EXPERIMENTAL INVESTIGATION ON DRILLING OF GLASS FIBRE REINFORCED PLASTIC (GFRP) COMPOSITES

Ragothaman A.[1], Vijayaraja K.[2], Mudhukrishnan M.[3]

[1]Research scholar, Department of Mechanical Engineering, Sathyabama University, Chennai, India
[2] Department of Aeronautical Engineering, Tagore Engineering College, Chennai
[3] Department of Mechanical Engineering, R.M.K. Engineering College, Chennai
Email: [1]ragomaan@gmail.com

Abstract

The applications of Glass Fibre Reinforced Plastic (GFRP) composite materials are very attractive due to their superior properties such as high specific strength and specific stiffness. These materials are most important and economic alternative to Engineering materials. The main objective of this work is to evaluate the performance characteristics of drilling Glass Fibre Reinforced Plastic composites. The experiments are conducted for a full factorial design on this GFRP laminates using helical flute straight shank drill and 'Brad and Spur' drill. The control factors considered during drilling are feed rate and cutting speed. The performances of drilling process are analyzed in terms of thrust force, torque,delamination and specific cutting pressure. The effects of control factors on the drilling performances are investigated in this study. The result shows that thrust force and torque increased with feed rate, due to their increasing in shear area. Also the delamination factors (peel up & push out) increased with increase in thrust force. Specific cutting pressure during drilling shows opposite trend to that of thrust force and torque.

Key words: GFRP, drilling, thrust force, torque, delamination

I. INTRODUCTION

Fibre Reinforced Plastic (FRP) composites are finding increasing applications in automotive, aerospace, machine elements, chemical industry and many other areas. Drilling is the most frequently employed operation for the final assembly of the components. In the aircraft industry, drilling-associated delamination accounts for 60% of all part rejections during final assembly of an aircraft [1]. The drilling of laminated composite materials by conventional tools, have shown that the quality of the cut surfaces is strongly dependent on the drilling process parameter, tool geometry and tool material [2-4]. The proper selection of these parameters can be lead to acceptable machining characteristics. Unacceptable material degradation, such as delamination, thermal damage, fiber pull-out and matrix cratering cab be eliminated or minimized by the proper selection of machining conditions. The delamination-free drilling process may be obtained by the proper selections of tool geometry and drilling parameter [5]. A high feed rate of drilling will cause a crack around the exit edge of the hole [6]. An increase of the cutting velocity leads to an increasing drill wear that in turn provokes it an increase in the thrust force at high speed drilling [7]. Researchers have studied analytically and experimentally how delamination in drilling is correlated to the thrust force below which no damage occurs [8]. A rapid increase in feed rate at the end of drilling will cause the cracking around the exit edge of the hole [9]. It was also stated that the larger the feeding force, the more serious the cracking. A helical drill and drill of special geometry leads to damage at the entrance in the wall and the exit of the hole, with the exception of special geometry drill which is possible to cause a significant reduction in the final damage while drilling of glass fibre composites [10]. The first analytical model to determine the critical thrust force of the twist drill was formulated by Hocheng and Dharan [11]. They employed linear elastic 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 [12]. The performance of the trepanning tool is superior to that of conventional twist drills in terms of thrust force, torque and hole quality [13]. The damage on drilled holes of small diameter in printed circuit boards are analyzed that the delamination was caused due to generation of the ion migration along the fiber in the hole wall surface. This lead to increased surface roughness [14]. 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 [15]. 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 [16]. 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.

II. EXPERIMENTAL APPROACH

A. Material

The glass/epoxy laminates were prepared by 12 layers of woven WFG 200 fabric glass fibre prepregs, LY556 epoxy resin and HY951 hardner using hand layup process with 0.5 weight fraction. The GFRP laminates were 3mm in thick. The GFRP composite mechanical properties are given in Table 1.

Table 1 Mechanical properties of GFRP composite

Properties	Value	Unit
Tensile strength	2200	N/mm^2
Tensile modulus	78000	N/mm^2
Tensile elongation	2	%
Flexural strength	60000	N/mm^2
Barcol Hardness	72	–
Izod Impact	360	kJ/m^2

B. Measurement of thrust force and torque

Drilling experiment was conducted on a three-axis CNC vertical milling machine shown in the 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' with 6mm diameter HSS drills. The two axis piezoelectric dynamometer is mounted on the table and fixture to hold a composite laminate specimen during the drilling experiment. Thrust force and torque during machining were measured by the dynamometer. The charge amplifier converts the resulting charge signals, which are proportional to the force, to voltage and managed through the data acquisition system.

