

Investigation of Optimum Cutting Conditions in End Milling on GFRP Sheet Using HSS Tool

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ABSTRACT: The present work is to investigate the effects of End milling process parameters on material removal rate (MRR), surface roughness (SR) and temperature (TEMP) in End milling on glass fibre reinforced plastic (GFRP) sheet using Taguchi methodology. Three input parameters were chosen namely: cutting speed, feed rate and depth of cut. The objective of the study was to maximize the MRR, minimize the SR and TEMP. Experimental work has been carried out as per L16 orthogonal array using Taguchi design of experiments. Signal to noise ratio (S/N ratio) and analysis of variance (ANOVA) were used to determine the influence of input parameters on the MRR, SR and TEMP.

KEYWORDS: GFRP sheet, END milling, MRR, SR, TEMP, S/N ratio, ANOVA.

I. INTRODUCTION

In recent years, the utilization of glass fibre reinforced plastics (GFRPs) are used in various engineering fields owing to its attractive properties such as high specific strength, light weight, high specific stiffness, high modulus of elasticity and excellent corrosion resistance which makes the use of GFRP composite especially suitable for aircraft, aerospace automobile and structural applications. Glass fibres are excellent raw materials for production of wide range of composites for different applications. Because of their availability, renewability, low density, price and better mechanical properties make them an attractive fibres used for the manufacturing of composites. The glass fibre-containing composites are used in transportation, military applications, building and construction industries and consumer products. The price of polymer composites reinforced with glass fibres is two to three times lower than that of other reinforcement polymers which make them feasible for composite applications. The heterogeneous nature of the GFRP composite material, its response to machining involves various undesirable effects like excess tool wear and poor surface finish. Milling operation is a fundamental machining process in material removal. Milling is a process of producing flat and complex shapes with the use of multi-point cutting tool, which is called a milling cutter and the cutting edges are called teeth. In milling process the important parameters we consider to analyse the efficiency of the operation are surface roughness, cutting temperature and material removal rate. Achieving optimal surface roughness during milling is necessary for the certain application which is affected by various cutting parameters. For this, we optimize these parameters by controlling some factors such as cutting speed, feed, depth of cut etc. The knowledge of these parameters would reduce the cost of machining along with improving the quality of work. While milling of composite materials, the surface quality is strongly dependent on machining parameter and tool geometry. Prasanth et al. [1] investigated that end milling parameters on SR, resultant force and delamination factor of GFRP composite laminates by using Taguchi method. Reddy sreenivasulu et al. [2] studied the machining parameters during end milling

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of GFRP composites by using desirability function. The input parameters are cutting speed, feed rate and depth of cut. The output responses are SR, Delamination damage factor. They concluded that SR is improved from 6.188 μm to 4.52 μm . Hari vasudevan et al. [3] optimized the milling parameters in the machining of NEMAG-11 GFRP composites using PCD tool and they reported that feed rate is most dominant factor in influencing the SR. Mahendra et al. [4] analyse the effect of milling parameters on minimum SR using Taguchi method. The input parameters were selected as spindle speed, feed rate and depth of cut. Spindle speed and feed rate are most significant parameter then depth of cut. Palanikumar et al. [5] optimized the turning process parameters on SR during machining of GFRP composites using polycrystalline diamond tool and they concluded that the most significant parameter is feed rate followed by cutting speed. Vatsal Sheth et al. [9] investigated that milling parameters in the machining of CFRP composite material using PCD tool. They reported that depth of cut and feed rate are found to the most significant factors. Anjaneyulu et al. [10] reported that fibre orientation angle is most dominant factor for affecting the all output responses while end milling of GFRP composites. The objective of the present work is to investigate the effect of END milling parameters namely cutting speed, feed rate and depth of cut on material removal rate, surface roughness and temperature during machining of glass fibre reinforced plastic (GFRP) sheet.

II. EXPERIMENTAL PROCEDURE

In present work, Glass fibre reinforced plastic (GFRP) sheet is used as a work material. The GFRP material is fabricated by hand layup method of 33% glass fibre and 66% general purpose resin. The size of the work piece is 150 mm x 100 mm x 10 mm. The experiments were carried out on a CNC vertical machining centre. The experimental setup is shown in Fig 1. The 10 mm diameter of the HSS end mill cutter is used for machining of GFRP sheet. The uniform slot was maintained at 5 mm for all the experiments. The machined GFRP material is shown in Fig 2.



