Milling machining GFRP composites using grey relational analysis and the response surface methodology approach

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Abstract - *In this study, a GRA-based mathematical approach is used to perform multi-functional optimization. This GRA is used when several variables are optimized for more than one response characteristic at the same time. The primary focus is on solving the non-linear problem of multi-objective optimization with limited data.*

The results of the confirmation experiment at optimal levels a2 b2 c1 d3 and e1 show that the machining force decreased from 17 19 to 15 92 n, the delamination factor decreased from 1 0063 to 1 0045, and the improved from 5 288 to 5 971 mm3/min. It explains how the DOE taguchi technique can be used to improve process outcomes in production planning and analysis. The analysis was conducted to evaluate the influences of the machining factors on the responses in order to determine the significant effect of the parameters on the quality characteristics of the test. This analysis was carried out with a 5% level of significance, i.e. with a 95% level of confidence. Surface roughness ANOVA result This study was carried out with a 5% level of significance, i.e. with a 95% level of confidence. Surface roughness ANOVA result The Cutting Tool (P=0.003) (47.73%%) has the greatest influence on the machining force. Spindle speed (P= 0.048) (18.30%) was followed by Feed rate (0.098) (13.30%) and Depth of cut (0.136) (11.27%). Surface roughness is a significant factor in the parameters of the current study.

Key Words DOE taguchi method, MRR, Grey relation analysis, glass fiber reinforced polymer, surface roughness and machining force

1. INTRODUCTION

GRA-based Taguchi optimization technique using experimental design assists in controlling/reducing various errors during manufacturing of GFRP composite gear.

(3) Selection of various parameters for ranking has been done through response table. The p-value is below 0.02 and hence it is found all the process parameters have significant effect on the performance characteristics of GFRP. Rotary feed, cutting speed, cutting fluid ratio and cutting fluid flow rate are identified as key significant parameters of gear shaper machine which control the performance characteristics. The optimum machining parameters are calculated as rotary feed 0.15 mm/stroke, cutting speed 240 strokes/min, cutting fluid ratio 12% and cutting fluid flow rate 30 ml/min. The significant parameters effect the performance characteristics are at 96% confidence level. The variation in predicted and experimental grey relational grade is very less (1.5%) and hence the results are validated.

From the review of existing literature it is apparent that many research have been carried out on polymer composite gears performance based on milling machine by varying reinforcement, process routes, gear pair combinations of different materials but no study available on single optimization of cutting parameters of milling machine for minimum variation/deviation of surface roughness of tooth which affects the noise, vibration and load carrying capacity. Root diameter deviation affects the root fillet radius, responsible for tooth beam strength; Tooth thickness variation controls the proper meshing of teeth, responsible for noise, vibration; Surface roughness affects the friction and life of teeth in wear.

Due to anisotropic and heterogeneous structures of composites machining of such materials with conventional machining processes often results in material failures such as matrix cracking fiber pull out swelling and delamination hole surface failure.[2]

1.1 Effect of input process parameters on machining force and surface roughness

In milling, machining force is regarded as one of the most important parameters that affects overall machining and has a significant impact on the surface quality of the milled surface. To achieve appropriate machining results, it is critical to minimize machining forces; this is influenced directly or indirectly by all milling process input variables such as spindle speed, feed rate, and depth of cut, cutting tool geometry, workpiece material, tool-workpiece interface characteristics, tool temperature, and machining vibrations.

1.2 Machining of composites

More research has been conducted in the field of machining, which includes both traditional procedures such as turning, milling, and drilling and unusual processes such as laser ablation and water jet cutting.[14]

The current work focuses on investigating the effects of spindle speed, feed rate, depth of cut, and cutting tool type, i.e., geometry, on milled surface performance in terms of Fm and Ra. Table 2 contains information about all of the combinations tested, as well as the machining force and surface roughness values for each experiment [10].

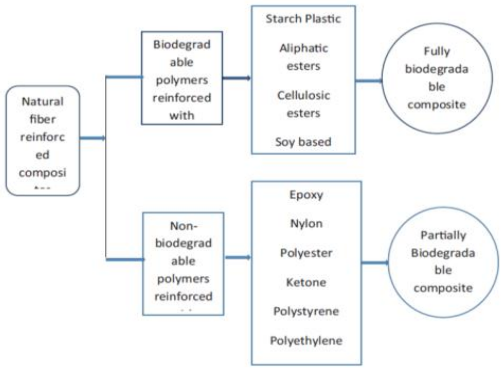

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Fig. 2 Types of polymers Vs composites [2]

1.2 LITERATURE REVIEW

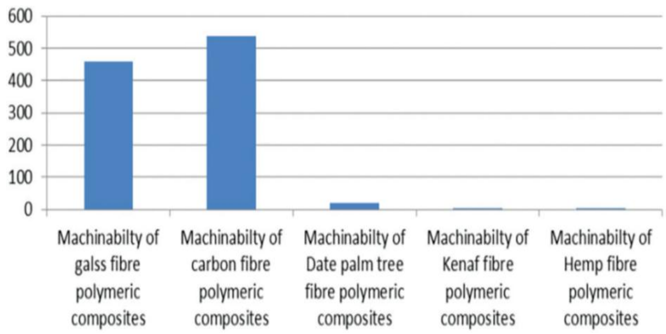
This paper has provided a comprehensive literature review on cfrp machining covering scientific and technological achievements over the past 30 yr. in terms of machining process conditions and characteristics cutting theories and thermal/mechanical responses.

