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Effect of Machining Parameters on the Surface Roughness During Turning Operation in Banana Micro, Macro Particle and Short Fiber Reinforced Epoxy Composites

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Abstract:

Based on the machining parameters (cutting speed, feed rate, and depth of cut), the machinability behaviors of banana fiber micro, macro, and short fiber-reinforced epoxy composites were evaluated. These parameters' effects on the surface roughness of composites during turning were investigated. The surface roughness of epoxy composites reinforced with banana fibers in three different sizes is significantly influenced by the machining parameters (feed rate and cutting speed). When compared to micro particle and short fiber epoxy composites, macro particle epoxy composites have lower surface roughness values for all depth of cut values. The comparison of experimental and predicted values was strong due to the high R^2 and low average absolute percentage error values obtained, implying a better linear relationship. The comparison of experimental and predicted surface roughness values revealed that they agreed well.

Keywords: *Surface roughness, Banana micro particle, Macro particle and Short fiber, Linear regression model, ANOVA*

Introduction

Due to their superior mechanical properties, such as high specific strengths and design flexibility, natural fiber-reinforced composites have recently gained significant attention from material scientists [1]. There is a high demand for joining some of the parts or components together to create the final product as the use of fiber-reinforced polymer composites grows. The adhesive bonding method has traditionally been used most frequently to join composite parts and components, but it has some drawbacks [2]. According to Baixauli (1995), there are several requirements for joining composites, including the need for surface preparation before joining, the need for heat and pressure for curing, the use of chemicals, the requirement for cure time, which can be low or very high, the risk to the safety and health of composite parts and components due to the use of chemicals, the risk of inspecting bonded joints for flaws, and the requirement for specialized labour.

Because adhesive bonding is a stable bond, components and parts cannot be reassembled. Mechanically joined parts and components, on the other hand, can be assembled and disassembled as desired. There is an increase in demand for machining natural fiber polymer composites due to their widespread use and the need to join their parts and components. The polymer composite material's type determines how it behaves during the machining process [3]. The removal of extra or unwanted material is involved in the machining of composite materials. Turning, facing, drilling, and milling are some of the most common machining processes used in fiber-reinforced polymer composites. During the machining of fiber reinforced polymer

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composites, major issues such as rapid tool wear due to the abrasiveness of the composites, fiber fracture, and matrix breaking are created [4].

Surface roughness is influenced by machining parameters such as tool nose radius, tool rake angle, feed, speed, depth of cut, and cutting environment. The authors [5-6] demonstrated that machining parameters have an effect on the performance of natural fiber composites. Surface roughness is primarily determined by the important parameters of feed rate, depth of cut, and cutting speed [7-11]. Furthermore, the delamination and breaking of fibers and particles result in a poor surface finish, necessitating further research into the machining of fiber-reinforced polymer composites. The surface roughness of fiber-reinforced polymer composites during turning was investigated by Vijaya Kini et al [12]. The main influencing factor for surface roughness is feed rate, followed by the depth of cut. This research examines machining parameters as well as the influence of banana fibers in three different forms on surface roughness. The surface roughness of epoxy composites reinforced with banana fibers in three sizes is significantly affected by machining parameters.

Experimental details

Materials

Banana fibers are extracted mechanically from the pseudo-stem of the banana plant (Musa Sepientum) and cleaned by hand. The fibers are then crushed as fine particles by a crushing machine with a density of 1.35 g/cm3, tensile strength of 54 MPa, and Young's modulus of 3.49 GPa. Following that, fine particles with an average size of 1-100 microns and larger are manually separated using a sieving machine. Micro particles range from 1 to 100 microns in size, while macro particles exceed 100 microns. For this study, a short fiber with a length of 10 mm is also prepared. In this study, the epoxy resin diglycidyl ether of biphenyl-A (LY 556) with hardener triethylenetetramine (HY 951) is used as the polymer matrix. All of the chemicals used in this study were obtained from GVR Enterprises in Madurai, Tamil Nadu, India. Table 1 lists the typical properties of the epoxy resin ($C_{18}H_{21}ClO_3$) used in this study.

