INFLUENCE OF FILLER MATERIAL ON GLASS FIBER/ EPOXY COMPOSITE LAMINATES DURING DRILLING

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ABSTRACT
The use of polymeric composite materials has increased considerably over the last decade. Drilling is a frequently practiced machining process in industry due to the need for component assembly in mechanical pieces and structures. Machining processes are generally used to cut; drill or contour composite laminates for building products. In fact, drilling is one of the most commonly used manufacturing processes to install fasteners for assembly of laminate composites. The material anisotropy resulting from fiber reinforcement heavily influences the machinability during machining. Machining of fiber reinforced plastic (FRP) components is often needed in spite of the fact that most FRP structures can be made to near-net shape and drilling is the most frequently employed secondary machining process for fiber reinforced materials. The use of filler material like TiO_2 and Graphite have shown that better bonding of the fiber matrix has got its effect on thrust and delamination factor values.

KEYWORDS: *Drilling; Polymer-matrix composites; Thrust force; Delamination*

I. INTRODUCTION

Fiber reinforced plastics have been widely used for manufacturing aircraft and spacecraft structural parts because of their particular mechanical and physical properties such as high specific strength and high specific stiffness. Another relevant application for fiber reinforced polymeric composites (especially glass fiber reinforced plastics) is in the electronic industry, in which they are employed for producing printed wiring boards. Drilling of these composite materials, irrespective of the application area, can be considered as a critical operation owing to their tendency to delaminate when subjected to mechanical stresses. With regard to the quality of machined component, the principal drawbacks are related to surface delamination, fiber/resin pullout and inadequate surface smoothness of the hole wall. Among the defects caused by drilling, delamination appears to be the most critical [1]

Figure 1 shows that the factors such as cutting parameters and tool geometry/material must be carefully selected aiming to obtain best performance on the drilling operation, i.e., to obtain best hole quality, which represents minimal damage to the machined component and satisfactory machined surface.

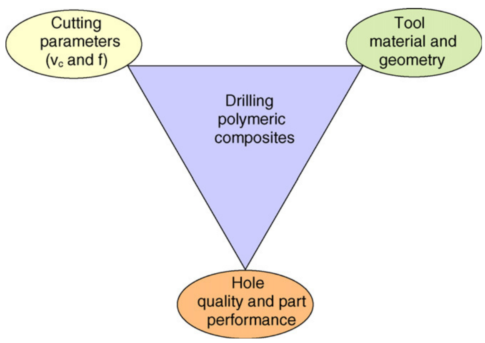

Figure 1. Principal aspects to be considered when drilling fibre reinforced plastics

Composite materials are constituted of two phases: the matrix, which is continuous and surrounds the other phase, often called as reinforcing phase [3]. Epoxy resins are widely used as matrix in many fibre reinforced composites; they are a class of thermoset materials of particular interest to structural engineers owing to the fact that they provide a unique balance of chemical and mechanical properties combined with wide processing versatility [4]. Within reinforcing materials, glass fibres are the most frequently used in structural constructions because of their specific strength properties [3]. The present study focuses on mach inability study of GFRP laminated composites with filler material Tio_2 and graphite and evaluation of thrust force, delamination factor for two drill diameters at different speeds

1.1. Machining of composite materials

The machining of GFRP is quite different from that of metals and results in many undesirable effects such as rapid tool wear, rough surface finish and defective subsurface layers caused by cracks and delaminations. At the beginning of drilling operation, the thickness of the laminated composite material is able to withstand the cutting force and as the tool approaches the exit plane, the stiffness provided by the remaining plies may not be enough to bear the cutting force, causing the laminate to separate resulting in delamination. The delaminations that occur during drilling severely influence 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 operation for fiber reinforced plastics (FRP) laminates 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 work piece [4]. The delamination on the exit surface, generally referred to as push down delamination, is more extensive, and is considered more severe. Hocheng and Tsao have beautifully explained the causes and mechanisms of formation of these push down delaminations and they have also reasoned out the dependence of extent of delamiantion on the feed rate [5]. In earlier studies it has been observed that the extent of delamination is related to the thrust force, feed, material properties and speed, etc. and that there is a critical value of the thrust force (dependent on the type of material drilled) below which the delamination is negligible [6].

