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Research Article

OPTIMIZING HIGH SPEED DRILLING PARAMETERS FOR GLASS FIBER REINFORCED POLYMER COMPOSITE USING GREY RELATIONAL ANALYSIS

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ABSTRACT

This paper reports the experimental investigation of high speed drilling of glass fiber reinforced composite. The response parameters considered are delamination factor at entry and exit and the input parameters are point angle, cutting speed and feed rate. Experiments are conducted on the basis of response surface methodology technique. Further grey relational analysis is used to optimize the parameters with lower the better output performance characteristic. Optimization can be used for selecting the values of process variables to get the desired values of response parameters.

INTRODUCTION

Composite laminate has superior properties such as higher strength to weight ratio, higher stiffness, lower thermal expansion over other conventional materials. As a result, composite laminates like GFRP is useful in aerospace industries, aircraft structural components [1]. Machining of GFRP has always been difficult because of multitude of difficulties like fiber pull out, fiber fuzzing, matrix burning, fiber-matrix detachment which result in subsurface damage, reduced strength and short product life. Many researchers have established that GFRP can be machined easily by HSD but detailed mathematical models representing the influence of predominant machining variables on machinability are yet to be established. Empirical models are developed using response surface methodology [19]. These linear regression models developed may be of interest to process planners dealing with such materials. Moreover, optimization using grey relational analysis is attempted for selecting the values of process variables to get desired response parameters.

Experimental Work

GFRP composite was prepared using hand layup technique. Lapox L-12 with hardener K-6 was used for specimen preparation. Wax was sprayed on the mold surface to avoid the sticking of resin to the surface. Thin polyester film was used at the top and bottom of the mold to get good surface finish. Woven glass fiber (600 GSM) was cut as per mold size (300 mmx250mm) for reinforcement. Lapox L-12 resin and hardener K-6 weremixed in mixing ratio 10:1by weight. Resin is spread with the help of brush and layer of woven glass fiber was placed on the resin and roller was moved to remove trapped air. This process was repeated for 10 layers of glass fiber and then the polyester film is applied on the top surface. Curing is done for 24 hours. After curing specimen of 275 mm x 220 mm was cut, with a thickness of 5.8 mm. High speed drilling was carried out using solid carbide drill.

Experimental Plan

RSM method is used for designing the experimenmts. A full factorial design includes effect of all main factors and interaction of factors, 3^3 full factorial design is selected for experimental work. The levels of input parameters chosen for experiment and their levels is shown in Table 1. Each experiment is performed on CNC micro drilling machine which is controlled with Mech Front V 1.0.0.0. In this investigation the delamination factor was measured as a ratio of total area with hole damage to nominal area of drilled hole. The images

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of the drilled hole were captured using 3D microscope with 0.97X magnification and 0.1µm resolution. The digital images of drilled hole were analysed using Image J (Version 1.5 1J8) – public domain software to calculate delamination factor at entry and exit.

Table 1 Input Parameters used for experimentation and their levels

Input Parameter	Coding	Level 1 (-1)	Level 2 (0)	Level 3 (+1)
Cutting Speed(m/min)	X_1	175	205	235
Feed rate (mm/min)	X_2	150	200	250
Point Angle (Degree)	X_3	90	104	118

Table 2 gives the design matrix and the responses obtained from experimentation.

Table 2 Design matrix and responses

	Input Parameters			Output Parameters	
S.No	Point Angle	Cutting Speed	Feed rate	Delamination at Entry	Delamination at Exit
1	90	175	150	1.133	1.152
2	90	175	200	1.145	1.150
3	90	175	250	1.159	1.171
4	90	205	150	1.136	1.146
5	90	205	200	1.140	1.160
6	90	205	250	1.186	1.183
7	90	235	150	1.150	1.155
8	90	235	200	1.169	1.164
9	90	235	250	1.166	1.213
10	104	175	150	1.186	1.238
11	104	175	200	1.219	1.228
12	104	175	250	1.169	1.275
13	104	205	150	1.197	1.215
14	104	205	200	1.214	1.228
15	104	205	250	1.176	1.237
16	104	235	150	1.140	1.220
17	104	235	200	1.171	1.213
18	104	235	250	1.180	1.249
19	118	175	150	1.258	1.266
20	118	175	200	1.271	1.260
21	118	175	250	1.229	1.284
22	118	205	150	1.250	1.250
23	118	205	200	1.294	1.231
24	118	205	250	1.241	1.299
25	118	235	150	1.269	1.231
26	118	235	200	1.236	1.259
27	118	235	250	1.255	1.306

Grey Relational Analysis

Grey theory steps

The information that is either incomplete or undetermined is called Grey. The Grey system provides multidisciplinary approaches for analysis and abstract modeling of systems for which the information is limited, incomplete and characterized by random uncertainty [14].

