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Effect of process parameters on drilling of woven glass fibre / polyester composites

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ABSTRACT

Glass Fibre Reinforced Plastic (GFRP) composite materials have wide applications in recent times due to their superior properties such as high specific strength and specific stiffness. These materials are most important and economic alternative to conventional materials. The main objective of this research is to analyse the experimental observations during drilling of Glass Fibre Reinforced Plastic composites using helical flute straight shank drill and 'Brad and Spur' drill. The process parameters such as feed rate and cutting speed are considered for the experiment. The performances of drilling process are measured and analyzed in terms of thrust force, torque, delamination and specific cutting pressure. The effects of process parameters on the drilling performances are investigated in this study. It was observed from the analysis that thrust force and torque increases with feed rate, due to their increasing in shear area. Also the delamination factors (peel up & push out) increases with increase in thrust force. Specific cutting pressure during drilling shows the opposite trend to that of thrust force and torque.

Key words: drilling thrust force, torque, delamination.

Abbreviation: GFRP - Glass Fibre Reinforced Plastic

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1. INTRODUCTION

Recently, the use of Fiber Reinforced Plastic (FRP) composite materials has increased in various engineering field due to their superior physical and mechanical properties such as high specific strength and high specific stiffness. FRP composites are widely used in mechanical joins in structure of aircraft and bridges (Ravishankar et al. 1996). Drilling of these FRP composites can be considered critical phenomena due to their tendency to delaminate when subjected to mechanical stresses. To overcome these difficulties, it is necessary to develop standards to select proper drilling process parameters. Fact that improper selection of process parameters leads to unacceptable work material degradation such as delamination, burrs, swelling, splintering and fiber pullout. Delamination is considered the major concern in FRP composite materials. The size of the delamination zone is determined by the thrust force developed during the drilling process (Koening et al. 1995). The studies on drilling of composite materials are carried out by many researchers. Ogawa et al. (1997) formulated the relation between the cutting force and the surface roughness of a drilled hole wall in small diameter drilling GFRP for a printed wiring board. They concluded that the major cutting edge of the drill is having more influence than the chisel edge of the drill in the quality of the drilled hole. A damage-free drilling process may be obtained by the proper selections of tool geometry and cutting parameters (Chen, 1997). The thrust force and torque increased with drill diameter and feed rate, due to the increase in the shear area, and also increasing cutting speed resulted in higher thrust force and torque, however, not to the same extent as when feed rate is elevated (Ei-sombath et al. 2004; Mohan et al. 2005). The drill run-out causes the thrust force to increase, consequently resulting in more severe delamination of the work piece (Tsao et al. 2003). The drilling induced delamination increased with feed rate and cutting speed and that the cemented tungsten carbide drill outperformed the high-speed steel material when machining under the same cutting conditions (Davim et al. 2003). When comparing the cemented tungsten carbide drills, the twist drill presented lower delamination factor compared to the four flute drill. Moreover, is contrast to the high speed steel drill, the carbide tools did not present any appreciable wear throughout the experimental work. The first analytical model to determine the critical thrust force of the twist drill was formulated by Hocheng and Dharan (1990). They employed linear elastic

Delamination:
When the bond between fibers and resin, or the fibers themselves outside the edge of the hole, or beyond a cut edge are fractured, causing an area of the composite to peel away from the main structure. These areas can potentially act as a starting point for mechanical fracture, so we optimize tool geometry and cutting conditions to limit delamination as far as possible.

Fiber pull out:
The defects caused when a machining tool catches a fiber within the composite, and causes it to break well away from the hole edge. Unlike splintering and delamination, these defects are not usually seen in the top and bottom layer of a composite, rather within the thickness.

Control factor and performance measures
The set of input variables of any process which influences the process performance of that process. Proper selection of control factor values will determine the optimum value of process characteristics.

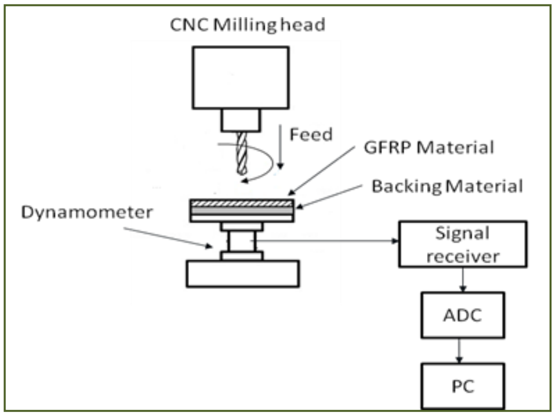

Figure 1
Experimental setup (three axis CNC vertical milling machine)

