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Experimental Study on Effect of Delamination

on Performance of GFRP Composites while Drilling

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Abstract—**Delamination is recognized as one of the most critical defects that can result from the machining of composites. Delamination has been a major form of failure in drilled composite materials due to the lack of strength in direction of drilling, which result in poor surface finish, reduction in anisotropic structure, and poor performance of the composite. Considerable amount of research work has been carried out to reduce this delamination in various composite structures. The main objective of this experimental analysis was to predict delamination in GFRP specimens by calculating the thrust force and cutting torque using Taguchi technique with Minitab 15 Analysis software which is used to determine the desired optimum cutting and material parameters for minimized appearance of delamination and surface roughness.**

Index Terms— **Composite, Delamination, Glass Fiber Reinforced Plastic, Taguchi Method, Analysis of Variance**

I. Introduction OF Composite materials

Materials are often chosen to fulfill certain structural or load requirements. Not all materials have all necessary properties, and not all the necessary properties are present in one material. To make optimum use of the properties needed and materials used, two or more materials can be combined to give desired properties. Thus, a composite material is defined as "A multiphase material with chemically dissimilar phases separated by a distinct interphase". Composite can be classified as Microscopic (e.g. Fiber Reinforced Plastic, Particle Reinforced Composite etc) and Macroscopic (e.g. Concrete, RCC etc); Fiber Reinforced composite may be carbon Fiber, Kevlar, aramid and Glass type. This experimental study deals exclusively with Glass Fiber Reinforced Plastic composite.

II. Objectives of experimental analysis

The machining of GFRP is quite different from that of metals and result in many undesirable effects such as rapid tool wear, rough surface finish, defective subsurface layers etc. The delamination that occurs during drilling severely influences the mechanical characteristics of the material around the hole. In order to avoid these problems, it is necessary to determine the optimum conditions for a particular machining operation. Drilling is a particularly critical and most often used operation for GFRP composite because the great concentrated forces generated can lead to widespread damage. The major damage is certainly the delamination that can occur both on the entrance and exit sides of the GFRP work specimens. The delamination on the entrance side generally referred to as Peel up delamination and at the exit side is pushdown delamination as shown in below (Fig. 1.1 & 1.2).

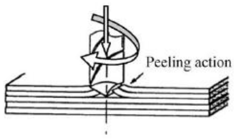

Fig. 1.1: Peel up

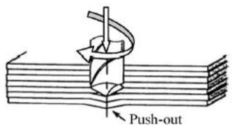

Fig. 1.2: Push out

(Types of Delamination)

III. Problem Formulation

Delamination is a damage characterized by the separation of adjacent layers caused by machining. It depends on fiber nature, resin type and respective adjacent properties. In drilling operations, delamination is a consequence of the indention force exerted by the drill chisel edge that acts more as a pierce than a drill. The material and process related problems encountered in drilling of GFRP composites are: Matrix Burning, Debonding, Fiber pull out, Delamination and Tool wear etc. Many of these problems are due to use of non optimal cutting tool designs and machining condition. Tool applied in industry for drilling composites were originally developed for metal removal properties, only recent years, manufacturers have started developing Tool Geometries for drilling of composite materials like Multi Facet Drill (MFD); Twist drill bit. The multi facet drill bit have the various advantages like; lower cutting forces, improved heat transfer, improved chip ejection, improved hole quality, higher productivity and longer tool life.

IV. Methodology for Experimental analysis

Present Experimental model estimate the edge defect during the drilling of GFRP composites. Thus the methodology used for this experimental analysis is summarized in following steps;

1. First identify the problem and select appropriate machine and tooling set up
2. Measurement of parameter like Thrust Force, Cutting Torque, Delamination and Surface roughness
3. By using Taguchi Method evaluate the S/N Ratio
4. Device ANOVA Table, Select Control factor and Output Responses
5. Apply concept of Design of Experiments (DOE) and Regression Analysis (RA)
6. Finally, Conclusion will be drawn.

V. PREPARATION FOR EXPERIMENT

The GFRP specimens used in this experiment were manufactured by Hand layup technique. Controlled pressure was adopted to make these laminates. A flat plate mold was adopted to make these laminates and laminates were left for 24 hours room temperature curing. Three number of test specimens are cut from the sheet of 20 ply laminates of size: (80 x 80 x 7 mm) by using diamond impregnated wheel, cooled by air. All the test specimens were finished by fine sand paper. The detail specifications of specimens were shown in Table I, as below.