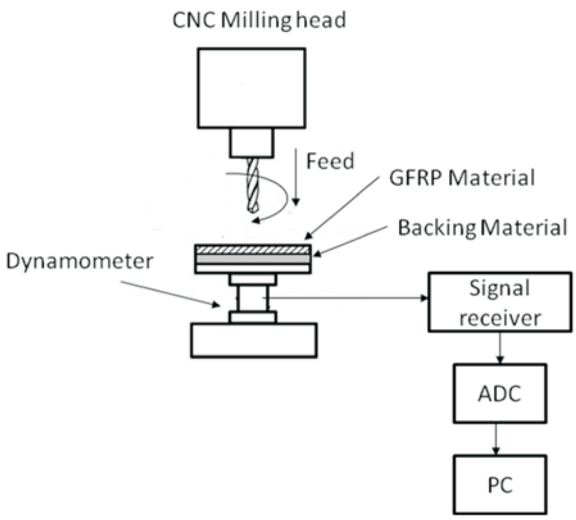

Fig. 1. Experimental setup (three axis CNC vertical milling machine)

Experiment conditions were repeated three times to get consistent value.The specific cutting pressure (K_c) and power consumption (P) were also calculated. The specific cutting pressure will indicates the nominal cutting stress on the rake face of the drill bit.

C. Measurement 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, which is calculated using equation (1).

$$F_d = D_{max}/D \qquad ...[1]$$

Where, D_{max} the maximum diameter of the damage zone in mm and D the diameter of hole in mm. The scheme of delamination is shown in figure 2.

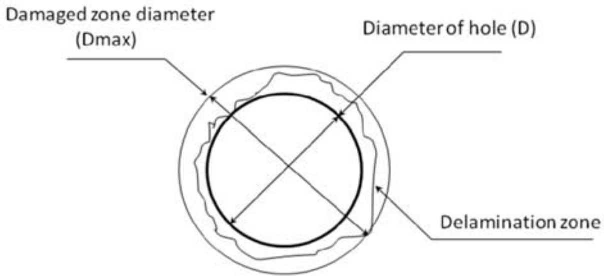

Fig. 2. Scheme of delamination

D. Plan of Experiments

Experiments were conducted at full factorial design. To achieve this L_{25} orthogonal array was used. The performance of GFRP composite in drilling were studied by conducting drilling experiments using helical flute straight shank and 'Brad and Spur' drill. To analyse the presence of any non-linearity in the machining, 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 and its levels.

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

III. RESULTS AND DISCUSSION

Typical Photographs illustrating the peel up and push out delamination at $V = 35$ m/min is shown in figure 3.

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. 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

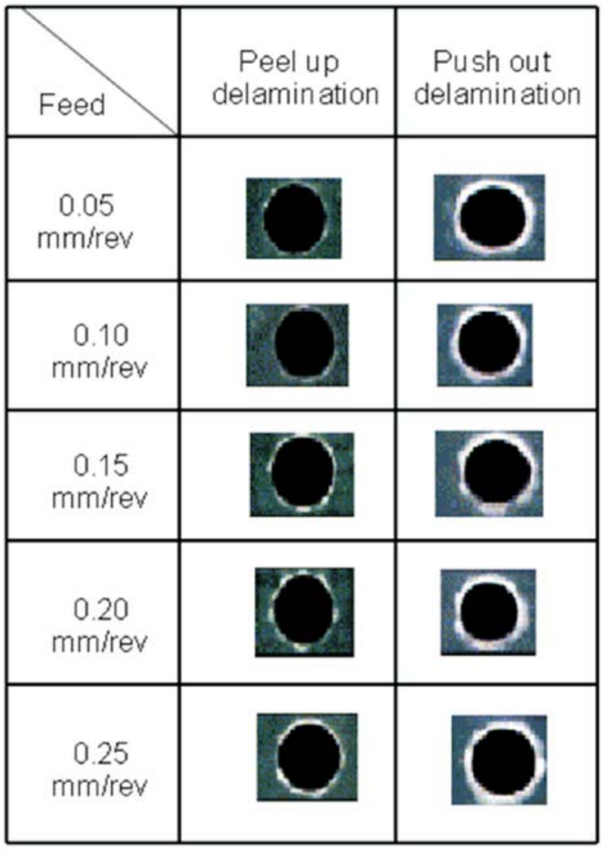

Fig. 3. Typical Photographs illustrating the peel up and push out delamination at $V = 35$ m/min

observed for Brad and Spur drill than helical flute SS drill at higher feed rates as shown in Figs. 4 and 5.

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 are 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.

