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PARAMETRIC OPTIMIZATION OF MILLING OPERATION ON GLASS FIBRE REINFORCED PLASTIC COMPOSITE MATERIAL

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ABSTRACT: *Now-a day's composite materials plays vital role in the manufacturing industries. Composite material like Glass Fibre Reinforced Plastics plays an important role in applications as an alternative to various heavy exotic materials. GFRP is used in aviation, automobile and other industries due to their advantages over the conventional materials. Main problem associated with the GFRP material in milling process is due to its heterogeneity and surface delamination during machining affects uniqueness of the material and the machining parameters. In this research work the GFRP composite is experimentally investigated by CNC milling process with various input parameter like depth of cut, spindle speed, feed rate. The effect of process parameters on the dimensional accuracy, surface accuracy, surface finish and damages of the slots produced by end milling on GFRP composite. Experiments were conducted based on the established Taguchi's technique L_{27} orthogonal array and ANOVA. The performance of various parameters are evaluated by measuring the delamination factor and surface roughness.*

KEYWORDS: *GFRP, Milling, Carbide Mill, Feed, Spindle Speed, Depth of Cut, ANOVA, Surface Roughness, Delamination Factor, Material Removal Rate*

1. INTRODUCTION

Fibre – Reinforced Plastic (FRP) is a composite material formed of polymer matrix strengthened with fibre. Fibre is usually glass, carbon, aramid or basalt. Provides an opportunity to give FRP composites' applications, cutting off, drilling, milling, etc. its fabrication has increased. The combined material content is engineered and is made from two or more component elements with significant physical and chemical properties. There are two type of elements phases in the composites are matrix and reinforcement. Generally most materials, especially brittle, have an important feature that shows the size of smaller diameter is stronger than bulk material.

Fibres have structural characteristics like much precision and hardness for the composite, while polymer matrix gives supports the fibres and also transfers the load to fibres and also saves from the bitter environment. Composites materials can easily fulfil the needs of modern technology which sometimes could not meet by the conventional materials.

Increasing demand of the composites has increased its demand for machining. Fineting machining is more worrying than refining, because FRPs make up almost the net shape, which often requires extra material to be removed to handle tolerances. It is also necessary to observe process differences such as speed, feed rate, and depth of cut to reduce the loss in the machine.

Milling is a process of machining in which to remove the material from the work piece in the direction at the corners of the tool axis by using rotary cutters. Milling process is one of the most widely used machining process in the industry for machining parts for specific sizes and shapes.

2. LITERATURE SURVEY

This section briefly discuss about the previous work carried out by the researchers in the field of optimization of GFRP Milling process parameters. ***R. S. Babu, C. Parthsarthy, J. Chandradas*** works mainly based on two ideas: Quality should be measured by the deviation from a specified target value rather than by conformance to pre-set tolerance limit; Quality can't be ensured through inspection and rework but must be built in through the appropriate design [1]. ***S. Syed Abutahir, Dr. T Parmeshwaram Pillai*** carried out the experimental analysis to achieve great finish and maximum material removal rate through their work they found feed rate is a dominant parameter which affects the surface finish and depth of cut increase the material removal rate [2]. ***Ketan Jagtap, Shubham Dabhade et al.*** concluded that tool material and spindle speed both have predominant influence on the delamination factor [3]. ***I.S.N.V.R. Prasanth, Dr. D. V. Ravishkumaret al.*** conducted through experimental investigation that fibre orientation angle is most significant factor which influenced on cutting parameters in milling of different orientation angles of UD and Bi-D GFRP composite laminates [4]. ***I.S.N.V.R. Prasanth, Dr. D. V. Ravishkumaret al.*** concluded that spindle speed has highest statistical influence on tool life, delamination damage, and surface roughness [5]. ***Hari Vasudevan, Ramesh Rajguru et al.***

