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Parametric optimization in machining of GFRP composite by taguchi grey relational analysis

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The glass fibre reinforce polymer composites are fabricated using compression molding technique. The epoxy resin is used as the matrix material and the glass fibres are used as the reinforcing element. The glass fibre with 30 percentage in weight proportion are used as the reinforcing element and the remaining is the epoxy based matrix material. The composite laminates are tested for its machining characteristics in CNC milling machine using solid carbide end mills. The cutting speed, feed rate and depth of cut are used as the milling process parameters and the responses are delamination factor and surface roughness. Optimal machining parameters are determined by the grey relational analysis (GRA) and discussed.

Keywords: Glass fibre reinforced composite (GFRP), Grey relational grade (GRG), ANOVA, Delamination factor, Surface roughness.

Introduction

The composites are found applications in several engineering fields due to its excellent properties such as light in weight and high modulus of elasticity. The glass fibre reinforced composite finds applications in space, aerospace, electronic components, energy, marine and defense sectors. The mechanical and the corrosion behavior of the composites are found to be higher because of its combination of properties of both the matrix and the reinforcing element. Initially the mold is prepared and the resin glue is poured into the mold and it is cured. The fabrication techniques used for the preparation of the composite laminate is compression moulding technique. The thickness of the composite laminate is 3mm approximately. The laminates are machined using CNC milling using carbide end mill cutter of diameter of 10mm. A vertical machine centre CNC milling machine is used in this work. The Table size is 800×400 mm with a spindle motor power of 7.5 KW. The spindle speed ranges from 100-7,000 rpm and the machine is capable of moving along X, Y and Z axis. The cutting parameters optimization of metal matrix composites are investigated using ANOVA and GRA [1]. Drilling of GFRP composite using GRA is carried out and optimal machining parameters are obtained using GRG from GRA [2]. Investigation on drilling performance characteristics on hybrid polymer composites using GRA, regression, fuzzy and ANN models are carried out. It is observed that the ANN is the suitable process that determines the optimum machining parameters [3]. The Taguchi method and Pareto analysis is carried out for the investigating the optimum cutting parameters in turning glass fibre reinforce polymer composite. Minimum number of experiments is sufficient to perform machining characterization to achieve best optimal solutions using Taguchi analysis [4].

Filament winding is used to fabricate hollow pipes made of glass fibre reinforce polymer composite. Machining characteristics studies are investigated using multi performance optimization techniques such as GRA and it is reported that the machining performance can be improved effectively using this techniques [5]. The optimal parameters to obtain better responses, the grey relational analysis (GRA) was followed [6]. GRA and Taguchi optimization methods are followed to evaluate the hard turning process [7], multi response characteristics can be solved in GRA as single solution. The degree of higher order of gray relational grade defines the process parameters significance on the responses are noticed [8]. The Taguchi method and GRA to optimize the turning operation to improve hardness and toughness are followed. The multi-objective of the turning process is converted as a single objective function to obtain optimal process parameters [9]. The machinability of the end milling operation through multi-objective function analyzing methodology is studied [10]. The optimization of drilling parameters on natural fibre reinforced composites using central composite design is carried out [11]. The epoxy based composite are tested for the mechanical properties and analysed using ANOVA and Taguchi analysis [12].

Experimental Methodology

The process parameters selected for this research work are cutting speed, feed rate and depth of cut. The levels of parameters are chosen and experimental design is carried out using design of experiments and L27 orthogonal array

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is implemented to perform 27 experiments. Delamination factor and surface roughness are investigated as the responses in this work. Delamination is caused by occurrence of cracks and breakages in the layers of the fibre reinforced polymer composite laminate. The delamination will have high influence on the mechanical properties of the composite material. Delamination factor is a dimensionless parameter and defined as ratio of the delaminated diameter and the hole diameter. Delamination is measured with the help of high resolution microscope by moving the cross hair along the direction of the composite laminate and the surface roughness is measured using surface roughness tester. The readings are recorded for every experiment and it is shown in Table 1.