Table 1. The typical properties of the epoxy resin ($C_{18}H_{21}ClO_3$)

Properties of epoxy resin	
Density at 25 °C (g/cm^3)	1.15 – 1.20
Weight per epoxide (g)	188.68 g (LY556) & 187.57 g (Lapox L-12)
Viscosity at 25 °C (mPas)	10000 – 12000
Molecular weight (g/mol)	320.8483

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Preparation of Banana Fibers into Particle Form

A mechanical process is used to extract banana fibers from the pseudo-stem sheath of the banana plant. They are then manually chopped with a chisel and crushed with a mixture grinder. Finally, the crushed particles are sieved with micron holes for use in composite preparation. This study makes use of micro particles with an average size of 1-100 microns, macro particles with an average size of more than 100 microns, and short fiber cut into 10 mm fiber lengths.

Preparation of Composites

As shown in Fig. 1, the composite rod materials used in the tests are made from various banana fiber reinforcements, including short fiber-reinforced epoxy composite, macro particle reinforced epoxy composite, and micro particle reinforced epoxy composite. The composite rod samples are made with a PVC pipe mould that is 50 mm long and 30 mm in diameter. One end of the pipe is closed with an end cup, and the pipe is surrounded by a plastic sheet for easy removal of the composite specimen. The micro particle, macro particle, and short fiber (120 gms) are measured and mixed with the epoxy resin (100 ml) and hardener (10 ml) in a 10:1 ratio. The mixture of reinforcements and resin matrix is manually stirred before being poured into the mould. The mould is exposed to sunlight for 24 hours to cure. The composites are then removed from the mould.

Figure 1: Digital image of the composite rod for micro, macro particle and short fiber reinforced with epoxy composites

Machinability Behavior

Based on the machining parameters cutting speed, feed rate, and depth of cut, the machinability behaviour of epoxy composites reinforced with three sizes (short fiber, macro, and micro particle) of banana fibers in cylindrical form was investigated. Turning experiments on the MTAB MAXTRON CNC Lathe machine are used to observe the machinability behaviour of composite specimens. Hand lay-up technique was used to prepare composite rods, and machining experiments were performed using three machining parameters designed by the Taguchi L9 orthogonal array. Table 2 shows the levels of parameters used in the experiments. During the turning of composite rods, the surface roughness values were measured with a surface roughness metre.

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Table 2. Levels of machining parameter used for the experiments

S.No	Parameters/Notations/Units	Level I	Level II	Level III
1.	Feed rate (F) in mm/rev	0.1	0.2	0.3
2.	Cutting speed (S) in rpm	300	450	600
3.	Depth of cut (DC) in mm	1	2	3

Surface roughness measurements are taken using a "Surf Test" stylus apparatus (MITUTOYO- SJ-301). The test apparatus was calibrated prior to the experiments using a reference with a surface roughness value of 3.01 m. The apparatus is set to the standard value with a 5% tolerance limit. Otherwise, the test procedure is repeated until the value falls within the required range.

Design of Experiments

To characterize the turning operation of a composite specimen, three important parameters were chosen to conduct the experiments: feed rate, cutting speed, and depth of cut. An L_9 orthogonal array with nine rows and three columns at three levels was chosen for this study. The experiment plan consists of nine tests (array rows), with the first column representing feed rate, the second column representing cutting speed, and the third column representing depth of cut. The surface roughness (Ra) of three different composites will be studied. Table 3 shows the experimental design for the current study.

Table 3. Experimental layout plan for the present study

Experiment No.	Cutting speed (s) (rpm)	Feed rate (F) (mm/rev)	Depth of cut (DC) (mm)
1	300	0.1	1
2	300	0.2	2
3	300	0.3	3
4	450	0.1	2
5	450	0.2	3
6	450	0.3	1
7	600	0.1	3
8	600	0.2	1
9	600	0.3	2

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Results and Discussion

Influence of the Machining Parameters

As a process response, the average values of three trials of surface roughness (Ra) were recorded during the machining process. Table 4 displays the calculated surface roughness (Ra) values for the three different composites. Figure 2 depicts a sample digital image for surface roughness measurement. Figures 3–8 show the evolution of surface roughness (Ra) with different feed rate, cutting speed, and depth of cut values.