Fig. 1. CNC milling machine



Fig. 2. Machined GFRP sheet

There are many input parameters to be considered within the END milling process, but in this process we have only three parameters with four levels to be selected. The process parameters and their levels are depicted in Table 1. The machining was carried out as per L16 orthogonal array shown in Table 2. The output responses were selected as material removal rate (MRR), surface roughness (SR) and temperature (TEMP). The MRR is calculated by the ratio of the initial and final weight of the work piece under a period of machining time. Surface roughness was measured at three places on each machined slot by using surface roughness tester. The cutting temperature was measured by using infrared thermometer. The measured and calculated output values and their S/N ratios are given in Table 3.

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Table 1 Process parameters and their levels

Symbol	Factors	Units	Level 1	Level 2	Level 3	Level 4
A	Cutting Speed	rpm	200	400	600	800
B	Feed Rate	mm/min	20	30	40	50
C	Depth of Cut	mm	0.5	0.8	1.2	1.6

Table 2 Experimental layout using L16 orthogonal array

Ex. No	A	B	C	Cutting Speed (rpm)	Feed Rate (mm/min)	Depth of Cut (mm)
1	1	1	1	200	20	0.5
2	1	2	2	200	30	0.8
3	1	3	3	200	40	1.2
4	1	4	4	200	50	1.6
5	2	1	2	400	20	0.8
6	2	2	1	400	30	0.5
7	2	3	4	400	40	1.6
8	2	4	3	400	50	1.2
9	3	1	3	600	20	1.2
10	3	2	4	600	30	1.6
11	3	3	1	600	40	0.5
12	3	4	2	600	50	0.8
13	4	1	4	800	20	1.6
14	4	2	3	800	30	1.2
15	4	3	2	800	40	0.8
16	4	4	1	800	50	0.5

Table 3 Output responses and their S/N ratios

Ex. No	Output Responses			S/N Ratios		
	MRR (g/min)	SR (μ m)	TEMP($^{\circ}$ C)	MRR (dB)	SR (dB)	TEMP(dB)
1	0.276536	6.689	35.1	-11.1650	-16.5072	-30.9061
2	0.483471	6.111	35.6	-6.3126	-15.7222	-31.029
3	0.772152	1.798	38.2	-2.2459	-5.09579	-31.6413
4	1.162963	2.285	59	1.3113	-7.17772	-35.417
5	0.271429	1.722	49.3	-11.3269	-4.72066	-33.8569
6	0.543478	2.181	52	-5.2964	-6.77311	-34.3201
7	0.955414	1.513	61	-0.3962	-3.59678	-35.7066
8	0.914286	2.549	57	-0.7784	-8.1274	-35.1175
9	0.328571	1.514	38	-9.6674	-3.60252	-31.5957
10	0.390909	1.621	57	-8.1585	-4.19566	-35.1175
11	0.104575	2.326	54.4	-19.6114	-7.33219	-34.712
12	0.72093	1.878	53.6	-2.8421	-5.47391	-34.5833
13	0.391549	2.614	47.9	-8.1443	-8.34611	-33.6067
14	0.449153	3.71	39.2	-6.9521	-11.3875	-31.8657
15	0.44878	1.908	44.8	-6.9593	-5.61157	-33.0256
16	0.385714	3.471	39	-8.2747	-10.8091	-31.8213

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III. RESULT AND DISCUSSIONS

In Taguchi method, the effects of machining parameters on performance measures are evaluated under optimal condition. It is used to determine appropriate combination of machining parameters to maximize MRR, minimize SR and TEMP. The experimental results of MRR, SR and TEMP were further transformed into a signal-to-noise (S/N) ratio. Generally, there are three types of quality characteristics to calculate the S/N ratio value, namely the lower-the-better, the nominal-the-better, and the higher-the-better. In this study, the objective is to produce machined samples with higher the material removal rate, lower the surface roughness and machining temperature. Thus, the higher-the-better criteria of quality characteristic can be suitable for MRR, while the lower-the-better criteria of quality characteristic can be suitable for SR and TEMP.

The equation for calculating the S/N ratio value with lower-the-better characteristic can be expressed as follows

$$S/N \text{ ratio} = -10 \log_{10} (1/n) \sum_{k=1}^n Y_{ij}^2 \quad (2)$$

The equation for calculating the S/N ratio value with higher-the-better characteristic can be expressed as follows:

$$S/N \text{ ratio} = -10 \log_{10} (1/n) \sum_{k=1}^n \frac{1}{Y_{ij}^2} \quad (1)$$

Where n – number of replications, Y_{ij} – observed responses value where $i = 1, 2, 3, \dots, n$; $j = 1, 2, 3, \dots, k$.

