Effects of Drill Points on Glass Fibre Reinforced Plastic Composite While Drilling at High Spindle Speed

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Abstract- **The most effective way of achieving good quality holes while drilling fibre reinforced plastics is by reducing the thrust and torque. Drilling experiments were conducted with drill points, namely standard twist drill, Zhirov-point drill, and multifacet drill, using wide range of spindle speed, and feed rate to analyse thrust force, delamination and surface roughness. At high spindle speed, cutting force is less and the special geometry improves the quality of the hole further, especially Zhirov point drill. Multifacet drill is found better as far as the delamination value is concerned.**

Index Terms- **High speed drilling, GFRP Composites, Hole quality**

I. Introduction

Polymer matrix composite structures are increasingly used in high performance applications because of superior strength to weight ratio and stiffness to weight ratio. Cut-outs and holes exist in most of the composite structures. For example in an aircraft fuselage structure, around 100,000 holes are required for joining purposes. However due to their laminated constructions several types of damages like matrix cratering and thermal alterations, fiber pullout and fuzzing, are introduced during drilling, in addition to geometrical defects similar to those found in metal drilling [1]. About 60% of the rejections are happening due to the defects in the holes. These defects would create reduction in structural stiffness, which may lead to variation of dynamic performance of the whole structure. Many of these problems are due to the use of non-optimal cutting tool designs, rapid tool wear, and machining conditions [2-7]. The drilling parameters have the main contribution for the delamination/defects in holes machined in composites [8-16]. Many researchers [17-24] focused on the machinability aspects and effect of modified drill points on drilling polymer matrix composites. Chen [22] carried out experimental investigation on carbon/epoxy composite and recommended that the high speed and low feed rate are key factors for producing delamination free and good surface finish holes. Increasing the cutting speed will certainly increase production rate. Another possible benefit of increasing the cutting speed is the reduction of cutting forces [25]. If increasing the cutting speed can reduce the thrust force, the delamination may be overcome. Drilling FRP at high spindle speed was analyzed by Lin et al [26-27]. Lin concluded that drill wear is the major problem at high speeds. Four facet, eight-facet, Jo-point, inverted cone and special geometry are some of the widely used tool designs in drilling composite materials [1, 3, 21, and 28-29]. The present work is an effort in this regard where the drilling forces and hole quality have been studied for Zhirov and multifacet and compared with twist drill.

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II. EXPERIMENTAL SETUP

Experiments were conducted using Acumac high-speed spindle (5kW) mounted on a vertical CNC machine. Figure 1 shows the experimental set-up. Due to the high abrasive nature of fiber-reinforced materials, micro-grain carbide (Ø 10 mm-K10) was used in this investigation. Drilling of laminates was carried out for the following conditions using full factorial design. Cutting speed values were selected between 15.7 m/min to 62.8 m/min and 440 m/min to 600 m/min to study the effect of normal and high spindle speed respectively on drill geometries, surface finish and delamination.

