Effect of Drilling Parameters Torque, Thrust Force and Delamination Factor on GFRP and CFRP Composites using Different Size of Drills

G. Ramprasad, K. S. R. Varun Teja, B.V. Ramana Murty

Abstract: ***The trend of the materials that are being used for various industrial applications has shown a drastic variation over the decades. Pure metals are replaced by alloys and these alloys in turn are being replaced by composites in most of the present day applications. Fiber reinforced polymer composites (FRPs) extensively used materials and a lot of research is going on for further improvement of properties of these materials. Drilling process is important in assembly of components in manufacturing. In case of FRPs drilling process is a great challenge when compared to that of conventional material because of de-bonding, metric cracking, and fiber pullout. The present work is a study on the effect of torque and thrust force on delamination of Carbon Fiber Reinforced Polymers (CFRP) and Glass Fiber Reinforced Polymers (GFRP) and by drilling process. Experiments are conducted at different feeds, drill diameters and speeds. Image processing approach is used to quantify the drill-induced delamination where helical flute HSS drills of diameters 4mm, 6mm and 8mm are used. Statistical analysis is made to optimize the drill parameters by ANOVA and Taguchi technique. It is observed that at 4mm drill diameter, torque and thrust force are minimum for both CFRP and GFRP. However, the delamination factor is minimum at drill diameter of 6mm in case of GFRP and at 8mm for CFRP.***

Keywords: ANOVA, CFRP, Delamination factor, GFRP Thrust force, Torque.

I. INTRODUCTION

The usage of composites in various areas like aerospace and automobiles has increased rapidly in the past few years because of their exceptional mechanical properties with the benefit of low weight. FRPs are one such composites which are being used and tested rigorously due their promising performance levels. But the anisotropy of these materials make them to act differently in different loading and machining conditions. Effects of drilling on these materials are predominantly tested, as the components made by these composites are mostly joined by screw fasteners and other temporary joining processes which makes it essential to drill holes in the material. Pull-out of fibers, fiber–matrix de-bonding, thermal damages and delamination occur during drilling operations of composites due to their in-homogeneity. Different researchers studied the effect of drill geometry [1], and cutting parameters [2] on delamination. Non-destructive techniques for measurement of delamination were also developed [3]. Delamination can be minimized by varying contact length of the drill and the hole [4]. The impact of spindle speed and feed rate on delamination and surface roughness is also studied [5]. It is observed in some studies that lower thrust force and lower feed rates results in lower delamination [6, 7]. When an element is subjected to fatigue and fastener loads, the surface roughness of the drilled hole plays a crucial role in the material failure. Studies clearly show that [8] cutting parameters have influence on surface roughness. It is discovered that surface roughness will increase with an increase in feed rate. This work is an attempt is made to analyze the impact of thrust force, torque and size of the drill on delamination of GFRPs and CFRPs.

II. EXPERIMENTAL PROCEDURE

The specimens for various tests are fabricated through hand layup and compression process with 55% fiber volume fraction. The carbon and glass bi-directional fiber with thickness of 0.2 mm is bought from Inducts Composites Technology Pvt Ltd, Vadodara-Gujarat, India. Resin (LY566) and hardener (HY951) are provided by Sree Industrial composite product, Telangana, India. HSS helical flute drills of three different sizes 4mm, 6mm, and 8mm are used to drill the FRP composites. Strain gauge type drilling dynamometer and LABVIEW software are used to quantify drill parameters. [9]Thrust force 'F', delamination factor 'F_d' and torque 'T' are the functions of spindle speed 'N', tool feed rate 'f' and drill diameter 'd'.

$$F = f(N, f, d), \quad F_d = g(N, f, d), \quad T = h(N, f, d)$$

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The diameter of drilled hole is scanned at 600 dpi and delamination is measured by using Image J software .Delamination factor (F_d) is obtained by the equation:

$$F_d = D_{max}/D$$

Where D_{max} is maximum damaged zone diameter and 'D' is the diameter of the hole.