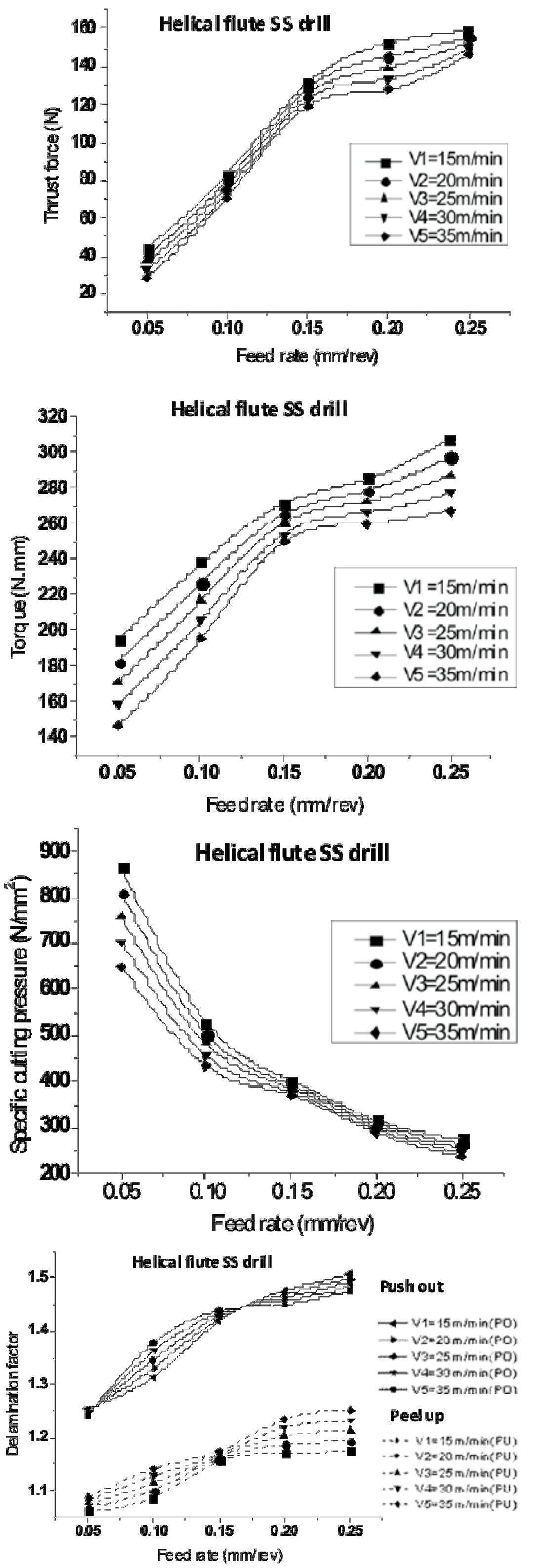

Fig. 4. a-d Effect of feed rate on thrust force, torque, specific cutting pressure and delamination factor for helical flute SS drill

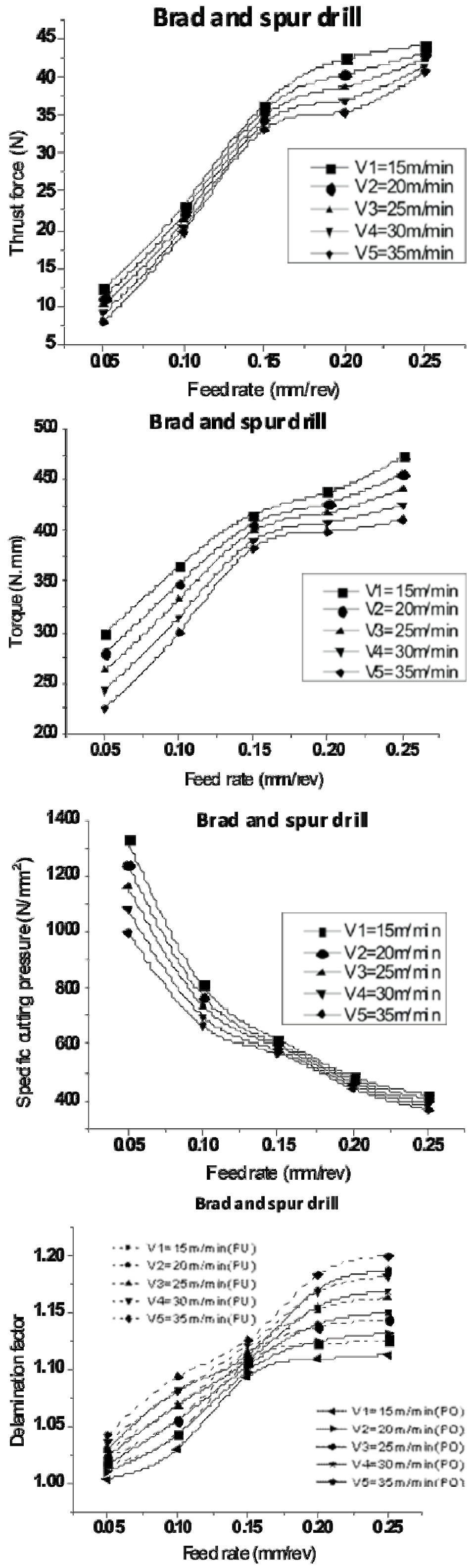

Fig. 5. a-d Effect of feed rate on thrust force, torque, specific cutting pressure and delamination factor for Brad and spur drill

IV. CONCLUSION

Based on the methodology used and experimental results, the following conclusions can be drawn;

- 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 (peel up & push out) is very insignificant for 'Brad and Spur' drill than helical flute SS drill.

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A. Ragothaman received his B.E. degree in Mechanical Engineering from Adichun chanagiri Institute of Technology, Karnataka in 2000 and M.E. degree in Computer Aided Design from Sathyabama University, Chennai, Tamilnadu. His research interest area is on composite materials, presently doing Ph.D work on the same field at Sathyabama University, Chennai, Tamilnadu. Currently, working as Manager, Research and Development Department for Ashok Leyland, Chennai.