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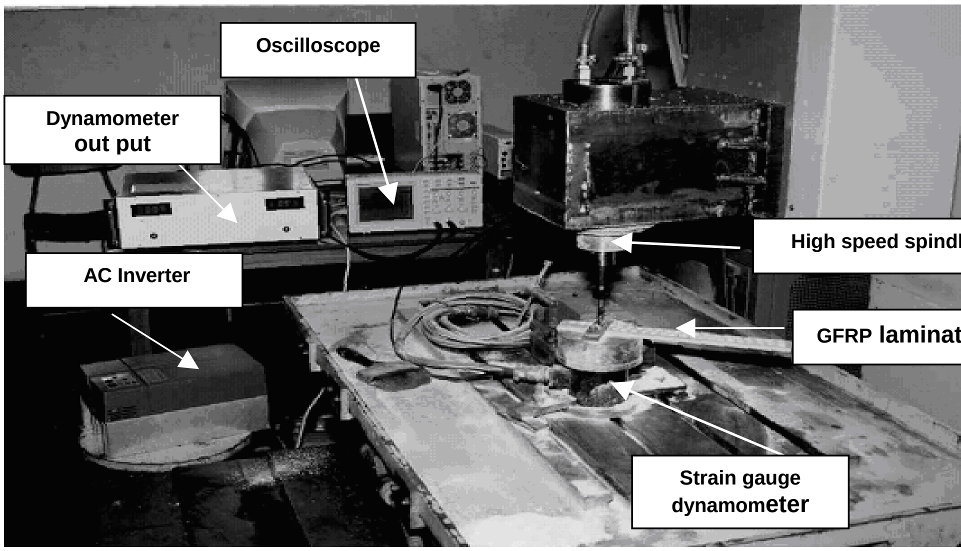
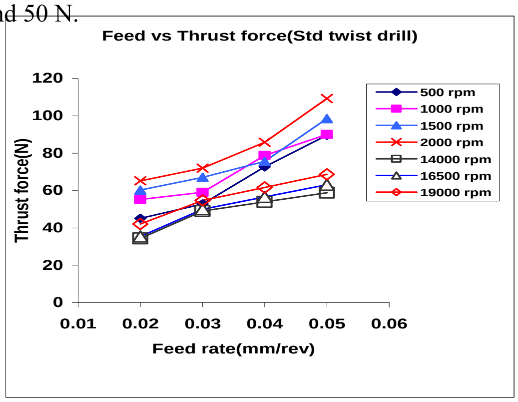
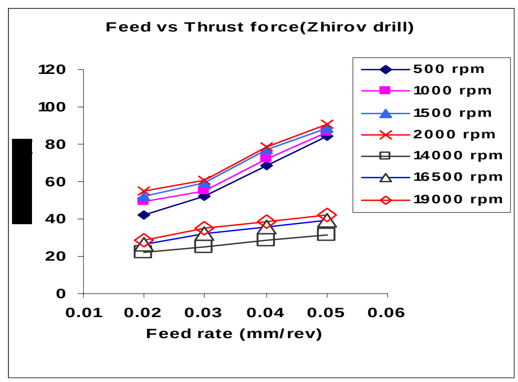


Fig 1 High speed spindle experimental setup

III. INFLUENCE OF CUTTING PARAMETERS ON THRUST FORCE

Drilling parameters cause change in cutting forces, which influence the quality of the holes in terms of surface finish, circularity, delamination, fiber pull out, matrix cratering, etc. As seen in Figure 2 Zhirov point drill experiences lower thrust force for the same operating conditions when compared to other geometries. This is because in the Zhirov drill the chisel edge has been replaced by cutting edges, therefore extrusion action is replaced by cutting action. The Zhirov-point drill also produces more dimensionally accurate holes because of less deflection in the spindle through a reduction of the thrust force. At lower feed rate (0.02 mm/rev) Zhirov point drill and multifacet generated more or less same thrust force (around 20 N). This value is very less when compared to drilling at normal spindle speed which is around 50 N.





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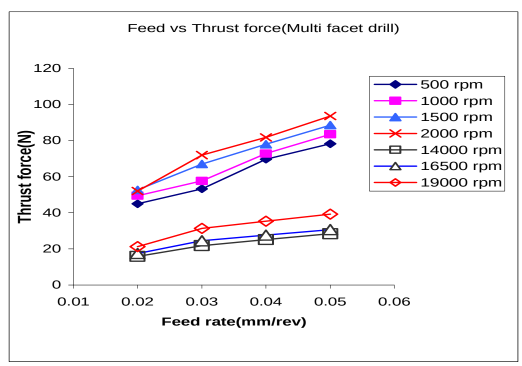