suggested that diamond or more usually Poly-Crystalline Diamond (PCD) tools are best for operation and feed rate is most dominant factor in surface roughness [6]. ***Soumya Dash, B. C. Routara et al.*** studied that surface roughness mainly depends on spindle speed whereas surface roughness methodology depends on the depth of cut and feed rate is influencing factor on delamination [7]. ***N. Naresh, K. Rajasekhar*** reviewed through experiments that delamination factor increases with fibre orientation angle, helix angle and feed rate and decreases with increases in spindle speed [8]. ***A. I. Azmi, R. J. T. Lin*** confirmed abrasive tool wear mechanism as well as concluded that presence of uncut fibres and serve delamination damage has offset the superior tool wear performance when machining across the fibre orientation [9]. ***Hussain M Ali, Asif Iqbal et al.*** concluded that in milling, machining force can be reduced by reducing feed rate and productivity can be increased by increasing the speed and feed rate [10]. ***M P Jenarthanan, N. Naresh*** carried out the ANOVA of the grey relational grade and revealed that the work-piece fibre orientation angle and feed rate are most significant parameters [11]. ***M. Manzoor Hussain, D. V. Ramana Reddy et al.*** found that from ANOVA analysis input factor fibre orientation angle has statistical and physical significance and when increases the fibre percentage has increased the surface roughness of the laminates [12]. ***S. Arvindan, A. Naveen Sait*** carried out the simple regression and cross product regression methods and compares the results and finds that feed rate following by cutting velocity are most significant parameters [13]. ***K. Palanikumar, L. Karunamoorthy et al.*** attempted to assess the influence of machining parameters on surface roughness and concludes that feed rate has more influence following cutting velocity [14]. ***Julie Z. Zhang, Joseph C. Chen et al.*** experimentally concluded that spindle speed and feed rate is more influential on surface than depth of cut [15].

3. METHODOLOGY AND MEASUREMENTS

3.1 Taguchi Method

Taguchi method has been most used in engineering field for the analysis and consists of a plan of experiments. The main advantage of this method is the reduction in experimental time, cost and discovering significant factors quickly. Taguchi's robust design method is very effective tool for the design of a high-quality system. In addition to the S/N Ratio, a statistical ANOVA can be used to show the effects of the factors of the process on surface roughness and delamination factor.

The following steps are applied in this work for the Taguchi Design:-

1. Choice of noise and control parameters.
2. Choice of Taguchi Orthogonal Array.
3. Experiments will be carried out.
4. Output factor measurement
5. Analyse Signal-To-Noise Ratio.
6. Predicting optimum levels for each response.

3.2 *Experimental Details*

Glass Fibre Reinforced Plastics (GFRP) composites plates made by calendaring process used for these experiments. GFRP plates are of 200 mm * 100 mm * 1.5 mm is used in the experiments. The cutting tool is made up of solid carbide end mill of 8 mm diameter having four flutes. The experiments are carried out based on the Taguchi's L_{27} orthogonal array using the CNC milling machine. The CNC milling machine specifications are shown in the table 1.

Type of Machine	Vertical Milling Centre
Maker	SURYA VF 30 CNC VS
Table Size	315 mm * 1060 mm
Power Controller	FANUC (3.7/5.5 KW)
Spindle Speed	6000 RPM
Feed Rates	1-5000 mm/min.
Longitudinal Movement (X – Axis)	800 mm
Transverse Movement (Y – Axis)	350 mm
Vertical Movement (Z – Axis)	380 mm
Positioning Accuracy	±0.010 mm
Power Supply	415 V, 50 Hz, 3 Phase

Table 1: Specification of the CNC Milling Machine [17]

Fig. 1: VMC CNC Machine [17]

