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STUDY ON MACHINABILITY EFFECT OF SURFACE ROUGHNESS IN MILLING KENAF FIBER REINFORCED PLASTIC COMPOSITE (UNIDIRECTIONAL) USING RESPONSE SURFACE METHODOLOGY

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ABSTRACT
The surface roughness factor (R_a) of a milled kenaf reinforced plastic 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. The composite panels were fabricated using vacuum assisted resin transfer molding (VARTM) method. A 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 which 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 factor (R_a) of milled kenaf reinforced plastic. The spindle speed and feed rate contributed the most in affecting the surface roughness factor (R_a) of the kenaf composite.

Keywords: kenaf reinforced epoxy, milling, surface roughness, full factorial design of experiments, RSM.

INTRODUCTION
In historical records, the use of natural fiber composite 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 (M. M. Davoodi *et al.*, 2010) . 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 (S. Jeyanthi and J. J. Rani, 2012). The East German car 'Trabant' was the first car which employed natural fiber composites in its production. The car's body was made from a composite of cotton and polyester (R. M. Rowell, 1995).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 causes less damage to cutting tool and fewer hazards 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 (G. D. Babu *et al.*, 2013). 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 wears off more quickly. Factor of delamination and surface roughness 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 factor delamination). 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.

Kenaf Composite
The main constituents of kenaf are cellulose (45–57 wt. %), hemicelluloses (21.5 wt. %), lignin (8–13 wt. %) and pectin (3–5 wt. %), (R. M. Rowell, 1995). Wambua *et al.* claimed that poor mechanical properties may be resulted due to insufficient firm between the polymers (hydrophobic) and the natural fiber (hydrophilic) (P. Wambua *et al.*, 2003). Kenaf fiber offers a better interfacial adhesion to matrix polymer than other natural fibers (B. F. Yousif *et al.*, 2012).

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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 (S. R. Schmid and S. Kalpakjian, 2009). Epoxy gives no toxic gases and offers high temperature resistance which enables it performs at a high temperature (K. K. Chawla, 2012).

N. A. K. Hafizah *et al.*, 2014, 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. There were various researches had been conducted and proved that machining parameters possess significant effects to performance and quality of natural fiber composite (G. D. Babu *et al.*, 2013), (N. Abilash and M. Sivapragash, 2013). Table-1 shows the comparison between natural and glass fibers.

Table-1. Comparison between Natural Fiber and Glass Fiber (P. Wambua *et al.*, 2003).

	Natural Fiber	Glass Fiber
Cost	Low	Higher than natural fiber's
Renewability	Renewable	Not renewable
Recyclability	Recyclable	Not recyclable
Energy consumption	Low	High
Density	Low	Double of natural fiber's
Carbon dioxide neutral	Neutral	Not neutral
Machine's abrasion	Not abrasive	Abrasive
Health hazardous	safe	Hazard if inhaled
Distribution	wide	wide
Disposal	Biodegradable	Not biodegradable

Milling of Kenaf composite

Ö. Erkan *et al.*, 2012, claimed that increased spindle speed worsen the damage factor and increase the plastic deformation rate on an end milled fiber reinforced plastic composite. J. Davim *et al.*, 2007, claimed that feed rate was expected to affect delamination rather than cutting speed on the machining of fiber reinforced plastic. M. Ramulu *et al.*, 1994, studied the machining of polymer composite. They stated that a better surface finish can be obtained with higher cutting speed. 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 (K. Palanikumar, 2007).
Besides, the milled surface is getting smoother as the flute of the cutting tool increases (Ö. Erkan *et al.*, 2012). 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.

Surface roughness

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. Ra is the value of the Roughness Average of surface measured microscopic peaks and valleys. Sorrentino and Turchetta claimed that a reduction of surface roughness (Ra) can be obtained by increasing the feed rate (L. Sorrentino and S. Turchetta, 2014). The other researchers also expressed that feed rate contributes the highest statistical and physical influence on surface roughness in end milling (J. P. Davim and P. Reis, 2005). G. H. K. Rao at el., 2013, 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.

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 (R. H. Myers, 2009). The sequential nature of the Response Surface Methodology is as follows (R. H. Myers, 2009):

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.

K. Palanikumar, 2007 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. S. A. Hussain *et al.*, 2014, 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

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effective genetic algorithm in determining optimum process parameters and this helps in enhancing the quality of the surface finish of workpiece (J. P. Davim at el., 2004). Sorrentino and Turchetta, 2014, 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.