Fig .1 .Drilling operation on fiber reinforced composite

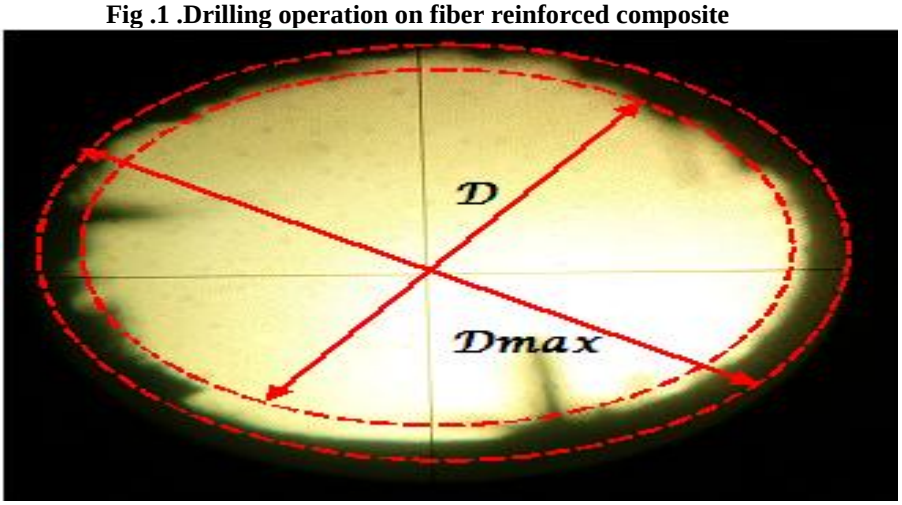


Fig .2 .Delamination image from IMAGE J software

Effect of control parameters such as speed, drill diameter and feed, and their interactions on delamination factor, thrust force and torque is evaluated using design of experiments (DoE). [10, 11] The number of experiments is reduced using Taguchi methodology. Three drilling parameters are used in the present study and three stages namely 1, 2 and 3 are considered for each parameter as shown in Table 1. The combination selection of drill parameters are shown in Table.2. Drilling operation on fiber reinforced composite shown in Fig.1.

Table- I: Drilling parameters of torque, thrust force and delamination factor

Parameters	Stage-1	Stage-2	Stage-3
Speed(RPM),N	1000	2000	3000
Drill diameter(mm),d	4	6	8
Feed(mm/min),f	50	100	150

Table- II: Selection parameters for GFRP and CFRP.

Experiments	Speed (RPM)	Drill Diameter (mm)	Feed Rate (mm/min)	F (N)	T (N-m)	F_d	F (N)	T (N-m)	F_d
				GRFP			*CRFP*		
1	1000	4	50	38	0.4322	1.014	94	1.023	1.017
2	1000	6	100	122	0.8101	1.002	167	2.828	1.017
3	1000	8	150	176	1.7210	1.011	285	5.472	1.01

4	2000	8	50	87	1.2518	1.018	191	4.516	1.008
5	2000	4	100	40	0.5115	1.010	138	1.027	1.015
6	2000	6	150	122	1.1025	1.001	214	4.728	1.015
7	3000	6	50	71	0.742	1.009	122	3.398	1.005
8	3000	8	100	131	1.532	1.012	206	6.822	1.006
9	3000	4	150	93	0.761	1.008	75	1.306	1.017

III. ANALYSIS OF VARIANCE (ANOVA)

Analysis of variance (ANOVA) is performed to identify the significance of process parameters and their interactions on performance characteristics. [12]They are determined by comparing calculated F-value and standard F-value at 95% confidence level. At 95% confidence level of standard F-value (F_p) is 4.459.

Table- III: Thrust force results

Source	Adj.SS	DOF	Adj. MS	F -value	P-value	
(CFRP)						
Speed	4450	2	2225	2.00	0.334	significant
Drill Dia.	23454	2	11727	10.52	0.087	
Feed	4742	2	2371	2.13	0.320	significant
Error	2230	2	1115			
Total	34876	8				
(GFRP)						
Speed	1209.6	2	604.78	36.05	0.027	
Drill Dia.	8476.2	2	4238.11	252.60	0.004	
Feed	7038.9	2	3519.44	209.77	0.005	
Error	33.6	2	16.78			
Total	16758.2	8				

Table- IV: Torque results

Source	Adj.SS	DOF	Adj. MS	F -value	P-value	
(CFRP)						
Speed	0.8141	2	0.4071	0.30	0.767	significant
Drill Dia.	30.3369	2	15.1685	11.33	0.081	
Feed	1.1461	2	0.5730	0.43	0.700	significant
Error	2.6784	2	1.3392			
Total	34.9755	8				
(GFRP)						
Speed	0.00599	2	0.002994	0.45	0.688	significant
Drill Dia.	1.30361	2	0.651807	98.60	0.010	
Feed	0.16568	2	0.082840	12.53	0.074	
Error	0.01322	2	0.006610			

