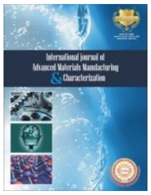

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Precision Drilling of Glass Fiber Reinforced Composite (GFRP) with Modified HSS Drill Geometry

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A R T I C L E I N F O

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A B S T R A C T

Even though near net shape manufacturing of fiber reinforced plastics (FRP) is possible, drilling is an unavoidable operation, particularly for assembly of structures/panels having holes of specified dimensional tolerance, surface texture and integrity. In the present work drilling tests were carried out on GFRP composites with conventional HSS (18-4-1) drill bit and then by modifying the drill geometry (web or chisel edge) i.e. web thinning in order to show the effect of drill geometry in general and web (chisel edge) in particular on the performance of the drilling of GFRP composite. It is observed that the fiber orientations and drill geometry plays a vital role on the cut quality and delamination.

1. Introduction

Composite materials are widely used in the diverse applications such as aircraft, automobile, sporting goods, marine vessels, audio equipment etc. Because of it's unique properties such as specific strength, fatigue strength, strength to weight ratio and corrosion resistance.

Machining of composite in general and Glass Reinforced plastics (GFRP) in particular differ in many respects from metal cutting. The material is inhomogeneous and its machining behavior depends on fiber, matrix properties, fiber orientation and type of weave. Most of the composite structures are fabricated to near net shape. Drilled holes are often required to assemble the near net-shaped structures or parts. Thus drilling is the most common cutting operations carried out on FRP. In spite of near-net shape manufacturing, machining of FRP products to some extent becomes usually necessary so as to achieve the shape and dimensional tolerance to facilitate assembly and also for the control of surface quality from functional viewpoint. The most common machining operation for GFRP parts is drilling. It is observed that delamination, fibre pullout, severe tool wear, damage to the surface finish and slow speeds are some of the major problems associated with the drilling operation. Laminated fiber-reinforced plys under machining forces are subject to the risk of interlaminar crack propagation, called delamination, which threatens structural reliability. Such damage results in a new limiting factor to the machinability of composite materials.

From literature survey it is found that the above problems are likely to develop as a result of the fiber orientations, feed rate and tool geometry, especially cutting edge of the drill [1-10].

They can be eliminated by using specially designed carbide tools, poly-crystalline diamond (PCD) tools, solid carbide tools etc. But these tools are very costly and not compatible with the existing machine tools. Therefore, in the present work High Speed Steel (HSS) 18-4-1 drill bit of 6mm diameter is used on the basis of availability, facility to maintain a sharp edge, toughness and easy grindability.

Some investigators have studied the delamination experimentally. A rapid feed rate of drilling will cause a crack around the exit edge of the hole. Other scientist postulated that lower axial thrust would create less delamination. Koenig et al. [1-2] ran a series of drilling tests on carbon reinforced epoxy and measured the critical thrust force at the one set of exit delamination. Some authors partly investigated the influence of fibre orientation while cutting plain fabric laminated plates whereas Sakuma et al. [3] considered simplified fibre orientations to examine cutting and surface forming mechanisms.

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They performed face-turning tests on filament wound GFRP (using right- as well as left-hand-winding) of single layer material with glass fibres oriented alternately right and left at fixed interval.

From the literature [3-9] it is clear that the major limiting factor of drilling of composite material (GFRP) are a delamination, fiber pull out, damage at entry and exit of the hole etc which are dependent on fiber orientation, feed rate, drill geometry etc. While many developments have taken place, there are still several problems that need to be researched. One such problem is regarding the effect of fibre orientation and drill geometry in general and web thickness (chisel edge) in particular on the drilling performance of GFRP composites.

This paper reports the findings of experimental investigations, which were carried out so as to address the effect of fiber orientation and web thickness on the drilling of GFRP composite so as to reduce the problems associated with the drilling of GFRP composite material. The work reported in this paper is an attempt in that direction.

2. Experimental details

The drilling experiments were carried out on a robust CNC machine with the following specifications:
Make: TRIAC make CNC Milling Machine
Table size: 500 x 160 x 280 mm,
Axes Travel X, Y and Z: 250 mm, 120 mm and 235 mm respectively.
Spindle Speed and Spindle Drive: Infinitely Variable and ½ HP, 240 AC res.
Axis Drive: X, Y, & Z axes (stepper motors-200 steps/rev).
Feed Rates: Infinitely Variable (0-1000 mm/min)
Linear Interpolation: On X, Y, and Z axes (vertically corrected feed rates).
Circular Interpolation: On XY plane.

