Hindawi
Journal of Nanomaterials
Volume 2023, Article ID 9485769, 10 pages
https://doi.org/10.1155/2023/9485769

Research Article

Optimization of Machining Parameters of Natural/Glass Fiber with Nanoclay Polymer Composite Using Response Surface Methodology

S. Ragunath,[1] Meenakshi L. Rathod,[2] K. G. Saravanan,[3] N. Rakesh,[4] and Melkamu Kifetew[5]

[1]*Mechanical Engineering, SVS College of Engineering, Coimbatore 642109, India*
[2]*Department of Electronics and Communications Engineering, Dr. Ambedkar Institute of Technology, Bangalore, Karnataka, India*
[3]*Department of Mechanical Engineering, Sona College of Technology, Salem 636005, India*
[4]*Department of Mechanical and Industrial Engineering, University of Technology and Applied Sciences, Nizwa, Oman*
[5]*Department of Environmental Engineering, College of Biological and Chemical Engineering, Addis Ababa Science and Technology University, Addis Ababa, Ethiopia*

Correspondence should be addressed to Melkamu Kifetew; melkamu.kifetew@aastustudent.edu.et

Received 8 September 2022; Revised 15 December 2022; Accepted 2 May 2023; Published 2 June 2023

Academic Editor: Samson Jerold Samuel Chelladurai

Machining processes are one of the most important finishing operations in the fabrication of composites, which contain natural fibers. However, it is difficult to attain a better fishing on the final components. Hence, an attempt has been made in the work to achieve a good surface finish in compression-molded hybrid fiber composites containing nanoclay particles by optimizing the milling parameters. Experiments were conducted by using Box–Behnken design (response surface methodology (RSM)) to optimize the milling process parameters such as spindle speed (16, 24, and 32 rpm), feed rate (0.1, 0.2, and 0.3 mm/rev.), and depth of cut (1, 1.5, 2 mm) along with different vol% of nanoclay content (3%, 6%, and 9%). The surface roughness of machined fiber composite was measured, and the most influential parameters were analyzed by analysis of variance, evaluation of signal-to-noise ratio, and mathematical models of responses were developed by RSM. The experimental results (A2B1C4D3) indicated that the feed rate is one of the most significant parameters, followed by nanoclay content, depth of cut, and spindle speed. Surface roughness was found to decrease continuously (2.18–2.08 μm) with increasing nanoclay content (up to 6%) at a certain limit and further addition of clay content (above 6%); the results were declined (2.42 μm) for the same levels of other parameters.

1. Introduction

Natural fiber-reinforced polymer composites are increasing by employed for several applications, including transportation industry, aerospace, offshore and marine industries, automobile, military and defense, power generation, and household applications. For such applications, these composites required a combination of good mechanical, thermal, physical, and chemical properties along with excellent machining characteristics [1–6]. The addition of nanoclay as filler materials with natural fibers were increased the mechanical and impact properties of the developed composite because clay content increased the bonding strength between reinforcement and matrix materials. The final results indicated that the tensile strength, impact strength, and compression strength of fiber-reinforced polymer composites showed significant improvement with the addition of filler content. Naturally available materials have wax, cellulose, hemicellulose content, and lignin has moisture content. It directly affects the strength of fabricated composite specimens. Hence, the raw fibers need to be treated under alkali solutions. The chemical treatment offered better mechanical properties due to excellent adhesion between fiber and epoxy materials [7–10].

Among the various machining techniques, milling is one of the best-suited operations to produce precise and high-quality surface in fiber-reinforced polymer composites [11]. Unlike metal matrix composites, milling is a challenging operation in fibre reinforced plastic composites (FRPC). Since fiber pull-outs, delamination, fiber damages, microcracking, and interlaminar crack propagation can occur. To avoid these defects in FRPC while machining, proper selection of process parameters is essential [12–16]. Optimization of surface roughness of glass fiber-reinforced plastic composites is influenced by factors such as cutting speed, feed rate, and depth of cut. Machining experiments were conducted using L27 orthogonal array by Pareto, and results were analyzed by analysis of variance (ANOVA) analysis and signal-to-noise (S/N) ratio, and it was concluded that feed rate was one of the most significant factors, followed by cutting speed [17].

Machining characteristics of glass fiber-reinforced plastics (GFRP) composites were evaluated through Grey Relational Analysis and Taguchi L27 orthogonal array techniques by Palanikumar et al. [18] metal removal rate, tool wear, and surface roughness were optimized with different process parameters. Experimental results showed that fiber orientation had the greatest influence, followed by machining time and feed rate [18]. Systematic investigations on milling of unidirectional carbon fiber-reinforced plastics composites with varying fiber orientations were carried out by Hintze et al. [19]. Results indicated that fiber orientation and choice of milling cutter were the most significant factors for the delamination of composite. During machining, delamination effects increased with repeated usage of cutting tools [18–21].

Taguchi optimization of tool life, cutting force, and surface roughness were evaluated by a study of process parameters, namely cutting speed, feed rate, and depth of cut by Lin [22]. Multiple performance characteristics evaluation by Grey Relational Analysis showed that these factors could be improved optimum cutting parameters [22]. Detailed machining studies were carried out by Azmi et al. [23] to understand the interaction effects of milling parameters (spindle speed, feed rate, and depth of cut) in kenaf fiber-reinforced plastic composites. A full factorial design was used to optimize the surface roughness factor of machined surfaces, and mathematical models were developed by response surface methodology (RSM). ANOVA was used to determine the most significant factors among the selected process parameters. It was concluded that the spindle speed and feed rate were the most influencing factors of surface roughness. During the machining of fiber composites by Vinayagamoorthy et al. [24], the optimum thrust force was obtained by using high level of speed, feed, and medium level of depth of cut, whereas torque, high speed, low feed, and low depth of cut to improve surface finishing of machined fiber composites. Depth of cut and spindle were the most influential factors on machining fiber-reinforced polymer composites [24].