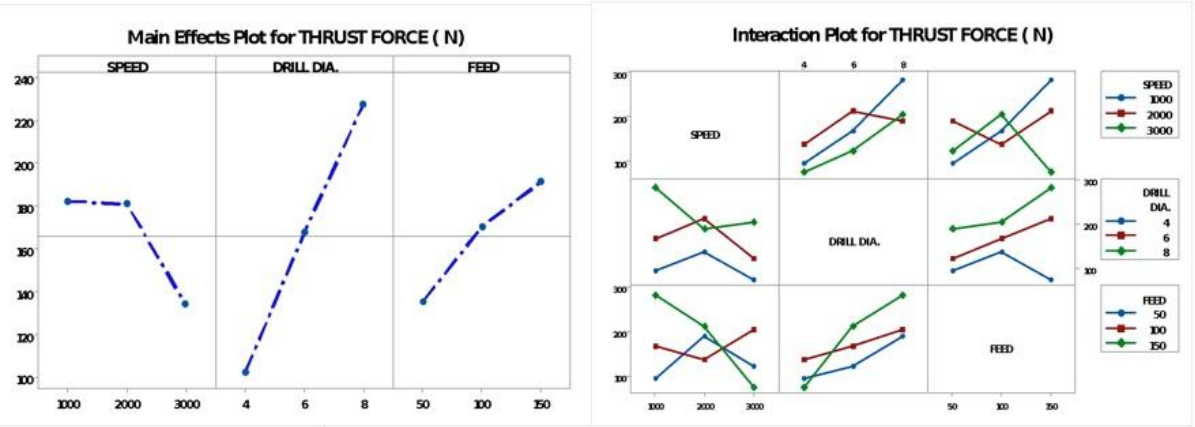
Total	1.48850	8	

Table- V: Delamination factor results

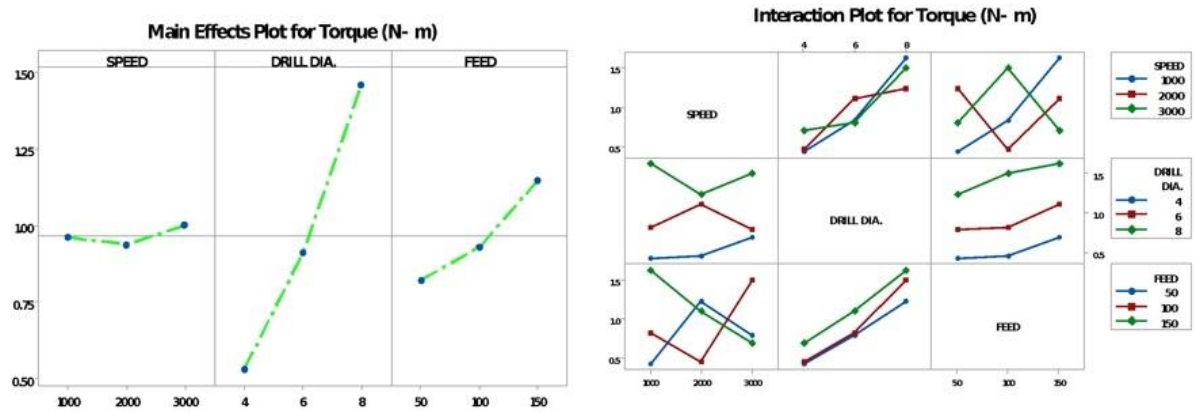
Source	Adj.SS	DOF	Adj. MS	F -value	P-value	
(CFRP)						
Speed	0.000044	2	0.000022	1.75	0.364	significant
Drill Dia.	0.000104	2	0.000052	4.19	0.193	significant
Feed	0.000025	2	0.000012	1.00	0.500	significant
Error	0.000025	2	0.000012			
Total	0.000198	8				
(GFRP)						
Speed	0.000026	2	0.000013	0.51	0.661	significant
Drill Dia.	0.000165	2	0.000082	3.25	0.235	significant
Feed	0.000021	2	0.000010	0.41	0.71	significant
Error	0.000051	2	0.000025			
Total	0.000262	8				

