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Fabrication and Experimental Study on Optimization of Process Parameters for Drilling of GFRP with Iron Ore as Filler Material using Taguchi And ANOVA

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Abstract
This paper represents the study of drilling characteristics on hybrid composite using conventional twist drill. Drill tool dynamometer has been utilized to measure the thrust force and torque. L16 orthogonal array has been selected for the study and experiments have been carried out on the bases of the selected orthogonal array. The ANOVA have been deployed to study the influence of process parameters on the thrust force and torque. Regression equations have been formulated for estimating the predicted values of the thrust force and torque.

Keywords: GFRP, Drilling, Taguchi Method

Introduction

Glass fiber reinforced polymer (GFRP) have wide applications in many manufacturing fields, due to their distinct properties viz., low weight, high strength and stiffness. Traditional machining of GFRPs is bit difficult, due to the presence of comparatively high volume fraction of hard fibers in the matrix, the different orientations of fiber and unlike properties of fiber & matrix [1-3].
The joining of composites is tough task, fastening is the best option to join the composites. Fastening with bolts or screws required predrilled holes, which can be drilled by drilling operation. The composite materials are neither homogenous nor isotropic, the drilling of composite may lead to damage the area around the drilled hole [4-8]. The thrust force and torque generated in drilling operation, lead to the drill-hole quality, which are affected by the parameters viz., as tool geometry, speed, feed, etc [9-10]. Greater the value of the thrust force and torque, greater will be the work damage and tool wear [11].
The objective of this work is to investigate the influence of speed, filler weight percentage, and drill diameter on thrust force and torque during drilling of GFRP filled with Hematite ore Hybrid Composite.

Material Details and Specimen Preparation

E-glass fabric (300 GSM) of plain woven construction have been used for the study. Orthophthalic polyester resin matrix with methyl ethyl ketone peroxide catalyst and cobalt octet accelerator have been used [12]. The Hematite ore (75-150 μm) has been used as filler material.
In this work, four types of composite, varying the percentage of filler, have been prepared of ϕ30mm and length of 150mm, by using hand layup technique with help mould which is shown in figure 1. The table 1 show the details of the composites constituents' proportion mixed.

TABLE.1. Details of specimens prepared for varied percentage of filler

Composites	% of filler	Matrix volume %		Reinforcement volume %	
A	0	polyester	50	Glass fiber	50
B	3	polyester	47	Glass fiber	50
C	6	polyester	44	Glass fiber	50
D	9	polyester	41	Glass fiber	50

Fig.1. Mould for preparation of specimen

Composite A | Composite B


Composite C


Composite D

Fig.2. Composite of varying % of filler material.

Plan of Experiments

The experiments have been conducted using L16 orthogonal array (OA). The thrust force and torque have measured and tabulate in table 3. As shown in table 2, the process parameters and their levels selected for the experiment are tabulated. The analysis has been carried out to optimize the process parameter levels within the selected range. Optimization of process parameter is to attain minimum thrust force and torque and defect controlled drilling of non-laminated composites. Analysis of variance has been determined for the experimental data obtained for thrust force and torque to study the relative significance of process parameters. In this analysis, "smaller the better" characteristics has been applied to calculate the S/N ratio for thrust force and torque. A higher the value of S/N ratio, better the fit for the combined objective.

TABLE.2. Process parameters and their levels in drilling

Process Parameters	Units	Code	Level 1	Level 2	Level 3	Level 4
% iron ore	-	A	0	3	6	9
Speed	RPM	B	50	71	105	155
Dia of drill	mm	C	4	6	8	10

TABLE.3. L16 orthogonal array with the assigned values

Sl.No	A	B	C	Thrust Force (N)	S/N ratio for Thrust Force	Torque (N-M)	S/N ratio for Torque
1	0	50	4	78.48	-37.8952	3.198	-10.0976
2	0	71	6	147.15	-43.3552	3.060	-9.7144
3	0	105	8	88.29	-38.9182	1.942	-5.7650
4	0	155	10	107.91	-40.6612	1.883	-5.4970
5	3	50	6	29.43	-29.3758	2.874	-9.1697
6	3	71	4	78.48	-37.8952	1.618	-4.1796
7	3	105	10	58.86	-35.3964	3.060	-9.7144
8	3	155	8	88.29	-38.9182	4.071	-12.1940
9	6	50	8	127.53	-42.1122	2.599	-8.2961
10	6	71	10	98.1	-39.8334	4.855	-13.7238
11	6	105	4	107.91	-40.6612	2.599	-8.2961
12	6	155	6	39.24	-31.8746	3.178	-10.0431
13	9	50	10	343.35	-50.7147	1.618	-4.1796
14	9	71	8	117.72	-41.4170	2.589	-8.2626
15	9	105	6	98.1	-39.8334	9.662	-19.7013
16	9	155	4	78.48	-37.8952	1.226	-1.7698