Taguchi optimization method was employed in optimizing the surface roughness of the milling operation of kenaf fiber-reinforced plastic composite. Process parameters combinations chosen were cutting speed, feed rate, and depth of cut in the range of 500–1,000 rpm, 200–1,200 mm/min, and 1.00–2.00 mm, respectively. Results showed that feed rate and the cutting speed were the most influencing factors for surface roughness. Optimum process parameters obtained were 1,000 rpm cutting speed, 200 mm/min feed rate, and 1.00 mm depth of cut [25]. Babu et al. [26] were employed with three levels of cutting speed and feed rate by 5 mm diameter of end mill cutter for machining on hemp fiber-reinforced plastics, jute fiber-reinforced plastics, banana fiber-reinforced plastics, and GFRP using Taguchi technique to evaluate the factor that influences delamination factor and surface roughness. Taguchi method and Fuzzy logic optimizations were carried out on woven type jute fiber-reinforced polymer composites by Vinayagamoorthy and Rajeswari [27] using 7 mm end mill cutter by varying process parameters, namely spindle speed (210, 660, 1,750 rpm), feed rate (0.04, 0.08, 0.15 mm/rev.), and depth of cut (1, 1.5, 2 mm). The authors reported that high level of speed, feed rate, and mean level of depth of cut were observed as optimum machining parameters for obtaining high thrust force. Also, it was found that low level of depth of cut, feed rate, and high level of speed offered high torque.

From the extensive literature survey, through machining of fiber composites is a difficult operation; suitable selection of materials, proper combination of machining process parameters, and use of optimization techniques can help in achieving good machined surfaces. Most of the researchers have studied milling investigations on either single or hybrid polymer composites. The present experimental study on natural fibers and glass fiber reinforced with the different percentile of nanoclay polymer hybrid composites. End milling operation of composites with varying addition of nanoclay to optimize cutting speed, feed rate, and depth of cut. The mathematical models have been developed by using RSM, and the results were correlated with selected process parameters. S/N ratio and ANOVA analyses were examined to determine the most influential factor among selected process parameters to minimize surface roughness during milling.

2. Experimental Procedure

2.1. Materials and Methods. A 40% of reinforcement materials in the composition of developed composites were produced better mechanical strength via high interfacial bending strength between the matrix and reinforcement materials. Increasing fiber loading with matrix material leads to decline strength of composite. Hence, the 5% of NaOH-treated natural fibers, namely jute and sisal fibers, contain 10 vol% each. The natural fiber alone does not meet the required strength of the developed composites. To overcome this, synthetic fibers have been used with 15 vol% of mat-type glass fiber improve the impact properties of developed polymer composite. A small amount of nanoclay material is added as filler content with reinforcement materials to increase bonding the strength of composites. During the machining of composite structure, the delamination occurs due to poor bonding between matrix and reinforcement materials. Almost 60% of matrix materials are taken as the ratio of 10 : 1 (LY-556 epoxy resin: HY-951 Hardener) were used for rapid curing in fabrication work and to achieve a fine finished specimens on natural fiber composites. Table 1 represents the mechanical

Table 1: Mechanical characteristics of given materials.

Materials	Density (g/cm^3)	Elongation (%)	Tensile strength (MPa)	Young's modulus (GPa)	Specific gravity
Nanoclay 20	1.8	7.8	100	4.7	1.8
Jute fiber	1.4–1.6	1.5–2.2	385–848	9.5–30.5	1.35–1.56
Sisal fiber	1.2–1.8	2.0–14	395–710	8.6–42	1.2
E glass fiber	2.4	2.4–3.1	2,100–3,400	72.8	2.7
Epoxy resin	1.2	0.75	84.5	10.45	1.2

Table 2: Volume fraction of matrix and reinforcement materials.

Materials	Sisal fiber	Jute fiber	E glass fiber	Nanoclay	Epoxy resin
Volume	10 vol%	10 vol%	15 vol%	3–9 vol%	60 vol% (approx.)

Table 3: Independent variables and levels used for design of experiments.

Independent factors	Unit	Notation	Levels		
			−1	0	+1
Nanoclay	%	X_1	3	6	9
Feed rate	mm/rev.	X_2	0.1	0.2	0.3
Spindle speed	rpm	X_3	16	24	32
Depth of cut	mm	X_4	1.0	1.5	2.0

characteristics of preferred materials for the fabrication of composites [28].

Compression molding technique was employed to fabricate fiber-reinforced polymer hybrid composites with different vol% of nanoclay content having dimensions of $300 \times 300 \times 10\,mm^3$. The compositions of selected materials are given in Table 2. During the fabrication of composites, glass fiber is located around the chopped form of natural fibers to cover the developed specimens for increasing bonding strength meanwhile to reduces the delamination of fibers on machining. Addition of nanoclay content is to control the melting of polymer due to thermal gradient. The specified compositions of sisal, jute fibers, and nanoclay with reinforcement materials (LY-556 epoxy resin: HY-951 Hardener) were poured inside the glass fiber on a molten box. The fabrication of composite is done under 500 psi at 95°C for 1.5 hr.

2.2. Machinbility Studies. In optimization, design of experiment plays a vital role in improving the consistency of results and to minimize the number of experiments without deviation of accuracy. RSM is one of the powerful tools for modeling and analyzing the controllable factors on responses, such as surface roughness. Delamination is one of the major defects occurring during machining fiber composites and can be minimized by improving the degree of bonding between lamina. In this work, nanoclay particles have been incorporated to enhance the interlamina bonding. For investigation on the significance of nanoclay content in machinability, the varying amount of nanoclay in composites was also considered as a material variable in designing the experiments. Table 3 shows selected independent factor and their levels [29, 30].