IV. RESULTS AND DISCUSSION

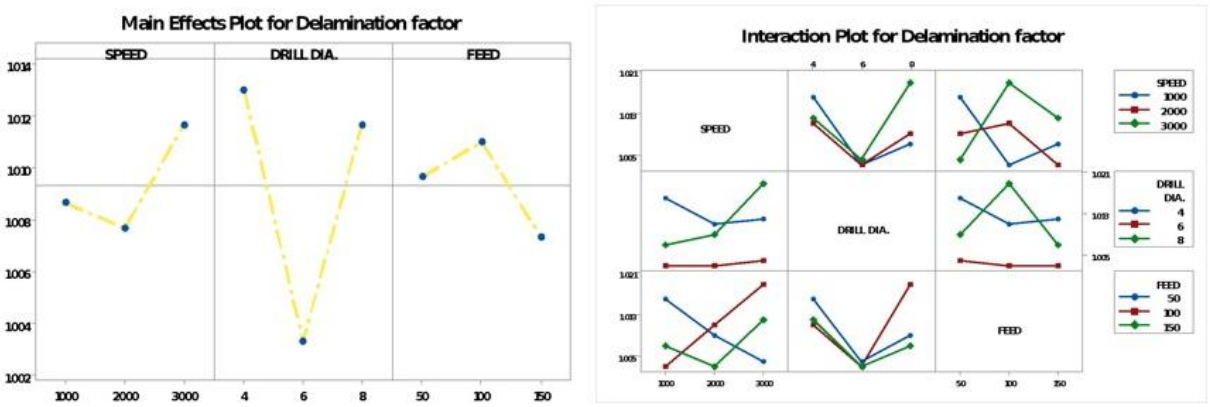
A. Glass fiber reinforced polymers



a) Thrust force



b) Torque

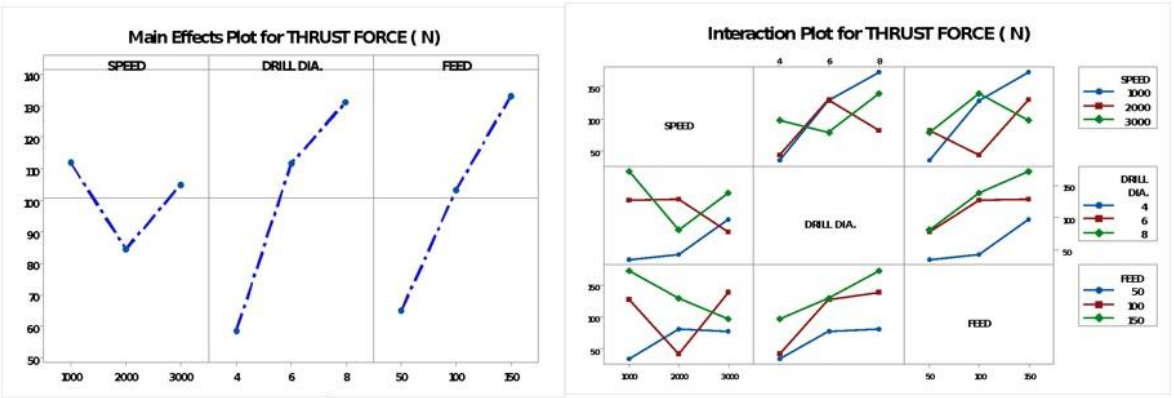


c) Delamination factor

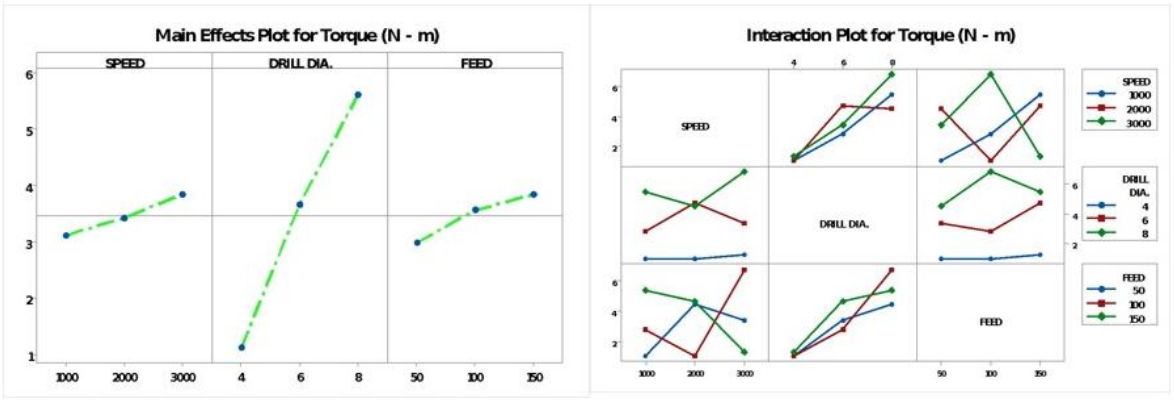
Fig.3. Main and interaction plot for a) thrust force b) torque c) delamination factor in Glass fiber reinforced composites