Table 4 S/N ratio table for MRR

Level	Cutting Speed A (rpm)	Feed Rate B (mm/min)	Depth of Cut C (mm)
1	-4.603	-10.076	-11.087
2	-4.449	-6.680	-6.860
3	-10.070	-7.303	-4.911
4	-7.583	-2.646	-3.847
Delta	5.620	7.430	7.240
Rank	3	1	2

The signal to noise ratio for MRR is given in Table 4. From the table, it is clearly indicated that MRR was mainly influenced by feed rate followed by depth of cut and cutting speed. The main effect plot for MRR is shown in Fig 3. It is observed that the optimal process parameters for the maximum MRR was A2B4C4, namely, cutting speed at level 2(400 rpm), feed rate at level 4 (50 mm/min) and depth of cut at level 4 (1.6 mm). From the figure, feed rate increases the MRR increases. The gradually increases in MRR with also increase in depth of cut.

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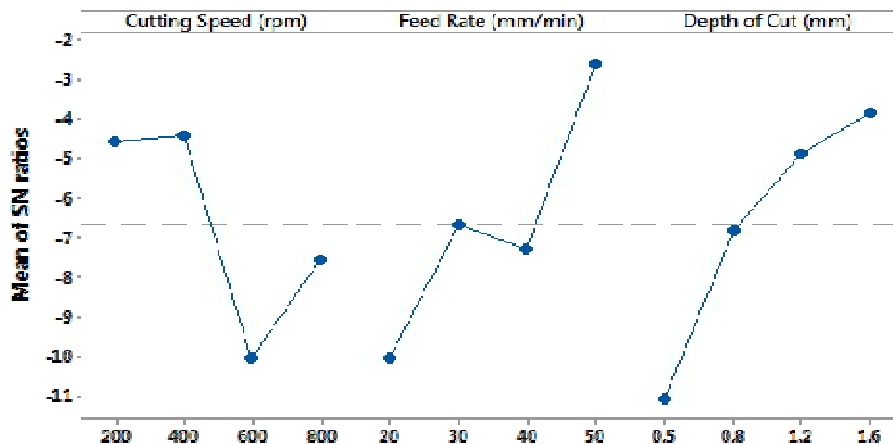


Fig. 3. Main effect plot for MRR

The signal to noise ratio for SR is depicted in Table 5. From the table, it is noticed that SR was mostly influenced by cutting speed followed by depth of cut and feed rate. The main effect plot for SR is shown in Fig 4. It is clearly observed that the optimal process parameters for the minimum SR was A3B3C4, namely, cutting speed at level 3(600 rpm), feed rate at level 3 (40 mm/min) and depth of cut at level 4 (1.6 mm). From the figure, SR increases with increase in depth of cut.

Table 5 S/N ratio table for SR

Level	Cutting Speed A (rpm)	Feed Rate B (mm/min)	Depth of Cut C (mm)
1	-11.126	-8.294	-10.355
2	-5.804	-9.520	-7.882
3	-5.151	-5.409	-7.053
4	-9.039	-7.897	-5.829
Delta	5.975	4.111	4.526
Rank	1	3	2