Box–Behnken design method was employed for selecting the independent level of factors. The interaction effects with selected factors and measured responses were developed by RSM [31]. A 27 run of experiments was developed to optimize the delamination during drilling on fiber-reinforced plastic composites using three process parameters with three levels by Taguchi analysis [32]. However, in the present work, 25 run of experiments was conducted effectively for four factors with three levels, and interrelation properties between the level of factors were examined by RSM. The combinations of different factors and their levels are presented in Table 4.

The milling operations are conducted by computer numerical control vertical machining center (HAAS Automation Inc. USA) with a maximum spindle speed of 4,000 rpm under the specified process parameters, and surface roughness on machined composite specimens ($90 \times 40 \times 10\,mm^3$) was measured by Mitutoyo talysurf tester [33]. The experiment results are described in Table 5. In addition to RSM, S/N ratio analysis are carried out for each experiment which is described in Table 5 by Minitab 17 tool and its one of the logarithmic function of optimization [34]. "Lower the better" approach suitable for minimizing surface roughness in S/N analysis was adopted and expressed as follows:

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

where n is the number of observations and y is the observed data.

In surface roughness, a simple and efficient mathematical model was built-in by RSM by Design Expert 11.0 software

Table 4: Box–Behnken design used in machining study.

Run order	Std. order	Levels of independent factors			
		Nanoclay (%)	Feed rate (mm/rev.)	Spindle speed (rpm)	Depth of cut (mm)
1	17	−1	0	−1	0
2	11	−1	0	0	1
3	8	0	0	1	1
4	20	1	0	1	0
5	18	1	0	−1	0
6	9	−1	0	0	−1
7	16	0	1	1	0
8	5	0	0	−1	−1
9	25	0	0	0	0
10	24	0	1	0	1
11	14	0	1	−1	0
12	10	1	0	0	−1
13	6	0	0	1	−1
14	12	1	0	0	1
15	1	−1	−1	0	0
16	22	0	1	0	−1
17	21	0	−1	0	−1
18	2	1	−1	0	0
19	7	0	0	−1	1
20	19	−1	0	1	0
21	13	0	−1	−1	0
22	15	0	−1	1	0
23	4	1	1	0	0
24	23	0	−1	0	1
25	3	−1	1	0	0

employing four independent factors with three levels. It can be used to predict the surface roughness of composite specimens and the process parameters successfully correlated by each experiment result.

$$y = \beta_0 + \sum_{i=1}^{4}\beta_i X_i + \sum_{i=1}^{4}\beta_{ii} X_i^2 + \sum_{i=1\ i<j}^{4}\beta_{ij} X_i X_j + \varepsilon, \quad (2)$$

where β_0, β_i, β_{ii}, β_{ij}, X_i, X_j are constant, liner coefficient, quadratic coefficient, interaction coefficient interaction independent variables, respectively, and y—response variables of fabricated composites.

The developed mathematical model was checked its fitness. If ANOVA results showed that the value of R^2 (adjusted) is approximately 95%, implying that the regression equation provides a better correlation of control factors with measured responses. If the value of P on developed model ≪0.05 (95% of confidence), the developed model can be considered to adequate in predicting the surface roughness [35].

3. Results and Discussion

Surface roughness of machined fiber-reinforced polymer composites was evaluated through 25 experiments as per the design matrix, and the machining of composites was completed by selected levels; the obtained results are presented in Table 5.

In general, surface roughness increased with an increment in spindle speed [23, 24]. However, from the experimental results, it can be noticed that three different response results were obtained for the same levels of feed rate (0.2 mm/rev.) and depth of cut (1.0 mm) with the variation of nanoclay content and spindle speed in the run order of 5, 9, and 10. The surface roughness was minimized (2.18–2.08 μm) because of increasing nanoclay particles and even when spindle speed was increased from 16 to 24 rpm, as can be observed from 9th to 5th run order experiments. Hence, with the addition of nanoclay, the surface roughness of composite can be controlled. It can also be noticed that further addition of nanoclay leads to increasing surface roughness, as seen from the 10th run order, since overload nanoclay filler materials developed poor bonding with the matrix materials and stress concentration [36].

ANOVA tool used to develop model under the different levels of parameters was significant. Table 6 presents the results of ANOVA analysis result on surface roughness. The obtained result shows that probability value ≪0.05, which represents that the developed mathematical model is significant since most of the influential factors have values less than 0.0001. Hence, it can be concluded that the developed model is well significant in a given level of independent

Table 5: Response results of trials based on Box–Behnken design.

Run order	Std. order	Levels of independent factors				Responses	
		Nanoclay (%)	Feed rate (mm/rev.)	Spindle speed (rpm)	Depth of cut (mm)	Surface roughness (Ra)	S/N ratio
1	17	9	0.2	24	2.0	2.75	51.21
2	11	3	0.2	32	1.5	2.38	52.47
3	8	6	0.2	16	2.0	2.18	53.23
4	20	3	0.3	24	1.5	2.85	50.90
5	18	9	0.3	24	1.5	2.98	50.52
6	9	6	0.3	24	2.0	2.64	51.57
7	16	6	0.1	24	1.0	1.72	55.29
8	5	3	0.2	24	2.0	2.42	52.32
9	25	9	0.1	24	1.5	2.34	52.62
10	24	6	0.3	24	1.0	2.42	52.32
11	14	9	0.2	16	1.5	2.56	51.84
12	10	6	0.3	16	1.5	2.51	52.01
13	6	6	0.1	16	1.5	1.86	54.61
14	12	6	0.2	32	2.0	2.34	52.62
15	1	6	0.2	32	1.0	2.12	53.47
16	22	9	0.2	24	1.0	2.38	52.47
17	21	3	0.2	16	1.5	2.13	53.43
18	2	6	0.2	16	1.0	2.08	53.64
19	7	6	0.1	32	1.5	1.93	54.29
20	19	9	0.2	32	1.5	2.62	51.63
21	13	6	0.1	24	2.0	1.96	54.15
22	15	3	0.2	24	1.0	2.18	53.23
23	4	3	0.1	24	1.5	1.98	54.07
24	23	6	0.2	24	1.5	2.25	52.96
25	3	6	0.3	32	1.5	2.58	51.77

Table 6: ANOVA analysis surface roughness.