METHODOLOGY

The kenaf reinforced epoxy composites were prepared using vaccum assisted resin transfer molding (VARTM). VARTM (see Figure-1) was used to transfer the resin to the natural fiber in vacuum condition for molding with assistance of vacuum pump. The resin was prepared in ratio 4 (800g epoxy): 1 (200g hardener). This ratio was recommended by VARTM manufacturer. The VARTM is gaining the interest of manufacturer due to its ease of handling and low cost of preparation. Figure-1 shows the actual set up of VARTM. The composite panels were then cut into small workpiece which about indimension 80mm X 50mm X 7mm for slotting purpose.

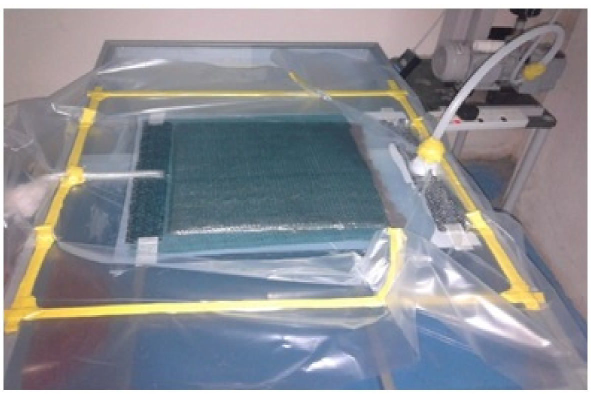

Figure-1. VARTM process.

Milling parameters

The milling parameters of this research were based on Babu *et al.* research since they studied machining of natural fiber composite. Table-2 shows the previous parameters used in research of G. D. Babu *et al.*, 2013. Table-3 shows the parameters used in this research which all the units are converted to suit the use of computer numerical control (CNC) milling. There were 3 parameters used in this research with low and high level. Thus, a 2-level factorial design of experiments was selected with the 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 no significant, a linear modelling equation is sufficient to express the optimization. If it shows significant, there is a chance for applying RSM. RSM is used to develop a second order modelling equation which is better in accuracy of expressing the optimization.

Table-2. Parameters setting in previous research (G. D. Babu *et al.*, 2013).

Milling parameters	Low	Medium	High
Spindle speed (m/min)	16	24	32
Feed rate (mm/rev)	0.10	0.20	0.30
Depth of cut (mm)	2		

Table-3. Parameters setting in this research.

Milling parameters	Low	High	Center point
Spindle speed (rpm)	509	1019	764
Feed rate (mm/min)	204	1223	713.5
Depth of cut (mm)	1	2	1.5

Table-4 shows the runs of the 2-level factorial design (2^3) of experiment. The central composite design was chosen to estimate a quadratic equation that satisfies the optimization of the parameters. 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 509 rpm and 1019 rpm respectively, thus, the axial point should be extended to 335 rpm and 1193 rpm.

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Table-4. A 2-Level factorial design of experiments (2^3).

Run	A (spindle speed, rpm)	B(Feed rate, mm/min)	C (depth of cut, mm)
1	509.0	204.0	2.0
2	1019.0	1223.0	1.0
3	764.0	713.5	1.5
4	1019.0	204.0	1.0
5	764.0	713.5	1.5
6	509.0	1223.0	2.0
7	1019.0	1223.0	2.0
8	509.0	204.0	1.0
9	1019.0	204.0	2.0
10	764.0	713.5	1.5
11	764.0	713.5	1.5
12	509.0	1223.0	1.0

Table-5 shows the augmented design of experiments for RSM, 6 more runs plus 2 center points. The kenaf composites were milled first according to the orders of runs which is shown in Table IV. If there are appearances of significant curvature, the kenaf composites are then milled according to the orders of runs in Table-5.

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Table-5. Augmented design of experiments for RSM.

Runs	A	B	C
13	335	713.5	1.5
14	764	713.5	1.5
15	764	713.5	1.5
16	764	713.5	0.66
17	764	713.5	2.34
18	1193	713.5	1.5
19	764	1570	1.5
20	764	143.37	1.5

Measurement of surface roughness

The results of surface roughness and factor of delamination were obtained after milling processes. The surface roughness of milled kenaf composites was measured using a surface roughness tester (Mitutoyo CS-3000 525-780E-1). 3 points were measured on slotted kenaf composite (see Figure-2) for surface roughness and average of them (R_a) were recorded in Table-6.

