Application of Grey Relational Analysis to Determine the Optimum Drilling Parameters of Rcc.

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Abstract

The growing use of Reinforced Carbon-Carbon (RCC) composite in aerospace and defence industries has prompted investigative studies in developing technology for machining of the composites. This paper emphasizes the application of Grey Theory to determine the optimum values of drilling parameters of these composites. By using the Grey Relational Analysis technique, optimization of the complicated multiple process responses can be converted into optimization of a single grey relational grade and Optimization of a factor is the level with the highest grey relational grade. The objective of this paper is to determine the suitable values of drilling parameters of this unique material with the help of experimental results by combining Taguchi method with the unique Grey theory method. The drilling experiments were carried with a Tin coated solid carbide tool on a plate of Reinforced carbon-carbon composite material.

Key Words: *GRA, RCC, CFRC, Orthogonal Array, Taguchi method, Carbon-Carbon composites.*

1. INTRODUCTION

Metal cutting is the most prominent manufacturing process in material removal and Drilling is the most common method used for metal cutting. Drilling is an operation that produces holes of desired diameter in the given material. Drilling is one of the complicated machining processes and is also a frequently used process of machining in the present industrial scenario. This drilling process further becomes more complicated, when the work piece is a composite material. Many studies have been under taken on the details of drilling processes of various composite materials.

The Drilling of composites is different from the approach that adopted for conventional materials. But much attention was not given on the drilling process of the most advanced and significant material called 'Reinforced Carbon-Carbon (RCC)', which is also simply referred as carbon-carbon composite material.

This article focuses on an approach, based on the Taguchi method with grey relational analysis for optimizing the process parameters of drilling of carbon-carbon composite material.

2. CFRC AND ITS FABRICATION METHOD

Reinforced carbon-carbon or so called Carbon/Carbon composite is nothing but the composite material, in which Graphite/Carbon fibres are reinforced in a Carbon Matrix. This composite may be manufactured with different orientations of reinforcing phase. i.e., unidirectional structure, bidirectional structure and multidirectional structure. Various fabrication methods for production of carbon/carbon composites are available. Generally the Carbon fibre preform, which is woven, is impregnated under heat and pressure with pitch. This is followed by pyrolysis of the pitch to obtain a carbonaceous matrix. .This cycle may be repeated to obtain the desired densification. This is also obtained by another method known as chemical vapour deposition from a gaseous phase [1]. A schematic of carbon-carbon composite manufacturing process is shown in Figure 1.

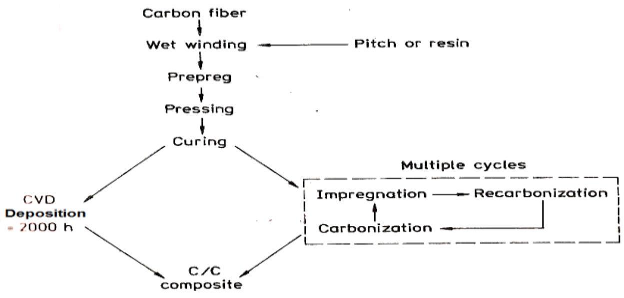

Figure 1. Carbon-Carbon manufacturing process

Most notable applications of this special material are Heat shields for re entry vehicles, aircraft brakes, hot pressing dies, nozzles, and nose cones of intercontinental ballistic missiles and leading edges of the space shuttles. Carbon/Carbon brakes are used in subsonic aircrafts; Concorde supersonic aircrafts and racing cars. The brakes of some high end super cars like Bugatti Veyron were made off with C/C material. Many advanced fighters, such as the US F-14, F-15,F-16 and French Mirage 2000, as well as commercial aircrafts such as the Boeing-747, airbus, Canadair Challenger and Gulfstream III etc.,[2,3]

3. GREY RELATIONAL ANALYSIS

The Grey theory, which was developed by Mr. Deng, provides a solution of a system in which the model is unsure or the information is incomplete and also provides an efficient solution to the uncertainty, multi-input and discrete data problems.