2.1 Selection of The Work Material

Woven glass fibre fabric was chosen as the work material. This material was cut into 350x350 mm pieces with 0°, 45°, 90° for laying the laminates. The workpieces were made by hand lay-up method with of 35% volume fraction of the glass fibres. Epoxy with 27% hardener was used as matrix. The laminates were hot cured in a furnace at a temperature of about 110°C for five hours. The laminates were laid at (0±0), (0±45), (0±90), and (0, 45, 90) degrees.

2.2 Selection of Cutting Tool

ϕ6 mm high speed steel (HSS) cutting tool was selected for cutting the unidirectional (UD) laminates. HSS was selected since it is cheap, easily grindable, highly tough and compatible with the above machine.

3. CHARACTERIZATION of Workpieces

All the workpieces, i.e. (0±0), (0±45), (0±90), and (0, 45, 90) degrees were characterized for tensile strength, shear strength and flexural strength. Test pieces of following dimensions were used for this purpose: (300x25) mm for tensile test, (200x20) mm for shear test and (80x10) mm for the flexural test. All these dimensions are based on ASTM standards. The results of these tests are presented in Table 1.

Table 1 Characterisation of Work pieces

Fiber orient^{n}	Tensile Strength (MPa)	Shear Strength (MPa)	Flexural Strength (MPa)
(0±0)	4512	110.4	159.7
	4213	84.9	153.8
	4712	78.6	161.6
(0±45)	760	423	57.3
	920	363	58.9
	818	397	50.6
(0±90)	2600	75	18.4
	2740	69	14.2
	2680	74	11.4
(0,45,90)	1750	215	38.5
	1650	270	44.6
	1762	212	37.6

4. Selection of Performance Measures

The previous work [1-9] on drilling of FRPs has shown that the quality of drilled hole depends on the thrust and torque acting on the drill and also the wear of the drill (tool wear). Hence, it was decided to choose all these parameters as the performance measures in this study as well. A drilling dynamometer was used for the measurement of thrust and torque.
A Toolmaker's Microscope with a least count of 0.01mm was used to measure the tool wear.

5. Experimental Procedure

The experiments were conducted on the above-mentioned CNC machine with a ϕ6 mm HSS drill bit. The experimental set up is a shown in figure 1. All the workpieces were drilled for 50,100,150 and 200 holes with following optimum operating speeds and feeds (Table 2) with a normal geometry drill bit and modified geometry i.e. web thickness (chisel edge) modification. After each interval of 50 holes, thrust, torque and tool wear i.e. flank wear, were measured.

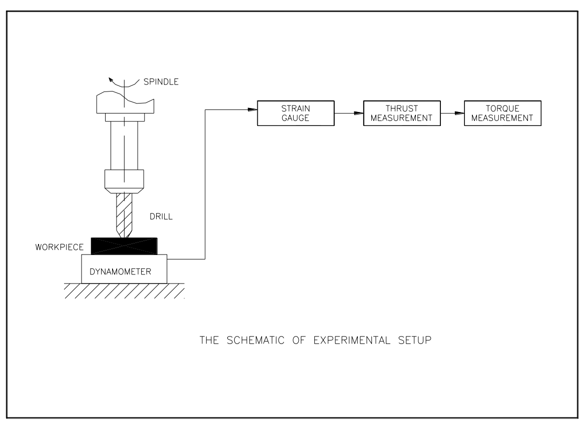


Fig. 1 Experimental Set-Up

Table 2: Optimal Operating Parameters

Work piece type	Cutting Speed (m/min)	Feed (mm/rev)
(0 ± 0^0)	32.04	0.16
(0 ± 45^0)	47.12	0.10
(0 ± 90^0)	47.12	0.16
$(0,45,90)^0$	18.84	0.16

After drilling every 50 holes with the above operating parameters measurements were taken for thrust, torque and tool wear. The variation of these performance measures with respect to number of holes were plotted.

