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Experimental Evaluation of Thrust Force, Torque, Ovality and Surface roughness in drilling of CFRC composites

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ABSTRACT—*The Technological advancement in materials division has created curiosity among engineers, scientists and researchers to develop new materials with the required properties. One such material is Carbon Fibre Reinforced Carbon (CFRC) composite material, which is used mostly in the fabrication of advanced structures like space shuttles, missiles, airbuses etc. Generally these composites are very expensive and the addition of machining cost of these materials makes them more expensive. Hence careful selection of proper machining parameters is required to machine these special composites. The prime objective of this paper is to investigate experimentally to find the optimal drilling parameters by using Grey Relational Analysis technique. The drilling experiments were carried out on a CFRC composite plate with High speed steel tool on the VMC100 computer numerically controlled drilling machine, which is in the workshop of Anna university campus, Chennai, India.*

Keywords—CFRC composites, Orthogonal array, Design of Experiments, GRA.

1, INTRODUCTION

The Carbon Fibre Reinforced Carbon (CFRC) composite material is gaining significant place among the materials of present industrial era. In these materials, the Carbon fibres are reinforced into the Carbon matrix. These composites are also known as Carbon-Carbon(C-C) composite materials. This light weight and high strength material is finding way in various advanced applications of modern industrial sector. These materials can resist temperatures up to 2700^{0}C and have excellent thermal shock resistance [1]. These innovative materials are the logical candidates for the construction of advanced structures and are used in Defence, Aerospace and Bio medical fields [2,3]. The EDAX graph shown in Figure.1 reveals that the carbon element constitutes a 98.2% of total composite material by weight.

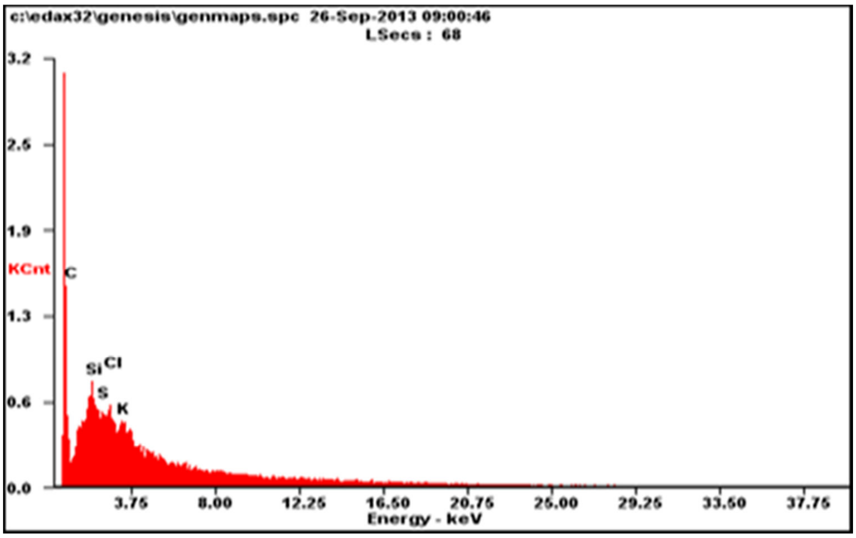

Figure.1 EDAX GRAPH

Drilling is one of the complicated and frequently used material removal processes. The drilling operation of composites is different from that of conventional monolithic materials. Though numerous studies have been undertaken on the details of drilling processes of various composite materials, due attention was not given on the drilling process of this important CFRC composite material. The need for accurate machining of composites has increased enormously.

Grey theory, which was developed by Mr. Deng, provides answer to the problem of a system in which the information is incomplete. This theory provides an efficient solution for multi input, uncertain and discrete data problems [4]. This paper focuses on optimization of process parameters by using the Grey Relational Analysis method.