In this GRA analysis, the experimental results are first normalized and then the grey relational coefficient is calculated from the normalized experimental data to express the relationship between the desired and actual experimental data. Then, the grey relational grade was computed by averaging the grey relational coefficients corresponding to each performance characteristic. The overall evaluation of the multiple process responses is based on the grey relational grade. As a result, optimization of the complicated multiple process responses can be converted into optimization of a single grey relational grade. In other words, the grey relational grade can be treated as the overall evaluation of experimental data for the multi response process. Optimization of a factor is the level with the highest grey relational grade. [4]

4. LITERATURE SURVEY

Very little information has been available in the literature about machining of CFRC Composites. George et.al determined the setting of process parameters on EDM machine, while machining carbon-carbon composites using a Taguchi technique based on RSM and ANOVA [5]. J.R.Ferreira et.al have carried out in rocket nozzle throats to study the performance of different tool materials. They also have carried out to observe the influence of cutting speed and feed rate on cemented carbide tool wear [6]. To the author's knowledge, this little work is also on turning process and no literature is available on drilling process. Hence an experimental investigation is taken on drilling of this special material.

5. EXPERIMENTAL INVESTIGATION

An L27 orthogonal array table was chosen for the experiments based on Taguchi's quality design technique [7]. Drill bit point Angle, Spindle speed and Feed rate were chosen as the three controlling factors and each parameter was designed to have three levels, denoted by 1, 2, and 3 as shown in Table 1. The drilling process performance is evaluated by the characteristics like Thrust Force in Newtons, Torque in N-m and Surface Roughness in microns.

Drilling Parameters	***Symbol***	***Unit***	***Level 1***	***Level 2***	***Level 3***
Point Angle	A	degree	135	100	118
Spindle Speed	N	r.p.m	1000	2000	3000
Feed Rate	F	mm/rev	100	300	500

TABLE 1: Control Factors and levels for the experimentation

The Drilling experiments were carried out on a CNC Vertical Machining centre (VMC100) at Anna University, Chennai. A Kistler piezoelectric dynamometer is attached to this machine to measure the Thrust Force (F) and Torque (M) values through sensors. The experimental setup is shown in Fig.2.

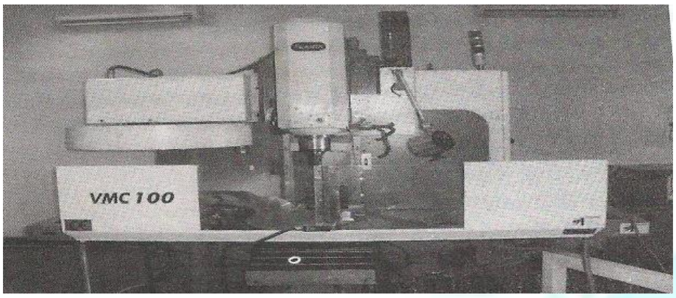

Fig.2 CNC VERTICAL MACHINING CENTRE

A data acquisition and analysis software, 'Dynoware' is used to plot the force and torque signals with respect to time. The typical plots observed in experimental study are shown in Figures 3 & 4.

