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Experimental Study of Influence of Drilling Tool Geometry for Hybrid Composite Materials

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Abstract: *Precision in mechanical fastening plays a major role in joining of engineering structures. Reliability of the fastening process depends on the hole geometry. With the advent of technology in materials science, hybrid composites are considered materials of great potential for engineering applications. One advantage of hybrid composite materials for the designer is that the properties of a composite can be controlled to a considerable extent by the choice of fibres and matrix. As tool geometry plays a major role in producing a quality hole with minimum damage. Hence it is important to thoroughly investigate the drill bit performance in terms of producing a better hole quality. This paper discusses the influence of drilling tool geometry on hole geometry in hybrid composites. Surface quality was evaluated in terms of surface roughness. Two different double point angles with different helix angles along with conventional twist drill are experimented. The experimental results show that delamination free drilling process may be obtained by the proper selections of drilling tool geometry and the process parameters. It is found that the crossed influence of the point angle and helix angles are significant to the thrust force. Also, cutting parameters i.e., spindle speed and feed rate are checked showing the feed's dominant influence on surface damage.*

Keywords: *Drilling, Tool geometry, hybrid composites, hole geometry, surface quality*

I. Introduction

Composite materials are replacing engineering metals and alloys for many applications. Their inherent ability to be custom tailored for any application has made fibre reinforced composite a very viable material option. Their superior specific weight to stiffness ratio has made them available for critical applications like aerospace, automotive and defence. Machining composite materials differs significantly in many aspects from machining of conventional metals and their alloys [1]. The mechanism of machining composites has been recognized as a process different from that of conventional materials. A suitable selection of cutting conditions is difficult due to the coexistence of hard abrasive fibers and a soft matrix. Due to the presence of two or more dissimilar phases, composite materials pose great challenges during machining Velayudham et al. [2]. In the machining of composites, the material behaviour is not only non-homogeneous and anisotropic, but also depends on diverse reinforcement and matrix properties, and the volume fraction of the matrix and reinforcement.

The tool encounters alternately matrix and reinforcement materials, whose response to machining can be entirely different. Thus, machining of composite material imposes special demands on the geometry and wear resistance of the cutting tools [3]. Among the machining operations, drilling is the most widely followed machining technique, as numerous holes must be drilled in order to use mechanical fasteners for assembly. Several types of damage can be introduced during drilling operations: matrix cracking, fibre pull out and fuzzing, interlaminar cracks and delamination in addition to geometrical defects commonly found in metal drilling.

Drilling fibre reinforced laminated composites requires special tools and techniques to control the hole quality. It is reported that the degree of surface damage is strongly dependent of the cutting parameters, especially feed rate during drilling of composite laminates [4]. It has also been observed that the level damage is related to the thrust force, and that there is a critical value of the thrust force below which the delamination is negligible [5]. Chen [6] studied the variation in cutting forces with or without onset of damage during drilling and concluded that the damage-free drilling may be obtained by the proper selection of tool geometry and drilling parameters. It is seen that all the machining strategies are focusing to thrust force, the vital factor which contributes for delamination. Thrust force can be minimised mostly by altering the tool geometry and adopting controlled feed rates, but controlling the feed rate may lead to reduced productivity and thus altering the tool geometry would be the better option to control the thrust force. Among the drill point geometry parameters the chisel edge and point angle have a major influence on the magnitude of thrust. It is reported that chisel edge contribute well in excess of 50% of the total thrust [7] produced during drilling. The mechanics of drilling composite materials has been examined along with the quality of the hole and the effect of tool design parameters. The fibrils or fuzz caused by conventional tools, which cut the holes in the centre and force chips against walls, can be significantly reduced. The drill geometry is considered to be the most important factor that affects drill performance [8,9]. Damage development and detection, new tooling design, and the influence of cutting conditions have been studied [10–14]. Palani kumar et al. [15] reported that delamination decreases as spindle speed increases and a combination of high speed, low feed and point angle of the tool could reduce delamination to a greater extent. Gaitonde et al.[16] studied the delamination tendency with respect to cutting speed, feed rate and point angle. Influential parameters on delamination were analyzed through 3D response surface plots it is reported high-speed cutting plays a major role in reducing damage at the hole entrance. Abroa et al. [17] presented a survey on drilling of carbon and glass fibre composites results reveal that the phenomena associated to shearing of polymeric composite materials require additional studies in order to have a better understanding of these materials. Thus the main objective of the present work is to study the influence of various drill point geometries on thrust and thereby the hole geometry while drilling. Roundness and cylindricity are measured by Co-ordinate measuring machine whereas the surface roughness of the drilled hole is measured using Mitutoyo surface roughness meter.