Table . 4 Experimental results of the L_9 orthogonal array experiments

Experiment No	Speed (rpm)	Feed (mm/min)	Depth of cut (mm)	Micro - surface roughness	Macro - surface roughness	Short - surface roughness
1	300	0.1	1	3.972	2.514	2.577
2	300	0.2	2	3.527	3.172	3.276
3	300	0.3	3	3.393	3.233	3.328
4	450	0.1	2	3.282	2.658	2.721
5	450	0.2	3	3.438	3.261	3.482
6	450	0.3	1	3.655	3.469	3.529
7	600	0.1	3	4.885	2.795	2.808
8	600	0.2	1	4.876	2.864	3.795
9	600	0.3	2	3.808	4.004	4.243

Figure 2: Digital image of composite specimen during surface roughness measurement

According to Table 4, the surface roughness values at micro particle epoxy composites are high with respect to feed rate and depth of cut at a cutting speed of 600 rpm, followed by 300 rpm and 450 rpm. In the case of macro particle epoxy composites, the surface

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roughness values increased with increasing cutting speed in relation to feed rate and depth of cut. Surface roughness values increased with increasing cutting speed from 300 rpm to 600 rpm in short fiber epoxy composites with respect to feed rate and depth of cut. The results show that macro particle epoxy composites have lower surface roughness values than micro particle and short fiber epoxy composites. It could be because the particles interact better with the epoxy resin matrix. The better the surface finish, the better the bonding within the composite specimens. The machined surface should have the required or low surface roughness after the tool makes contact with the surface of the composite specimens during the machining process. It is determined by the interfacial adhesion of the reinforcement to the resin matrix.

The surface roughness values of three different epoxy composites are analyzed in relation to the cutting speed and feed rate. Figs. 3–5 show the variations in surface roughness based on feed rate in relation to cutting speed. Surface roughness values decreased with increasing feed rate of the micro particle epoxy composite at a cutting speed of 300 rpm. Surface roughness values, on the other hand, increased as the feed rate of the macro particle and short fiber epoxy composites increased. When compared to micro particle and short fiber epoxy composites, macro particle epoxy composites have lower surface roughness values.

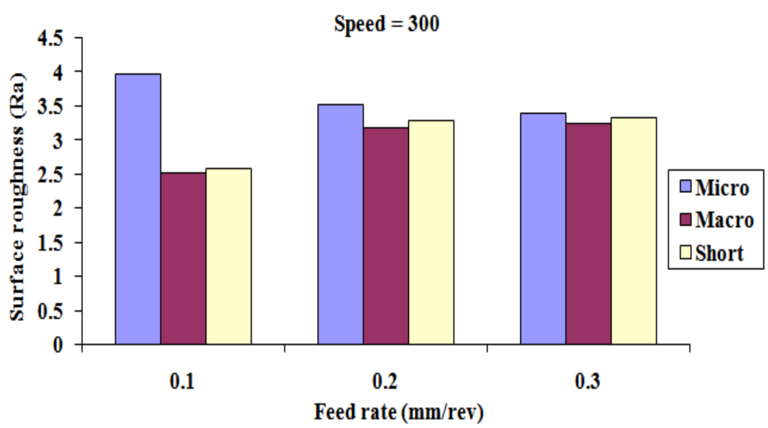

Figure 3: Variations of surface roughness based on the feed rate with a cutting speed of 300 rpm

Surface roughness values increased with increasing feed rate at all types of epoxy composites with 450 rpm cutting speed. In this case, macro particle epoxy composites have lower surface roughness values than micro particle and short fiber epoxy composites.

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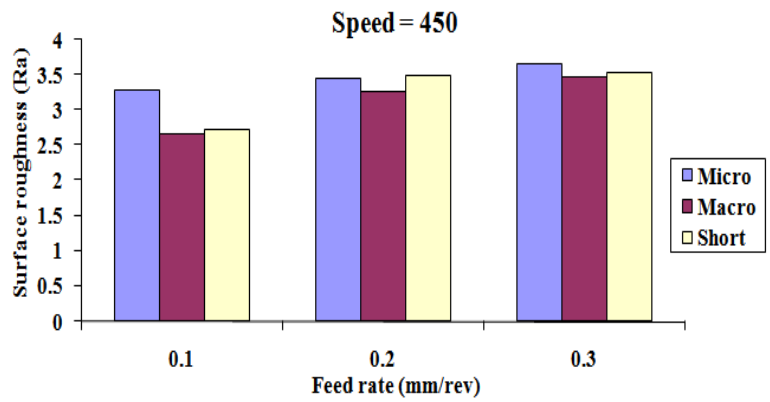

Figure 4: Variations of surface roughness based on the feed rate with a cutting speed of 450 rpm

Surface roughness values of micro particle epoxy composite decreased with increasing feed rate during machining at a cutting speed of 600 rpm. However, as the feed rate increased, the surface roughness values of the macro particle and short fibre epoxy composites increased. When compared to the other epoxy composites, macro particle epoxy composites have lower surface roughness values.