2, EXPERIMENTAL INVESTIGATION

Since literature on the machinability of CFRC is scarce, an investigation is carried out to study the hole quality. J.R.Ferreira et.al have carried out in rocket nozzle throats to study the performance of different tool materials [5]. George et.al determined the setting of process parameters on EDM machine [6]. To the authors' knowledge, this little information is also available on turning process and not on drilling process. Hence it is decided to conduct an experimental investigation on the drilling process of this special material. The photograph of CFRC material is shown in Figure.2

The Drilling experiments were carried out on a computer numerical control Vertical Machining Centre (VMC100), which is manufactured ARIX CNC MACHINE Co. Ltd. Taiwan. A HSS drill bit of 10mm diameter is used for drilling of carbon-carbon composite material plate. The experimental setup is shown in Figure3

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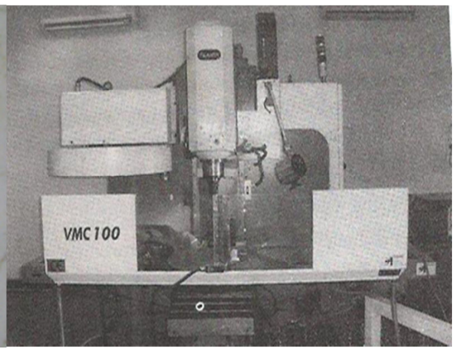


Fig.2 C-C composite material **Fig.3 Vertical Machining Centre100**

2.1 Plan of Experiments

The experiments are planned to conduct as per L_{27} Orthogonal Array Table chosen based on Taguchi's quality design method and the table is shown in Figure.4.

Experiment	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	P11	P12	P13
1	1	1	1	1	1	1	1	1	1	1	1	1	1
2	1	1	1	1	2	2	2	2	2	2	2	2	2
3	1	1	1	1	3	3	3	3	3	3	3	3	3
4	1	2	2	2	1	1	1	2	2	2	3	3	3
5	1	2	2	2	2	2	2	3	3	3	1	1	1
6	1	2	2	2	3	3	3	1	1	1	2	2	2
7	1	3	3	3	1	1	1	3	3	3	2	2	2
8	1	3	3	3	2	2	2	1	1	1	3	3	3
9	1	3	3	3	3	3	3	2	2	2	1	1	1
10	2	1	2	3	1	2	3	1	2	3	1	2	3
11	2	1	2	3	2	3	1	2	3	1	2	3	1
12	2	1	2	3	3	1	2	3	1	2	3	1	2
13	2	2	3	1	1	2	3	2	3	1	3	1	2
14	2	2	3	1	2	3	1	3	1	2	1	2	3
15	2	2	3	1	3	1	2	1	2	3	2	3	1
16	2	3	1	2	1	2	3	3	1	2	2	3	1
17	2	3	1	2	2	3	1	1	2	3	3	1	2
18	2	3	1	2	3	1	2	2	3	1	1	2	3
19	3	1	3	2	1	3	2	1	3	2	1	3	2
20	3	1	3	2	2	1	3	2	1	3	2	1	3
21	3	1	3	2	3	2	1	3	2	1	3	2	1
22	3	2	1	3	1	3	2	2	1	3	3	2	1
23	3	2	1	3	2	1	3	3	2	1	1	3	2
24	3	2	1	3	3	2	1	1	3	2	2	1	3
25	3	3	2	1	1	3	2	3	2	1	2	1	3
26	3	3	2	1	2	1	3	1	3	2	3	2	1
27	3	3	2	1	3	2	1	2	1	3	1	3	2

Fig.4 A model of L27Orthogonal Array

Drill bit point Angle, Spindle speed and Feed rate were chosen as the process control parameters and each parameter was designed to have three levels, denoted by 1, 2, and 3 as shown in Table 1.

TABLE 1. CONTROL FACTORS AND LEVELS FOR THE EXPERIMENTATION

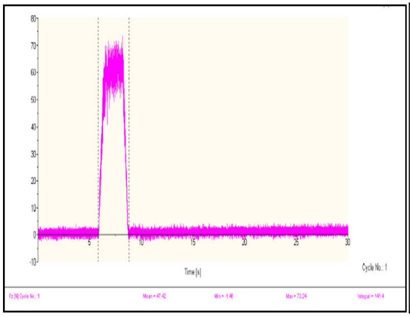
Drilling Parameters	Point Angle	Spindle Speed	Feed Rate
Symbol	*A*	*N*	*F*
Unit	*degree*	*r.p.m*	*mm/min*
Level 1	100	1000	100

Level 2	118	2000	200
Level 3	135	3000	300

The drilling performance is evaluated by four response parameters i.e., Thrust Force, Torque, Surface Roughness and Ovality.