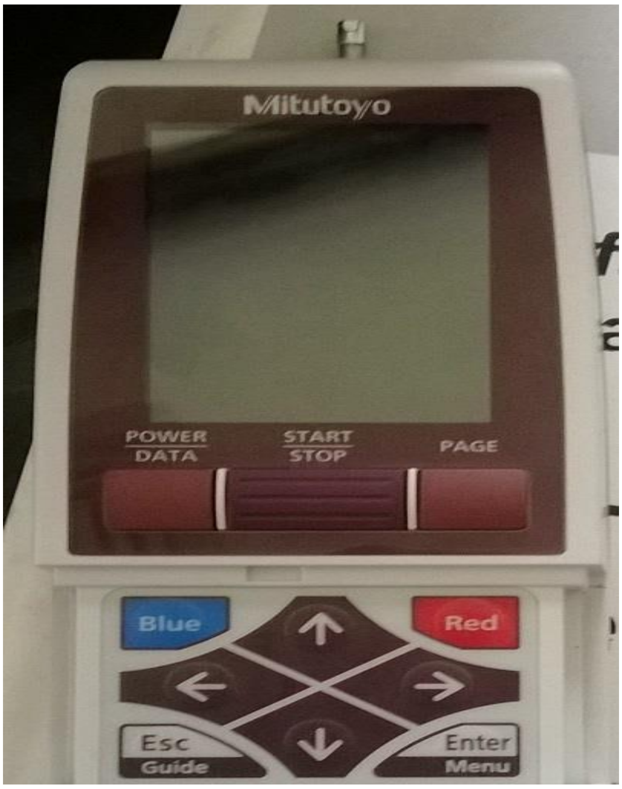

Fig.2: Surface Roughness Tester [16]

3.3 *Measurements*

The value of the roughness of the machined surface is measured in order to analyse the surface quality. The surface of the machined product can affect the rigidity of the contact, the ability to distribute and hold the surface friction, wearing, light reflection, heat transmission, lubricant, coating, and mild fatigue. Surface Roughness (Ra) was evaluated using stylus type profilometer *MITUTOYO SJ210.*

The damage caused on the GFRP composite material was measured perpendicular to the feed rate with Vernier callipers. After the measurement of the maximum width damage (Wmax) caused by the material the losses normally designated by the Delamination Factor (Fd) were determined. This factor is defined by the maximum width (Wmax) to the width of cut (W). Delamination factor's value can be obtained by the following equation:

$$Fd = \frac{Wmax}{W}$$

Where, Fd = delamination factor,
Wmax = maximum damage of damage, mm
W = width of cut, mm

3.4 *Plan Of Experiments*

In the DOE design, experiments have been organized using Taguchi's orthogonal arrays which help in reducing the number of experiments. According to the orthogonal array experiments were conducted. The selected machining parameters for the present work are Spindle Speed (N) in RPM; Feed Rate (F) in mm/sec.; Depth Of Cut (DOC) in mm. The used machining parameters and their levels are shown in table 2.

Machining Parameters	Units	Levels		
		1	2	3
Spindle Speed (N)	RPM	1000	1500	2000
Feed Rate (F)	mm/sec.	1	2	3
Depth Of Cut (DOC)	mm	0.3	0.6	0.9

Table 2: Machining Parameters and their Levels

4. RESULTS AND DISCUSSIONS

Exp No.	SS	FR	DOC	MRR	SR	DF	SNR MRR	SNR SR	SNR DF
1	1000	1	0.3	0.00004	1.4000	1.0020	-87.9588	-2.9225	-0.01735
2	1000	1	0.6	0.00008	1.4620	1.0026	-81.9382	-3.2989	-0.02255
3	1000	1	0.9	0.00012	15406	1.0021	-78.4164	-3.7538	-0.01822
4	1000	2	0.3	0.00008	1.9400	1.0041	-81.9382	-5.7560	-0.03553
5	1000	2	0.6	0.00016	1.9684	1.0054	-75.9176	-5.8822	-0.04677
6	1000	2	0.9	0.00024	2.0632	1.0061	-72.3958	-6.2908	-0.05282
7	1000	3	0.3	0.00012	2.1229	1.0042	-78.4164	-6.5385	-0.03640
8	1000	3	0.6	0.00024	2.1574	1.0049	-72.3958	-6.6786	-0.04245
9	1000	3	0.9	0.00036	2.2011	1.0056	-68.8739	-6.8528	-0.04850
10	1500	1	0.3	0.00004	1.7391	1.0034	-87.9588	-4.8064	-0.02948
11	1500	1	0.6	0.00008	1.7485	1.0047	-81.9382	-4.8533	-0.04072
12	1500	1	0.9	0.00012	1.7496	1.0051	-78.4164	-4.8587	-0.04418
13	1500	2	0.3	0.00008	1.8744	1.0067	-81.9382	-5.4572	-0.05800
14	1500	2	0.6	0.00016	1.9654	1.0051	-75.9176	-5.8690	-0.04418
15	1500	2	0.9	0.00024	2.0095	1.0074	-72.3958	-6.0617	-0.06403
16	1500	3	0.3	0.00012	2.1247	1.0080	-78.4164	-6.5459	-0.06921
17	1500	3	0.6	0.00024	2.1475	1.0073	-72.3958	-6.6386	-0.06317
18	1500	3	0.9	0.00036	2.1698	1.0084	-68.8739	-6.7283	-0.07265
19	2000	1	0.3	0.00004	1.3248	1.0031	-87.9588	-2.4430	-0.02688
20	2000	1	0.6	0.00008	1.7824	1.0042	-81.9382	-5.0201	-0.03640
21	2000	1	0.9	0.00012	1.5300	1.0061	-78.4164	-3.6938	-0.05282
22	2000	2	0.3	0.00008	1.6951	1.0050	-81.9382	-4.5839	-0.04332
23	2000	2	0.6	0.00016	1.7966	1.0052	-75.9176	-5.0890	-0.04504
24	2000	2	0.9	0.00024	1.8696	1.0068	-72.3958	-5.4349	-0.05886
25	2000	3	0.3	0.00012	2.3261	1.0080	-78.4164	-7..3325	-0.06921
26	2000	3	0.6	0.00024	2.4255	1.0083	-72.3958	-7.6960	-0.07179
27	2000	3	0.9	0.00036	2.5411	1.0090	-68.8739	-8.1004	-0.07782