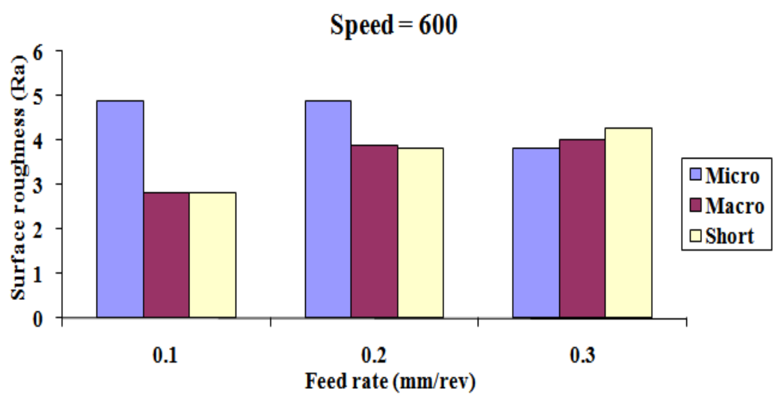

Figure 5: Variations of surface roughness based on the feed rate with a cutting speed of 600 rpm

Figures 6–8 show the variations in surface roughness with respect to cutting speed based on the depth of cut. When the machining process was carried out at a cutting speed of 300 rpm, the surface roughness values at micro particle epoxy composite decreased as the depth of cut values increased. However, in the case of macro particle and short fiber epoxy composites, the surface roughness values increased as the depth of cut increased. When compared to micro particle and short fiber epoxy composites, macro particle epoxy composites have lower surface roughness values for all depth of cut values.

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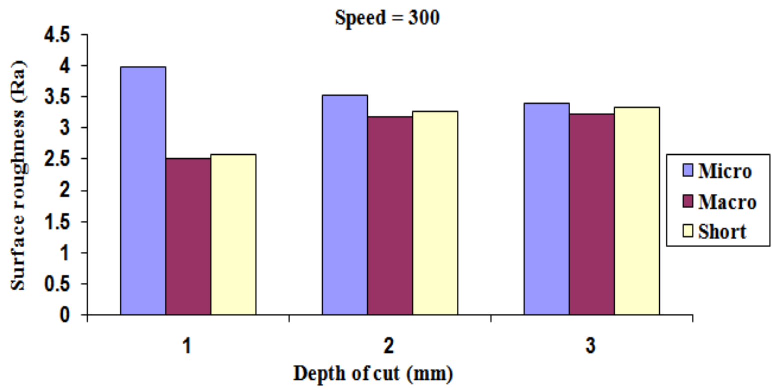

Figure 6: Variations of surface roughness based on the depth of cut with a cutting speed of 300 rpm

Surface roughness scatter values were obtained while machining at 450 and 600 rpm. However, as shown in Figures 7 and 8, macro particle epoxy composites have lower surface roughness values than micro particle and short fiber epoxy composites.

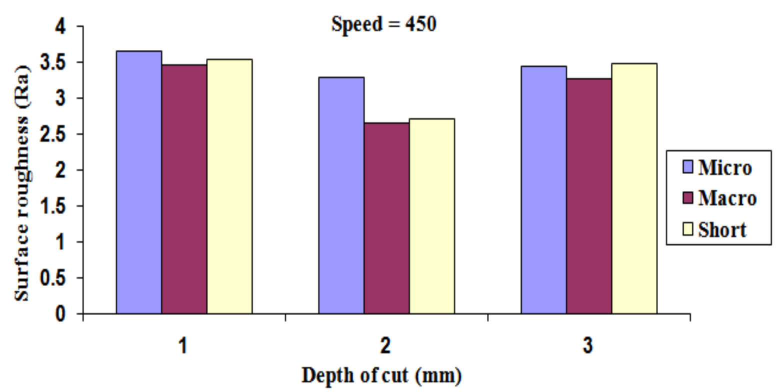

Figure 7: Variations of surface roughness based on the depth of cut with a cutting speed of 450 rpm