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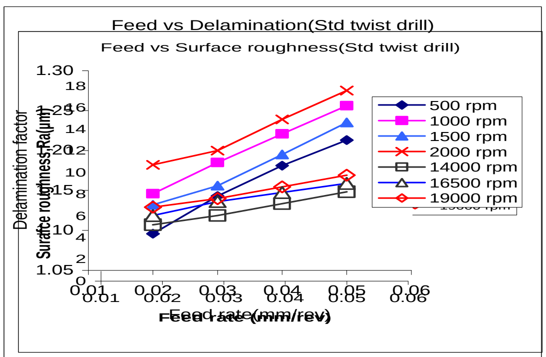
Fig 2 Effect of Feed Rate and Spindle Speed on Thrust (a) Standard twist (b) Zhirov Point (c) Multifacet Drill

IV. INFLUENCE OF CUTTING PARAMETERS ON DELAMINATION FACTOR

Delamination near the exit side is introduced as the tool acts like a punch, separating the thin uncut layer from the remainder of the laminate. Fiber pull out at exit was more in the case of twist drill and Zhirov point drill. Multifacet drill produced clean cut holes at the exit side of the laminate. The delamination was evaluated in terms of delamination factor. The delamination factor is the ratio of maximum diameter (Dmax) of the damaged zone to the actual hole diameter (D). Figure 3 shows the relationship between the delamination factor and drilling parameters. It is concluded that delamination factor increases with feed rate and spindle speed.



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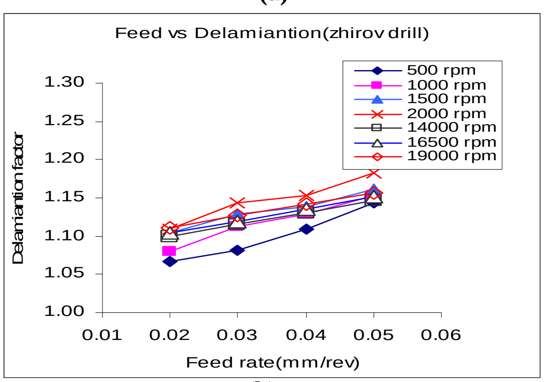

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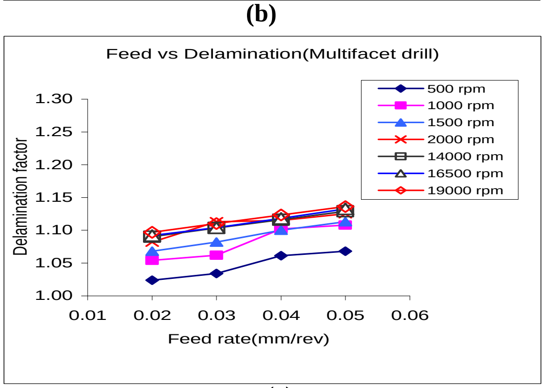

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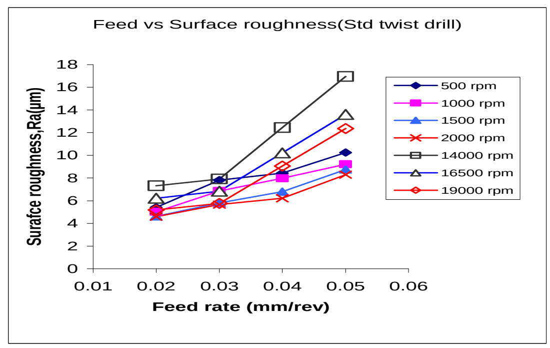
Fig 3 Effect of feed and spindle speed on delamination (a) Twist drill (b) Zhirov point (c) Multifacet drill

V INFLUENCE OF CUTTING PARAMETERS ON SURFACE ROUGHNESS

The surface roughness (Ra) was evaluated as per ISO 4287/1. For each test 3 measurements over drilling surfaces were made. Figure 4 shows the effect of drill geometry on surface finish. Zhirov drill produced better surface finish (4-5 µm) at lower feed rate. The outer most lip produced thin chip which improved the finish of the hole. Multifacet drill also generated better surface finish at lower feed rate when compared to standard twist drill. The effect of spindle speed on surface finish is less compared to feed rate for Zhirov point and multifacet drill. However the drilled hole exhibits higher order surface roughness and only a marginal difference in delamination factor (Possibly due to higher order drilling temperature). It is seen that for standard twist drill and mulitifacet drill beyond 0.03 mm/rev steeper rise in surface roughness.