Resource	SS	DOE	MS	F value	P value prob > F	Status
Model	2.39	14	0.1709	46.75	<0.0001	Significant
X_1-nanoclay	0.2380	1	0.2380	65.12	<0.0001	
X_2-feed rate	1.46	1	1.46	400.28	<0.0001	
X_3-spindle speed	0.0352	1	0.0352	9.63	0.0112	
X_4-depth of cut	0.1610	1	0.1610	44.05	<0.0001	
$X_1 X_2$	0.0132	1	0.0132	3.62	0.0863	
$X_1 X_3$	0.0090	1	0.0090	2.47	0.1472	
$X_1 X_4$	0.0042	1	0.0042	1.16	0.3076	
$X_2 X_3$	0.0000	1	0.0000	0.0000	1.0000	
$X_2 X_4$	0.0001	1	0.0001	0.0274	0.8719	
$X_3 X_4$	0.0036	1	0.0036	0.9850	0.3444	
X_1^2	0.1649	1	0.1649	45.12	<0.0001	
X_2^2	0.0008	1	0.0008	0.2146	0.6531	
X_3^2	0.0053	1	0.0053	1.45	0.2562	
X_4^2	0.0088	1	0.0088	2.41	0.1517	
Residual	0.0366	10	0.0037			
Cor. total	2.43	24				

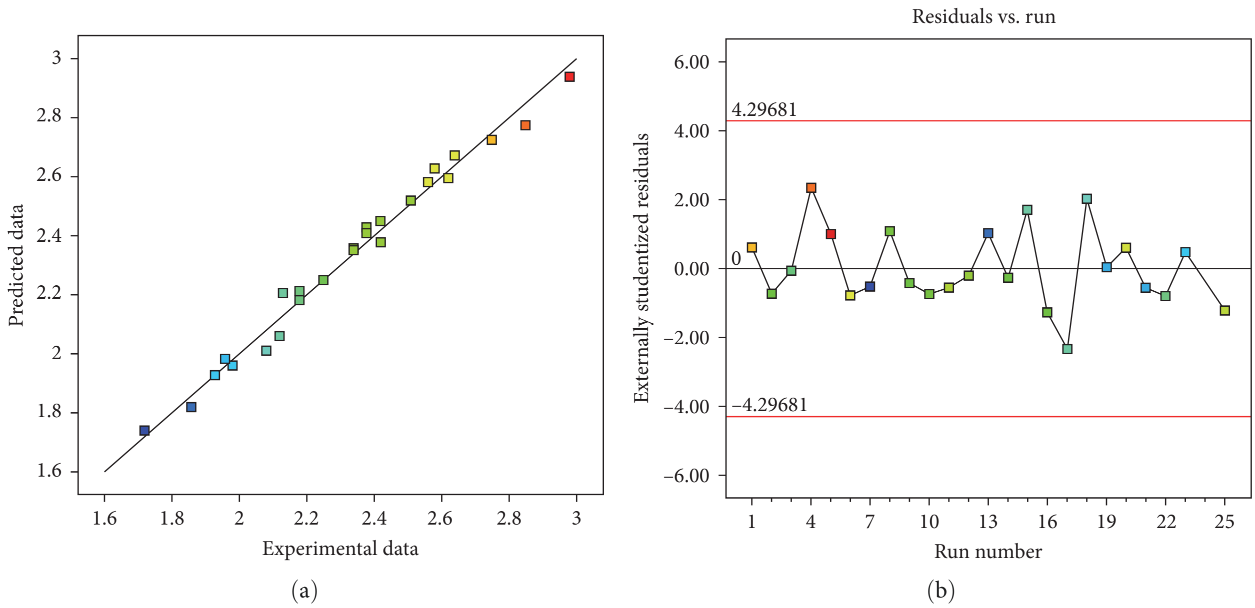

Figure 1: (a) Scatter diagram and (b) residual versus run order of surface roughness.

factors. The Model F-value of 46.75 also confirms that the model is significant [18, 37].

The mathematical model of the surface roughness of composites is a function of independent factors, and it is represented by the following equation [38]:

$$\begin{aligned}\text{Surface roughness (Ra)} \\ &= 2.25 + 0.140\,X_1 + 0.349\,X_2 + 0.054\,X_3 + 0.116\,X_4 \\ &\quad -0.057\,X_1X_2 - 0.047\,X_1X_3 + 0.032\,X_1X_4 \\ &\quad +1.11\times 10^{-16}X_2X_3 - 0.005\,X_2X_4 + 0.030\,X_3X_1 \\ &\quad +0.241\,X_1^2 + 0.016\,X_2^2 - 0.043\,X_3^2 - 0.056\,X_4^2. \end{aligned} \quad (3)$$

The previous mathematical models were used to predict interaction effects on surface roughness. The adequacy of response models was confirmed by coefficients of determinant R^2. The value of R^2 is very near to unity indicating a high degree of correlation between the predicted and experimented data. In this investigation, the R^2 value is 0.985 and adjusted R^2 value is 0.964. In consequently, it is concluded that the experimental results and predicted data were well correlated. Hence, the developed regression model could be effectively used to predict the surface roughness of machined composites [39].

Figure 1(a) shows the relation between the experimental results and predicted data for the surface roughness of machined fiber-reinforced polymer composites. The graph indicating a very close relationship between the predicted and experimental data, and an adequate level of 98% confidence of mathematical model can be obtained for machining behavior during the milling of fiber composite structure [40, 41].

$$(\%)\ \text{Error} = \frac{(\text{Experimental value} - \text{predicted value})}{\text{Predicted value}} \times 100. \quad (4)$$

From Figure 1(b), it can be clearly observed that the residuals and run orders were well correlated and evenly distributed on both sides for the entire run of experiments in the range of ±5, described in design matrix [42].