The three Terms that are Typical Symbols and Features for Grey System are

a. The Grey number in Grey system is a number with incomplete information.
b. The Grey element represents an element with incomplete information.
c. The Grey relation is the relation with incomplete information.

Grey relational analysis

The generation of Grey relation for experimental runs is shown in Figure 1. The process is elaborated here.

Let the number of the experimental runs be *m*, and the number of the response parameters be *n.* Then a *m* x *n* value matrix (called eigen value matrix) is set up.

$$X = \begin{bmatrix} x_1(1), x_1(2), \ldots\ldots x_1(n) \\ x_2(1), x_2(2), \ldots\ldots x_2(n) \\ \ldots\ldots \\ \ldots\ldots \\ x_m(1), x_m(2), \ldots\ldots x_m(n) \end{bmatrix} \quad (1),$$

Where, $x_i(k)$ is the value of the number *i* experiment run and the number *k* response factors.

Usually, Three Kinds of Influence Factors are Included, they are

1. Benefit – type factor (the bigger the better),
2. Defect – type (the smaller the better)
3. Medium – type, or nominal-the-best (the nearer to a certain standard value the better).

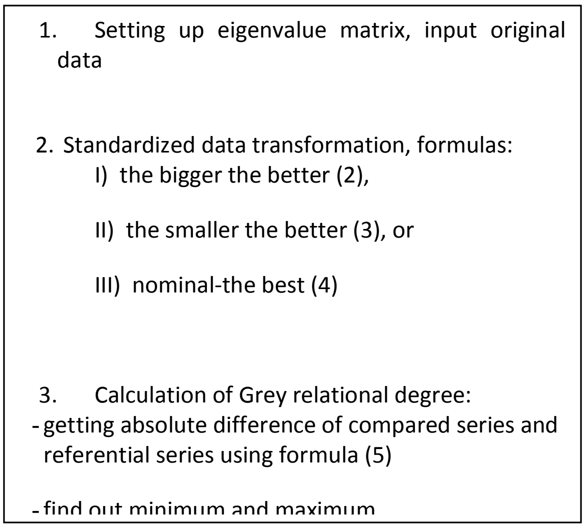

Figure 1 The generation of Grey relation degree

It is difficult to compare between the different kinds of factors because they exert a different influence. Therefore, the standardized transformation of these factors must be done. Three formulas can be used for this purpose.

$$x_i(k) = \frac{x_i(k) - \min x_i(k)}{\max x_i(k) - \min x_i(k)} \quad (2)$$

The first standardized formula is suitable for the benefit – type factor.

$$x_i(k) = \frac{\max x_i(k) - x_i(k)}{\max x_i(k) - \min x_i(k)} \quad (3)$$

The second standardized formula is suitable for defect – type factor.

$$x_i(k) = \frac{|x_i(k) - x_0(k)|}{\max x_i(k) - x_0(k)} \quad (4)$$

The third standardized formula is suitable for the medium – type factor.

The Grey Relation Degree can be Calculated by steps as Follows

a) The absolute difference of the compared series and the referential series should be obtained by using the following formula:
b)

$$\Delta x_i(k) = |x_0(k) - x_i(k)| \quad (5)$$

and the maximum and the minimum difference should be found.

c) The distinguishing coefficient *p* is between 0 and 1. Generally, the distinguishing coefficient *p* is set to 0.5.
d) Calculation of the relational coefficient and relational degree by (6) as follows.

In Grey relational analysis, Grey relational coefficient ξ can be expressed as follows

$$\xi_i(k) = \frac{\Delta \min + p\Delta \max}{\Delta x_i(k) + p\Delta \max} \quad (6)$$

and then the relational degree follows as:

$$r_i = \sum [w(k)\xi(k)] \quad (7)$$

In equation (7), ξ is the Grey relational coefficient, *w (k)* is the proportion of the number *k* influence factor to the total influence indicators. The sum of *w (k)* is 100%. The result obtained when using (6) can be applied to measure the effectiveness of the experimental run.

Grey Relational Optimization for Plasma Arc Cutting process

Based on the theory and procedure of grey analysis discussed above the grey relational analysis for high speed drilling of glass fiber reinforced polymer is carried out. The preprocessing of data for both delamination factors is calculated and represented in table 3.

The table shows the normalized results of delamination factor The higher normalized values correspond to better performance and the best results are shown by value 1.