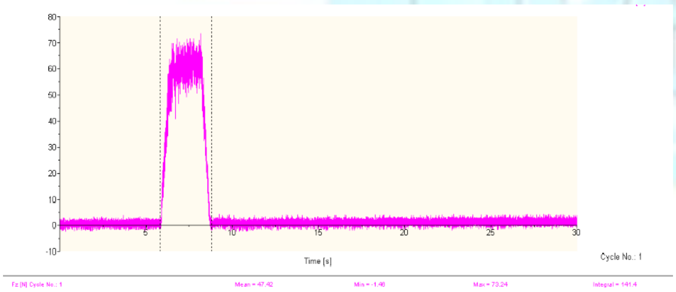

Fig.3 A typical thrust force observed from Kistler Dynamometer

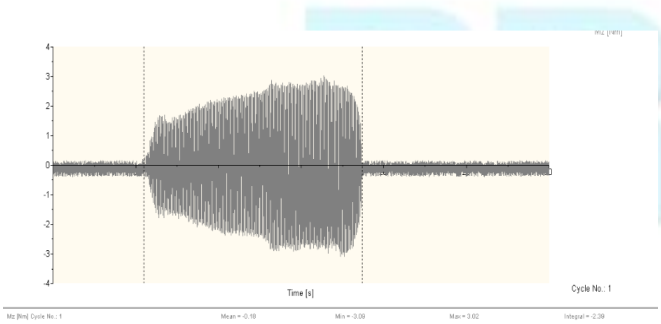

Fig.4 typical torque observed from Kistler Dynamometer

The Surface Roughness values were measured by using surface roughness tester at Micro Labs, Chennai. This setup is shown in Fig.5.

Fig.5 SURFACE ROUGHNESS TESTER

The experimental values of Thrust Force, Torque and Surface Roughness are given in Table 2.

6. NORMALIZATION OF GIVEN DATA

Generally the normalized value of the data is known as comparable sequence. The range and unit in one data sequence may differ from others, hence normalization is necessary. It is also necessary when the sequence scatter range is too large, or when the directions of the target in the sequences are different.

If the target value of original sequence is infinite, the normalized value is taken for "higher-the-better" characteristic and it is expressed as,

$$x_i^*(k) = \frac{x_i^0(k) - \min x_i^0(k)}{\max x_i^0(k) - \min x_i^0(k)} \qquad \text{- (1)}$$

The normalized value of "lower-the-better characteristic is expressed as,

$$x_i^*(k) = \frac{\max x_i^0(k) - x_i^0(k)}{\max x_i^0(k) - \min x_i^0(k)} \qquad \text{- (2)}$$

If the characteristic is "nominal-the-best", then the normalized value is expressed as

$$x_i^*(k) = 1 - \frac{|x_i^0(k) - x^0|}{\max x_i^0(k) - x^0} \qquad \text{- (3)}$$

Where i=1… m; k=1… n. m is the number of experimental data items and n is the number of parameters. $x_i^0(k)$ is the original sequence, $x_i^*(k)$ is the sequence after the normalization, $max\ x_i^0(k)$ is the largest value and $\min x_i^0(k)$ is the smallest value of $x_i^0(k)$ and x^0 is the desired target value.

The normalized or data preprocessing results for response parameters i.e. Thrust Force, Torque and Surface roughness of the process by the Tin coated solid carbide drill is presented in Table 3.

Expt.No.	Thrust Force F (N)	Torque M (N-m)	Surface Roughness R_a(μ m)
1	40.67	8.89	4.57
2	39.18	2.2	3.74
3	178.53	9.14	3.80
4	29.29	5.74	5.72
5	38.54	7.04	4.45
6	66.23	6.8	4.84
7	26.49	10.12	4.03
8	31.37	8	4.68
9	43.05	7.67	3.82
10	20.48	3.65	7.59
11	22.25	2.83	4.42
12	33.77	4.15	3.56
13	16.3	5.46	4.34
14	14.93	5.42	5.59
15	24.44	7.71	4.74
16	12.18	1.32	3.93
17	13.11	2.03	6.49
18	13.49	2.69	4.70
19	59.81	4.21	3.09
20	121.6	9.75	6.42
21	98.36	7.76	5.37
22	39.25	9.81	7.67
23	70.44	11.29	7.30
24	104.42	12.01	8.63
25	29.07	6.75	6.21
26	44.71	7.17	6.73
27	63.06	10.3	4.20

7. CALCULATION OF GRC AND GRG

After the calculation of normalized values, the GRC (grey relational coefficient) is calculated. The GRC expresses the relationship between the ideal and the actual normalized experimental results. The Grey Relational Coefficient, ξ_{ij} is expressed as,

$$\xi_{ij} = \{ \Delta_{min} + \zeta\Delta_{max}\} / \{|x_i^0 - x_{ij}| + \zeta\Delta_{max}\} \quad - \quad (4)$$

Where x_i^o is the ideal normalized results for the i^{th} performance characteristic and ζ is the distinguishing coefficient, which is defined in the range $0 \leq \zeta \geq 1$. But for practical purposes**,** ζ is taken as 0.5.