The interactions between the given factors for surface roughness are shown in 3D surface graphs in Figure 2(a)–2(f). The interaction effects of nanoclay with feed rate (Figure 2(a)), spindle speed (Figure 2(b)), and depth of cut (Figure 2(c)) clearly show that at low level of nanoclay (3 vol%) and high level of nanoclay (9 vol%) resulted in considerable surface roughness as compared to mean level of nanoclay (6 vol%). This indicates that the addition of optimum level of nanoclay particles to fiber composite produces minimum surface roughness, whereas the addition of nanoclay above and below these levels leads to increasing surface roughness [43]. Due to excess clay of materials causes debonding with matrix and reinforcement materials in natural fiber-reinforced hybrid polymer composite [29]. The effect of feed rate with spindle speed and depth of cut on surface roughness on composite are shown in Figures 2(d) and 2(e)). With an increase in the feed rate from 0.1 to 0.3 mm/rev., the surface roughness also increased gradually with other process parameters. However, no such effects produced on spindle speed with depth of cut are shown in Figure 2(f). Minimum effect was observed at low depth of cut (1.0 mm) and it increased with increase in depth of cut [44–46].

From the analysis of all interaction graphs on machining parameters, it can be concluded that feed rate is one of the most significant factors compared to other process parameters; meanwhile, filler content act as a major role for improving surface roughness on machining of fiber-reinforced hybrid polymer composite. Results confirm that for obtaining

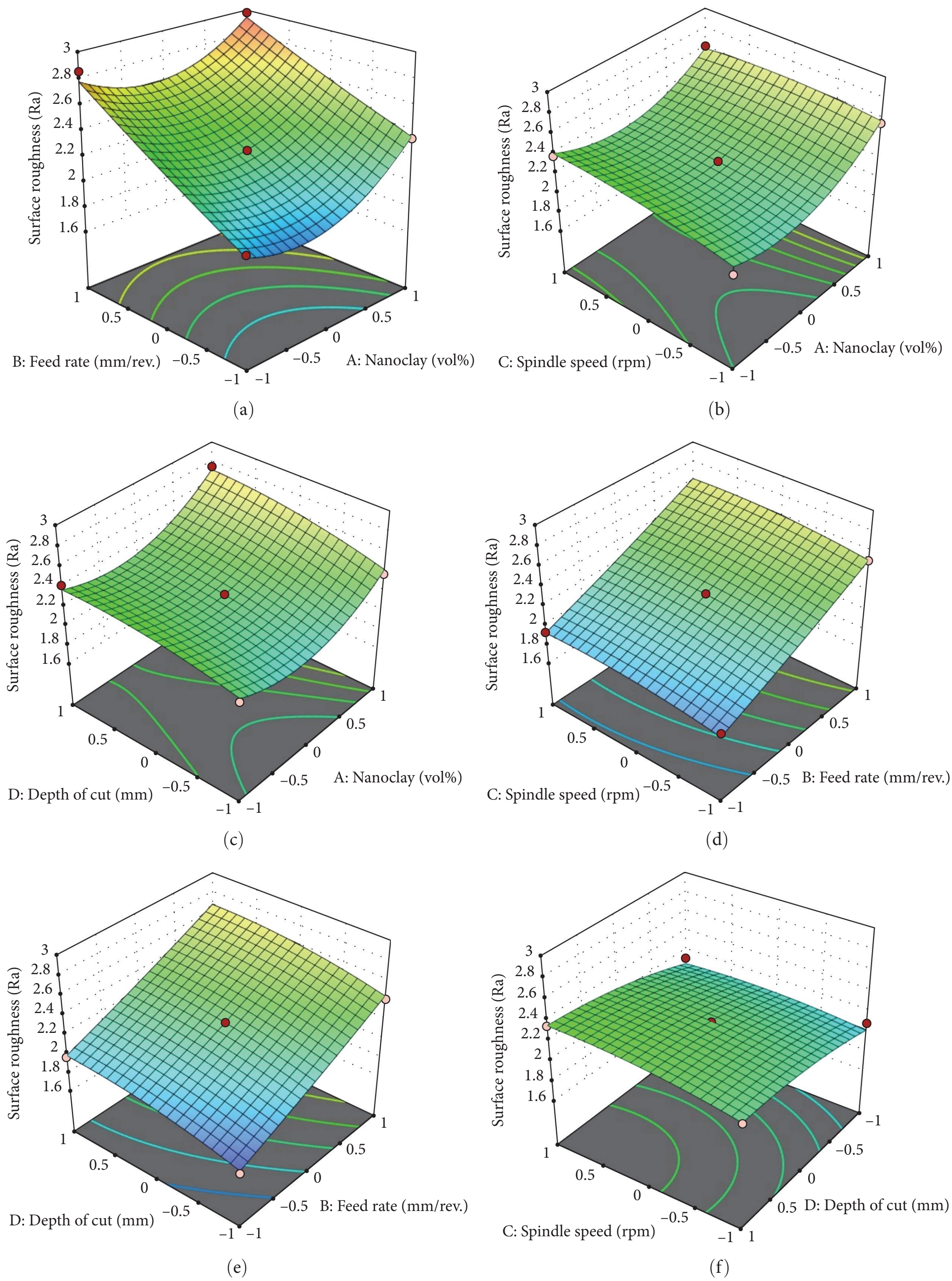

Figure 2: (a–f) 3D surface plots for interaction effect of process parameters.

