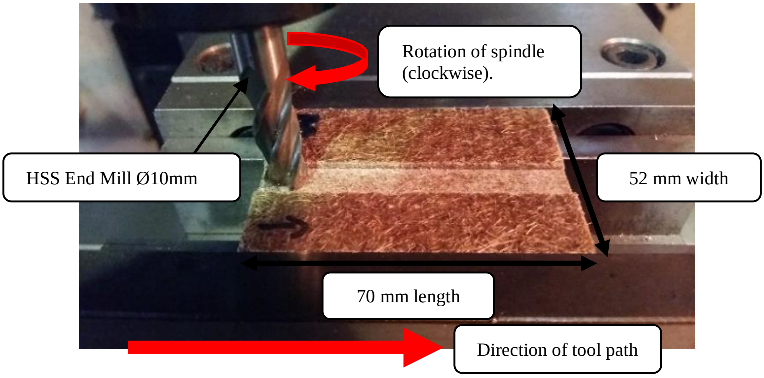


Figure 3: Milling operation on kenaf fiber reinforced plastic composite (Horizontal Cutting)

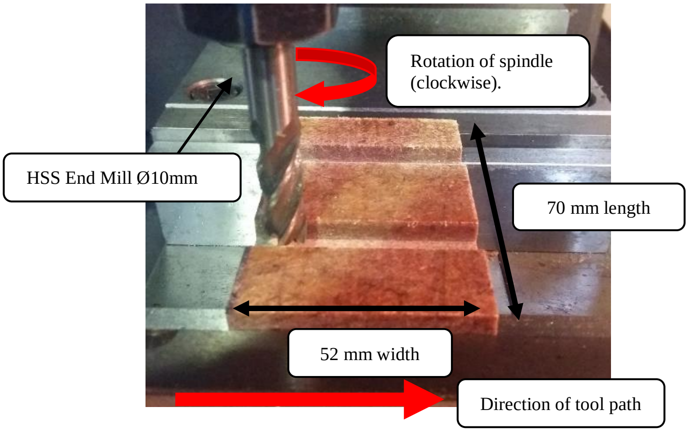


Figure 4: Milling operation on kenaf fiber reinforced plastic composite (Vertical Cutting)

Measurement of the Delamination factor (F_d)

Delamination factor is one of the failure mechanisms in a composite structure. It will reduce the structural quality of the material, resulted in poor assembly tolerance [7]. Delamination factor mainly relies on the cutting parameters such as cutting speed, feed rate, depth of cut, and tools' material. Increasing the feed rate causing high delamination factor while increases the cutting speed will rise torques and reduce tool life [1].

The structure of the fractured surface of the sample is observed using Scanning Electron Microscope (SEM) with a magnification up to 1000x. The value for the delamination factor can be calculated using Equation. (1) [5]. The measurements of the delamination factor in this research were carried out in two ways: (1) horizontal (F_d 1), where the sample is parallel with the cutting tool (Figure 3); and (2) vertical (F_d 2) (Figure 4).

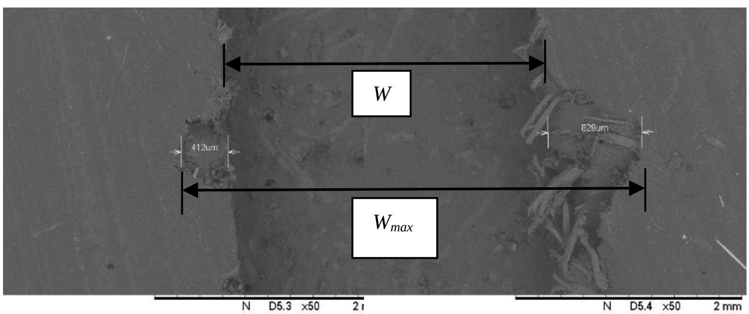


Figure 5: The measurement of the maximum width (W_{max}) for delamination

$$F_d = \frac{W_{max}}{W} \tag{1}$$

Where; [5]
W_{max} = maximum width of damage/delamination
F_d = delamination factor, and
W = width of cut.

S/N Ratio

The main purpose of this method is to manufacture good quality products to minimize the cost of manufacturing. This resulted in much reduced variance for the experiment with optimum setting of control parameters based on orthogonal array (OA) experiments. Moreover, OA has given a set of well-balanced experiments, which served as the objective functions for optimization. Furthermore, the Taguchi method used for this research is due to its ability to give better graphic visualization in order to determine the optimum conditions by calculating the S/N ratio [9]. In this study, the smaller the better characteristic as in the Equation (2) will be used to calculate the S/N values. Smaller is better:

$$S/N = -10 log^{1/n}(\sum y^2 \quad (2)$$

Where;

S/N = S/N Ratio
y = value of the quality characteristic
n = total number of trial runs.