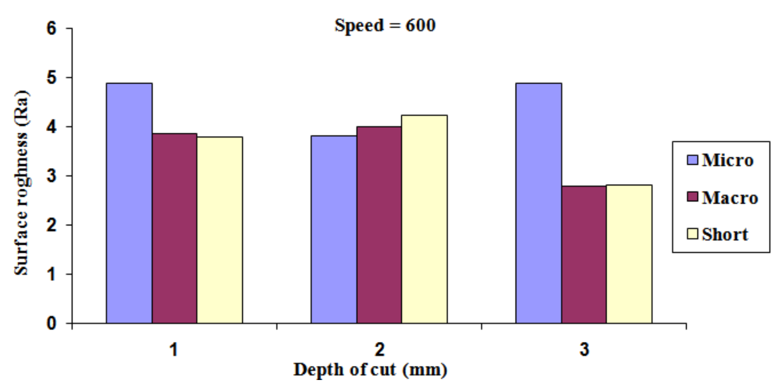

Figure 8: Variations of surface roughness based on the depth of cut with a cutting speed of 600 rpm

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Regression Model

Several prediction techniques have been used to model the machinability behaviors of fiber and particle reinforced polymer composite material in terms of different machining parameters. The regression model is found to be useful in determining the machinability behaviors of fiber-reinforced polymer composites. The surface roughness values are recorded during turning of epoxy composites reinforced banana fibers at three different forms (short, macro and micro particle). Therefore, we are taking surface roughness data for statistical prediction using RM. The data collected from the experiment was used to build a mathematical model using regression analysis. Regression equations were found to get the relation between response variable (surface roughness) and the input parameters (cutting speed, feed rate, and depth of cut) using MINITAP 17 software.

Development of Regression Equations

The linear regression equation 1 to 3 for surface roughness of micro particle, macro particle and short fiber reinforced epoxy composites were developed as:

1. Micro - Surface roughness

$$(Ra) = 4.22 - 0.000159\ S - 2.10\ F - 0.0445\ DC \quad (1)$$

2. Macro - Surface roughness

$$(Ra) = 1.62 + 0.00194\ S + 4.57\ F - 0.0930\ DC \quad (2)$$

3. Short - Surface roughness

$$(Ra) = 1.57 + 0.00185\ S + 4.99\ F - 0.047\ DC \quad (3)$$

The squared residual values (R^2) for surface roughness of micro particle, macro particle and short fiber composites are found to be 0.850, 0.865 and 0.849 respectively in the Regression model. The term 'R^2 'is a statistic value which gives some information about the goodness of fit of a developed model. In regression method, the determination of 'R^2' coefficient is a statistical compute of how well the regression line in the analysis approximates the real value of data points. If $R^2 = 1.0$, the developed regression line perfectly fits the data values. The normal probability plots for micro particle, macro particle and short fiber composite are shown in Fig. 9 to 11. Tables 5, 7, and 9 give the coefficients values for three types of epoxy composites. The analysis of variance for surface roughness recorded during turning of composites was given in Tables 6, 8, and 10.

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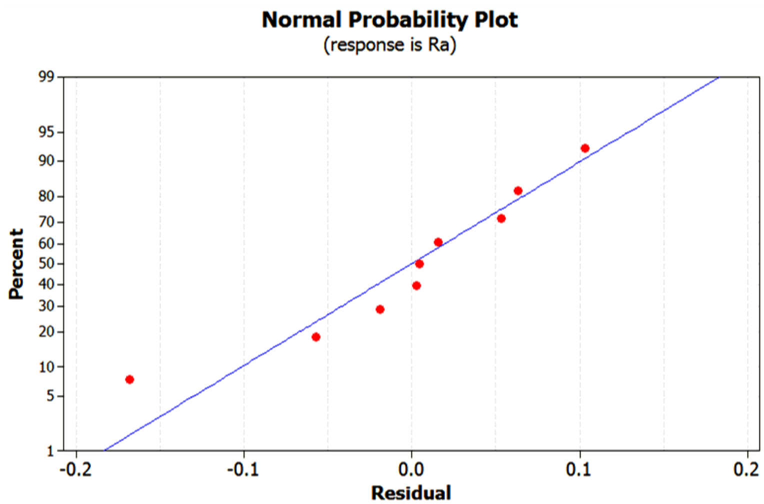