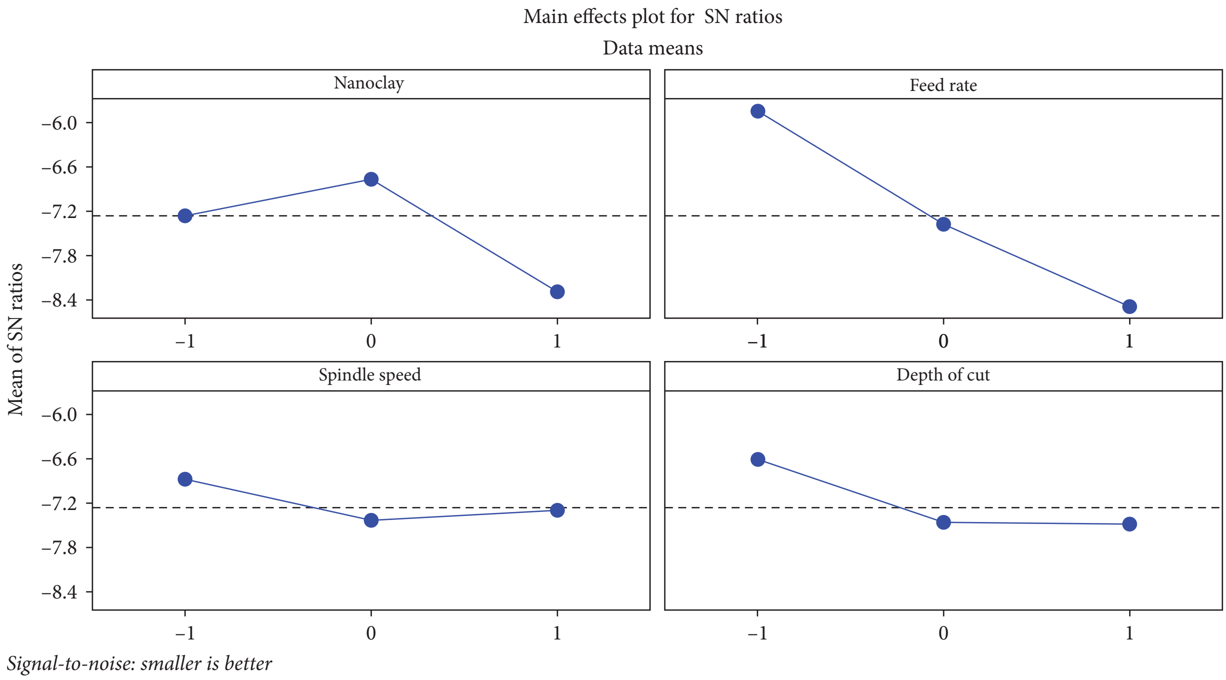

Figure 3: Effect of independent variables on surface roughness.

Table 7: S/N ratio for responses.

Response table for signal-to-noise ratios (smaller is better)				
Level	*A* nanoclay	*B* feed rate	*C* spindle speed	*D* depth of cut
1	−7.262	−5.829	−6.874	−6.596
2	−6.775	−7.345	−7.413	−7.454
3	−8.286	−8.486	−7.292	−7.482
Delta	1.511	2.657	0.539	0.886
Rank	2	1	4	3

quality of machining on composites, minimum feed rate with moderate nanoclay content is preferred.

The surface roughness experimental results on fiber-reinforced hybrid polymer composite are presented in Table 5. The 8th column of Table 5 shows the S/N ratio of response. The purpose of using the S/N ratio is to measure the performance of developed model [47]. The main effects of the surface roughness are graphically shown in Figure 3 for mean values of S/N ratio. Figure 3 shows the result of process parameters, namely nanoclay, feed rate, spindle speed, and depth of cut on surface roughness of machined composite. The slope of each factor under the levels shows influences of the response of machining operation [17, 48]. From Figure 3, it can be concluded that the feed rate is one of the most influential factors with the other process parameters.

As compared to other process parameters, feed rate is the most significant factor for required response (surface roughness), as concluded in Table 7. It simply indicates the combination of independent factors A2B1C4D3 for obtaining minimum surface roughness in the fiber-reinforced hybrid polymer composite.

4. Conclusion

Important conclusions from the present study are as follows:

(i) It can be concluded that the feed rate is one of the most significant factors (A2B1C4D3), followed by nanoclay, depth of cut, and spindle speed from the previous investigation on FRP composites.

(ii) The experimental results indicating that the nanoclay content has a significant influence on the surface roughness of hybrid composites.

(iii) Optimum addition of clay content minimized the surface roughness (2.18–2.08 μm), while further addition with fiber materials leads to increasing of response (2.42 μm) due to excessive clay content at the same levels of other parameters.

(iv) The optimum effect produced with combination levels of independent factors is A2B1C4D3 on machining composite by S/N ratio.

(v) Mathematical model developed can be successfully used to calculate surface roughness and correlates well with investigational results (R^2—0.985).

(vi) The proper selection of machining parameters is essential to get better quality of machined surface on fiber composites.

Data Availability

The data used to support the findings of this study are included in the article.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

References

[1] M. Boumaaza, A. Belaadi, and M. Bourchak, "Performance of natural fibers-reinforced plaster: optimization using RSM," *Journal of Natural fibers*, vol. 18, no. 12, pp. 2220–2240, 2020.

[2] M. Rahman, S. Ramakrishna, J. R. S. Prakash, and D. C. G. Tan, "Machinability study of carbon fiber reinforced composite," *Journal of Materials Processing Technology*, vol. 89-90, pp. 292–297, 1999.

[3] J. A. Ghani, I. A. Choudhury, and H. H. Hassan, "Application of Taguchi method in the optimization of end milling parameters," *Journal of Materials Processing Technology*, vol. 145, no. 1, pp. 84–92, 2004.

[4] C. Velmurugan, R. Subramanian, S. Thirugnanm, T. Kannan, and B. Anandavel, "Experimental study on the effect of SiC and graphite particles on weight loss of Al6061 hybrid composite materials," *Journal of Tribology and Surface Engineering*, vol. 2, no. 1/2, pp. 49–68, 2011.