2.2 Procedure of Experiments

The values of first response parameter of drilling process, Thrust force are obtained by observing through Kistler make piezoelectric dynamometer by means of sensors. This dynamometer is attached to VMC100 CNC drilling machine. Data acquisition and analysis software, *Dynoware* is used to plot the force signals with respect to time. The values of another response parameter, Torque are also determined from same dynamometer. Dynoware is used to plot the torque signals with respect to time. The typical plots of Thrust Force and Torque observed in experimental study are shown in Figures 5&6.



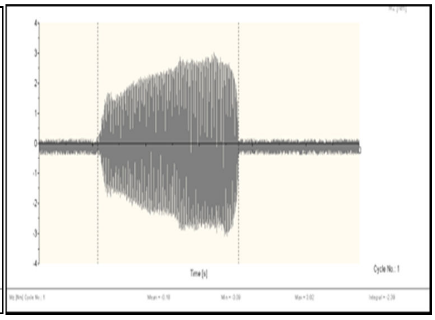


Fig.5 Thrust Force Plot **Fig.6 Torque Plot**

The remaining response parameters Surface Roughness and Ovality values are measured by using Surface Roughness Tester at Micro labs, Chennai and Coordinating Measuring Machine (CMM) at Opus precision ltd., Chennai respectively. The Photographs of both Surface roughness tester and CMM are shown in Figures.7&8.

Fig.7 Surface Roughness Tester

Fig.8 CMM

3, EXPERIMENTAL ANALYSIS

After completion of all tests, the experimental values of all four response parameters i.e. Thrust Force, Torque, Surface roughness and Ovality are entered in Table.2.Then the data to be preprocessed by normalizing the data. The range and unit in one data sequence may differ from others, hence normalization is necessary. The Grey relational coefficients are calculated and then overall grade is calculated as per the procedure mentioned below and then the optimal grade gives the optimal combination of process parameters.

TABLE 3.EXPERIMENTAL VALUES OF RESPONSE PARAMETERS

Expt. No.	Thrust Force [N]	Torque [N-m]	Surface Roughness [µ m]	Ovality [mm]
1	19.61	1.68	6.41	10.152
2	41.81	1.71	2.36	10.11567
3	59.24	1.1	5.18	10.16133
4	16.89	2.7	6.59	10.70633
5	27.95	2.37	4.27	10.62367
6	42.35	2.25	4.02	10.19067
7	11.04	0.68	2.31	10.17067
8	18.73	2.42	5.12	10.15667
9	17.47	1.17	4.39	10.11133

10	34.17	4.14	1.56	10.20767
11	96.22	4.75	6.01	10.13567
12	28.46	3.56	4.65	10.22867
13	27.16	4.41	4.90	10.21233
14	39.19	4.83	2.56	10.199
15	50.12	2.38	6.70	10.15633
16	45.98	2.99	3.28	10.20433
17	32.79	4.43	2.62	10.07767
18	39.19	4.04	3.13	10.20467
19	47.42	3.02	2.21	10.121
20	49.05	3.1	3.27	10.17667
21	51.52	3.22	4.28	10.20033
22	20.42	2.6	4.07	10.19267
23	34.82	2.86	5.24	10.19067
24	41.88	2.37	4.60	10.16467
25	23.22	3.65	3.15	10.186
26	34.81	2.27	3.30	10.12533
27	39.7	2.2	3.89	10.16333

3.1 Calculation of Normalized Values

Generally the normalized value of the data is known as comparable sequence. This is 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,

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

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

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

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

$$x_i^*(k) = 1 - \frac{|x_i^0(k) - x^0|}{\text{Max}\, x_i^0(k) - x^0} \quad - \quad (3)$$

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 [7,8].Calculated normalized values are given in Table.3

3.2 Calculation of GRC values

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

$$Gij = \{ \Delta\min + \zeta\Delta\max\} / \{|x_{io} - x_{ij}| + \zeta\Delta\max\} \quad - \quad (4)$$

Where x_{io} 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.