1.2. Specimen Preparation

The method that is used in the present work for manufacturing the laminated composite plates is hand lay-up as shown in Figure 2, which is the oldest method that was used to get the composite materials. The type of Glass Fiber mat selected to make specimens was, Mat – II (330GSM). The matrix material used was a medium viscosity epoxy resin (LAPOX L-12) and a room temperature curing polyamine hardener (K-6), both manufactured by ATUL India Ltd, Gujarat, India. This matrix was chosen since it provides good resistance to alkalis and has good adhesive properties. Based on volume fraction the calculations were made for 60-40 (60% Glass Fiber – 40% Epoxy Resin) combination showed a better result. Two filler materials TiO_2 and Graphite were added to Mat II 60-40 combination by keeping Epoxy percentage constant (40%). Based on literature survey the amount of filler added was 3, 6, & 9 % of Graphite and 1, 2, & 3 % of TiO_2, the details are as shown in Table 1. after preparation of the specimen the specimens were tested in impact testing machine to obtain impact toughness value.

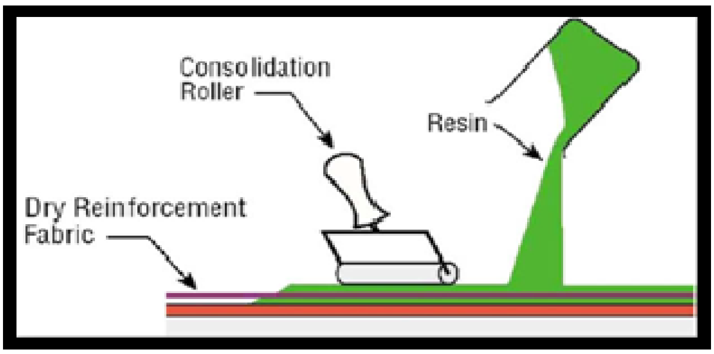

Figure 2. Hand lay-up Technique

Table 1. Filler material specimen details

	Mat II (330GSM)		
	Glass Fiber Content %	Epoxy Resin %	TiO_2 %
1	59	40	1
2	58	40	2
3	57	40	3

	Mat II (330GSM)		
	Glass Fiber Content %	Epoxy Resin %	Graphite %
1	57	40	3
2	54	40	6
3	51	40	9

1.3. Experimental Setup

The high speed steel twist drill has an 118^0 point angle. Two diameters 6.35mm and 4.76mm were selected to work on radial drilling machine which has a maximum spindle speed of 2650 rpm. There details are shown in Table 2. A piezoelectric dynamometer was used to acquire the thrust force as shown in Figure 3. The damage around the holes was measured using a tool maker's microscope.

Table 2: Drill tool dia and corresponding speed

Tool- Twist Drill Drill dia (mm)	Cutting speed (rpm)
6.35	525
	951
	1625
	2650
4.76	525
	951
	1625
	2650

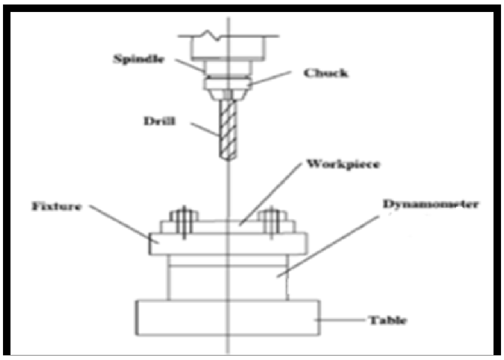

Figure 3. Schematic setup to measure thrust force

II. Results and Discussions

2.1 Thrust force

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 thrust force. Due to the thrust developed during drilling, many common problems exist. Some of the problem causes in drilling are fiber breakage, matrix cracking, fiber/matrix debonding, fiber pull-out, fuzzing, thermal degradation, spalling and delamination. The thrust force and torque developed in drilling operation is an important concern. Monitoring of thrust force in drilling is needed for the industry.