Experimental Results and Discussion

Analysis of Control factors:

The influence of control factors viz., Percentage (%) of hematite ore, Speed (N) and Drill diameter (mm) on the thrust force and torque have been criticized by using S/N ratio response analysis.

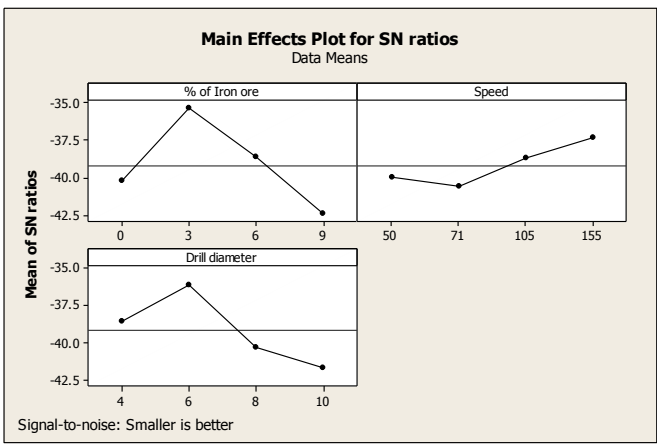
The ranking of control factors for different parameters levels for Thrust force is tabulated in Table 4, for the Torque in Table 5. The effect plots of S/N, mean for Thrust force and torque for Hybrid composite is shown in figure 3 (a &b) and figure 4 (c & d). It suggests that the optimum condition for minimum thrust force and torque force is the combination of $A_2B_5C_2$ and $A_1B_5C_1$ respectively.

TABLE.4. Response Table of different parameters levels for Thrust force

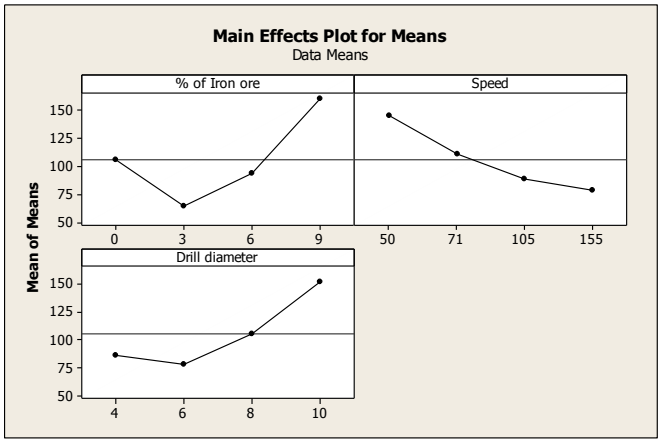
	Signal to Noise Ratios			Mean		
Level	A	B	C	A	B	C
1	-40.21	-40.02	-38.59	105.46	144.70	85.84
2	-35.40	-40.63	-36.11	63.77	110.36	78.48
3	-38.62	-38.70	-40.34	93.19	88.29	105.46
4	-42.47	-37.34	-41.65	159.41	78.48	152.06
Delta	7.07	3.29	5.54	95.65	66.22	73.58
Rank	1	3	2	1	3	2

TABLE.5. Response Table of different parameters levels for Torque

	Signal to Noise Ratios			Mean		
Level	A	B	C	A	B	C
1	-7.768	-7.936	-6.086	2.521	2.572	2.160
2	-8.814	-8.970	-12.157	2.906	3.031	4.694
3	-10.090	-10.869	-8.629	3.308	4.316	2.800
4	-8.478	-7.376	-8.279	3.774	2.590	2.854
Delta	2.321	3.493	6.071	1.253	1.744	2.533
Rank	3	2	1	3	2	1