Table 3: Observed data from the experiments

The results of the end milling experimental shows the GFRP composites material made by Calendaring method, by solid carbide end mill. Machinability was assessed by surface roughness (Ra), delamination factor (Fd), and material removal rate.

4.1 Process Parameter's influence based on S/N Ratio

Table 3 shows the results gained from the experiments for the surface roughness, delamination factor, and material removal rate as a function of the process parameters for the GFRP composites. Table 4-6 shows the results of Taguchi analysis or S/N Ratio for the surface roughness, delamination factor and material removal rate. The approach for the surface roughness and delamination factor is smaller is better whereas for the material removal rate the approach is larger is better.

From the table 4 it is shown that feed rate is most significant process parameter followed by the depth of cut and spindle speed for the GFRP composite material. Table 5 shows feed rate is most predominant process parameter followed by the spindle speed and depth of cut. Table 7 gives the influence results on material which shows that feed rate and depth of cut have same effect on the process followed by spindle speed. From the above S/N Ratio analysis it is seen that feed rate is most contributing parameter on the process performance.

Levels	Factors		
	Spindle Speed	Feed Rate	Delamination Factor
1	-5.330	-3.961	-5.154
2	-5.758	-5.603	-5.670
3	-5.488	-7.012	-5.753
Delta	0.427	3.051	0.599
Rank	3	1	2

Table 4: Response table for S/N Ratio of Surface Roughness

Levels	Factors		
	Spindle Speed	Feed Rate	Delamination Factor
1	-0.03563	-0.03207	-0.04282
2	-0.05396	-0.04984	-0.04590
3	-0.05358	-0.06125	-0.05444
Delta	0.01834	0.02918	0.01161
Rank	2	1	3

Table 5: Response table for S/N Ratio of Delamination Factor

Levels	Factors		
	Spindle Speed	Feed Rate	Delamination Factor
1	-77.58	-82.77	-82.77
2	-77.58	-76.75	-76.75
3	-77.58	-73.23	-73.23
Delta	0.00	9.54	9.54
Rank	3	1.5	1.5

Table 6: Response table for S/N Ratio of Material Removal Rate

4.2 Process Parameters effect on output parameter based on response table

Response graphs and response tables are used for the examination of the influence of different control parameters on end milling of GFRP material. Process parameters influence on output parameters are shown in in fig. 3-5 and their response are shown in table 7-9.

From the fig. 3 it is seen that surface roughness increase linearly as feed rate and depth of cut increases whereas it varies as spindle speed changes. From the plot and response table 7 for surface roughness the best level of each parameter is set at N1 F1 DOC1 for the surface roughness.