Analysis of Variances (ANOVA)

Analysis of variance (ANOVA) is the method used to compare continuous measurements to determine if the measurements are sampled from the same or different distributions. It is an analytical tool used to determine the significance of factors on measurements by analyzing the relationship between a quantitative response variable and a proposed explanatory factor [10].

This method is similar to the process of comparing the statistical difference between two samples, in that it invokes the concept of hypothesis testing. Instead of comparing two samples, however, a variable is correlated with one or more explanatory factors, typically using the F-statistic. From this F-statistic, the P-value can be calculated to see if the difference is significant [10]. For example, if the P-value is low (P-value<0.05 or P-value<0.01), depending on the desired level of significance, then there is a low probability that the two groups are the same. This method is highly versatile because it can be used to analyze complicated systems, with numerous variables and factors [10].

The Confirmation test

After the optimum cutting conditions were determined and the predicted delamination values at the optimum conditions were estimated using the Minitab software, a confirmation test was conducted to validate the prediction result.

Results And Discussion

Analysis of the S/N ratio for the Delamination factor (F_d)

The analysis of the signal-to-noise (S/N) ratio for the delamination factor used the smaller the better characteristic. The S/N ratio represents the response of the experiment. It measured the variation of noise factors and contributes to the reduction of variation. Table 4 shows the value of the delamination factor as well as the S/N ratio for each control factor level, which was calculated via Minitab 16 software.

Table 4**:** The summary of the response and S/N ratio for the factor of delamination (F_d).

Sample	A (m/min)	B (mm/tooth)	C	F_d 1	S/N Ratio	F_d 2	S/N Ratio
1	16	0.1	1.0	1.034	–0.294	1.015	–0.129
2	16	0.1	2.0	1.037	–0.317	1.034	–0.294
3	16	0.3	1.0	1.026	–0.219	1.077	–0.640
4	16	0.3	2.0	1.037	–0.314	1.049	–0.420
5	32	0.1	1.0	1.045	–0.384	1.024	–0.205
6	32	0.1	2.0	1.109	–0.895	1.016	–0.136
7	32	0.3	1.0	1.090	–0.751	1.083	–0.693
8	32	0.3	2.0	1.075	–0.627	1.077	–0.648

Labels;
A = Spindle Speed
B = Feed Rate
C = Depth of Cut
F_d 1 = F_d horizontal (Figure 3)
F_d 2 = F_d vertical (Figure 4)

Table 4 shows the summary of responses and the S/N ratio for the delamination factor, F_d 1 (horizontal cutting) and F_d 2 (vertical cutting). The lowest value for F_d 1 is Sample no. 1 with a value of 1.0255 and for F_d 2 is Sample no. 3 with a value of 1.01498. In contrast, the highest value of delamination factor among F_d 1 is Sample no. 6 with a value of 1.1086 and for F_d 2 is Sample no. 7 with a value of 1.0831. This result is similarly obtained with result from other researcher in which the minimum values of the delamination factor will lead to better quality in milling natural fiber reinforced plastic composite materials [5].

In addition, F_d 1 Sample 3 had the S/N ratio of –0.218713, which is the highest value of the delamination factor, while the lower S/N ratio among F_d 1 is Sample 6 with a value of –0.895497. Furthermore, the S/N ratio for F_d 2 Sample 1 had a value closest to zero, which was about –0.129150 indicated the higher value, and the lower S/N ratio is Sample 7 with a value of –0.693371. The higher value of S/N ratio and the minimum delamination factor value will result in better quality in milling natural fiber reinforced plastic composite materials [5]. Similarly, the highest value for the S/N ratio from zero means that it has produced minimum quality in milling operation [5].

Main effects plot for the Delamination factor (F_d)

Figure 6 and 7 indicate the main effect plots for the S/N ratios for the delamination factor F_d 1 (horizontal cutting) and F_d 2 (vertical cutting). The main effect plots show that the trends of the factor were influenced, by observing the slope of the line in the graph. Consequently, in Figure 5, it can be seen that with an increase in spindle speed (A), feed rate (B), and depth of cut (C), the delamination factor's value will increase. According to this main effect plot, the optimal condition for F_d 1 is: spindle speed at level 1 is 16 m/min, feed rate at level 1 is 0.1 mm/tooth, and depth of cut at level 1 is 1.0 mm.

Figure 6 shows that with the increase in spindle speed (A) and feed rate (B), will increase the value of the delamination factor. The increase in the depth of cut (C) will decrease the value of the delamination factor. Based on the main effect plot, the optimal condition for F_d 2 is: spindle speed at level 1 is 16 m/min, feed rate at level 1 is 0.1 mm/tooth, and depth of cut at level 2 is 2.0 mm.