II. Experimental Procedure

Two new tools are developed to drill holes using existing machines with minimum damage to the machined surface and to assess the damage of drilled hybrid composite laminates. Holes are drilled with optimum speed and feed using conventional twist drill and the newly developed drill bits. Point angle and Helix angle are changed to observe the influence of drill geometry on the hole geometry. The conventional twist drill specifications i.e., Tool 1 are 2 flutes, 30° Helix angle, 2 mm web thickness, 118° point angle. The design specifications of the newly designed tools i.e., Tool 2 and Tool 3 are Solid carbide Twist drill with 2 flutes, 30°helix angle, 2 mm web thickness, 120° and 90° double point angles and Solid carbide Twist drill with 2 flutes, 20^0 helix angle, 2 mm web thickness, 120^0 and 180^0 double point angles. The twist drill Tool 1 and the newly designed tools i.e., Tool 2 and Tool 3 are shown in Fig. 1, 2 and 3 respectively.

Fig. 1. Conventional Twist drill (Tool 1)

Fig. 2. Newly developed drill (Tool 2)

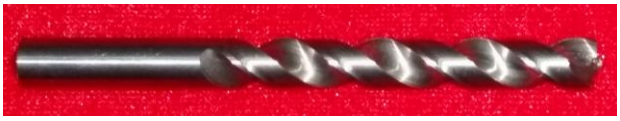

Fig. 3. Newly developed drill (Tool 3)

Fig. 4. Experimental set-up

Drilling tests are conducted under different drilling conditions on FANUC CNC machining center on the workpiece with different drilling bits. The thrust force for different cutting conditions is measured using digital drilling tool dynamometer. A vacuum blower is used to remove the dust and powder particles generated during drilling. The general arrangement of the experimental set-up is shown in Fig. 4. The Coordinate Measuring Machine (CMM), model GX600 is used to measure the roundness and cylindricity of the drilled holes as depicted in Fig. 5. The Mitutoyo surface roughness tester was used to measure the surface roughness of the drilled hole.

III. Results And Discussions

It is infered from the Fig. 6. that the thrust force is minimum when the hole is drilled by Tool 2. The thrust force is maximum for Tool 1. This is mainly due to higher web thickness of conventional point drill. During drilling with conventional drill, instead of cutting, the chisel edge of the drill point pushes aside the material at the centre as it penetrates into the hole. In addition, the cutting action at the chisel edge region is extremely poor due to large negative rake angles and low cutting speeds leading to indentation process very close to the drill axis where the dynamic clearance angles are negative. As a consequence, the chisel edge is subjected to high cutting forces.

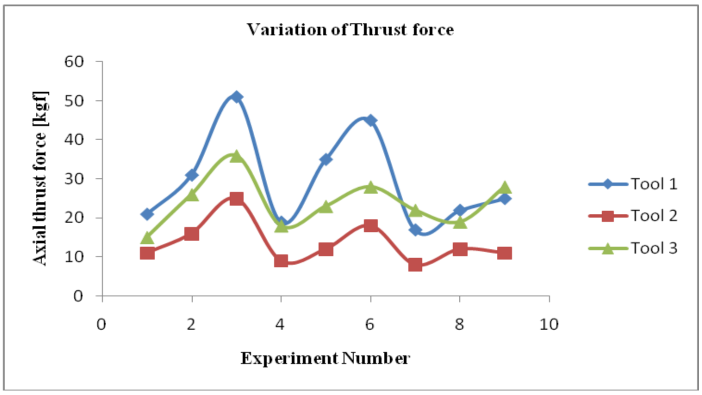

Fig. 6. Experiment Number Vs. Axial thrust force [kgf]

The thrust experienced by the Tool 2 geometry drill is less than the conventional twist drill. The basic cutting mechanism of point geometry is the main reason for this reduction. Due to positive radial rake angle, the radial component of the cutting force pulls the fibre from the outside diameter towards centre. At the same time, the axial rake angle at the periphery of the tool has a high positive value, due to which the fibres are also subjected to an axial force directed upwards, which induces a decrease of total thrust force. Observations on thrust indicate
Tool 2 geometry drill perform better comparing other drills.

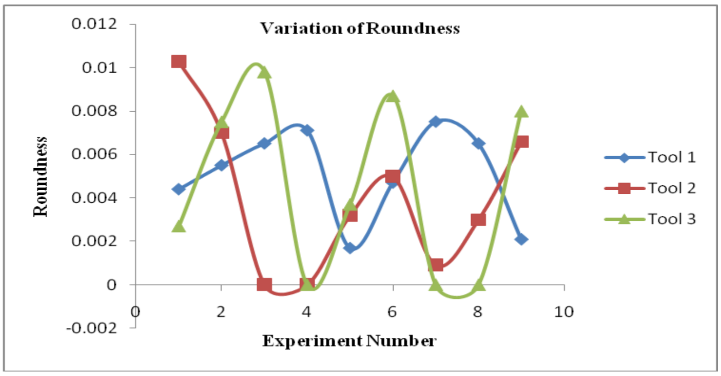

Fig. 7. Experiment Number Vs. Roundness

It is infered from the Fig. 7. that roundness of the hole drilled by Tool 3 is better compare to the other drills. At high speed and high feed roundness increases but the roundness decreses as the drilling progresses mainly due to the decrease in eccentricity of the drill bit. It can also be seen that the roundness is zero for the holes drilled by newly developed tools for experiment numbers 4 and 7 as per the standard trial order.