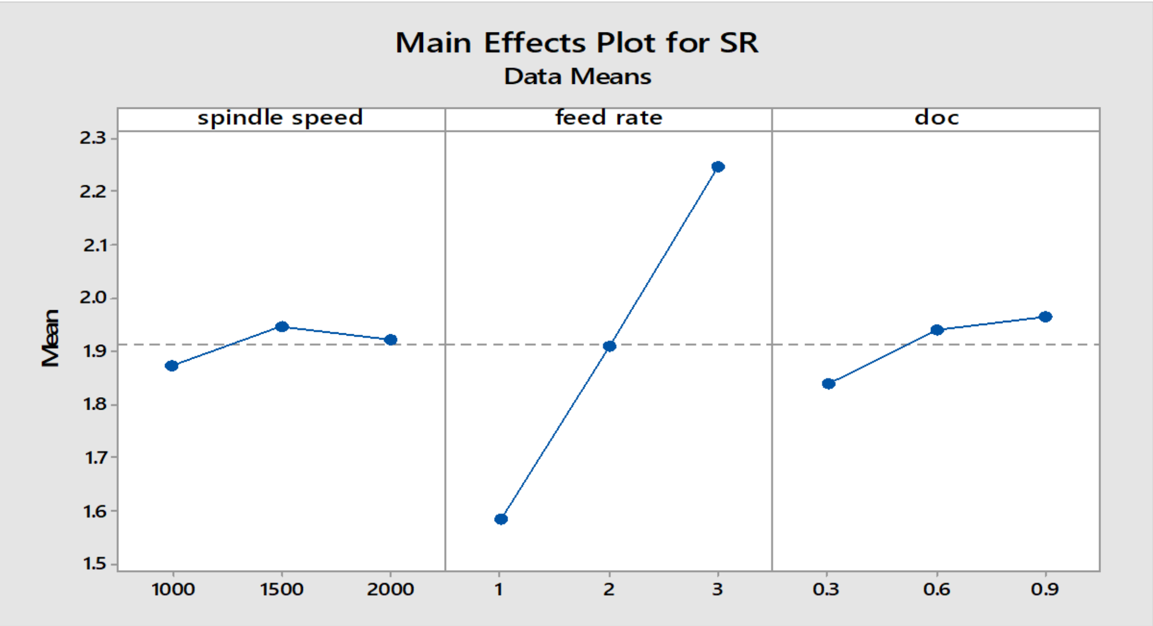

Fig. 3: Main Effects Plot of Surface Roughness

Levels	Spindle Speed	Feed Rate	Delamination Factor
1	1.873	1.586	1.839
2	1.948	1.909	1.939
3	1.921	2.246	1.964
Delta	0.075	0.660	0.125
Rank	3	1	2

Table 7: Response table for means of Surface Roughness

From the fig. 4 it is seen that delamination factor increase with increase of feed rate and depth of cut but doesn’t shows linear effect against spindle speed. It varies with change of spindle speed. From the effect plot and response table 8 for delamination factor the best level of each parameter is set at N1 F1 DOC1 for the delamination factor.