Table 1. Experimental data

Expt .Run	CS	FR	DoC	Surface Roughness (μm)	Delamination Factor
1	1500	100	1	0.864	1.096
2	1500	100	1	0.845	1.099
3	1500	100	1	0.797	1.093
4	1500	200	1.5	0.886	1.082
5	1500	200	1.5	0.951	1.067
6	1500	200	1.5	0.881	1.086
7	1500	300	2	0.814	1.081
8	1500	300	2	0.678	1.069
9	1500	300	2	0.699	1.081
10	2000	100	1.5	0.789	1.061
11	2000	100	1.5	0.774	1.069
12	2000	100	1.5	0.814	1.076
13	2000	200	2	0.856	1.039
14	2000	200	2	0.889	1.026
15	2000	200	2	0.785	1.028
16	2000	300	1	0.792	1.068
17	2000	300	1	0.823	1.052
18	2000	300	1	0.782	1.067
19	2500	100	2	0.601	1.045
20	2500	100	2	0.606	1.055
21	2500	100	2	0.585	1.059
22	2500	200	1	0.557	1.037
23	2500	200	1	0.645	1.047
24	2500	200	1	0.658	1.036
25	2500	300	1.5	0.442	1.049
26	2500	300	1.5	0.511	1.065
27	2500	300	1.5	0.457	1.069

Results and Discussions

The normal probability plots and the residual plots for the surface roughness are shown in Fig. 1 and Fig. 2 respectively. It is observed that all the values are very close to the central median line and it is highly satisfactory. The ANOVA for surface roughness is analysed and given in

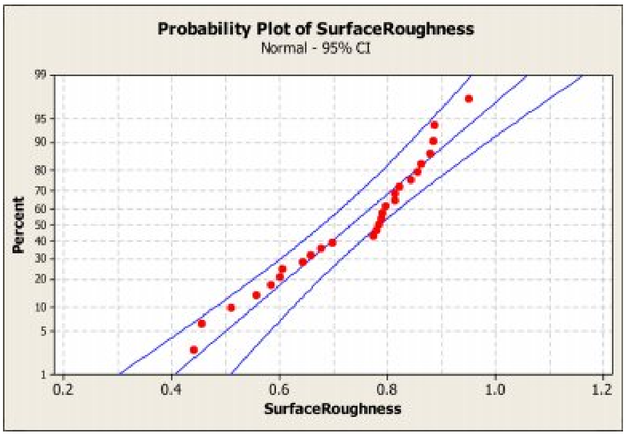

Fig. 1. Probability plots for Surface roughness.

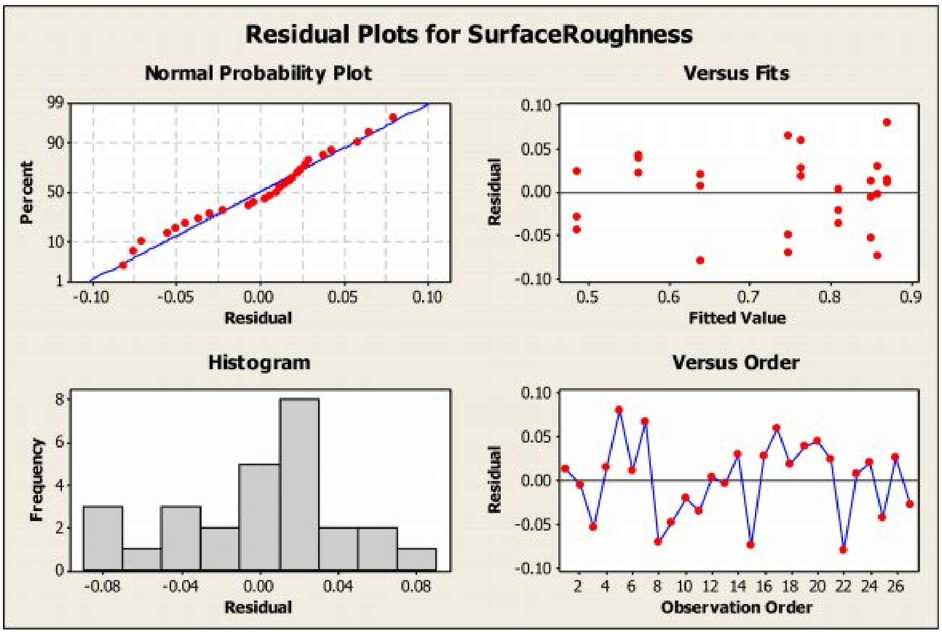

Fig. 2. Residual plots for Surface roughness.