The GRC values of various response parameters are entered in Table 4. After the calculation of GRC values, the data can be reduced to a single value known as Grey Relational Grade (GRG). The GRG is calculated by the following formula by giving equal importance to the influence of various response parameters.

TABLE 2: Experimental values of T.F, Torque and Surface Roughness

xpt.No.	Thrust Force F (N)	Torque M (N-m)	Surface Roughness R_a(μ m)
1	0.8287	0.2919	0.7331
2	0.8377	0.9177	0.8831
3	0.0000	0.2685	0.8723
4	0.8971	0.5865	0.5247
5	0.8415	0.4649	0.7554
6	0.6751	0.4874	0.6849
7	0.9140	0.1768	0.8307
8	0.8846	0.3751	0.7127
9	0.8144	0.4060	0.8693
10	0.9501	0.7820	0.1873
11	0.9395	0.8587	0.7608
12	0.8702	0.7353	0.9163
13	0.9752	0.6127	0.7741
14	0.9835	0.6165	0.5488
15	0.9263	0.4022	0.7018
16	1.0000	1.0000	0.8488
17	0.9944	0.9336	0.3855
18	0.9921	0.8718	0.7090
19	0.7137	0.7297	1.0000
20	0.3422	0.2114	0.3988
21	0.4819	0.3976	0.5886
22	0.8373	0.2058	0.1735
23	0.6498	0.0674	0.2398
24	0.4455	0.0000	0.0000
25	0.8985	0.4920	0.4361
26	0.8044	0.4528	0.3434
27	0.6941	0.1600	0.7994

TABLE 3: Normalized values (Data Preprocessing of experimental results)

Expt.No.	Thrust Force F (N)	Torque M (N-m)	Surface Roughness R_a(μ m)
1	0.7449	0.4139	0.6520
2	0.7549	0.8586	0.8105
3	0.3333	0.4060	0.7965
4	0.8294	0.5474	0.5127
5	0.7593	0.4831	0.6715
6	0.6061	0.4938	0.6135
7	0.8532	0.3779	0.7471
8	0.8125	0.4445	0.6350
9	0.7293	0.4570	0.7927
10	0.9093	0.6964	0.3809
11	0.8920	0.7797	0.6764
12	0.7939	0.6538	0.8566
13	0.9528	0.5635	0.6888
14	0.9680	0.5659	0.5256
15	0.8715	0.4555	0.6264
16	1.0000	1.0000	0.7678
17	0.9889	0.8827	0.4486
18	0.9845	0.7960	0.6321
19	0.6359	0.6491	1.0000
20	0.4319	0.3880	0.4540
21	0.4911	0.4535	0.5486
22	0.7545	0.3863	0.3769
23	0.5881	0.3490	0.3967
24	0.4742	0.3333	0.3333

25	0.8312	0.4961	0.4700
26	0.7189	0.4774	0.4323
27	0.6205	0.3731	0.7137

TABLE 4: Grade Relational Coefficients

Expt...No.	Grey Relational Grade
1	0.6036
2	0.8080
3	0.5120
4	0.6298
5	0.6380
6	0.5711
7	0.6594
8	0.6307
9	0.6597
10	0.6622
11	0.7827
12	0.7681
13	0.7350
14	0.6865
15	0.6511
16	**0.9226**
17	0.7734
18	0.8042
19	0.7616
20	0.4246
21	0.4977
22	0.5059
23	0.4446
24	0.3803
25	0.5991
26	0.5429
27	0.5691

TABLE 5: Grey Relational Grades

$$\textbf{GRG}\ (\alpha_j) = \frac{1}{N}\sum_{i=1}^{N} \xi_{ij} \quad - \qquad \textbf{(5)}$$

This is nothing but average value of GRC's of various response parameters i.e. Thrust Force, Torque and Surface Roughness. The GRG values for all the 27 trials are given Table 5.