In Figure 4 a qualitative trend of thrust force as a function of the drilling is shown. As can be seen, a pushing action is exerted by the drill on the work piece. In the first phase the thrust force continues to increase as an increasing part of the cutting lips is engaged in the material; in the second phase the thrust force remains at an almost constant value as the drill sinks into the work piece. In the third phase the thrust force rapidly decreases when the twist drill exits.

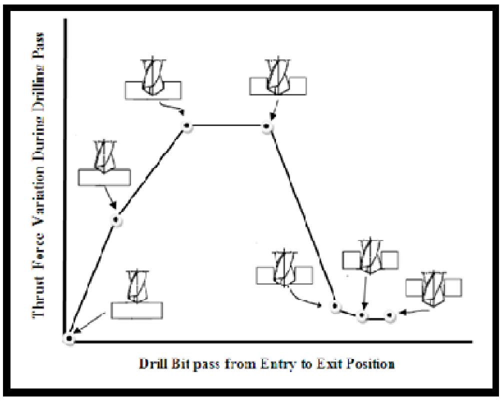

Figure 4. Responses of cutting forces during drilling showing key process points

The value of thrust force was measured using a piezoelectric dynamometer. Figures 5 and 6 show the results of the thrust force for the two sets of drilling tests, as a function of the cutting parameters.

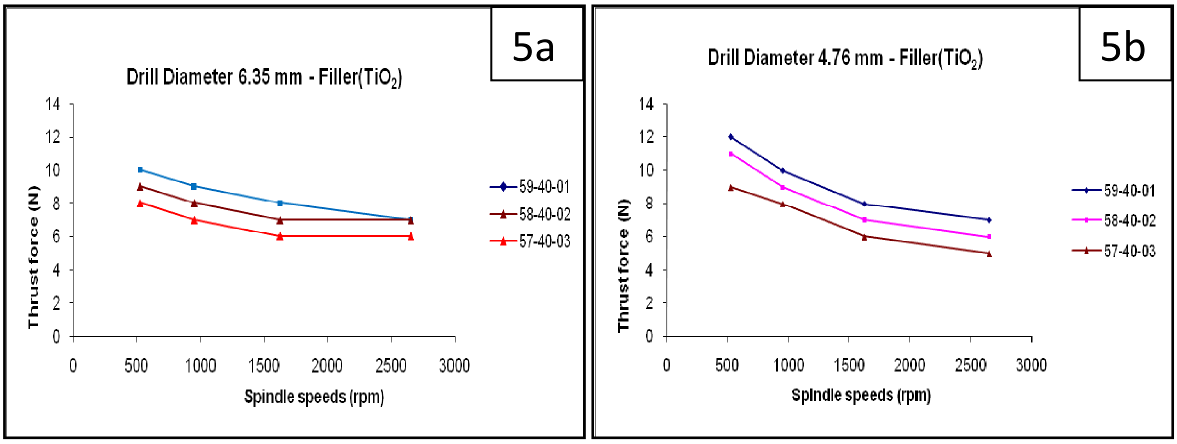

Figure 5. Effect of spindle speed on thrust force for 6.35mm and 4.76mm twist drill for TiO_2 filler material.