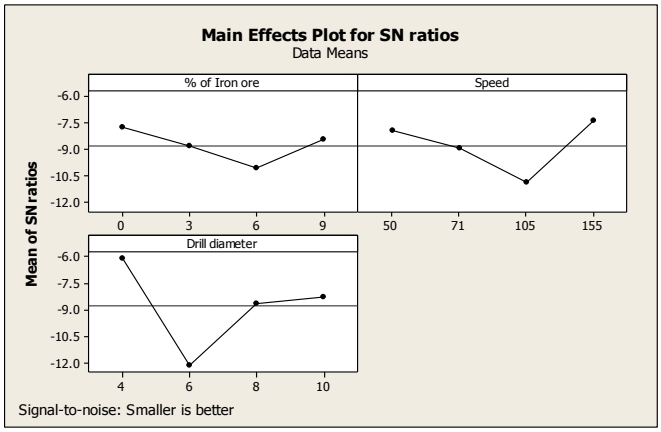


a) S/N Ratios

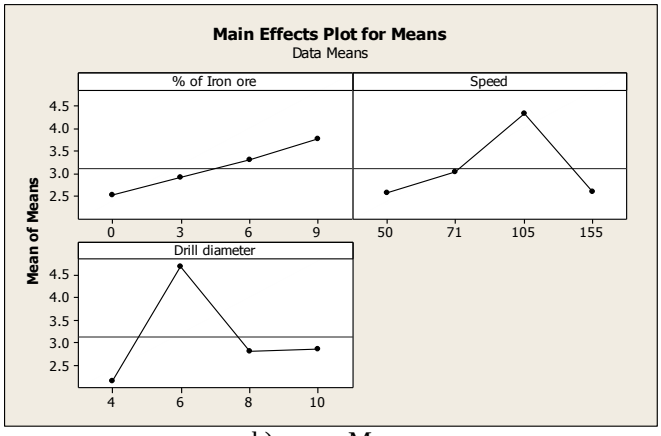


b) Mean

Fig.3. Main effects plots for thrust force



a) S/N Ratios



b) Mean

Fig.4. Main effects plots for torque force

Analysis of variance (ANOVA)

The analysis of variance of the experimental data has been done to analyze statistically, the relative significance of the process parameters viz., % of iron ore (A), Speed (B) and Diameter of drill (C), on thrust force and torque as shown in Table 6 and Table 7 respectively. The last column of the ANOVA tables shows the percentage of contribution of each parameter.

As shown on tables, the % of iron ore contribute the more by (25.88%) followed by Diameter of drill (17.70%) and speed (13.94%) on thrust force. For torque force, the most significance factor to be considered is Diameter of drill (24.36%) followed by speed (13.78%) and % of iron ore (5.92%).

TABLE.6. Analysis of Variance for Thrust force

Sour-ce	DF	Seq SS	Adj SS	Seq MS	F	P	% of contribution
A	3	19199	19199	6400	1.22	0.381	25.88
B	3	10345	10345	3448	0.66	0.608	13.94
C	3	13136	13136	4379	0.83	0.522	17.70
Error	6	31517	31517	5253			
Total	15	74198					

TABLE.7. Analysis of Variance for Torque

Source	DF	Seq SS	Adj SS	Seq MS	F	P	% of contribution
A	3	3.470	3.470	1.157	0.21	0.885	05.92
B	3	8.076	8.076	2.692	0.49	0.700	13.78
C	3	14.279	14.279	4.760	0.87	0.506	24.36
Error	6	32.805	32.805	5.468			
Total	15	58.631					

Regression Analysis

The correlations for thrust force and torque with process parameters in drilling laminated GFRP composites were obtained using statistical software MINITAB 16.

The Regression equations for thrust force is;

Thrust force = 53.3312+6.3765(A)-0.583081(B)+11.2815(C)

R-sq = 57.52%

The Regression equation for torque is; Torque =2.33248+0.1387 (A)+0.00109785 (B)+0.0094 (C)

R-sq = 44.05%

Conclusion

From the analysis of results in drilling of hybrid composite plates using conceptual S/N ratio approach, ANOVA the following can be concluded from the present study within the range of the experiments.

- Based on the S/N, the optimal parameters for the minimum thrust force are the % iron ore level 2 (3%), the speed at level 4 (155 rpm), drill tool diameter at level 2 (6 mm).
- Based on the S/N, the optimal parameters for the minimum torque are the % iron ore level 1 (0%), the speed at level 4 (155 rpm), drill tool diameter at level 1 (4 mm).
- The % of iron ore (25.88%) has significant effect on thrust force, followed by Dia. of drill (17.70%) and speed (13.94%).

- The Dia of drill (24.36%) has significant effect on torque followed by speed (13.78%) and % of iron ore (5.92%).

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