The use of high cutting speed and low feed rate will favor minimum delamination and will lead to better quality of slots [5]. The results obtained for F_d 1 and F_d 2 did not correspond to other researcher which had stated that the delamination factor increases steadily with an increase in the feed rate and decrease in the spindle speed [5,11]. In milling natural fiber composite materials, the feed rate and cutting speed are the largest contributions to the delamination, with the high cutting speed and low feed rate favoring the minimum delamination factor [8]. In this study an unsaturated polyester was used for preparing the specimen while others researcher used polyester resin in the preparation of the specimen [5]. Due to the bonding between the polymers or the mixtures, which did not mix uniformly with some parts of the binder bonding with the kenaf fiber resulted in contradict with previous findings.

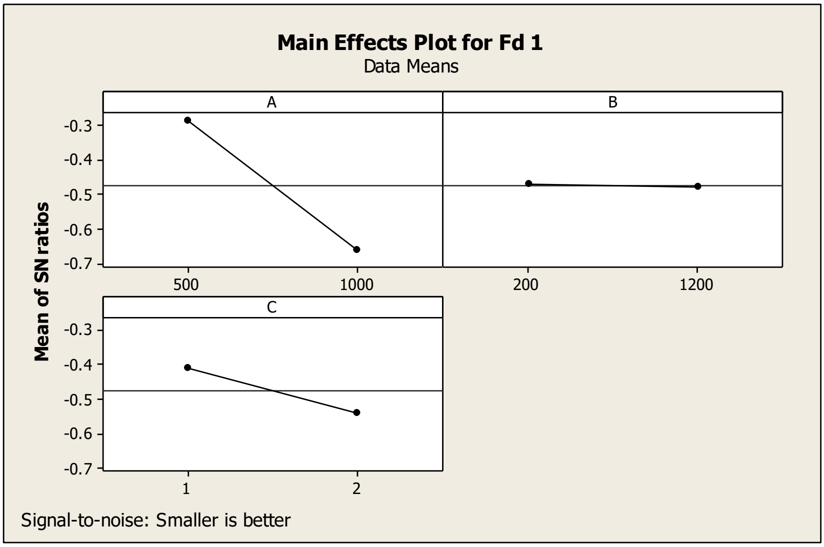


Figure 6: Graphs of the main effects plot for F_d 1.

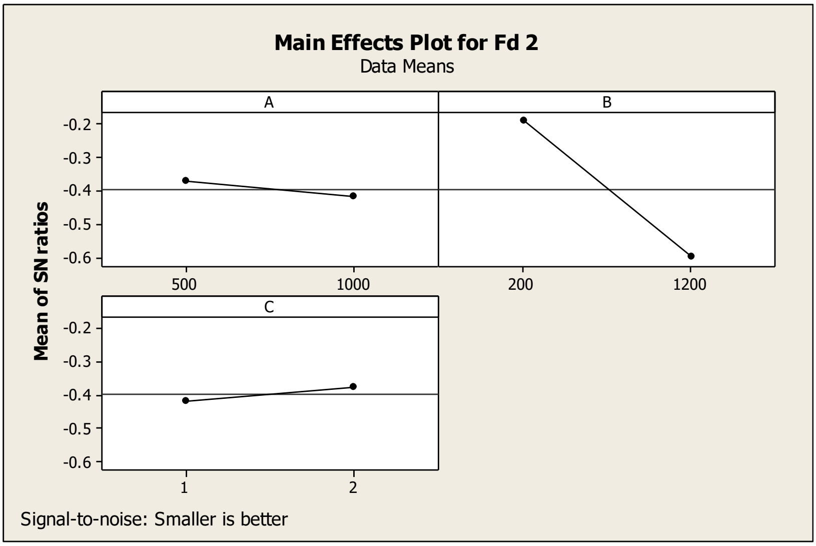


Figure 7: Graphs of the main effects plot for F_d2.

Analysis of Variance (ANOVA) of the Delamination factor (F_d)

The experimental results are analyzed by ANOVA, which is used for identifying the factors significantly affecting the performance measures. This analysis was carried out for a significance level of $\alpha = 0.05$ or for a confidence level of 95%. The sources with P-values that are less than 0.05 were considered to have a statistically significant contribution to the performance of measurement [12]. The sum of squares (SS) shows the relative contribution of each factor to the total variance of the factor.

Table 5: Analysis of variance of F_d 1.