From Fig.3. (a) minimum thrust force is observed at high speed, low feed, and smaller drill diameter. From Fig. 3. (b) torque increased with increase in speed, drill diameter and feed. From the results it is observed that for GFRP, the torque is optimum at mean speed of 2000 rpm, 4 mm drill diameter and 50 mm/min feed. From Fig. 3. (c) the delamination factor is minimum at 2000 rpm, 6mm drill diameter and 150mm/min feed.

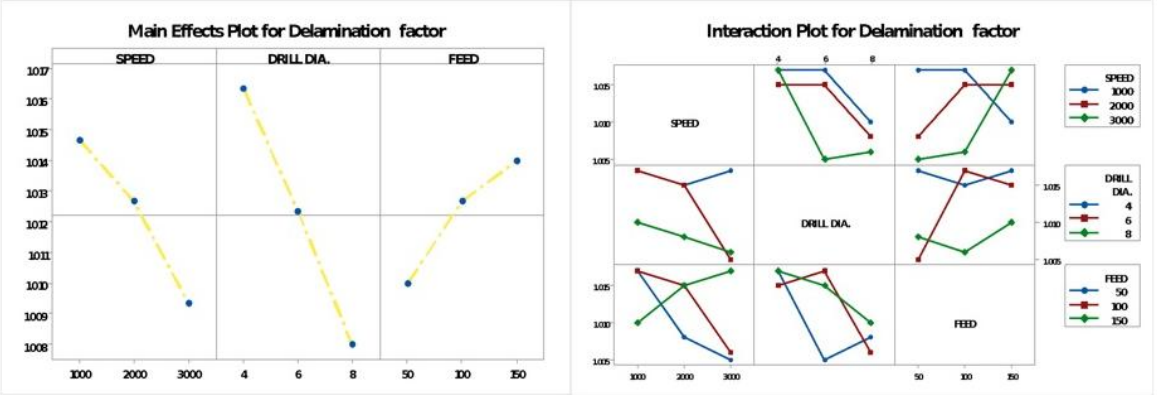
B. Carbon fiber reinforced polymers



a)Thrust force



b) Torque



c) Delamination factor

Fig.4. Main and interaction plot for a) thrust force b) torque c) delamination factor in carbon fiber reinforced composites

For CFRP, from Fig.4. (a), the thrust force is minimum at the average speed of 2000 rpm, 4mm drill diameter and 50mm/min feed. From Fig.4. (b), Torque is minimum at minimum speed of 1000rpm, low feed of 50 mm/min and smaller drill diameter of 4 mm, and from Fig.4.(c), the delamination factor is minimum at speed of 3000 rpm , drill diameter of 8 mm and feed rate of 50 mm/min.

V. CONCLUSIONS

A statistical model is developed to study effect of thrust force and torque on delamination factor. From ANOVA it is observed that feed rate and speed have significant impact on thrust and torque. For both GFRP and CFRP, all the drill parameters have significant impact on delamination factor. Thrust force for CFRP decreases with increase in feed rate and increases with increase in spindle speed. Whereas, for GFRP it increases with feed rate and reduces with increase in spindle speed. For CFRP, torque increases with the increase of feed rate and spindle speed. However, for GFRP, it decreases with increase in spindle speed. For CFRP and GFRP, minimum thrust force and torque are observed at 4mm drill diameter. The delamination factor for CFRP increases with spindle speed and drill diameter, and decreases with feed rate, Whereas for GFRP, delamination factor decreases with spindle speed and drill diameter and increases with feed rate. Minimum delamination factor is observed at 6mm drill diameter for GFRP and 8mm drill diameter for CFRP.

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