6. Results and Discussion

Drilling is a complex 3D cutting operation with the cutting conditions varying along the entire cutting edge from the axis to periphery. Drills specially small drills are characterized by relatively high thrust force due to large web thickness predominant negative rake and low cutting speed at the cutting edge, which again is quite sizable compared to the drill size in case of small drills. Vibration and rapid wear lead to inaccuracy; poor surface finish and reduced tool life.

A fundamental analysis of drilling operation on metal by Oxford [13] reveled the thrust to be made up of three components. As shown in figure 2 the three components are 1. Primary cutting at two lips 2. Secondary cutting at the outer part of the chisel edge and 3. Indentation (or extrusion) at the center of the chisel.

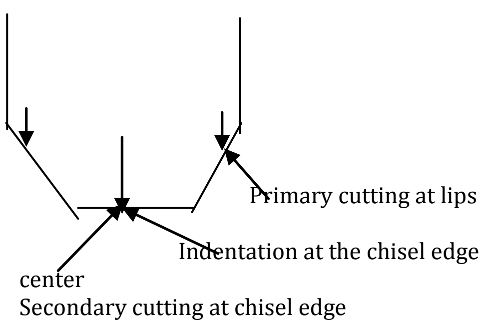


Fig. 2 Three Components of Thrust Force

During drilling of each laminate of different fibre orientations, it is found that the cutting edge of the drill bit abrades with the laminate initially and pulls the abraded material along the flute. This, in turn, introduces an upward peeling force due to which upper laminates separate from the uncut portion held by the downward acting thrust force. Cutting force acting in the peripheral direction is found to be responsible for the delamination. It gives rise to the peeling force in the axial direction through the slope of the drill bit and is a function of drill geometry, fibre orientation and friction between tool and workpiece.

The work pieces were characterised as per the ASTM standards and presented in the form of table to highlight the effect of fiber orientations.

Here GFRP laminates of different fiber orientations were drilled with normal geometry and modified web thickness of drill geometry as shown in figure 3. Modification of cutting edge was done on the Electrical discharge machine (EDM). Because of reduced web thickness we got powdery chips which are quit common while machining GFRP. The material is cut by the long curved cutting edge and this results in segmental chips of powdery form.

Figure 4 and 5 shows the variation of thrust, torque and tool wear with optimal parameters for different fiber orientation, with normal geometry and modified drill geometry i.e. web thinned.

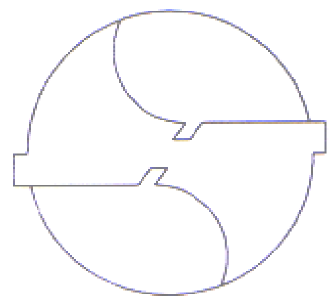
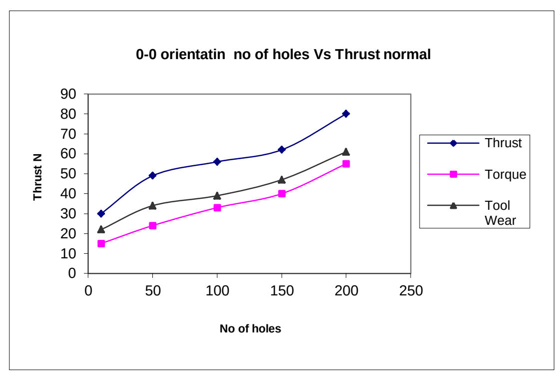
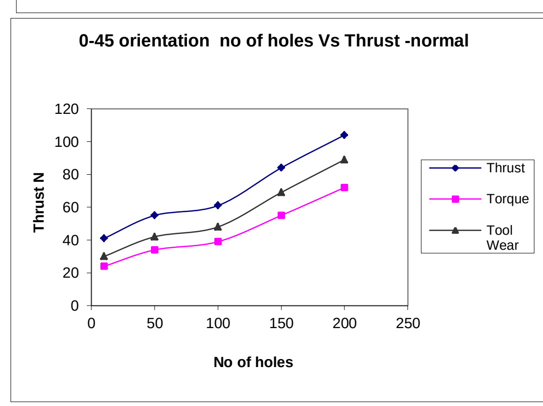


Fig. 3 Modified Cutting Edge

Figure 6 shows the deviation of the hole from basic size with normal geometry and web thinned geometry.