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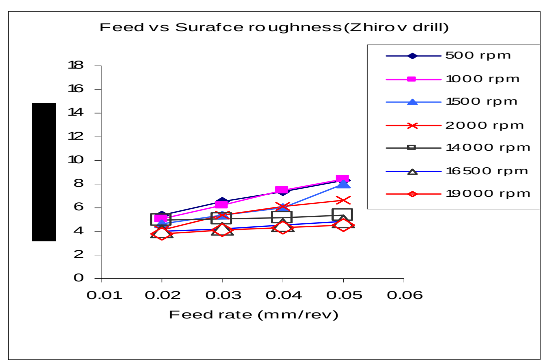

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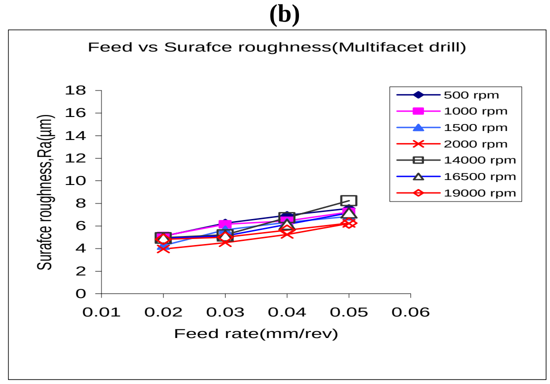

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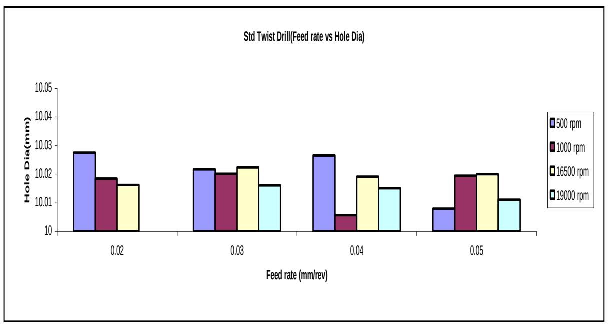
Fig.4 Effect of feed & spindle speed on surface roughness (a) Twist drill (b) Zhirov point (c) Multifacet drill

VI. INFLUENCE OF THE CUTTING PARAMETER ON HOLE QUALITY

The diameter of the holes drilled by carbide drill (φ10 mm) are measured with the Co-ordinate Measuring Machine (CMM-MITUTOYA) using φ 3 mm ruby crystal probe. The dimensions of the holes are measured at the middle of the laminate thickness. Lower order thrust force, i.e better cutting action of carbides, higher order material stability, lower order wear, possible lower order cutting temperature on workpiece, all will induce less stress and consequently less relaxing, so mostly over sized holes are seen (Figure.5). Better circularity values are found when holes are drilled using Zhirov point and multifacet drills (Figure.6). 6–8 µm circularity error in drilling of composite can be treated as negligible.



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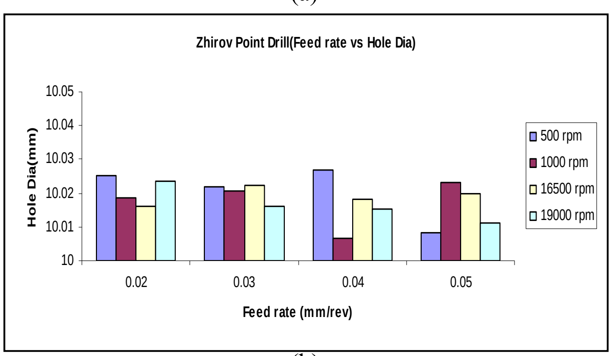