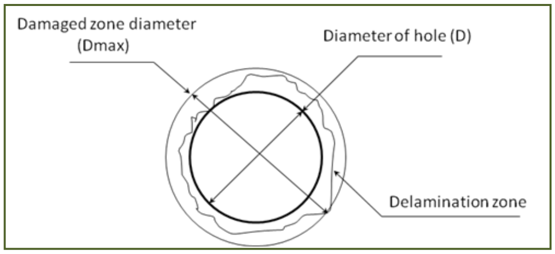

Figure 2
Scheme of delamination

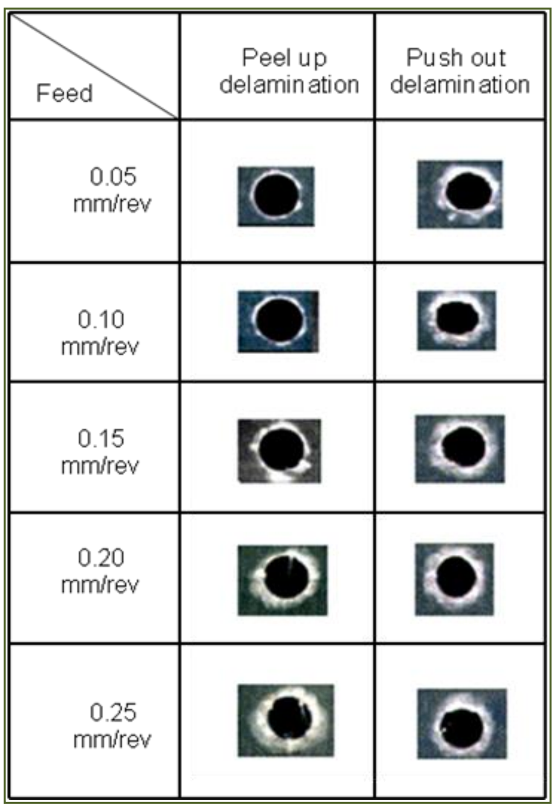

Figure 3
Typical Photographs illustrating the peel up and push out delamination at V=35m/min

$$F_d = D_{max}/D,$$

Table 1
Mechanical properties of GFRP (polyester) composite

Properties	Value	Unit
Tensile strength	54	N/mm^2
Tensile modulus	3600	N/mm^2
Tensile elongation	7	%
Flexural strength	104	N/mm^2
Barcol Hardness	42	-
Izod Impact	7	kJ/m^2

Table 2
Levels of drilling parameters

Control factor	Level 1	Level 2	Level 3	Level 4	Level 5
Cutting speed (m/min)	15	20	25	30	35
Feed rate (mm/rev)	0.05	0.10	0.15	0.20	0.25

fracture mechanics and solved for the critical thrust force that relates the delamination of composite laminates to drilling parameters and composite material properties.An approach combining Taguchi's method and multi-objective optimization criterion was developed to obtain the optimum drilling conditions for delamination-free drilling in composite laminates (Ugo Enemuoh et al. 2001). The performance of the trepanning tool is superior to that of conventional twist drills in terms of thrust force, torque and hole quality (Mathew et al. 1999). The damage on drilling holes of small diameter in printed circuit boards and analyzed that the delamination cause of generation of the ion migration is generated along the fiber in the hole wall surface where the surface roughness increases (Aoyama et al. 2001). The interaction mechanisms between drilling tool and work piece was compared and the results obtained are useful in describing the history and helping design drill geometries specifically conceived for composite machining (Caprino et al. 1995). A model was proposed to link the axial penetration of the drill bit to the conditions of delamination of the last few plies in a composite laminate (Lachaud, 2002). The main objective of this paper is to examine the influence of cutting parameters , such as cutting speed and feed rate on thrust force, torque, specific cutting pressure, and delamination factor during drilling of GFRP composite using helical flute straight shank and 'Brad and Spur' drills.

2. EXPERIMENTATION

2.1. Workpiece Material

The glass/polyester laminates were prepared by 12 layers of woven WFG 200 fabric glass fibre prepregs by hand layup process. The GFRP laminates were 3mm in thick (Table 1).

2.2. Evaluation of thrust force and torque

Drilling experiment was conducted on a three-axis CNC vertical milling machine shown in Figure 1. To neglect the effect of drill wear only one set of experiments were conducted using new helical flute straight shank and 'Brad and Spur' drills with 6mm diameter. The two axis dynamometer is mounted on a table had a fixture to hold a composite laminate specimen for the drilling experiment. Thrust force and torque during machining were measure by piezoelectric dynamometer. The charge amplifier converts the resulting charge signals, which are proportional to the force, to voltage and managed through the data acquisition system. Experiment conditions were repeated three times to get consistent value.