TABLE I. SPECIFICATION OF GFRP WORK SPECIMEN

S. N.	Parameter	Specimen 01	Specimen 02	Specimen 03
1	**Glass Fiber**	Standard E-Glass Fiber (60 %)		
	Epoxy Resin	LY-556 (25 %)		
	Hardener	Catalyst: HY 951 (15 %)		
2	**Weight(gm)**	70	70	70
3	**Fiber Orientation**	 45°	 60°	 90°

The drill bits used in this experiment was a multifacet twist drill with different materials because it can produce high thrust forces, which were required for one or two specimen as shown below.

TABLE II. SPECIFICATION OF DRILL BITS

S. N.	Drill Bits used for Experiment	Specification of Drill
A		**High Speed Steel (HSS),** Make: MIRANDA Ø 10 mm Twist Drill
B		**Plain Carbide (PC),** Make: MET CUT Ø 10 mm Twist Drill
C		**Coated Carbide (CC),** Make: MA FORD Ø 10 mm Twist Drill

The drilling set up used for this experiment was a vertical spindle computer numerical control (CNC) Tool Room mill which is specifically designed for drilling experiments. The feed rate and spindle speed are controlled by a program written with G and M code. A Kistler Drill dynamometer was used to measure the cutting torque and thrust force. Each of these values was measured by the voltage fluctuations recorded by the dynamometer during drilling. Beside all of these equipments, the surface roughness was measured by stylus method and delamination factor (D_f) was measured by an accurate, inexpensive optical microscope.

VI. EXPERIMENTAL SET UP

A schematic diagram of the experimental set up is shown in Fig. 2. The drilling experiment was carried out on a Vertical spindle CNC Mill. The specimens are held in rigid fixture attached to Kistler Drill dynamometer. The dynamometer signals were processed to make them suitable for computer capture. This was achieved via charge amplifiers and an analog to digital converter, then to the computer. The output signals from the dynamometer were fed to the computer via a charge amplifier and digital storage oscilloscope. The drilling cycles were incorporated into a CNC program which took account of changes in speed and feed rates. Once the first drill had finished its cutting cycle and had been changed by the machine tool, automatic tool changer for the next drill. The test was then allowed to continue. Finally, the experimental validations of optimum value of the objective function were done as the optimum run may not be necessarily among the many experiments those were already carried out.

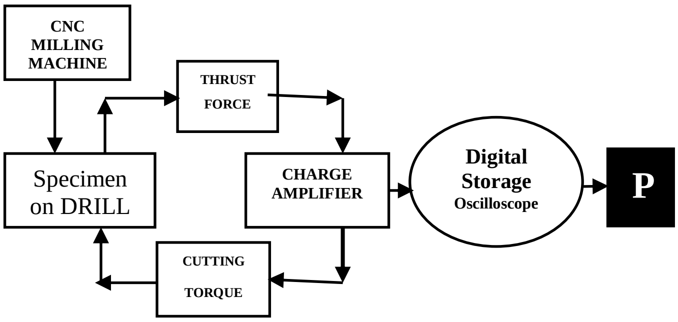

Fig.2: Schematic Layout of Experimental Setup

TABLE III. FACTORS & LEVEL USED FOR EXPERIMENT

S. No.	Parameters	Level
1	Spindle Speed (S) (RPM)	800
		1600
		2700
2	Feed Rate (F) (mm/rev)	0.15
		0.20
		0.25
3	Fiber Orientation (Fo)	45°
		60°
		90°
4	Drill Bit Material	HSS
		PC

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		CC

Taguchi method also known as Quality Engineering combines the experiment design theory and quality loss function concept has been applied to the robust design of products and process has solved some confusing problems in manufacturing. In order to observe the influence, considering degree of four control factors and three levels with $L_{27}^3(13)$, Orthogonal array.