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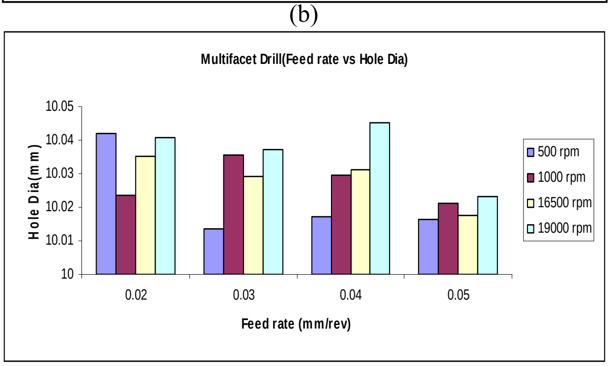

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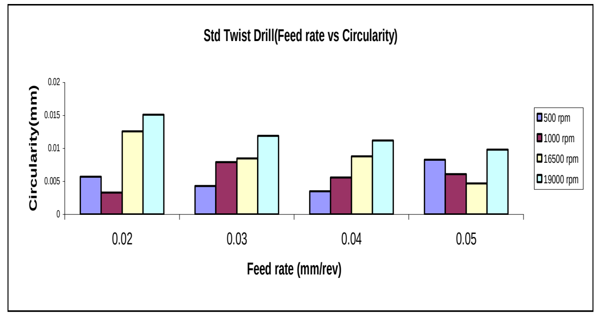
Fig 5 Hole diameter for (a) Standard twist drill (b) Zhirov point (c) Multifacet drill



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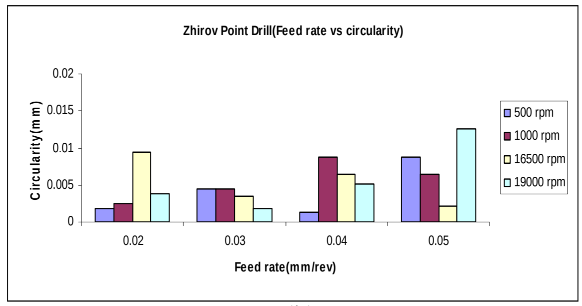

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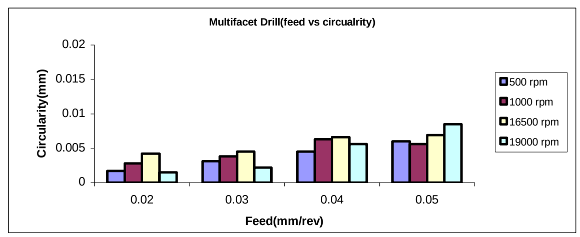

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Fig 6 Circularity for (a) Twist drill (b) Zhirov point (c) Multifacet drill

VII. TOOL WEAR STUDY

In high speed drilling, the major reason for tool wear is the thermal softening of the tool material, and the abrasive nature of the chip. Because of tool wear, thrust force will increase. So, tool life can be predicted by measuring the thrust force with respect to the number of holes. In this tool wear study, carbide drill geometries are used at 16500 rpm (518 m/min) spindle speed and 0.02 mm/rev (330mm/min) to study the extent of tool geometry at high spindle speeds (Figure 7).

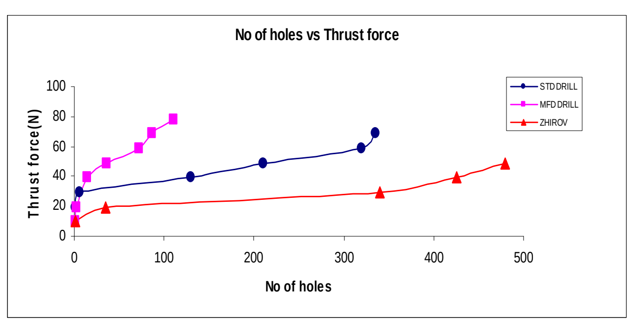
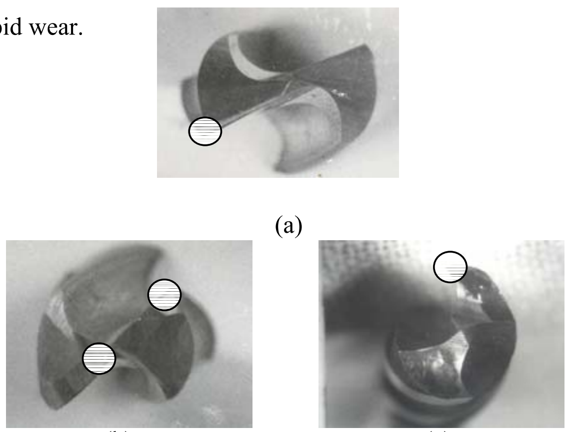