Table 3 Pre-processed Data for Delamination Factors

Exp.No	Original Data		Pre-processed Data	
	DF Entry	DF Exit	DF Entry	DF Exit
1	1.134	1.16	1	0.8848
2	1.145	1.15	0.9313	0.9455
3	1.159	1.171	0.8438	0.8182
4	1.136	1.141	0.9875	1
5	1.14	1.16	0.9625	0.8848
6	1.186	1.183	0.675	0.7455
7	1.15	1.155	0.9	0.9152
8	1.216	1.164	0.4875	0.8606
9	1.215	1.213	0.4938	0.5636
10	1.186	1.238	0.675	0.4121
11	1.219	1.228	0.4688	0.4727
12	1.169	1.275	0.7813	0.1879
13	1.197	1.215	0.6063	0.5515
14	1.214	1.228	0.5	0.4727
15	1.176	1.237	0.7375	0.4182
16	1.141	1.226	0.9563	0.4848
17	1.171	1.213	0.7688	0.5636
18	1.18	1.25	0.7125	0.3394
19	1.258	1.266	0.225	0.2424
20	1.271	1.26	0.1438	0.2788
21	1.229	1.285	0.4063	0.1273
22	1.25	1.25	0.275	0.3394
23	1.294	1.231	0	0.4545
24	1.241	1.299	0.3313	0.0424
25	1.269	1.232	0.1563	0.4485
26	1.236	1.259	0.3625	0.2848
27	1.255	1.306	0.2438	0

The determination of grey relational co-efficient is carried out for each quality parameters considering value of distinguishing coefficient as 0.5. The Grey Relational grade is calculated and rank is given as shown in table 4.

Table 4 Gray relational coefficients of the individual quality characteristics, Grey Relational Grade and its Order

Exp. No	GR Coefficient		GR Grade	Rank
	DF Entry	DF Exit		
1	1.0000	0.8128	0.9064	2
2	0.8791	0.9016	0.8904	3
3	0.7619	0.7333	0.7476	6
4	0.9756	1.0000	0.9878	1
5	0.9302	0.8128	0.8715	4
6	0.6061	0.6627	0.6344	9
7	0.8333	0.8549	0.8441	5
8	0.4938	0.7820	0.6379	8
9	0.4969	0.5340	0.5154	16
10	0.6061	0.4596	0.5328	15
11	0.4848	0.4867	0.4858	18
12	0.6957	0.3811	0.5384	13
13	0.5594	0.5272	0.5433	12
14	0.5000	0.4867	0.4934	17
15	0.6557	0.4622	0.5590	11
16	0.9195	0.4925	0.7060	7
17	0.6838	0.5340	0.6089	10
18	0.6349	0.4308	0.5329	14
19	0.3922	0.3976	0.3949	24
20	0.3687	0.4094	0.3890	25
21	0.4571	0.3642	0.4107	22
22	0.4082	0.4308	0.4195	21
23	0.3333	0.4783	0.4058	23
24	0.4278	0.3430	0.3854	26
25	0.3721	0.4755	0.4238	20
26	0.4396	0.4115	0.4255	19
27	0.3980	0.3333	0.3657	27

After calculating grey relational grade and its order in optimization process the effect of each level of each parameter is calculated and the results are listed in Table 5 and shown in Figure 2.

Table 5 Response table for grey relational grade

Symbol	Input Parameter	Grey Relational Grade			Delta	Rank
		Level 1	Level 2	Level 3		
PA	Point angle	0.7817	0.5556	0.4023	0.3794	1
CS	Cutting speed	0.5884	0.5932	0.5622	0.031	3
FR	Feed rate	0.6399	0.5787	0.5210	0.1189	2
Total Mean of grey relational grade = 0.5803						

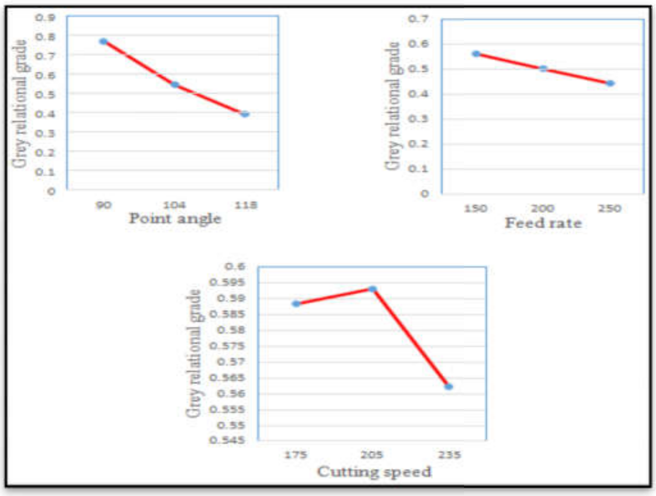

Figure 2 Grey relational graphs for response

CONCLUSION

The effect of selected input parameters on the output responses like delamination at entry and exit are studied by experimentation performed using Response Surface Methodology.

Grey relational analysis helps to grade the experimental levels for each of the individual variables and to find the most suitable levels for weighted combination of response variables. Here, for the selected weighted combination of responses, higher levels of point angle and feed rate; and medium level of cutting speed are observed to be the optimum levels.

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