Fig. 3: GFRP Specimen after Machining

TABLE IV. PROCESS RELATED FACTORS

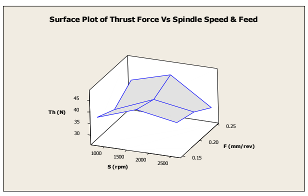
S. N.	Input Variables	Output Response
1	Spindle Speed (S)	Thrust Force (T_h)
2	Feed Rate (f)	Cutting Torque (T_q)
3	Fiber Orientation (F_o)	Delamination (D_f)
4	Drill Bit (D_r)	Surface Roughness (S_r)

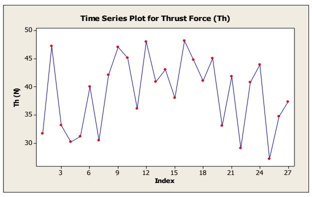
VII. RESULT DISCUSSION

In this experimental analysis the Machinability of GFRP composite is measured in terms of the response variable as discussed as above i.e. (Thrust, Torque, Delamination and Surface Roughness etc)

A. Statistical Analysis of Thrust Force:

Thrust force during drilling can be defined as the 'Force acting along the axis of the drill during cutting process". Thrust force is also used to monitor tool wear and in turn, monitor tool life. From the ANOVA, it is observed that, the near best condition which produces smaller magnitude of the thrust force is spindle speed at 800 rpm, feed rate of 0.20 mm/rev, 45° fiber orientation and coated carbide drill bit material. As shown in Graph 1.1. (Surface Plot of T_h V_s S and F); the spindle speed increases from 800 to 1600 rpm there is a stiff increase in the thrust Forces. However, a further increase in spindle speed rapidly decreases the thrust forces during drilling of GFRP Composite. It is also seen from surface plot that at lower feed, thrust force is low. A variation of thrust forces in all 27 experiments observed during drilling of GFRP composite is shown using Time Series Plot in Graph 1.2 The magnitude of thrust forces produce lowest in experiment no. 25 and 22, however, maximum forces were produce in experiment no. 12 and 17.



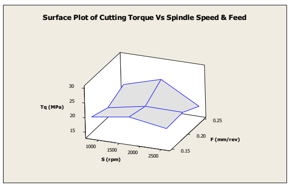


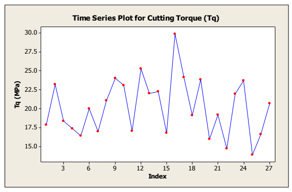
Graph 1.1: Surface Plot of T_h V_s S and F

Graph 1.2: Time series Plot for T_h

B. Statistical Analysis of Cutting Torque

Cutting forces are very useful for drill wear monitoring, because these forces generally increase with tool wear. Thus, within the tool wear region, cutting forces provide good assessment of the tool condition. If the tool cannot withstand the increased cutting forces, catastrophic tool failure becomes inevitable. Consequently, tool life, which is a direct function of tool wear, is best determined by monitoring cutting torque. It is observed from the Surface plot Graph 1.3, at lower spindle speeds and lower feed, cutting torque is low. When the drill change from 0.15 mm/rev feed to 0.20 mm/rev, the cutting torque decreases, but again increases in feed at 0.25 mm/rev, because of increase in cutting torque. As shown in Time Series Plot for T_q Graph 1.4, a variation of cutting torques in all 27 experiments observed during drilling of GFRP composite. The magnitude of cutting torque produces lowest in experiment. No. 22 and 25, however, maximum forces were produce in experiment. No. 12 and 16.





Graph 1.3: Surface Plot of T_q V_s S and F

Graph 1.4: Time series Plot for T_q

C. Statistical Analysis of Delamination Factor

Damage in the surface layers is an essential quality criterion in drilling of GFRP composite materials. It is clear from the Surface Plot of D_f V_s F_o and F, Graph 1.5**;** that the delamination, which is major culprit of all the problems associated with the drilling of GFRP composite, is minimum for feed rate of 0.20 mm/rev and (45°, 60°) is the most optimum feed and fiber orientation from the viewpoint of drilling performance. Thus, it can be conducted that feed, fiber orientation and tool materials in GFRP plays an important role in reducing the delamination as well as thrust and torque, thereby improving drilling performance in GFRP composite. It can be seen from the Time series Plot Graph 1.6 for D_f; that the torque has lowest magnitude at medium values of feed. Here, the feed value 0.20 mm /rev have shown the best performance. And for the speed, it was found that, 2700 rpm, the best performance for tool material was found to be coated carbide and plain carbide drill. The magnitude of delamination factor produces lowest in experiment no.6 and 21. However, the maximum forces were produce in experiment no. 13 & 15.