Fig 7 Number of hole Vs Thrust force for drill points

In standard twist drill, the thrust force at the beginning of the cut increased sharply because of initial wear. Initial wear was up to 10th hole and after that gradual wear took place. Beyond 325 holes the thrust force started increasing steeply. This could be because of rapid wear. Thrust force at the end of 325th hole is 60 N. In Zhirov point drill, thrust force increased sharply because of initial wear. Initial wear was up to 25 holes and after that gradual wear took place. Beyond 340 holes thrust force started increasing steeply. Thrust force at the end of 340th hole is 30 N. In multifacet drill within 10 holes thrust force increased rapidly from 10 N to 40 N after that gradual wear took place. Thrust force at the end of 60th hole is 60 N. After that the force raised steeply because of rapid wear.



(a)

(b) (c)

Fig 8 Worn out regions of (a) Twist drill (b) Zhirov point (c) Multifacet drill

Figure 8 shows the worn out regions of the drill points. When the tool wear was observed using Tool maker's microscope, uniform wear on the flank region was observed in standard twist drill. After the end of its tool life, a wear land of 0.15mm was measured on its flank with minute chipping along the lips. In the Zhirov point drill, cutting edge near the groove (Cutting edges ground to replace chisel edge) may worn out rapidly that could have led to rapid increase in thrust force. Flank wear at the extreme end was 0.1 mm. Higher tool wear in multifacet drill at the end of cutting edge was observed, because of its sharp edge at the periphery. In all the drills along the cutting edges minute chipping was observed because of cutting hard glass fibers. Zhirov point could drill with lower thrust force and more number of holes, whereas multifacet drill cuts the hole with out any fibre pull out.

VIII SUMMARY

In drilling of composites, high spindle speed and low feed rate can be used effectively to improve production rate within the range examined. The cutting force is less (thrust force and torque both recorded a very low value). The special geometry improves the quality of the hole further, especially Zhirov point drill. From the experimental results, (Fig 7) standard twist drill and Zhirov point drill were found suitable for producing more number of holes at high spindle speed with low feed rate.

Multifacet drill cuts the hole better than other drill geometries. The special characteristic of the drill is the extreme sickle-form design of the cutting edges. This pre-stresses the fibers in the direction of pull and separates them in the direction of thrust. This results in a clean cut with a smooth surface. The delamination is less compared to other drill geometries.

Zhirov drill produces better surface finish (3-5µm) at lower feed rate. The outer most lip produces thin chips which improve the finish of the hole. Multifacet drill also generates better surface finish at lower feed rate when compared to standard twist drill. With high speed drilling a considerable reduction in thrust force can be seen, however the drilled hole exhibits higher order surface roughness and only a marginal difference in delamination factor possibly due to higher order drilling temperature.

In standard twist drill, thrust force at the beginning of the cut increases sharply because of initial wear. Initial wear is up to 10 holes and after that gradual wear has takes place. Thrust force at the end of 325th hole is around 60 N. In Zhirov point drill, thrust force increases sharply because of initial wear. Initial wear is up to 25 holes and after that gradual wear has taken place. Thrust force at the end of 340th hole is 30 N. In multifacet drill within 10 holes thrust force increases rapidly from 10 N to 40 after that gradual wear takes place. Thrust force at the end of 60th hole is 60 N. After that the force rises steeply because of rapid wear.

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