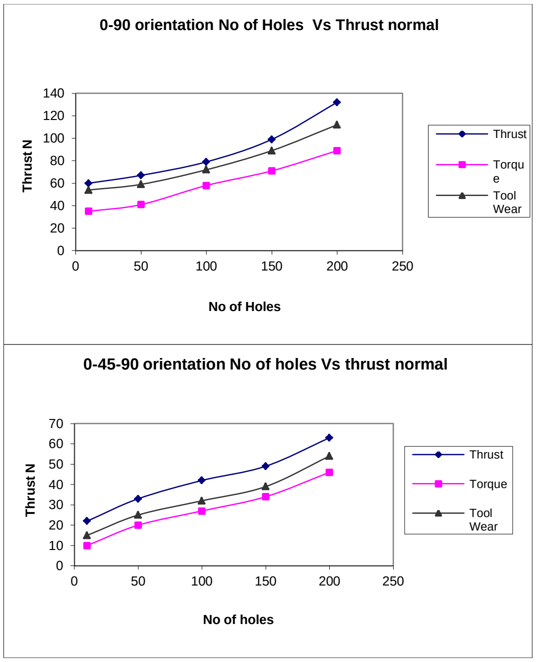
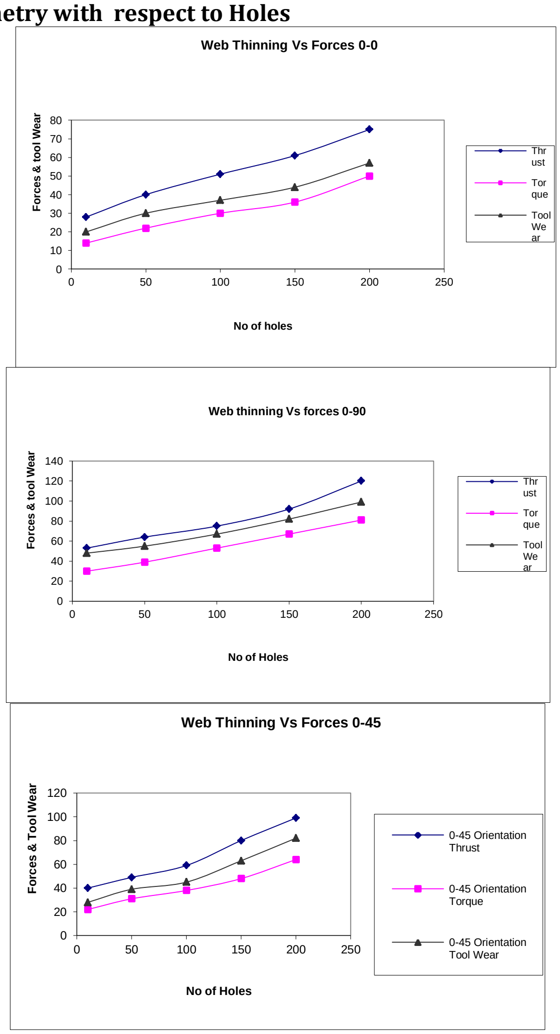


Fig. 4 Variation of Performance Measures using Normal geometry with respect to Holes



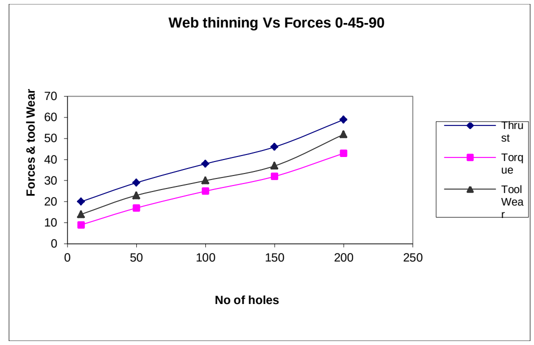


Fig. 5 Variation of Performance Measures using web thinned geometry with respect to Holes