Figure 9: Normal probability plot for micro particle reinforced with epoxy composites

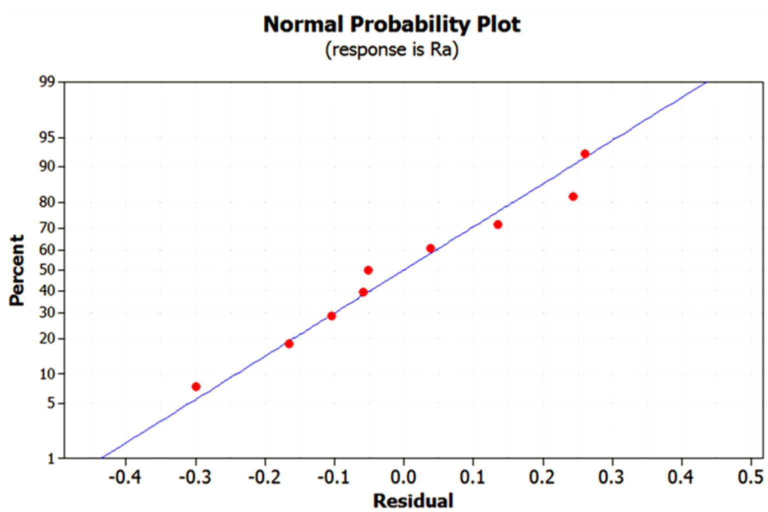

Figure 10: Normal probanility plot for macro particle reinforced with epoxy composites

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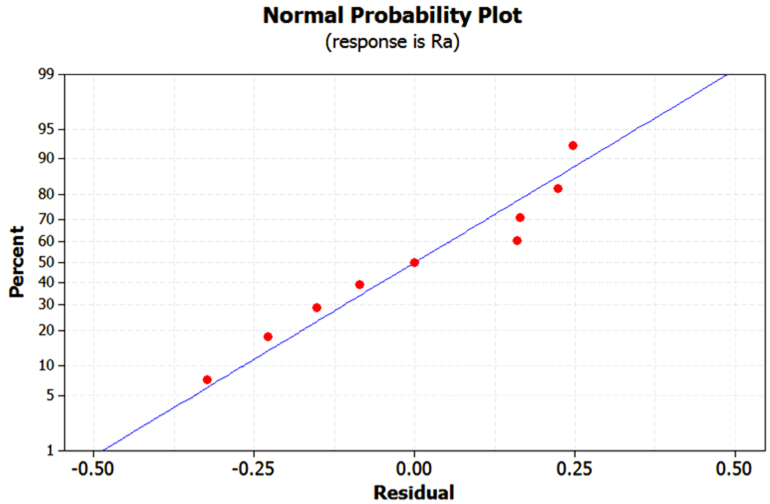

Figure 11: Normal probability plot for short fiber reinforced with epoxy composites

Table 5 shows that the p-value for feed rate is 0.004, indicating that the levels of surface roughness during machining of micro particle reinforced epoxy composites are related to feed rate. Table 6 shows the Analysis of Variance (ANOVA) for surface roughness obtained during machining of micro particle reinforced epoxy composite. The predicted surface roughness values (p = 0.017) are associated with experimental surface roughness values based on p-values and a significance level of 0.05.

Table 5. Response table for surface roughness (Micro particle reinforced epoxy composite)

Predictor	Coefficient	SE Coefficient	T	P
Constant	4.2211	0.1711	24.67	0.000
S	-0.0001589	0.0002714	-0.59	0.584
F	-2.1050	0.4071	-5.17	0.004
DC	-0.04450	0.04071	-1.09	0.324

Table 6. Analysis of Variance for surface roughness (Micro particle reinforced epoxy composite)

Source	DF	SS	MS	F	P
Regression	3	0.281151	0.093717	9.43	0.017
Residual Error	5	0.049707	0.009941		
Total	8	0.330858			

Table 7 shows the surface roughness response table (macro particle reinforced epoxy composite). The p-values for cutting speed and feed rate are 0.030 and 0.005, respectively, indicating that the levels of surface roughness for macro particle reinforced epoxy composites are related to cutting speed and feed rate. Table 8 shows the ANOVA for surface roughness in a macro particle reinforced epoxy composite. Table 8 shows that the predicted surface roughness values (p = 0.013) are related to the experimental surface roughness values.