The highest grey relational grade calculated from the above expression will give the optimal combination of various process parameters, i.e. 16th experiment.

7.ANALYSIS OF RESULTS USING RESPONSE TABLE AND RESPONSE GRAPHS

Since the experimental design is orthogonal, it is then possible to separate out the effect of each drilling parameter on the grey relational grade at different levels. The mean grey relational grade for each level of all input parameters can be computed and the overall mean also calculated and entered in the Table 6.

DRILLING PARAMETER	SYMBOL	GREY RELATIONAL GRADE		
		Level 1	Level 2	Level 3
Point Angle	A	0.6347	**0.7540**	0.6128

Spindle Speed	N	0.6467	0.5825	**0.6846**
Feed Rate	F	**0.6754**	0.6368	0.6014
Overall mean of Grey Relational Grade =	**0.6477**			

Table 6: Response table for the grey relational grade (tin coated carbide tool)

The influence of each drilling parameter can be clearly presented by means of the response graph shown in Fig 6.

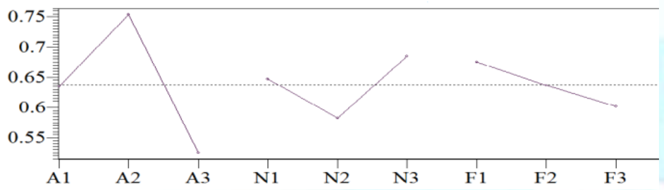

Fig .6 RESPONSE GRAPH FOR GRG VALUES

It is evident from the response table and response graph that the optimal combination of the parameters are point angle at level 2, spindle speed at level 3 and feed rate at level 1 to produce the best output.

8. PREDICTION AND VALIDATION TEST

After the optimal level has been selected, the last step is to predict and verify the improvement in the performance characteristics for the CFRC plate by drilling process with respect to the chosen initial parameter setting. This validation test is crucial and final part of the parametric design. The expected mean grey relational grade at the optimal settings is calculated by using the following model.

$$\tilde{\alpha} = \alpha_m + \sum_{i=1}^{n}[\bar{\alpha}_i - \alpha_m] \quad - \quad (6)$$

where α is the total mean of grey relational grade, $\bar{\alpha}$ is the mean grey relational grade corresponding to the i^{th} significant factor on the j^{th} level and n is the no. of significant factors that affect the multiple response parameters.

The predicted value of GRG, $\tilde{\alpha}$ = 0.6477+ {(0.754- 0.6477) + (0.6846-0.6477) + (0.6754-0.6477) = 0.8186

Table 7, shows the comparison of the predicted and the actual drilling performance of the tin coated solid carbide drill for multiple performance characteristic using their optimal cutting parameters.

Setting Level	Initial Drilling Parameters	Optimal Drilling Parameters	
		Prediction	Experiment
Response	$A_3N_2F_3$	$A_2N_3F_1$	$A_2N_3F_1$
Thrust Force(N)	104.42	-	12.18
Torque(N-m)	12.01	-	1.32
R_a(µm)	8.63	-	3.93
G R Grade	**0.3803**	0.8186	**0.9226**

TABLE 7: RESULTS OF VALIDATION EXPERIMENT

The confirmation experiment results at the optimal level show that Thrust Force is decreased from 104.42 N to 12.18 N, Torque is also decreased from 12.01 N-m to 1.32 N-m and Surface finish has improved from 8.63 µm to 3.93 µm due to the improvement of grade by 0.5423.It is clearly evident from the results that the multiple performance characteristics in the CFRC composite drilling process are greatly improved through this approach.

9. CONCLUSION

1. Experiments are conducted on a CNC Drilling machine to optimize the process parameters.
2. From the values observed from the GRA table, it is clearly understood that a point angle of 100^0, a feed rate of 100mm/rev and a spindle speed of 3000 rpm of 16^{th} experiment is the optimal combination to have good drilling results.
3. The predicted results were checked with experimental results and a good agreement was found.

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