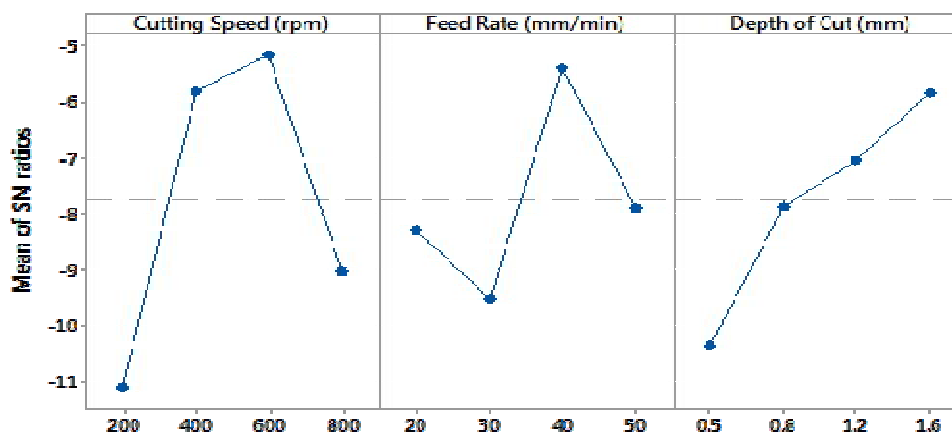


Fig. 4. Main effect plot for SR

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The signal to noise ratio for temperature is given in Table 6. From the table, it is clearly observed that temperature was mainly influenced by cutting speed followed by depth of cut and feed rate. The main effect plot for temperature is shown in Fig 5. It is recommended that the optimal process parameters for the minimum temperature was A1B1C3, namely, cutting speed at level 1(200 rpm), feed rate at level 1 (20 mm/min) and depth of cut at level 3 (1.2 mm). From the figure noticed that minimum level of feed rate which gives the minimum temperature.

Table 6 S/N ratio table for Temperature

Level	Cutting Speed A (rpm)	Feed Rate B (mm/min)	Depth of Cut C (mm)
1	-32.25	-32.49	-32.94
2	-34.75	-33.08	-33.12
3	-34.00	-33.77	-32.56
4	-32.58	-34.23	-34.96
Delta	2.50	1.74	2.41
Rank	1	3	2

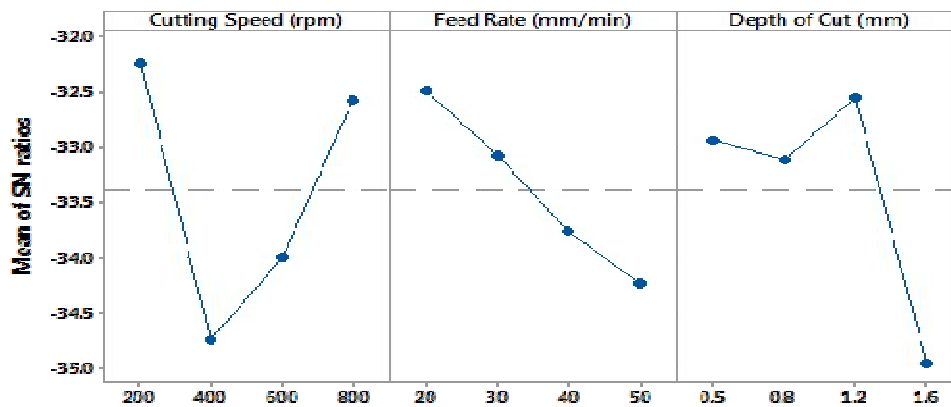


Fig. 5. Main effect plot for Temperature

ANALYSIS OF VARIANCE:

The purpose of the analysis of variance is to determine the process parameters that have strongly affect on the machining performance. The analysis was made using MINITAB 17 one of the popular software specifically used for Taguchi's design of experiment. The significance of each parameter on the responses such as MRR, SR and Temperature can be determined through their percent contribution value. The ANOVA results and percentage contribution of each process parameters for MRR are shown in Table 7 and Fig 6. It is clearly evident that feed rate is most significant factor that contributed maximum (38.84%) to the MRR followed by depth of cut and cutting speed which are contributed (28.34%) & (23.47%). The interaction plot for MRR is shown in Fig 7.

Table 7 ANOVA table for MRR

Source	DF	Seq SS	Adj MS	F	% Contribution
Cutting Speed (A)	3	0.29361	0.09787	5.03	23.47
Feed Rate (B)	3	0.48598	0.16199	8.32	38.84
Depth of Cut (C)	3	0.35459	0.11820	6.07	28.34
Error	6	0.11678	0.01946	-	9.33
Total	15	1.25096	-	-	100

S = 0.139514 R-Sq = 90.66% R-Sq(adj) = 76.66%

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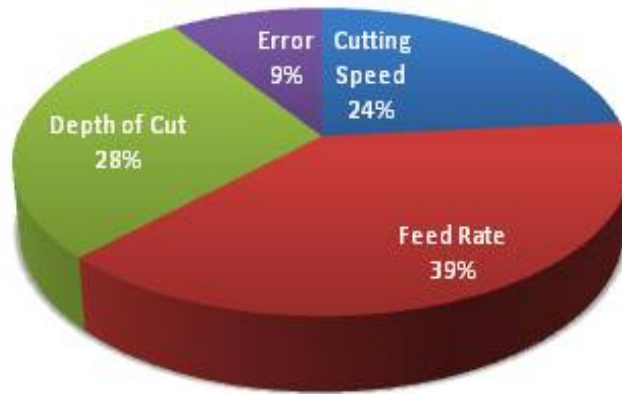