2.3. Computation of delamination

The specimen was placed directly on the glass plate of the flat bed scanner. The photo of the drilled specimen was obtained. Shadow zone was clearly observed around the drilled hole due to the transmitted light through it by using the corel Draw software. The shadow zone indicates the delamination size. Delamination at entrance (peel up) and at exit (push out) can be determined. The damage of hole was denoted by the delamination factor F_d. The scheme of delamination shown in Figure 2.

2.4. Experimental Approach

Experiments were conducted at full factorial design. The performance of GFRP composite in drilling were studied by conducting various drilling experiments using Helical flute straight shank and 'Brad and Spur' drill. To analyse the presence any non-linearity in the machining experiment five levels are considered. Although many factors affect the drilling process, the machining parameter such as cutting speed, feed rate and drill diameter are the important parameters. For this work, only cutting speed and feed rate are considered at five levels. Table 2 shows the process parameters considered, its symbol and its levels.

3. EXPERIMENTAL ANALYSIS

Delamination factor F_d:
The value of delamination factor (F_d) can be obtained by the following formula;

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Unsaturated Polyesters:
Unsaturated polyesters can claim to be among the first of the many synthetic resins which are now the basis of the composite materials industry. These are formed by condensation of polyhydric alcohols and polybasic acids (one of them must contain non-aromatic unsaturation) and it is cross-linked with a polymerizable monomer such as styrene monomer.

Feed rate:
The speed at which a drill moves through a material (or a cutter moves into a material). Generally, for composites, try to maintain a low feed, as this keeps thrust forces low, and avoids delamination. However, feed rate also determines the temperature reached during cutting, with lower feeds meaning higher temperatures, so this strategy may not be suitable for low melting temperature resins.