From literature minimize all the output factors during drilling model optimization is carried out by setting the objectives and a desirability based approach is used to select the optimum condition The objective function/optimizing variable bounds and optimum values of the factors are presented in table 7 a spindle speed of 1070 rpm feed of 0 1 mm/rev tool angle of 900 and tool diameter of 8 mm is optimum conditions for drilling[16]

The results of ANN concluded that experiment no3 obtained relatively more error than remaining the deviation between experimental values and prediction values are found in the range of 3 7% Depth of cut factor has moderate significance 22 92% .

The fit summary recommended that the quadratic model is statistically significant for analysis of delamination the result of the quadratic model for delamination in the form of Anova The associated p value for the model is lower than 0 05 i e a¼ 0 05 or 95 per cent confidence which shows that the model is considered to be statistically significant further factor a b c and b2 only have significant effects on delamination.[17]

In this experimental study conducting the Anova and considering to checking the results of the machining of customized carbide tipped tool 2 why because it gives the better performance among the other three tools. There was good reliability made between the prediction and experimental values for both of two performance characteristics the machining force and the surface roughness. As per taguchi optimum machining parameters availed and according to s/n ratios in comparison with actual parameters there was improvement of machining force and surface roughness are 0 63db and 0 60db[18]



1.3 METHODOLOGY

1.3.1 Materials and Procedure

A total of 25 tests were scheduled. The L25 orthogonal array architecture developed by Taguchi was used. Four critical parameters were considered when organizing the tests: spindle speed, feed rate, depth of cut, and type of milling tool used in the milling process; each parameter was adjusted at five levels. During the Taguchi study, the average value of experimental response and its related signal-to-noise (S/N) ratio for each run were obtained to investigate the effects of various machining process parameters.

The S/N ratio was chosen for the Taguchi analysis because it aids in describing the trial data's average (mean) and variables (standard deviation). The goal of this study was to achieve the lowest machining force and surface roughness possible by optimizing the input process parameters. As a result, the S/N ratio will fall into the category of "lower is better." Experiments were carried out on a universal milling machine with a spindle power of 10 kW and a maximum speed of 3000 rpm. To keep the workpiece central and avoid vibrations, a specially designed fixture was used.

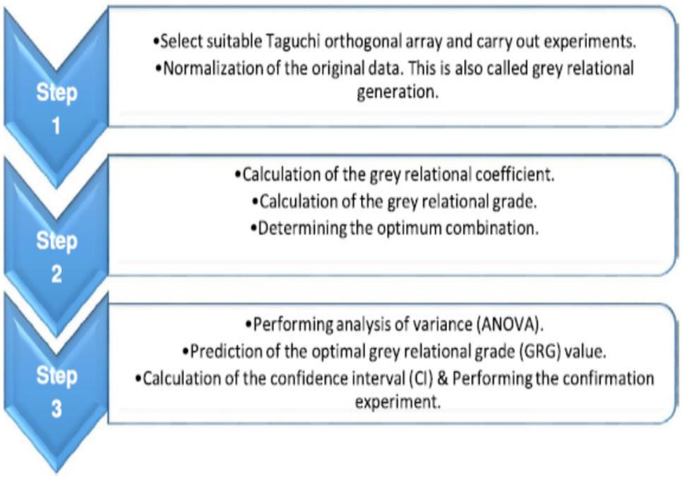


Fig 3.2 Flow Chart Steps for grey relational analysis [2]

Table3.2 Details of input parameters and considered responses for all 25 experiments[10

Exp. No.	Cutting Tool	Spindle speed	Feed rate	Depth of cut	Machining force	Surface roughness "Ra
1	1	690	0.6	0.5	23.3	4.11
2	1	960	0..8	1	23.5	4.07
3	1	1153	1	1.5	24.6	3.86
4	1	1950	1.2	2	24.1	3.66
5	1	2500	1.4	2.5	23.4	3.24
6	2	690	0.8	1.5	23.4	3.18
7	2	960	1	2	22.9	3.86
8	2	1153	1.2	2.5	23.5	3.26
9	2	1950	1.4	0.5	23.6	3.51
10	2	2500	0.6	1	23.3	3.13
11	3	690	1	2.5	23.7	2.83
12	3	960	1.2	0.5	23.7	3.87
13	3	1153	1.4	1	23.2	2.65
14	3	1950	0.6	1.5	23.2	3.84
15	3	2500	0.8	2	23.5	3.25
16	4	690	1.2	1	22.7	3.14
17	4	960	1.4	1.5	23.1	3.13
18	4	1153	0.6	2	22.4	3.52
19	4	1950	0.8	2.5	22.5	3.53
20	4	2500	1	0.5	22.8	3.39
21	5	690	1.4	2	22.2	2.75
22	5	960	0.6	2.5	21.2	3.1
23	5	1153	0.8	0.5	21.6	2.97
24	5	1950	1	1	20.6	2.88
25	5	2500	1.2	1.5	21.9	2.49