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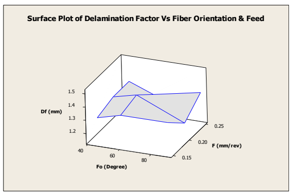
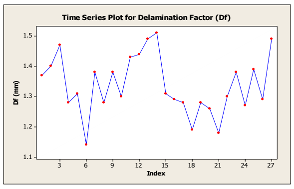
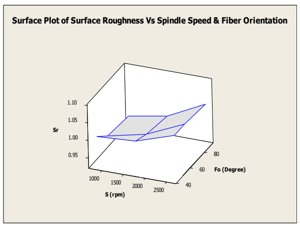


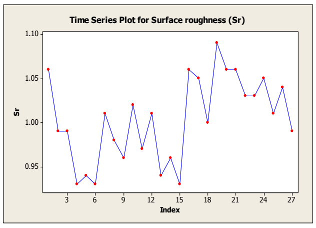


Graph 1.5: Surface Plot of D_f V_s F_o and F
Graph 1.6: Time Series Plot for D_f

D. Statistical Analysis of Surface Roughness

Surface roughness during drilling was measured using Stylus Method. Considering surface roughness as response variable ANOVA is carried out to see the effect of process parameters on surface roughness in drilling of GFRP. It is observed from the surface plot of S_r V_s S and F_o, Graph 1.7**;** that, the feed, drill material, fiber orientation and spindle speed is most significant factor governing S_r from ANOVA that at 800 rpm, feed 0.20 mm/rev, fiber orientation is 90° and plain carbide drill material was minimum observed. From the experimental data, it is observed that the surface roughness at a feed rate of 0.15 mm/rev is high than that of feed rate of 0.20 mm/rev for both plain carbide and coated carbide. Comparing the surface roughness of the specimens using different drill material and different fiber orientation for the GFRP composite, plain carbide shows superior surface finish. From the Time Series Plot for Sr, as shown in Graph 1.8; the magnitude of surface roughness produces lowest in experiment no.6 and 15. However, the maximum forces were produce in experiment no. 16 & 20.





Graph 1.7: Surface Plot of S_r V_s F_o and S
Graph 1.8: Time Series Plot for S_r

VIII. Conclusions

The following conclusions can be drawn from the results of above experimental investigation based on Taguchi Method, carried out on three GFRP composite specimens using HSS, PC and CC drill tool:

1. The constituent materials of the composite specimens, specimen thickness and machining time have a significant effect on the behavior of thrust force and torque over the machining time. It is observed from the ANOVA, the input factors like feed, spindle speed, fiber orientation and drill material have statistically significant influence on the drilling of GFRP composite

2. Delamination can be reduced, if proper cutting parameters are selected. Considering the parameter used in this work, the best set (based on the S/N ratio, the optimal parameters for the minimum delamination) quality of hole and surface roughness was: Feed Rate: 0.20 mm/rev, Spindle Speed: 800 rpm, Drill Material: Coated Carbide and Fiber Orientation: 45° and 90°.

3. From the above drills experimented; HSS twist drill had the lowest results, showing the inadequacy of the use of this material in drilling tools for Glass Fiber Reinforced Plastics (GFRP). Carbide twist drill had the best results for thrust force and Delamination Factor.

References

[1] Luis Miguel Durao, Antonio G. Magalhaes, Joao Manuel R. S. Tavares, A. Torres Marques, "Analyzing objects in images for estimating the delamination influence on load carrying capacity of composite laminates", Electronic Letters on Computer Vision and Image Analysis 7(2): 2008, pp.1-11.

[2] C.C. Tsao, H. Hocheng, "Taguchi analysis of delamination associated with various drill bits in drilling of composite material", International Journal of Machine Tools & Manufacture 44, 2004, pp.1-6.

[3] C.C. Tsao,, H. Hocheng, "Effect of eccentricity of twist drill and candle stick drill on delamination in drilling composite materials", International Journal of Machine Tools & Manufacture 45,2005, pp.1-6.

[4] H. Hocheng., C.C. Tsao, "The path towards delamination-free drilling of composite materials", Journal of Materials Processing Technology 167, 2005, pp.1-14.

[5] C.C. Tsao, "The effect of pilot hole on delamination when core drill drilling composite materials", International Journal of Machine Tools & Manufacture 46, 2006, pp. 1-9.

[6] H. Hocheng, C.C. Tsao, "Effects of special drill bits on drilling-induced delamination of Composite materials", International Journal of Machine Tools & Manufacture 46, 2006, pp. 1-14.