Table 2. ANOVA for Surface Roughness

Source	DoF	SS of squares	Adj sum of squares	Adj. means sum of squares	F value	P value
CS	2	0.391685	0.391685	0.195842	80.22	0.000
FR	2	0.069553	0.069553	0.034776	14.24	0.000
DoC	2	0.004783	0.004783	0.002391	0.98	0.393
Error	20	0.048828	0.048828	0.002441		
Total	26	0.514848				

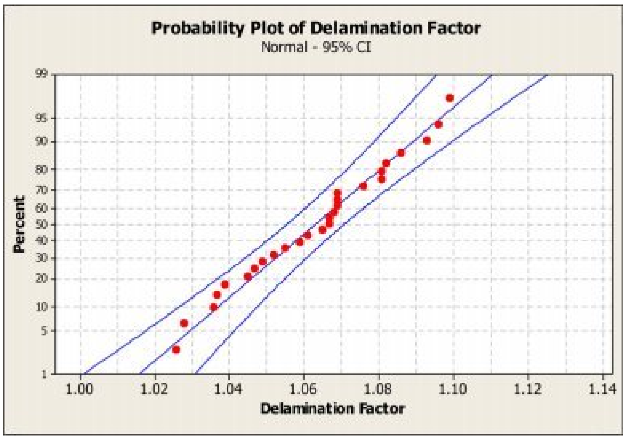

Fig. 3. Probability plots for Delamination factor.

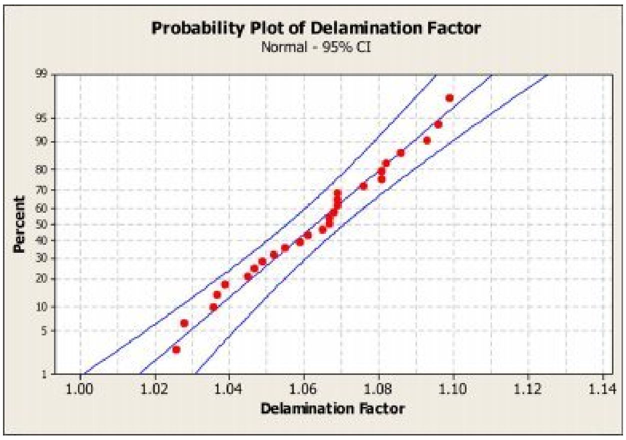

Fig. 4. Residual plots for Delamination factor.

Table 2. It is observed that the contribution of cutting speed is higher while the objective function is the minimization of the surface roughness. The R-squared value is found to 90.62% and it is satisfactory. It is observed that the contribution of cutting speed is 38.03%, feed rate is 6.75% and depth of cut is 0.464%. It is concluded that the cutting is the most dominating parameter in the minimization of the surface roughness.

The normal probability plots and the residual plots for the Delamination factor are shown in Fig. 3 and Fig. 4 respectively. It is observed that all the values are very close to the central median line and it is highly satisfactory. The ANOVA for delamination factor is analysed and given in Table 3. It is observed that the contribution of cutting speed is higher while the objective function is the minimization of the Delamination factor. The R-squared value is found to 89.15% and it is satisfactory. It is observed that the contribution of cutting speed is 27.24%, feed rate is 11.7% and depth of cut is 5.74%. It is concluded that the cutting is the most influencing parameter in the minimization for the delamination factor. From the residual plots for the responses, it is noted that all the experimental values are very close to the median line and it represents a good representation of fitting of the model.