			NORMALIZATION		Deviation sequence	
EXPERIMENT NO	Machining force	Surface roughness "Ra	Machining force	Surface roughness "Ra	Machining force	Surface roughness "Ra
1	23.3	4.11	0.325	0.000	0.675	1.000
2	23.5	4.07	0.275	0.025	0.725	0.975
3	24.6	3.86	0	0.154	1	0.846
4	24.1	3.66	0.125	0.278	0.875	0.722
5	23.4	3.24	0.3	0.537	0.7	0.463
6	23.4	3.18	0.3	0.574	0.7	0.426
7	22.9	3.86	0.425	0.154	0.575	0.846
8	23.5	3.26	0.275	0.525	0.725	0.475
9	23.6	3.51	0.25	0.370	0.75	0.630
10	23.3	3.13	0.325	0.605	0.675	0.395
11	23.7	2.83	0.225	0.790	0.775	0.210
12	23.7	3.87	0.225	0.148	0.775	0.852
13	23.2	2.65	0.35	0.901	0.65	0.099
14	23.2	3.84	0.35	0.167	0.65	0.833
15	23.5	3.25	0.275	0.531	0.725	0.469
16	22.7	3.14	0.475	0.599	0.525	0.401
17	23.1	3.13	0.375	0.605	0.625	0.395
18	22.4	3.52	0.55	0.364	0.45	0.636
19	22.5	3.53	0.525	0.358	0.475	0.642
20	22.8	3.39	0.45	0.444	0.55	0.556
21	22.2	2.75	0.6	0.840	0.4	0.160
22	21.2	3.1	0.85	0.623	0.15	0.377
23	21.6	2.97	0.75	0.704	0.25	0.296
24	20.6	2.88	1	0.759	0	0.241
25	21.9	2.49	0.675	1.000	0.325	0.000

Grey relation coefficient		GRG	Rank
Machining force	Surface roughness "Ra		
0.426	0.333	0.379	13
0.408	0.339	0.374	15
0.333	0.372	0.352	17
0.364	0.409	0.386	14
0.417	0.519	0.468	9
0.417	0.540	0.478	7
0.465	0.372	0.418	15
0.408	0.513	0.460	14
0.400	0.443	0.421	16
0.426	0.559	0.492	9
0.392	0.704	0.548	7
0.392	0.370	0.381	19
0.435	0.835	0.635	6
0.435	0.375	0.405	16
0.408	0.516	0.462	14
0.488	0.555	0.521	8
0.444	0.559	0.502	8
0.526	0.440	0.483	9
0.513	0.438	0.475	9
0.476	0.474	0.475	10
0.556	0.757	0.656	4
0.769	0.570	0.670	3
0.667	0.628	0.647	5
1.000	0.675	0.838	1
0.606	1.000	0.803	2

The Taguchi Orthogonal Array (OA) technique, which was used to design the experimental layout, was used to obtain the response values of Machining force and Surface roughness "Ra." Experiment 24 was determined to have the highest value of grey relational grade and was ranked first. The factors for experiment number 24 are machining force "Fm" (N) 20.6, surface roughness "Ra" (m) 2.88.

Performance characteristics Optimal	Initial machining parameters	Optimum process machining parameters	
		Experimental value	Predicted value
	A1 B1 C1 D1	A5 B4 C3 D2	A5 B4 C3 D2
Cutting Tool (A)	0.379	0.838	0.8431
Spindle speed (B)			
Feed rate(C)			
Depth of cut(D)			
Grey relational grade			
Grey relational grade improvement	0.0051		

Hence the grey relational analysis based on taguchi method for the optimization of the A particularly important tool is multi-response problems. For predicting the Machining force and surface roughness.

The improvement of grey relational grade from initial parameter combination (A1–B1–C1 D1 to the optimal parameter combination (A5 B4 C3 D2) is found to be 0.0051

CONCLUSION

1. The spindle speed and feed rate have no effect on the SR and Machining force of CFRP composite laminates.

2. The Grey-Taguchi method can be used to simplify and improve the optimization of numerous common performance criteria. According to the response table, the maximum setting for the GRG for spindle speed is 4000 rpm, feed rate is 200 mm/min, and cut depth is 0.5mm (A5 B4 C3 D2).

3. The depth of cut is the most important factor influencing the SR and DLF. To determine the SR and DLF, cutting depth is a critical parameter that interacts heavily with spindle speed.

4. Machining force ANOVA result The Cutting Tool (P=0.003) (47.73%%) has the greatest influence on the machining force. Spindle speed (P= 0.048) (18.30%), Feed rate (0.098) (13.30%), and Depth of cut (0.136) (11.27%) are the next most significant factors for surface roughness in the current study.

5. The R -sq value is 91.51%, indicating good agreement between the input and output relationships. It demonstrates that the input and output variables have a strong relationship. Now, the R-Sq (adj) value is 74.52%, indicating that the data are well fitted for the new sets of variables.

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