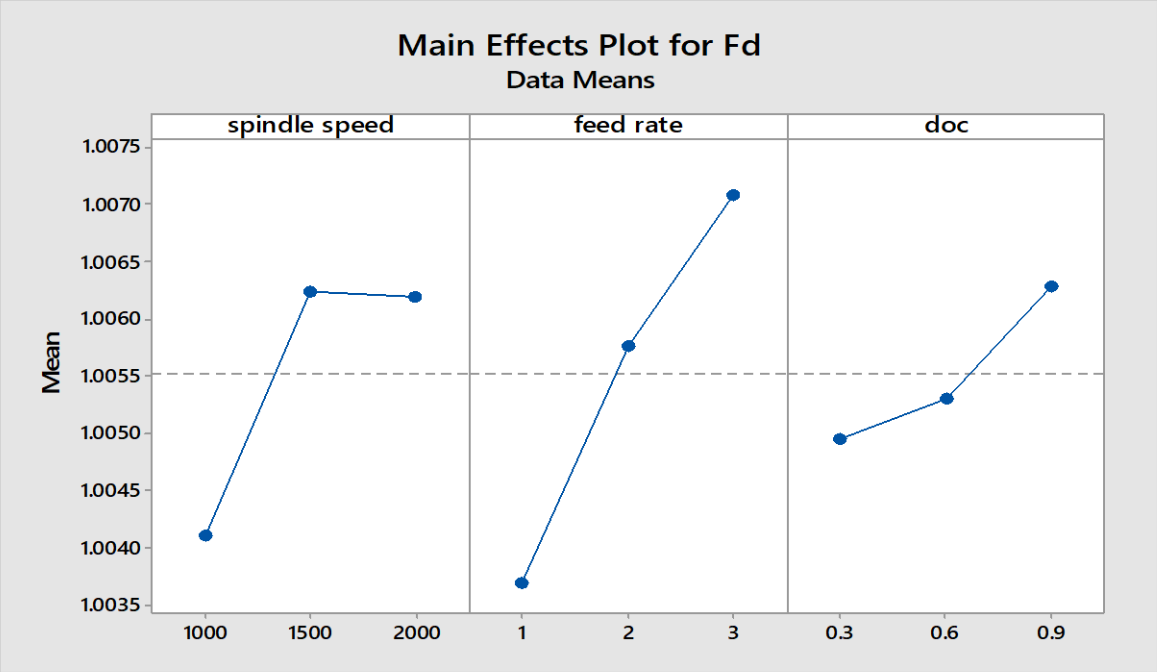

Fig. 4: Main Effect Plot for Delamination Factor

Levels	Spindle Speed	Feed Rate	Delamination Factor
1	1.004	1.004	1.005
2	1.006	1.006	1.005
3	1.006	1.007	1.006
Delta	0.002	0.003	0.001
Rank	2	1	3

Table 8: Response table for means of Delamination Factor

From the fig. 5 it is found that material removal rate increases with increase of federate and depth of cut. It is also seen that the spindle speed has not any much influential effect on the material removal rate. So all the parameters shows linear effect. From the plot and response table 9 for material removal rate the best level of each parameter is set at N3 F3 DOC3 for the material removal rate.

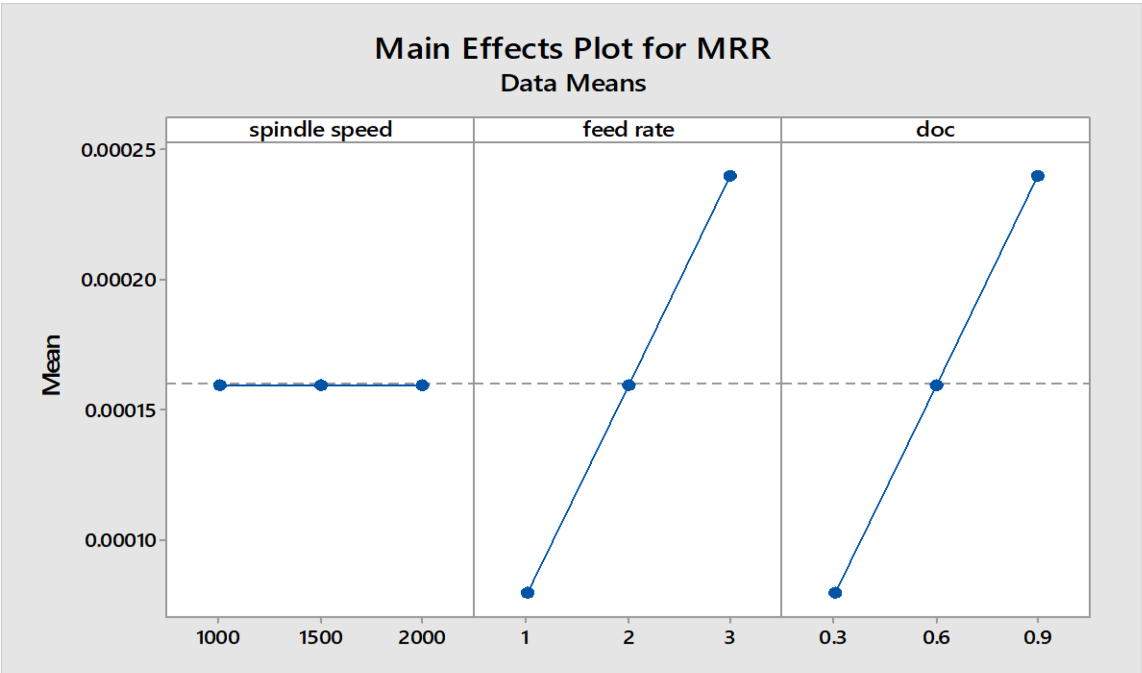

Fig. 5: Main Effect Plot for Material Removal Rate

Levels	Spindle Speed	Feed Rate	Delamination Factor
1	0.000160	0.000080	0.000080
2	0.000160	0.000160	0.000160
3	0.000160	0.000240	0.000240
Delta	0.000000	0.000160	0.000160
Rank	3	1.5	1.5