Source	DOF	SS	MS	F-value	P-value	C (%)
(A) Spindle Speed	1	0.285625	0.285625	9.94	0.034	65.96
(B) Feed Rate	1	0.000066	0.000066	0.00	0.964	0.02
(C) Depth of Cut	1	0.032402	0.324020	1.13	0.348	7.48
Residual error	4	0.114916	0.028729	–	–	26.54
Total	7	0.433007	–	–	–	100.00

DOF = Degree of Freedom, SS=Sum of squares, MS= Mean squares, C=Contribution

Based on the ANOVA results as shown in Table 5, A-spindle speed with percentage contribution 65.96% is the most significant parameter followed by C-depth of cut with 7.48% and B-feed rate with 0.02%. This means that for F_d 1, spindle speed had given a larger contribution for the value of the delamination factor. In addition, it was also found that the spindle speed is statistically significant because the P-value of F_d 1 is 0.034, which is less than α=0.05 [12]. The residual error occurred from the ANOVA analysis for F_d 1 is 26.54%. Based on the results, the most influenced factor on the delamination F_d 1 is A-spindle speed.

The ANOVA analysis is shown in Table 6, whereby the B-feed rate with percentage contribution of 84.27% gave bigger contribution for F_d 2 and was followed by A-spindle speed with 1.22% and then C-depth of cut with 0.90%. For F_d 2, only the feed rate was statistically significant, which had the p-value of 0.008 that is less than α=0.05 [12]. The percentage error for F_d 2 is 13.61%. The most influenced factor on the delamination F_d 2 is B-feed rate.

Table 6: Analysis of variance of F_d 2.

Source	DOF	SS	MS	F-value	P-value	C (%)
(A) Spindle Speed	1	0.004852	0.004852	0.36	0.582	1.22
(B) Feed Rate	1	0.335221	0.335221	24.76	0.008	84.27
(C) Depth of Cut	1	0.003570	0.003570	0.26	0.635	0.90
Residual Error	4	0.054151	0.013538	–	–	13.61
Total	7	0.397795	–	–	–	100.00

DOF = Degree of Freedom, SS=Sum of squares, MS= Mean squares, C=Contribution

Predictions for the Optimized Conditions for the Delamination factor (F_d)

The optimal condition of the cutting parameter, which can minimize the value of the delamination factor for each cutting surface, is identified based on the main effect plots in Figure 6 and Figure 7. The prediction for the optimal conditions for the delamination factor of each cutting surface was done by using Minitab 16 software as shown in Table 7. The predicted delamination factor for F_d 1 (horizontal) is 1.02545 when conducting the milling operation at an optimal condition for the confirmation test, while the predicted delamination factor for F_d 2 is 1.01655.

Table 7: Prediction for optimize condition.

Cutting surface	Spindle speed, (Vm/min)	Feed rate, (mm/tooth)	Depth of Cut, (mm)	Predicted F_d
F_d 1	16	0.1	1.0	1.02545
F_d 2	16	0.1	2.0	1.01655

The confirmation Test for the delamination factor (F_d)

The predicted values for the delamination factor in optimal conditions obtained from the Minitab 16 software was validated experimentally. The experimental and theoretical results for the delamination factor are tabulated in Table 8. From the results, the lower percentage error for the delamination factor is F_d 1 (2.66%) compared to F_d 2 (5.05%). It is shown that the horizontal (0°) cutting operation was better than the vertical (90°) cutting operation, which produced the minimum value of the delamination factor. The error occurred because the direction of the kenaf fiber is unidirectional, which resulted in a bigger value of error in the delamination factor.

Table 8: Percentage of error for the experimental and theoretical results for the delamination factor (F_d).

Cutting surface	**Spindle speed, (Vm/min)**	**Feed rate, (mm/tooth)**	**Depth of Cut, (mm)**	**Predicted F_d**	**Experimatal F_d**	**%**
F_d 1	16	0.1	1.0	1.02545	1.0527	2.66
F_d 2	16	0.1	2.0	1.01655	1.0679	5.05

Conclusion

ANOVA for the delamination factor F_d 1 found that the spindle speed had the largest contribution for the delamination factor, which was 65.96%, followed by depth of cut of 7.48% and feed rate was the least significant parameter of 0.02%. On the other hand, for F_d 2, the feed rate had the largest contribution to the delamination factor of 84.27%, followed by spindle speed with 1.33% and lastly depth of cut with 0.90%.

Based on the S/N graphs of the main effects plot, the spindle speed for F_d 1 and feed rate for F_d 2 have the biggest contributions to the delamination factor in milling kenaf fiber reinforced plastic composite. The higher spindle speed for F_d 1 and the higher feed rate for F_d 2 gave the less of delamination factor (good quality) in milling kenaf fiber reinforced plastic composite. Therefore, the use of high spindle speed and low feed rate will lead to minimum delamination factor. The confirmation tests were carried out and found that the experimental and theoretical results are in good agreement. The optimum parameters for the delamination factor are spindle speed of 16 m/min, feed rate of 0.1 mm/tooth, and depth of cut of 2.0 mm in milling kenaf fiber reinforced plastic composite.

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