3.2 Calculation of Grade values

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.

$$\text{GRG}\ (\alpha_j) = \frac{1}{N}\sum_{l=1}^{N} G_{ij} \quad - \quad (5)$$

The GRC and GRG values of all 27 trials are entered in Table 4. The highest grey relational grade calculated from the equation will give the optimal combination of various process parameters.i.e.0.954532 of 7^{th} experiment.

TABLE 3. NORMALIZED VALUES OF EXPERIMENTAL RESULTS

Expt. No.	Thrust Force	Torque	Surface Roughness	Ovality
1	0.92701	0.75903	0.05638	0.881764
2	0.73794	0.75180	0.84381	0.939554
3	0.58950	0.89879	0.29488	0.866923
4	0.95017	0.51325	0.02073	0
5	0.85598	0.59277	0.47180	0.131486

6	0.73335	0.62168	0.52041	0.820253
7	1	1	0.85288	0.852066
8	0.93450	0.58072	0.30784	0.874336
9	0.94523	0.88192	0.44912	0.946458
10	0.80301	0.16626	1	0.793211
11	0.27457	0.01927	0.13415	0.90774
12	0.7955	0.30602	0.39922	0.759807
13	0.86271	0.10120	0.35061	0.785798
14	0.76026	0	0.80492	0.807002
15	0.66717	0.59036	0	0.874877
16	0.70243	0.44337	0.6642	0.798524
17	0.81476	0.09638	0.7926	1
18	0.76026	0.19036	0.6941	0.797983
19	0.69017	0.43614	0.8729	0.931076
20	0.67629	0.41686	0.6668	0.842522
21	0.65525	0.38795	0.4705	0.804887
22	0.92011	0.53734	0.5119	0.817071
23	0.79747	0.47469	0.2838	0.820253
24	0.73735	0.59277	0.4076	0.86161
25	0.89627	0.28433	0.6908	0.827681
26	0.79756	0.61686	0.6604	0.924188
27	0.755919	0.633735	0.54569	0.863742

TABLE 5 GRADE RELATIONAL COEFFICIENTS& GREY RELATIONAL GRADES

Ex. No	GRC(TF)	GRC(TORQUE)	GRC(SR)	GRC(OVALITY)	GRG
1	0.8726	0.6747	0.3463	0.808753	0.540471
2	0.6561	0.6682	0.7619	0.892147	0.595669
3	0.5491	0.8316	0.4148	0.789794	0.517059
4	0.9093	0.5067	0.3380	0.333333	0.417467
5	0.7763	0.5511	0.4862	0.36536	0.435792
6	0.6521	0.5692	0.5104	0.735567	0.493453
7	1	1	0.7726	0.771684	**0.708857**
8	0.8841	0.5439	0.4194	0.799151	0.52931
9	0.9012	0.8089	0.4757	0.903273	0.617815
10	0.7173	0.3748	1	0.707425	0.559905
11	0.4082	0.3376	0.3642	0.844224	0.390845

12	0.7097	0.4187	0.4542	0.675499	0.45162
13	0.7845	0.3574	0.4350	0.700082	0.455396
14	0.6759	0.3333	0.7193	0.721503	0.490001
15	0.6003	0.5496	0.3333	0.799842	0.456608
16	0.6269	0.4732	0.5982	0.712783	0.482217
17	0.7296	0.3562	0.7068	1	0.55852
18	0.6252	0.3817	0.6204	0.712233	0.467907
19	0.6174	0.4699	0.7974	0.878851	0.55271
20	0.6070	0.4616	0.9378	0.760482	0.553376
21	0.5918	0.4496	0.4856	0.719307	0.449261
22	0.8622	0.5193	0.5060	0.732141	0.523928
23	0.7117	0.4876	0.4111	0.735567	0.469193
24	0.6556	0.5511	0.4577	0.783221	0.489524
25	0.8281	0.4112	0.6179	0.743695	0.520179
26	0.7118	0.5661	0.5955	0.868339	0.548348
27	0.6719	0.5771	0.5239	0.785845	0.511749

5, CONCLUSION.

1. Experiments are conducted on a CNC vertical machining Centre to optimize the process parameters.

2. From the values observed from the GRA table, it is clearly understood that a point angle of 1000, a feed rate of 100mm/min and a spindle speed of 3000 rpm of 7th experiment is the optimal combination to have good drilling results.

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BIOGRAPHY

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