Table 7. Response table for surface roughness (Macro particle reinforced epoxy composite)

Predictor	Coefficient	SE Coefficient	T	P
Constant	1.6199	0.4070	3.98	0.011
S	0.0019378	0.0006455	3.00	0.030
F	4.5650	0.9683	4.71	0.005
DC	-0.09300	0.09683	-0.96	0.381

Table 8. Analysis of Variance for surface roughness (Macro particle reinforced epoxy composite)

Source	DF	SS	MS	F	P
Regression	3	1.80917	0.60306	10.72	0.013
Residual Error	5	0.28127	0.05625		
Total	8	2.09044			

Table 9 shows that the p-values for cutting speed and feed rate are 0.050 and 0.006, respectively, indicating that the levels of surface roughness during machining of short fibre reinforced epoxy composites are associated with cutting speed and feed rate. Table 10 shows the ANOVA to surface roughness for short fibre reinforced epoxy composite. The predicted surface roughness values (p = 0.017) are associated with the experimental surface roughness values based on p-values and a significance level of 0.05.

Table 9. Response table for surface roughness (Short fiber reinforced epoxy composite)

Predictor	Coefficient	SE Coefficient	T	P
Constant	1.5704	0.4549	3.45	0.018
S	0.0018500	0.0007216	2.56	0.050
F	4.990	1.082	4.61	0.006
DC	-0.0472	0.1082	-0.44	0.681

Table 10. Analysis of Variance for surface roughness (Short fiber reinforced epoxy composite)

Source	DF	SS	MS	F	P
Regression	3	1.96939	0.65646	9.34	0.017
Residual Error	5	0.35145	0.07029		
Total	8	2.32085			

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Comparisons

The comparison of another set of values obtained through experimental measurements and predicted values by a linear regression model. The equation (4) [15] was used to calculate the error percentages for three types of composites. Tables 11–13 show the measured and predicted surface roughness values with process parameters for three different composites.

$$Error(\%) = \frac{V_m - V_{\exp}}{V_{\exp}} \times 100 \quad (4)$$

where V_m is the value of the model and V_{exp} the experimental value measured.

The average absolute percentage errors to surface roughness for micro particle, macro particle, and short fiber epoxy composites obtained from the tables are 3.83%, 3.92%, and 4.02%, respectively. The linear regression model is found to be in good agreement with experimental surface roughness values when considering the surface roughness during turning of micro particle, macro particle, and short fiber composites based on the values of average absolute percentage errors and R^2. Figures 12–14 show a comparison of the experimental and predicted surface roughness values.

Table 11. Comparison of experimental and predicted value for surface roughness (Micro particle reinforced epoxy composite)

S.No	Speed (rev/min)	Feed (mm/rev)	Depth of cut (mm)	Measured value (µm)	Predicted value (µm)	Error (%)
1.	350	0.15	1.5	3.636	3.782	4.02
2.	400	0.25	2.5	3.394	3.52	3.71
3.	500	0.27	2.75	3.318	3.451	4.01
4.	550	0.28	2.8	3.295	3.42	3.79
5.	575	0.29	2.9	3.271	3.39	3.64
Average absolute percentage error						3.83

Table 12. Comparison of experimental and predicted value for surface roughness (Macro particle reinforced epoxy composite)

S.No	Speed (rev/min)	Feed (mm/rev)	Depth of cut (mm)	Measured value (µm)	Predicted value (µm)	Error (%)
1.	350	0.15	1.5	2.256	2.345	3.95
2.	400	0.25	2.5	3.175	3.306	4.13
3.	500	0.27	2.75	3.447	3.568	3.51
4.	550	0.28	2.8	3.549	3.706	4.42
5.	575	0.29	2.9	3.659	3.791	3.61
Average absolute percentage error						3.92

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Table 13. Comparison of experimental and predicted value for surface roughness (Short fiber reinforced with epoxy matrix composites)

S.No	Speed (rev/min)	Feed (mm/rev)	Depth of cut (mm)	Measured value (µm)	Predicted value (µm)	Error (%)
1.	350	0.15	1.5	2.784	2.895	3.99
2.	400	0.25	2.5	3.304	3.44	4.12
3.	500	0.27	2.75	3.587	3.713	3.51
4.	550	0.28	2.8	3.697	3.853	4.22
5.	575	0.29	2.9	3.781	3.944	4.31
Average absolute percentage error						4.02