[5] K. Palanikumar, J. C. Rubio, A. M. Abrao, A. E. Correia, and J. P. Davim, "Influence of drill point angle in high speed drilling of glass fiber reinforced plastics," *Journal of Composite Materials*, vol. 42, no. 24, pp. 2585–2597, 2008.

[6] V. K. Vankanti and V. Ganta, "Optimization of process parameters in drilling of GFRP composite using Taguchi method," *Journal of Materials Research and Technology*, vol. 3, no. 1, pp. 35–41, 2014.

[7] N. S. V. Gupta, Akash, K. V. S. Rao, and D. S. A. Kumar, "Fabrication and evaluation of mechanical properties of alkaline treated sisal/hemp fibre reinforced hybrid composite," *IOP Conference Series: Materials Science and Engineering*, vol. 149, Article ID 012093, 2016.

[8] M. M. Kabir, H. Wang, K. T. Lau, and F. Cardona, "Chemical treatments on plant-based natural fibre reinforced polymer composites: an overview," *Composites Part B: Engineering*, vol. 43, no. 7, pp. 2883–2892, 2012.

[9] K. Deepak, S. V. P. Vattikuti, and B. Venkatesh, "Experimental investigation of jute fibre reinforced nano clay composite," *Procedia Materials Science*, vol. 10, pp. 238–242, 2015.

[10] M. H. Gabr, N. T. Phong, M. A. Abdelkareem et al., "Mechanical, thermal, and moisture absorption properties of nano-clay reinforced nano-cellulose biocomposites," *Cellulose*, vol. 20, pp. 819–826, 2013.

[11] J. P. Davim and P. Reis, "Damage and dimensional precision on milling carbon fiber-reinforced plastics using design experiments," *Journal of Materials Processing Technology*, vol. 160, no. 2, pp. 160–167, 2005.

[12] P. K. Bajpai and I. Singh, "Drilling behavior of sisal fiber-reinforced polypropylene composite laminates," *Journal of Reinforced Plastics and Composites*, vol. 32, no. 20, pp. 1569–1576, 2013.

[13] F. Lachaud, R. Piquet, F. Collombet, and L. Surcin, "Drilling of composite structures," *Composite Structures*, vol. 52, no. 3-4, pp. 511–516, 2001.

[14] H. Zhang, W. Chen, D. Chen, and L. Zhang, "Assessment of the exit defects in carbon fibre-reinforced plastic plates caused by drilling," *Key Engineering Materials*, vol. 196, pp. 43–52, 2001.

[15] A. Krishnamoorthy, S. R. Boopathy, and K. Palanikumar, "Delamination analysis in drilling of CFRP composites using response surface methodology," *Journal of Composite Materials*, vol. 43, no. 24, pp. 2885–2902, 2009.

[16] R. Zitoune and F. Collombet, "Numerical prediction of the thrust force responsible of delamination during the drilling of the long-fibre composite structures," *Composites Part A: Applied Science and Manufacturing*, vol. 38, no. 3, pp. 858–866, 2007.

[17] K. Palanikumar, "Cutting parameters optimization for surface roughness in machining of GFRP composites using Taguchi's method," *Journal of Reinforced Plastics and Composites*, vol. 25, no. 16, pp. 1739–1751, 2006.

[18] K. Palanikumar, L. Karunamoorthy, and R. Karthikeyan, "Multiple performance optimization of machining parameters on the machining of GFRP composites using carbide (K10) tool," *Materials and Manufacturing Processes*, vol. 21, no. 8, pp. 846–852, 2006.

[19] W. Hintze, D. Hartmann, and C. Schütte, "Occurrence and propagation of delamination during the machining of carbon fibre reinforced plastics (CFRPs)–an experimental study," *Composites Science and Technology*, vol. 71, no. 15, pp. 1719–1726, 2011.

[20] V. N. Gaitonde, S. R. Karnik, J. C. Rubio, A. E. Correia, A. M. Abrão, and J. P. Davim, "Analysis of parametric influence on delamination in high-speed drilling of carbon fiber reinforced plastic composites," *Journal of Materials Processing Technology*, vol. 203, no. 1–3, pp. 431–438, 2008.

[21] C. C. Tsao and H. Hocheng, "Effect of tool wear on delamination in drilling composite materials," *International Journal of Mechanical Sciences*, vol. 49, no. 8, pp. 983–988, 2007.

[22] C. L. Lin, "Use of the Taguchi method and grey relational analysis to optimize turning operations with multiple performance characteristics," *Materials and Manufacturing Processes*, vol. 19, no. 2, pp. 209–220, 2004.

[23] H. Azmi, C. H. C. Haron, J. A. Ghani, M. Suhaily, A. B. Sanuddin, and J. H. Song, "Study on machinability effect of surface roughness in milling kenaf fiber reinforced plastic composite (unidirectional) using response surface methodology," *ARPN Journal of Engineering and Applied Sciences*, vol. 11, no. 7, pp. 4761–4766, 2016.

[24] R. Vinayagamoorthy, N. Rajeswari, and S. Karthikeyan, "Investigations of damages during drilling of natural sandwich composites," *Applied Mechanics and Materials*, vol. 766-767, pp. 812–817, 2015.

[25] S. Ghalme, A. Mankar, and Y. J. Bhalerao, "Parameter optimization in milling of glass fiber reinforced plastic (GFRP)

using DOE-Taguchi method," *SpringerPlus*, vol. 5, Article ID 1376, 2016.

[26] G. D. Babu, K. S. Babu, and B. U. M. Gowd, "Effect of machining parameters on milled natural fiber-reinforced plastic composites," *Journal of Advanced Mechanical Engineering*, vol. 1, pp. 1–12, 2013.