Fig. 6. Percentage contribution of parameters on MRR

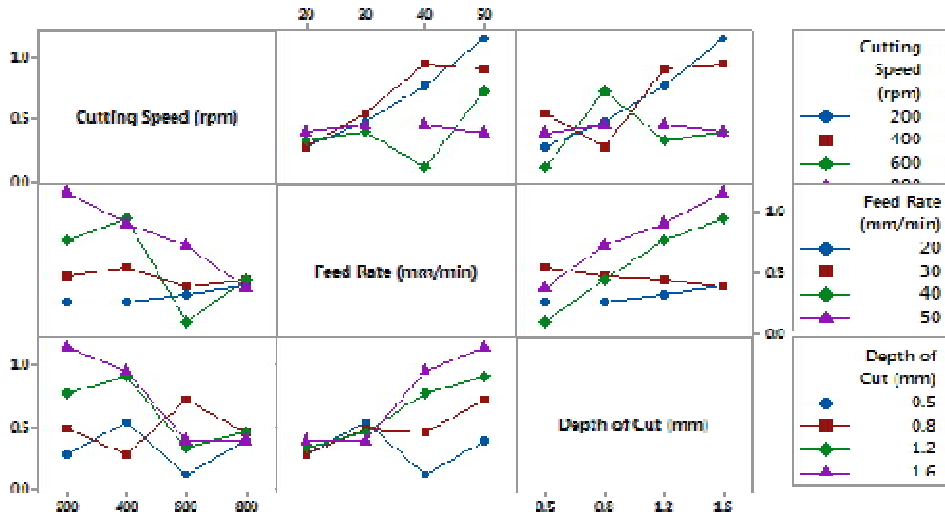


Fig. 7. Interaction plot for MRR

The ANOVA results and percentage contribution of each process parameters for SR are shown in Table 8 and Fig 8. It is clearly understood that cutting speed is most significant factor that contributed maximum (39.24%) to the SR. The other factors followed by depth of cut and feed rate which are contributed (16.77%) & (14.85%). The interaction plot for SR is shown in Fig 9.

Table 8 ANOVA table for SR

Source	DF	Seq SS	Adj MS	F	% Contribution
Cutting Speed (A)	3	14.429	4.810	2.69	39.24
Feed Rate (B)	3	5.463	1.821	1.02	14.85
Depth of Cut (C)	3	6.168	2.056	1.15	16.77
Error	6	10.737	1.789	-	29.20
Total	15	36.769	-	-	100

S = 1.33772 R-Sq = 70.82% R-Sq(adj) = 72.05%

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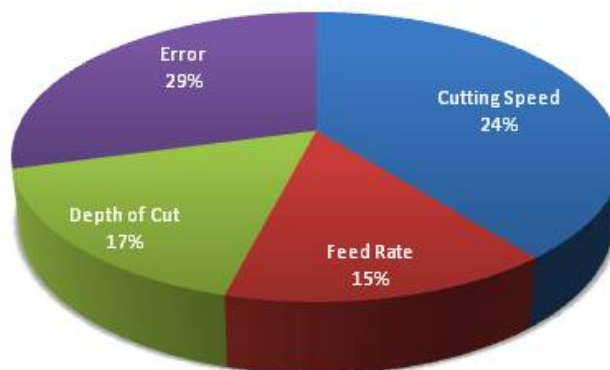