GREY Relational Analysis

GRA is used to analyse the multi performance characteristics and it is implemented in this work to determine multi performance characterization for the optimization of the machining of GFRP composite. Taguchi Grey Relational Analysis (TGRA) is useful in determining the optimum process parameters in obtaining the minimum surface roughness and minimum delamination factor. The grey relational coefficients are calculated for each sequence and grey relational grade are obtained by averaging the grey relational coefficients. The optimum sequence is determined from the higher grey relational grade and the optimum process parameters are determined. The GRG for the surface roughness and delamination factor are obtained. Higher the GRG, it is concluded that the values are closer to ideally normalized value. In this work, experiment run 25 has the optimum multiple performance characterization

Table 3. ANOVA for Delamination Factor

Source	DoF	SS of squares	Adj sum of squares	Adj. means sum of squares	F value	P value
CS	2	0.0058394	0.0058394	0.0029197	52.05	0.000
FR	2	0.0025236	0.0025236	0.0012618	22.50	0.000
DoC	2	0.0012321	0.0012321	0.0006160	10.98	0.001
Error	20	0.0011219	0.0011219	0.0000561		
Total	26	0.0107170				

Table 4. Grey relational Coefficient and GRG

Expt. Run	GRG - Ra	GRG - DF	Deviation Sequence - Ra	Deviation Sequence - DF	GRC - Ra	GRC – DF	GRG	Rank
1	0.171	0.041	0.829	0.959	0.376	0.343	0.359	27
2	0.208	0.000	0.792	1.000	0.387	0.333	0.360	26
3	0.303	0.082	0.697	0.918	0.418	0.353	0.385	23
4	0.128	0.233	0.872	0.767	0.364	0.395	0.379	24
5	0.000	0.438	1.000	0.562	0.333	0.471	0.402	22
6	0.138	0.178	0.862	0.822	0.367	0.378	0.373	25
7	0.269	0.247	0.731	0.753	0.406	0.399	0.403	21
8	0.536	0.411	0.464	0.589	0.519	0.459	0.489	14
9	0.495	0.247	0.505	0.753	0.498	0.399	0.448	17
10	0.318	0.521	0.682	0.479	0.423	0.510	0.467	15
11	0.348	0.411	0.652	0.589	0.434	0.459	0.447	18
12	0.269	0.315	0.731	0.685	0.406	0.422	0.414	20
13	0.187	0.822	0.813	0.178	0.381	0.737	0.559	12
14	0.122	1.000	0.878	0.000	0.363	1.000	0.681	5
15	0.326	0.973	0.674	0.027	0.426	0.948	0.687	4
16	0.312	0.425	0.688	0.575	0.421	0.465	0.443	19
17	0.251	0.644	0.749	0.356	0.400	0.584	0.492	13
18	0.332	0.438	0.668	0.562	0.428	0.471	0.450	16
19	0.688	0.740	0.312	0.260	0.615	0.658	0.637	7
20	0.678	0.603	0.322	0.397	0.608	0.557	0.583	10
21	0.719	0.548	0.281	0.452	0.640	0.525	0.583	11
22	0.774	0.849	0.226	0.151	0.689	0.768	0.729	2
23	0.601	0.712	0.399	0.288	0.556	0.635	0.596	9
24	0.576	0.863	0.424	0.137	0.541	0.785	0.663	6
25	1.000	0.685	0.000	0.315	1.000	0.613	0.807	1
26	0.864	0.466	0.136	0.534	0.787	0.483	0.635	8
27	0.971	0.411	0.029	0.589	0.944	0.459	0.702	3

Table 5. Analysis of Variance for GRG, using Adjusted SS for Tests

Source	DoF	SS of squares	Adj sum of squares	Adj. means sum of squares	F value	P value
CS	2	0.303759	0.303759	0.151880	36.50	0.000
FR	2	0.042170	0.042170	0.021085	5.07	0.017
DoC	2	0.021126	0.021126	0.010563	2.54	0.104
Error	20	0.083226	0.083226	0.004161		
Total	26	0.450281				

and has the highest GRG and machining condition at this level are; cutting speed 2,500 m/min, feed rate 300 rpm and depth of cut 1.5 mm. Table 4 represents the grey relational coefficient and GRG for surface roughness and delamination factor. It is observed that the experimental run 25 provides the best optimal results and it is ranked 1. The ANOVA table for the GRG is presented in Table 5 and it is found that the cutting speed is the most influencing parameter in parametric optimization of the machining characteristics of the composite laminate. The response table for means for GRG is also presented in Table 6 and it is noted that the most significant parameter is cutting speed and it is followed by feed rate and depth of cut. The main effect plots for Surface roughness, Delamination factor and GRG are plotted in Fig. 5, 6 and 7 respectively. It is observed that higher cutting speed will provide the minimum surface roughness and delamination factor and it is the most influencing parameter in the determination of the optimum parameter.