[27] R. Vinayagamoorthy and N. Rajeswari, "Drilling performance investigations on hybrid composites by using D-optimal design," *International Journal of Composite Materials and Manufacturing*, vol. 2, pp. 15–21, 2012.

[28] S. Ragunath, C. Velmurugan, and T. Kannan, "Optimization of tribological behavior of nano clay particle with sisal/jute/glass/epoxy polymer hybrid composites using RSM," *Polymers for Advanced Technologies*, vol. 28, no. 12, pp. 1813–1822, 2017.

[29] N. A. Özbek, O. Özbek, and F. Kara, "Statistical analysis of the effect of the cutting tool coating type on sustainable machining parameters," *Journal of Materials Engineering and Performance*, vol. 30, pp. 7783–7795, 2021.

[30] B. Rajeswari and K. S. Amirthagadeswaran, "Experimental investigation of machinability characteristics and multi-response optimization of end milling in aluminium composites using RSM based grey relational analysis," *Measurement*, vol. 105, pp. 78–86, 2017.

[31] I. V. Manoj, H. Soni, S. Narendranath, P. M. Mashinini, and F. Kara, "Examination of machining parameters and prediction of cutting velocity and surface roughness using RSM and ANN using WEDM of altemp HX," *Advances in Materials Science and Engineering*, vol. 2022, Article ID 5192981, 9 pages, 2022.

[32] B. Latha, V. S. Senthilkumar, and K. Palanikumar, "Modeling and optimization of process parameters for delamination in drilling glass fibre reinforced plastic (GFRP) composites," *Machining Science and Technology*, vol. 15, no. 2, pp. 172–191, 2011.

[33] M. K. N. Khairusshima, A. K. N. Aqella, and I. S. S. Sharifah, "Optimization of milling carbon fibre reinforced plastic using RSM," *Procedia Engineering*, vol. 184, pp. 518–528, 2017.

[34] P. Panda, S. Mantry, S. Mohapatra, S. K. Singh, and A. Satapathy, "A study on erosive wear analysis of glass fiber–epoxy–AlN hybrid composites," *Journal of Composite Materials*, vol. 48, no. 1, pp. 107–118, 2014.

[35] S. Ragunath, C. Velmurugan, and T. Kannan, "Optimization of drilling delamination behavior of GFRP/clay nano-composites using RSM and GRA methods," *Fibers and Polymers*, vol. 18, no. 12, pp. 2400–2409, 2017.

[36] T. P. Mohan and K. Kanny, "Influence of nanoclay on rheological and mechanical properties of short glass fiber-reinforced polypropylene composites," *Journal of Reinforced Plastics and Composites*, vol. 30, no. 2, pp. 152–160, 2011.

[37] N. Muthukrishnan and J. P. Davim, "Optimization of machining parameters of Al/SiC-MMC with ANOVA and ANN analysis," *Journal of Materials Processing Technology*, vol. 209, no. 1, pp. 225–232, 2009.

[38] P. S. Paul and A. S. Varadarajan, "A multi-sensor fusion model based on artificial neural network to predict tool wear during hard turning," *Proceedings of the Institution of Mechanical Engineers, Part B: Journal of Engineering Manufacture*, vol. 226, no. 5, pp. 853–860, 2012.

[39] A. V. M. Subramanian, M. D. G. Nachimuthu, and V. Cinnasamy, "Assessment of cutting force and surface roughness in LM6/SiCp using response surface methodology," *Journal of Applied Research and Technology*, vol. 15, no. 3, pp. 283–296, 2017.

[40] M. Y. Noordin, V. C. Venkatesh, S. Sharif, S. Elting, and A. Abdullah, "Application of response surface methodology in describing the performance of coated carbide tools when turning AISI 1045 steel," *Journal of Materials Processing Technology*, vol. 145, no. 1, pp. 46–58, 2004.

[41] S. Ranganathan, T. Senthilvelan, and G. Sriram, "Evaluation of machining parameters of hot turning of stainless steel (type 316) by applying ANN and RSM," *Materials and Manufacturing Processes*, vol. 25, no. 10, pp. 1131–1141, 2010.

[42] C. Velmurugan, R. Subramanian, S. Thirugnanam, and B. Ananadavel, "Experimental investigations on machining characteristics of Al 6061 hybrid metal matrix composites processed by electrical discharge machining," *International Journal of Engineering, Science and Technology*, vol. 3, no. 8, pp. 87–101, 2011.

[43] R. Kumar and S. Dhiman, "A study of sliding wear behaviors of Al-7075 alloy and Al-7075 hybrid composite by response surface methodology analysis," *Materials & Design*, vol. 50, pp. 351–359, 2013.

[44] M. Akgün and F. Kara, "Analysis and optimization of cutting tool coating effects on surface roughness and cutting forces on turning of AA 6061 alloy," *Advances in Materials Science and Engineering*, vol. 2021, Article ID 6498261, 12 pages, 2021.

[45] M. Akgün and H. Demir, "Optimization of cutting parameters affecting surface roughness in turning of Inconel 625 superalloy by cryogenically treated tungsten carbide inserts," *SN Applied Sciences*, vol. 3, Article ID 277, 2021.

[46] H. Majumder, T. R. Paul, V. Dey, P. Dutta, and A. Saha, "Use of PCA-grey analysis and RSM to model cutting time and surface finish of Inconel 800 during wire electro discharge cutting," *Measurement*, vol. 107, pp. 19–30, 2017.

[47] B. Ozturk and F. Kara, "Calculation and estimation of surface roughness and energy consumption in milling of 6061 alloy," *Advances in Materials Science and Engineering*, vol. 2020, Article ID 5687951, 12 pages, 2020.

[48] B. Balamugundan and L. Karthikeyan, "Optimization of process parameters during milling of friction stir processed GFRP composites," *Advanced Materials Research*, vol. 984-985, pp. 297–303, 2014.