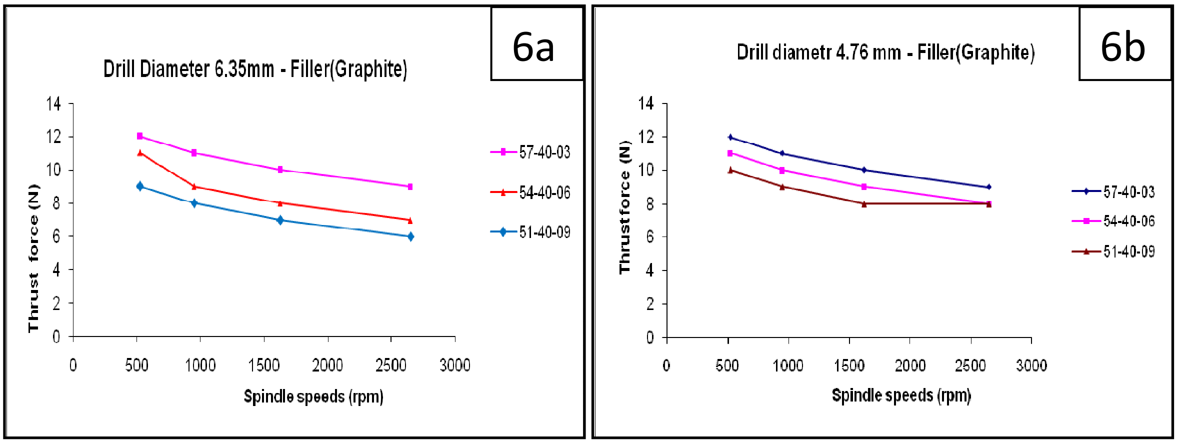

Figure 6. Effect of spindle speed on thrust force for 6.35mm and 4.76mm twist drill for graphite filler material.

After drilling glass fiber reinforced epoxy composite laminates manufactured by hand lay-up; using two different HSS twist drill and various cutting speeds, the cutting speed is the cutting parameter that has the highest physical as well as statistical influence on the thrust force and surface roughness in GFRP material, the following conclusions can be drawn:

- From the Figures 5 and 6 it could be seen that as the speed increases the thrust force decreases for both the drill diameters. This is due to abrasiveness inherent property of the filler material.

- As the filler percentage increased from (1% to 3%) TiO_2 and (3% to 6%) Graphite the thrust force values are less at all the speed intervals and has shown downward trend.
- When comparing among drill diameters 4.76mm have recorded higher values than 6.35 mm

2.2 Delamination factor (F_d)

Delamination is caused by different drilling parameters. Several ratios were established for damage evaluation. One of them is delamination Factor (F_d), a ratio between the maximum delaminated diameter (D_{max}) and drill diameter (D_0). $\mathbf{F_d = D_{max}/D_0}$. Figure 7 shows Tool Maker's microscope with which delamination was measured.

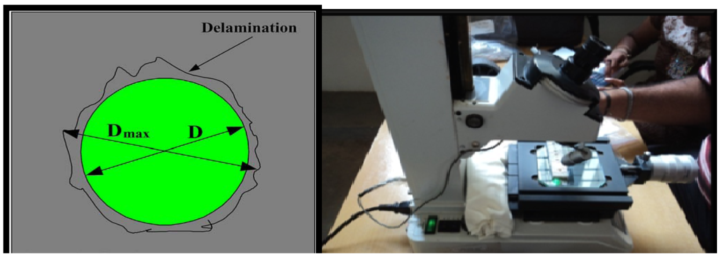

Figure 7. Schematic view of delamination factor and a view of tool makers microscope

Delamination is commonly classified as peel-up delamination at the twist drill entrance and push-down delamination at the twist drill exit as shown in Figure 8.

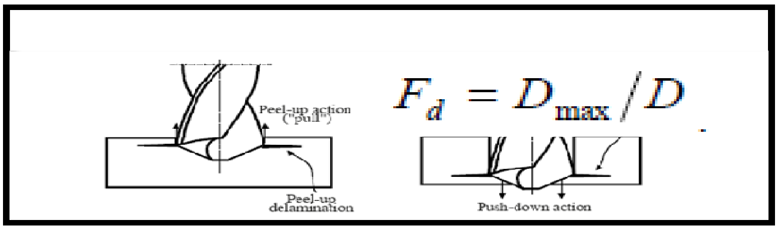

Figure 8. Delamination at the twist drill entrance (left) and exit (right) when drilling laminates