Fig. 8. Percentage contribution of parameters on SR

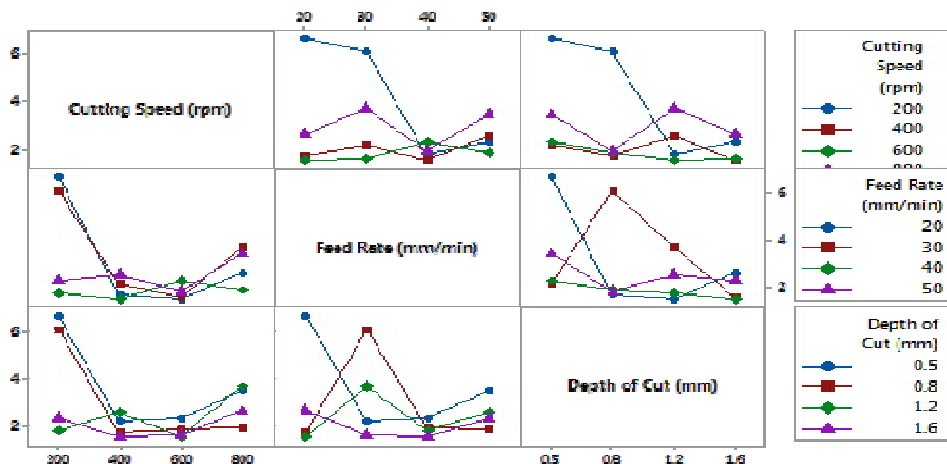


Fig. 9. Interaction plot for SR

The ANOVA results and percentage contribution of each process parameters for temperature are shown in Table 9 and Fig 10. From the analysis it can be understood that the most significant parameters with respect to temperature are. The percentage contribution for cutting speed and depth of cut as 38.40% and 33.96% respectively. The feed rate contributes 17.21% which are found to be the least significant factor. The interaction plot for temperature is shown in Fig 11.

Table 9 ANOVA table for Temperature

Source	DF	Seq SS	Adj MS	F	% Contribution
Cutting Speed (A)	3	470.10	156.70	7.37	38.40
Feed Rate (B)	3	210.69	70.23	3.31	17.21
Depth of Cut (C)	3	415.65	138.55	6.52	33.96
Error	6	127.49	21.25	-	10.41
Total	15	1223.93	-	-	100

S = 4.60966 R-Sq = 89.58% R-Sq(adj) = 73.96%

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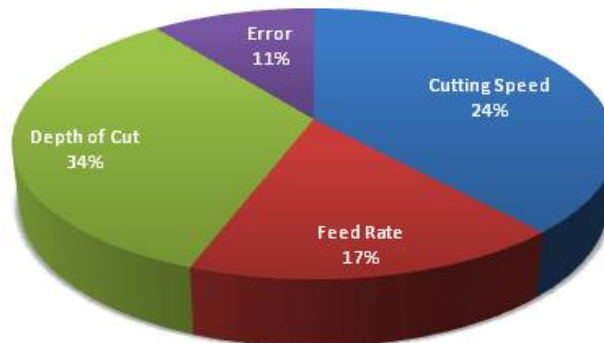


Fig. 10. Percentage contribution of parameters on Temperature

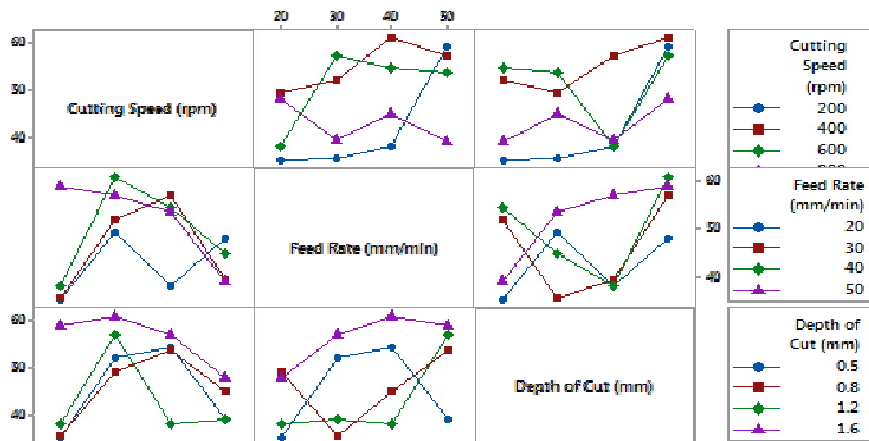


Fig. 11. Interaction plot for Temperature

IV. CONCLUSION

This attempt was made to find the optimal machining conditions for END milling of GFRP sheets by using Taguchi methodology. The following conclusions are made: The optimum parameters obtained for maximum MRR: cutting speed 400 rpm, feed rate 50 mm/min and depth of cut 1.6 mm. From ANOVA, it is found that feed rate is the most significant factor affecting MRR which contributes 38.84% followed by depth of cut 28.34%. The optimum parameters obtained for minimum SR: cutting speed 600 rpm, feed rate 40 mm/min and depth of cut 1.6 mm. The optimum parameters obtained for minimum TEMP: cutting speed 200 rpm, feed rate 20 mm/min and depth of cut 1.2 mm. The cutting speed is most dominant factor affecting the SR and TEMP which contribute 39.24% & 38.40% respectively.

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