Table 6. Response Table for Means for GRG

Level	CS	FR	DoC
1	0.3999	0.4705	0.4974
2	0.5155	0.5632	0.5139
3	0.6592	0.5409	0.5632
Delta	0.2593	0.0927	0.0658
Rank	1	2	3

Conclusions

This work investigates the machining performance characteristics of glass fibre reinforce polymer composites.

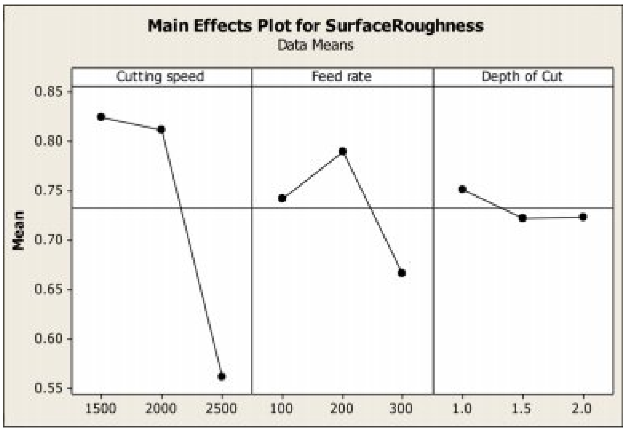

Fig. 5. Main effect plots for means – Surface roughness.

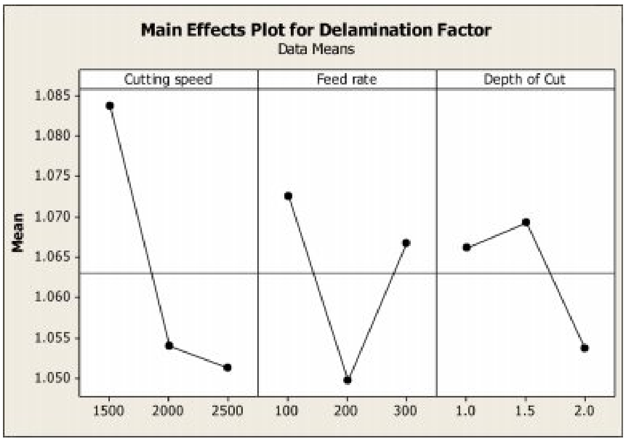

Fig. 6. Main effect plots for means – Delamination factor.

L27 orthogonal array is implemented to carry out 27 experiments. The responses considered in the work are delamination factor and surface roughness. The grey relation grades for the surface roughness and delamination factor are obtained. Higher the GRG, it is concluded that the values are closer to ideally normalized value. The ANOVA tables for surface roughness, delamination factor and GRG are analysed and main effects plots are also plotted. The 25th run is observed to be ranked 1 among the 27 experiments and the corresponding parameters are cutting speed – 2500 rpm; Feed rate – 300 rpm and depth of cut – 1.5 mm. The validation test is conducted at the

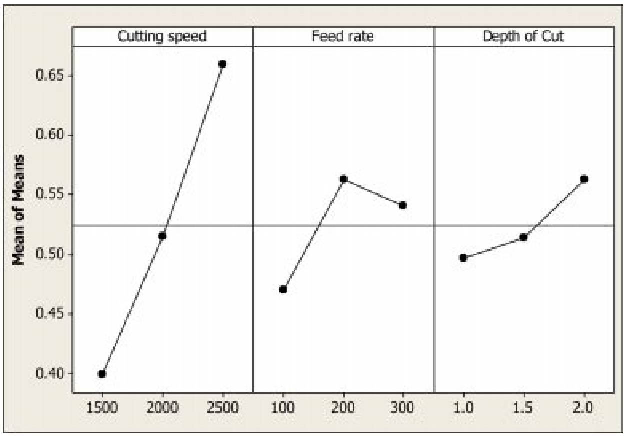

Fig. 7. Main effect plots for means – GRG.

optimum parameters and the surface roughness is measured to be 0.461μm and delamination factor is found to be 1.053 and the results are validated.

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