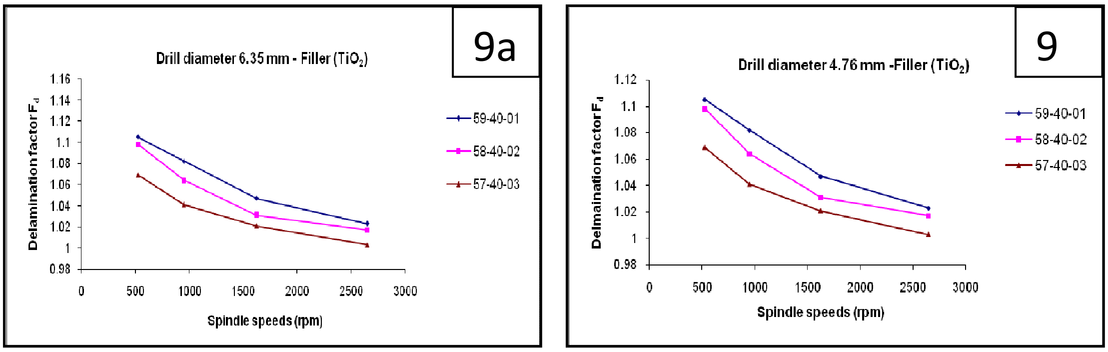

Figure 9. The Effect of Spindle Speed on the Delamination Factor (F_d) for 6.35 mm and 4.76 mm twist drill for TiO_2 filler material.

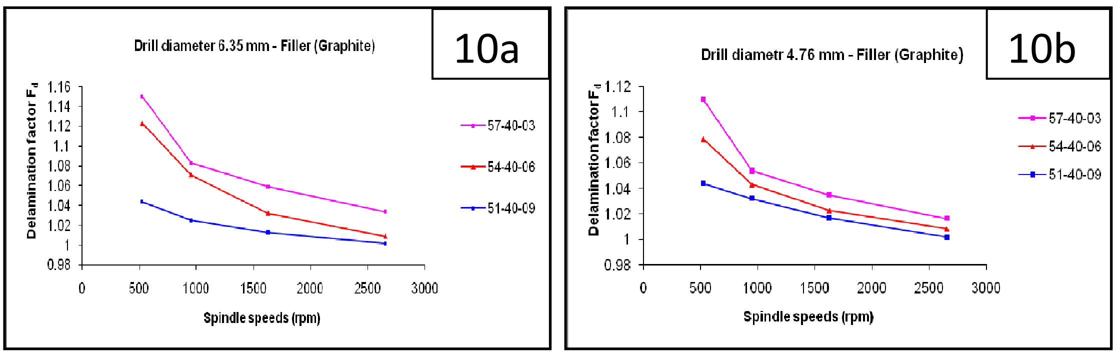

Figure 10. The Effect of Spindle Speed on the Delamination Factor (F_d) for 6.35mm and 4.76 mm twist drill for Graphite filler material.

- From the Figures 9 and 10 it could be seen that as the speed increases the delamination factor decreases for both drill diameters .
- It is seen that decrease in spindle speed results in increase in the thrust force. This increase in thrust force causes increased delamination. Hence , thrust force is recognized as the main cause of damage
- As the filler percentage increased from 1% to 3% for TiO_2 and 3% to 9% for Graphite the delamination factor values are less at all the speeds and has shown downward trend.

III. CONCLUSIONS

Based on the experimental results presented, the following conclusions can be drawn:
Considerable efforts have been focused on the better understanding of the phenomena associated with the cutting mechanism. Conventional high speed steel twist drills are used for drilling operation Abrasion, was the principal wear mechanism and led to the elevation of the thrust force. The increasing of thrust force as a result of increasing drill pre-wear leads to destroying the matrix and micro-cracking at the ply interfaces, which deteriorates the surface finish. The principal factors used to evaluate the performance of the process are undoubtedly the damage caused at the drill entry or exit of the hole produced. The damage decreases with cutting parameters, which means that the composite damage is smaller for higher cutting speed within the cutting range tested. Delamination decreases as the spindle speed is elevated, probably owing to the fact that the cutting temperature is elevated with spindle speed, thus promoting the softening of the matrix and inducing less delamination. The effect of addition of filler material like TiO_2 and Graphite have shown that higher the percentage lesser the values of thrust and delamination factor , which insists that the better bonding of the filler material with the fiber matrix have increased the capacity of force sustainability.

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