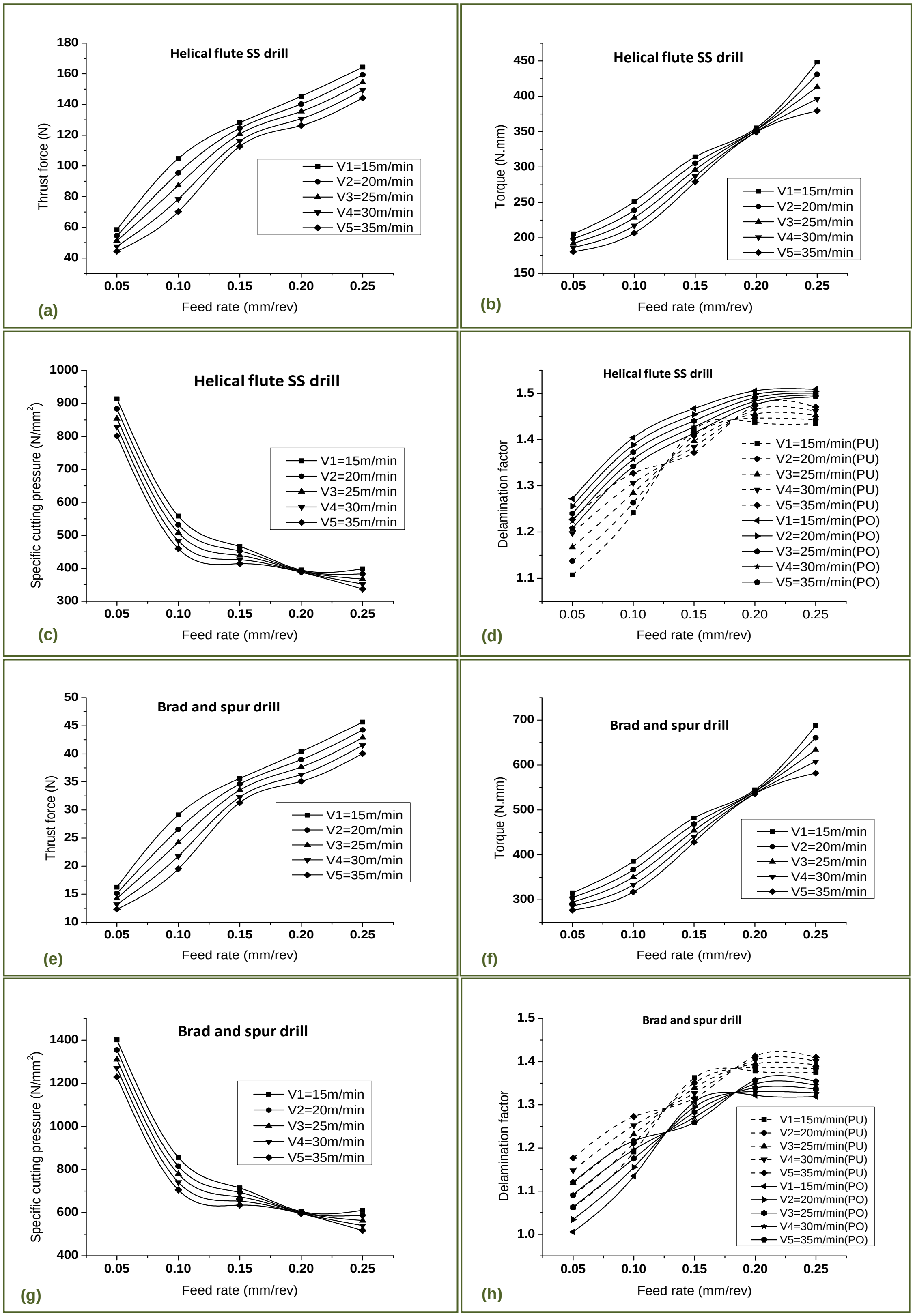

Figure 4

a-d Effect of feed rate on thrust force, torque, specific cutting pressure and delamination factor for helical flute SS drill; e-h Effect of feed rate on thrust force , torque, specific cutting pressure and delamination factor for Brad and spur drill

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where D_{max} the maximum diameter of the damage zone in mm and D the diameter of hole in mm. The value of specific cutting pressure (K_c) and power consumption (P) also calculated. Typical Photographs illustrating the peel up and push out delamination at V=35m/min is shown in Figure 3.

4. RESULT AND DISCUSSION

Thrust force:
The force produced during drilling parallel to the direction of drill movement. High thrust force has frequently been blamed for causing delamination; however, our experiments have shown that there is not always a direct relationship. Some higher thrust geometries can still produce delamination-free holes, and vice versa. Thrust force can be reduced by optimizing drill geometry, or by minimizing feed rate.

Thrust force and torque generated during the drilling process shows an increasing trend with feed rate for the both the types of drills namely helical flute SS drill and 'Brad and Spur' drill (Figure 4). For the same feed rate the thrust force is maximum for helical flute SS drill than Brad and spur drill. This attributed to the fact that the contact area is more during drilling in case of helical flute SS drill. The maximum torques was observed for Brad and Spur drill than helical flute SS drill at higher feed rates. The specific cutting pressure shows a decreasing trend for both the drills. The maximum specific cutting pressure is noticed at minimum feed rate and minimum cutting speed for both the drills. At higher feed rates, the influence of cutting speed for the both the drills is insignificant. The delamination factor is measured for two conditions such as peel up and push out and observed that the delamination factor for the both the conditions increases with feed rate irrespective of the type of drills. The maximum delamination factor was observed for helical flute SS drill. The variation in the delamination factor is more significant for helical flute SS drill whereas less significant for Brad and Spur drill. This may be due to increase in contact between drill and laminate along its thickness incase of helical flute SS drill.

5. CONCLUSION

Based on the methodology used and experimental results, the following conclusions can be drawn from drilling GFRP composite using helical flute SS drill and 'Brad and Spur' drill:

- Thrust force and torque increases with feed rate for all cutting speeds
- Specific cutting pressure decreases with feed rate for all cutting speeds
- Delamination factor under peel up and push out conditions increases with feed rates for all cutting speeds. Variation of delamination factor between the two conditions is very insignificant for 'Brad and Spur' drill than helical flute SS drill.

SUMMARY OF RESEARCH

The experimental observations such as thrust force and specific cutting pressure during drilling of Glass Fibre Reinforced Plastic composites using helical flute straight shank drill and 'Brad and Spur' drill was analyzed. The process parameters such as feed rate and cutting speed are considered for the experiment. The effects of process parameters on the drilling performances such as thrust force, specific cutting pressure and delamination factor (peel up and push out) are investigated in this study. Thrust force and torque increases with feed rate, due to their increasing in shear area also the delamination factors (peel up & push out) increases with increase in thrust force. Specific cutting pressure during drilling shows the opposite trend to that of thrust force and torque.

FUTURE ISSUES

Further research work can be carried out to measure the surface roughness and roundness of the drilled hole. The drilling process can be optimized by using any one of the optimization techniques to find the optimum value of control factors.

DISCLOSURE STATEMENT

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