Table 9: Response table for means of Material Removal Rate

4.3 GFRP Composites' ANOVA

From table 10 it is seen that the factor feed rate has most statistical and physical contribution of 78.95% on the surface roughness of GFRP composites materials. The error related to the ANOVA table for the surface roughness was by stock 17.78%

Source	DOF	Seq SS	Contribution	Adj SS	Adj MS	F-Value	P-Value
Regression	3	2.04076	82.22 %	2.04076	0.6802	35.45	0.000
Spindle Speed	1	0.01054	0.42 %	0.01054	0.01054	0.55	0.466
Feed Rate	1	1.95961	78.95 %	1.95961	1.95961	102.11	0.000
Depth Of Cut	1	0.07061	2.84 %	0.07061	0.07061	3.68	0.068
Error	23	0.44138	17.78 %	0.44138	0.01919		
Total	26	2.48214	100.00 %				

Table 10: ANOVA for surface roughness

From table 11 it is seen that the factor feed rate has most influential both statistical and physical contribution of 50.78 % on the delamination of GFRP composites. The error related to the ANOVA table for the delamination factor was by stock 21.96 %.

Source	DOF	Seq SS	Contribution	Adj SS	Adj MS	F-Value	P-Value
Regression	3	0.000079	78.04 %	0.000079	0.000026	27.24	0.000
Spindle Speed	1	0.000019	19.21 %	0.000019	0.000019	20.12	0.000
Feed Rate	1	0.000051	50.78 %	0.000051	0.000051	53.18	0.000
Depth Of Cut	1	0.000008	8.04 %	0.000008	0.000008	8.43	0.008
Error	23	0.000022	21.96 %	0.000022	0.000001		
Total	26	0.000101	100.00 %				

Table 11: ANOVA for delamination factor

From table 12 it is seen that the factor feed rate and depth of cut both have equal statistical and physical contribution. Their contribution is 92.31 % on the milling process of GFRP composites. The error related to the ANOVA table for the material removal rate was by stock 7.69 %.

Source	DOF	Seq SS	Contribution	Adj SS	Adj MS	F-Value	P-Value
Regression	3	0.0000	92.31 %	0.0000	0.0000	92.00	0.000
Spindle Speed	1	0.0000	0.00 %	0.0000	0.0000	0.0	1.000
Feed Rate	1	0.0000	46.15 %	0.0000	0.0000	138.00	0.000
Depth Of Cut	1	0.00000	46.15 %	0.0000	0.0000	138.00	0.008
Error	23	0.0000	7.69 %	0.0000	0.0000		
Total	26	0.0000	100.00 %				

Table 12: ANOVA for material removal rate

4.2 Regression Analysis

Relationship between GFRP composite materials processing parameters and the gained response is obtained by Regression Analysis with the sample size of 27. Regression Analysis equations for the surface roughness, delamination factor and material removal rate are obtained as follows:-

Surface Roughness (Ra) = 1.056 + 0.000048 N + 0.3300 F + 0209 DOC

Delamination Factor (Fd) = 0.997672 + 0.000002 N + 0.001689 F + 0.002241 DOC

Material Removal Rate (MRR) = - 0.000160 + 0.000 N + 0.000080 F + 0.000267 DOC

N is Spindle Speed in RPM, F is Feed Rate in mm/sec. and DOC is Depth Of Cut in mm.

These equations can be used to differentiate machining parameters and to evaluate milling induced surface roughness, delamination factor, and material removal rate.

5. CONCLUSIONS

1. Feed Rate is the most significant parameter and the spindle speed is least significant process parameter for the milling of the GFRP composite material to achieve the minimum surface roughness and delamination factor.
2. The best level for the process parameter to achieve minimum surface roughness and delamination factor are N1 F1 DOC1, N1 F1 DOC1 respectively and for the maximum material removal rate N3 F3 DOC3.
3. The surface roughness and delamination factor increases with the increase of the federate and depth of cut.
4. Feed Rate is the most highly influential statistical and physical parameter on surface roughness (78.95 %) and delamination factor (50.78 %).
5. The ANOVA equations are effective tool to predict the end milling induced surface roughness, delamination factor and material removal rate.

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