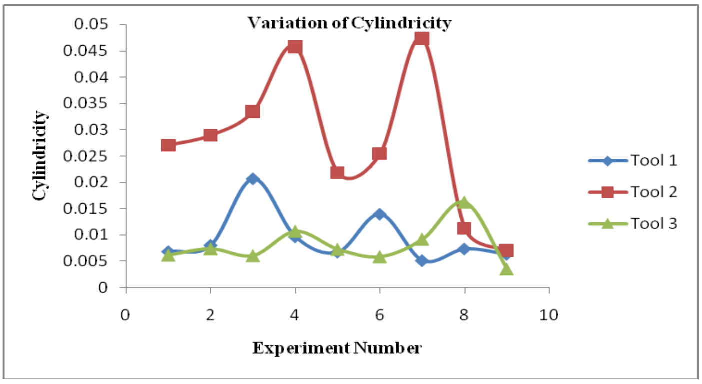

Fig. 8. Experiment Number Vs. Cylindricity

It is infered from the Fig. 8. that the devation in cylindricity of the drilled hole obtained by Tool 3 is less compare to the other drills. As the drilling progresses the deviation is decreased except for experiment number 8. The deviation in roundness obatined by Tool 2 is more than the conventional twist drill but at high speed and high feed both the tools almost gives the same value.

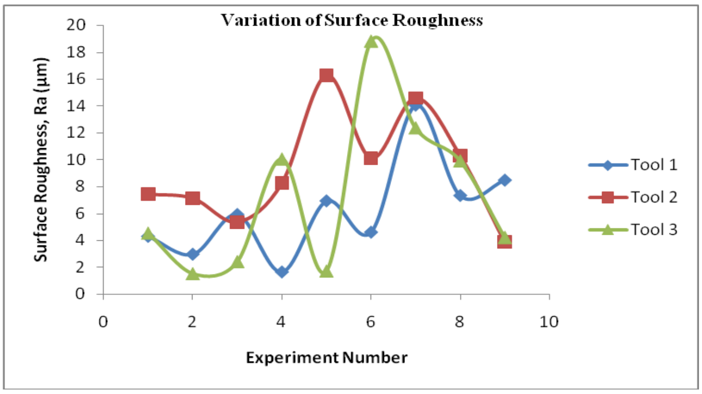

Fig. 8. Experiment Number Vs. Surface Roughness, R_a (µm)

From Fig. 8 it can be realized that the surface roughness increases with increase in speed and feed first and the decreases. It is observed that Tool 3 gives better surface finish compare to the other tools. Also it is observed that lower surface roughness of the drilled hole wall can be obtained with medium feed (0.13 mm/rev) and low speed (640 rpm). From Table. 3. it is observed that experiment no. 2 gives minimum surface roughness. The surface roughness decreases as the feed rate increases but decrease with increasing chisel edge, such as might arise due to tool wear. The surface roughness was measured along the drilling direction using a Mitutoyo 301 Surface roughness tester. There is slight overall increase in the roughness values at 1120 rpm, 0.20 mm/rev and there is a decrease in the surface roughness for those tests conducted at 640 rpm, 0.13 mm/rev. This is possibly due to the influence of primary relief angle and the flute at this speed, which gives rise to a rounding of the cutting edge leading to a slight reduction in roughness. Fig. 8. shows the variation of surface roughness at different speeds and feeds. Feed rate clearly affects the surface roughness; speed is only of minor influence. In general the values recorded for surface finish were better than the expected for this type of drilling operation. This is because of the burnishing effect produced by the rubbing action of the drill on the sides of the drilled hole. There was evidence of burnished surfaces at various locations within each drilled hole. These results can also be influenced by the number and orientation of fibres that are within the stylus evaluation length.

IV. Conclusions

Conclusions drawn from the experimental work are:

- It is observe that the newly developed drill bit i.e., Tool 3 presents a better performance than the conventional drill bit under the same conditions (i.e., spindle speed and feed rate).
- Low feed rates are appropriate for hybrid composites drilling, as it reduces the thrust force. However, it will result in thermal degradation of the matrix and may not be suitable for industrial processes where productivity is of importance. Large helix angle in the Carbide drill significantly reduces the thrust force.
- The surface roughness obtained by Tool 3 is less than obtained by conventional drill bit i.e., Tool 1 and newly developed drill bit i.e., Tool 2.

- Tool 3 provides good surface finish at high cutting speed and feed rate, because the work done is more due to lower helix angle which facilitates the initial penetration.
- Considering the parameters used in this work, a speed of 1760 rpm with a feed rate of 0.08 mm/rev produced better hole geometry.
- The drilling tool geometry has an influence on the results used for evaluation of hole quality.
- Tool geometry and machining parameters are important aspects that are to be considered while drilling hybrid composites, when the quality of the machined hole is important.

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