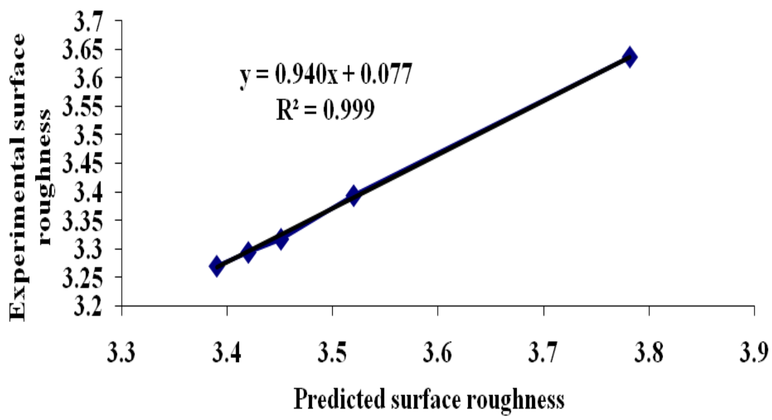

Figure 12: Comparison between the experimental and predicted surface roughness during turning of micro particle reinforced epoxy composite

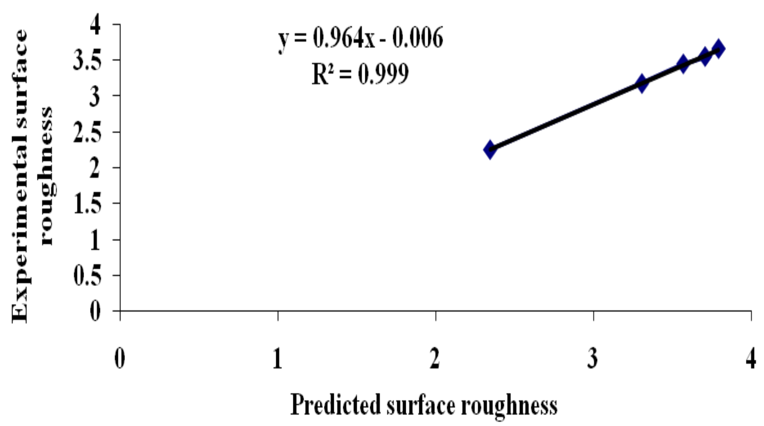

Figure 13: Comparison between the experimental and predicted surface roughness during turning of macro particle reinforced epoxy composite

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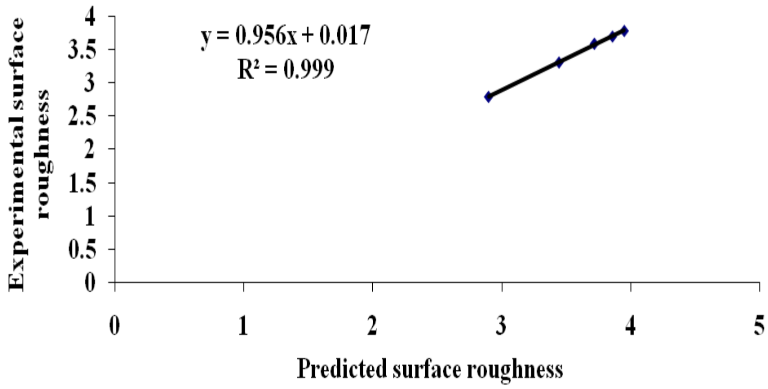

Figure 14: Comparison between the experimental and predicted surface roughness during turning of short fiber reinforced epoxy composite

Conclusions

The effects of machining parameters (cutting speed, feed rate, and depth of cut) on the surface roughness of three different types of epoxy composites reinforced with banana fibers are investigated. The surface roughness of epoxy composites reinforced with banana fibers in three sizes is significantly affected by the machining parameters (feed rate and cutting speed). When compared to microparticle and short fiber epoxy composites, macro particle epoxy composites have lower surface roughness values for all depths of cut. The comparison between experimental and predicted (Regression model) values is conducted to be strong by the high R^2 and low average absolute percentage error values obtained, i.e., expectation of a better linear relationship. The comparison between experimental and predicted surface roughness values showed that they were in good agreement.

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