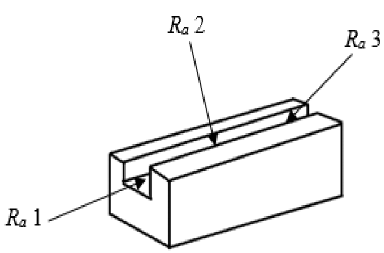

Figure-2. Regions for measurement of surface roughness

RESULT AND DISCUSSIONS

Optimization of surface roughness

The experimental result of surface roughness is recorded in Table-6. ANOVA (see Table-7) was used to identify the significance of the factors on surface roughness. The ANOVA was done using Design Expert software. The null hypothesis is the factor has no significant effect on surface roughness of milled kenaf composite. By using confidence level 95%, the factors are significant on surface roughness if the p-value less than 0.05 (reject null hypothesis).

Table-6. Experimental results of surface roughness.

Runs	A (Spindle speed, rpm)	B (Feed rate, mm/min)	C (Depth of cut, mm)	Surface roughness, R_a (µm)
1	509.0	204.0	2.0	1.7
2	1019.0	1223.0	1.0	3.47
3	764.0	713.5	1.5	3.28
4	1019.0	204.0	1.0	2.248
5	764.0	713.5	1.5	2.952
6	509.0	1223.0	2.0	6.012
7	1019.0	1223.0	2.0	4.743
8	509.0	204.0	1.0	3.073
9	1019.0	204.0	2.0	2.539
10	764.0	713.5	1.5	4.02
11	764.0	713.5	1.5	4.133
12	509.0	1223.0	1.0	6.725

Table-7. ANOVA of parameters on surface roughness.

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
Pure of error	0.98	3	0.33	-	-

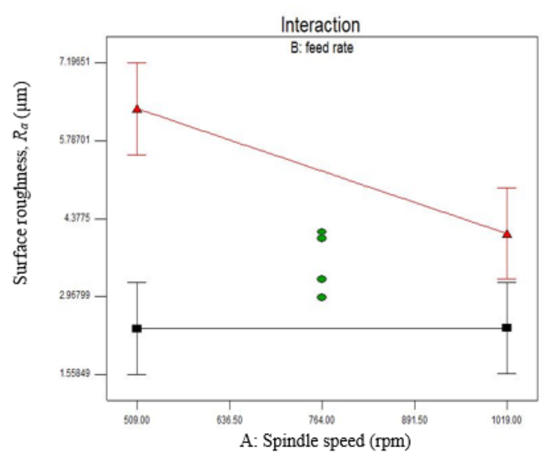

Figure-3. Effect of AB interaction on surface roughness.

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According to Table-7, 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 depth of cut cannot be ignored since it was the main factor. 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.

Figure-3 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 by G. D. Babu *et al.* 2013, 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. G. D. Babu *et al.* 2013, done the research for others natural fiber such as Hemp, Jute, and Banana were the result shows the same trand with Kenaf Fiber. The result from this study also compare with other synthetics fiber such as carbon fiber and glass fiber that by J. Paulo Davim and Pedro Reis, 2005. They found the, R_a is increases with feed rate and decreases with the cutting velocity, i.e. with a higher cutting velocity and a lower feed rate it is possible obtain a better surface finish for boths carbon fiber and glass fiber (J. Paulo at el., 2004). Although the depth of cut shows least significant, it still plays an essential role in affecting surface roughness but not in critical way. K. Palanikumar, 2007, believed that high depth of cut leads to a total removal of fiber which results in having a good surface finish.

Optimum parameters and modelling 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 509 rpm spindle speed, 204 mm/min feed rate and 2 mm depth of cut. The prediction of surface roughness was 1.865 µm with the range between 0.13 µm 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).

$$\text{Surface roughness } (R_a) = 5.42561 - 4.4632 \times 10^{-3} A + 6.13008 \times 10^{-3} B - 2.8644C - 4.36606 \times 10^{-6} A + 3.57843 \times 10^{-3} AC \quad (3)$$

Where

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

Confirmation tests

In order to verify the suggested optimum parameters and the modelling equations, confirmation tests had been conducted. The suggested milling parameters for optimizing surface roughness and delamination were the same, 509 rpm spindle speed, 204 mm/min feed rate and 2 mm depth of cut. These parameters were rounded off for the ease of machining.

Table-8 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.

Table-8. Percentage error between calculated R_a, and measured R_a.

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

CONCLUSIONS

Both suggested optimum milling parameters in this research for minimization of surface roughness is 500 rpm spindle speed, 200 mm/min feed rate and 2 mm depth of cut (rounded off) gave the minimum surface roughness.

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.

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