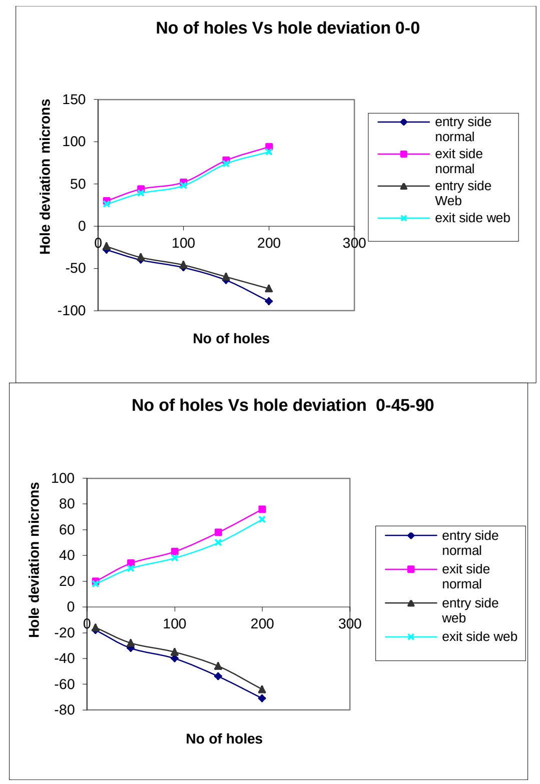


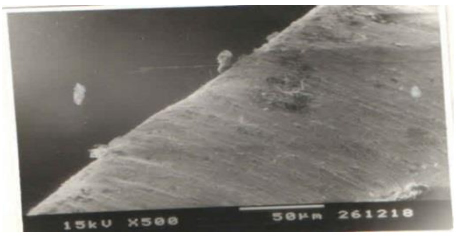
Fig. 6 Hole deviation with respect to No. of Holes

It was clear from the series of the experimental results obtained in both the series of drilling tests that the effect of the cutting edge shapes on the thrust, torque and tool wear tend to be the same as the effect of the web thinned on the fiber orientations. Thus, the smaller the cutting force, lesser will be the delamination, fiber pullout and damage at entry and exit of the hole. It is, therefore, necessary to reduce the thrust which has got major role in delamination, fiber pullout and hole quality where as torque has got less effect on the problems, hence neglected.

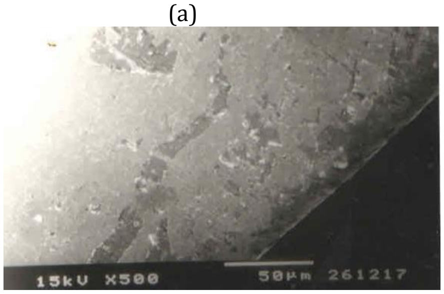
Based on these experiments, it became clear that the fiber orientations and drill geometry (web thickness) are the major contributors to the thrust force and hence the occurrence of delamination in laminated composite.

STUDY OF SEM MICROGRAPH:

Fig. 7 (a) shows abrasion wear on the flank of HSS tool i.e. Normal geometry. Also, regular striations are found on the flank. Localized pull out of material due to attrition can be seen. This phenomenon can be attributed to localized burnishing or small scale deformation of the material on the flank surface due to the sliding workpiece. Whereas, in case of modified cutting edge of drill bit it has been observed that the abrasion wear had significantly reduced. Moreover, localized pull over of material was not observed in the SEM images (Fig 7 (b).



(a)



(b)

Fig. 7 SEM images of wear damage a) (normal geometry) b) Modified cutting edge geometry.

7.Conclusion

The present investigations reports the following conclusions after characterizing and precision drilling of GFRP composite materials with normal drill point geometry and modified (web thickness) geometry:

i. The mechanical properties of the GFRP composites are found to strongly depend on the orientation of the fibres. While the (0±0) orientation is superior in tensile strength because the load applied is in the direction of the fibre axis. An optimum fibre orientation, i.e. (0,45,90), is found to show moderate properties in tension as well as shear.

ii. It is found from the experiments that the drill geometry plays a prominent role in reducing the thrust which in turn reduces the delamination, fiber pull out, damage at entry and exit of hole of GFRP composite. The modified geometry(web thinning) of HSS drill reduces the thrust force, torque and tool wear for all four fiber orientations by around 20-30% compared to normal drill point geometry.

iii. Also, damage at the entry and exit of the hole is reduces due to the web thinning. SEM images revealed that cutting edge wear had reduced due to modified geometry. This highlights the need to modify tool geometry to obtain the subcritical thrust at a reasonable feed rate.

Hence, the type of damages induced in a GFRP composite material during drilling is strongly dependent on fiber orientations and the drill geometry.

Acknowledgement

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