MACHINING QUALITY OF CARBON FIBER REINFORCED PLASTICS WITH DIFFERENT DRILLS

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1 Introduction

With the development of fabrication of advanced materials, Carbon Fiber Reinforced Plastics (CFRP) has been used extensively in many industries due to its superior specific strength and high temperature resistance, high corrosion resistance and good thermal shock resistance. The CFRP parts are usually made as near-net-shape parts, but drilling is the most frequently employed operation due to the need of structure. Because of the inherent anisotropy, inhomogeneous properties of CFRP and low bonding strength within the laminates, drilling operation has several undesirable effects such as delamination, microcracking, burr, fiber pull out and breakage. Besides the composite itself, the rapidly tool wear caused by high hardness of carbon fiber, also results in the low material removal rate and high machining cost. In order to be able to solve the drilling-induced problems, many researches are concentrated on drilling parameters, geometries and materials of drill[1-4]. V.N. Gaitonde et al. revealed that the delamination tendency decrease with increase in cutting speed, decrease in feed rate and point angle[3]. Hocheng and Tsao analyzed the critical thrust force (onset of delamination) for saw, candle stick, core, and step drills[5]. And they found that core drills offer the highest threshold values for critical thrust forces[6]. Due to the abrasive nature of the CFRP, the service life of high speed steel and carbide drills are short, so the materials of drills should be higher hardness to resist abrasive wear. To solve this problem, PCD and diamond coated carbide drills has been developed to machining CFRP parts[7]. Richard Garrick revealed that the application of PCD veined drills to CFRP/Ti stacks increases tool life and improves hole quality[8].

As above mentioned, most of these researches focused on studies of varied drills, little study was devoted to the brazed diamond core drill in drilling composite materials. With the features of high grain protrusion, large swarf clearance space and high bonding strength, the brazed diamond core drill has the advantages of high sharpness, machining efficiency and grains utilization ratio. In the present study, the brazed diamond core drill was developed and explored to improve the machining quality. The accuracy to size, delamination, roughness of hole wall in drilling CFRP laminates with traditional cemented carbide twist drill and brazed diamond core drill were experimentally investigated. The results indicated that the degree of delamination decrease with the decrease of feed rate, or the increase of spindle speed. The entrance and exit damage type used brazed diamond core drill were different from that used the twist drill due to the direction and the abrupt change of axial force. The roughness of hole wall varied with the feed rate and the drill geometries.

2 Experimental procedures

In this study, the CFRP material is consisted of 15 plies of woven carbon/epoxy prepreg. The composite laminate is 3.6mm thick, and fiber volume fraction is 60%. The experiments were carried out on a numerical-control engraving and milling machine HG410J as shown in Fig. 1. The engraving and milling machine has maximum spindle speed of 24 000rpm and maximum feed rate of 5 m/min.

The diameter of used twist drill was 6mm. The brazed diamond core drill with diamond grits orderly set was made as shown in Fig. 2. The end of the core drill was divided into four segments, and the slots were for discharging chips during drilling. The diameter of brazed diamond core drill used in the experiment was 6mm, and the thickness of the core drill was 1mm. The length of the core drill was 50mm, while the length of the part covered with diamond grits is 2mm. The size of diamond grits plated at the top of the core drill was 40/45 mesh (355~425μm). The brazing alloy was Ag-Cu-Ti.

The drilling tests were executed without coolant at spindle speed of 5000, 8000, 12000 rpm, and feed rate of 0.03, 0.06, 0.1, 0.15 mm/r. The test of

different parameter combinations were replicated three times.

After drilling, the diameters of the drilled holes were measured by a numerical type all-powerful tool microscope JGW-S. To detect the delamination, the drilling holes were permeated with mixed solution with gold trichloride and aether, and resin matrix was removed by burning above 450 degree centigrade in the furnace. Therefore, the carbon fiber would impressed by the gold trichloride if there were delamintion. The delamination images were observed by a digital microscope HIROX KH-7700 and the delamination factor was evaluated. Fig. 3 showed the image of delamination. And the surface quality of the hole wall was observed by scanning electron microscope (SEM) and roughness of the hole wall was measured by a roughness measure instrument Perthometer M1.

3 Results and Discussion

3.1 Diameters Appraisement

Table 1 showed the measured diameters of holes with cemented carbide twist drill and brazed diamond core drill at spindle speed of 8000 rpm and feed rate of 100 mm/min. The diameter tolerance of hole with the brazed core drill was bigger than that of twist drill as shown in table 1. This mainly created by the exposing heights of grits were not identical in the brazed diamond core drill. To improve the quality, the diamond grits must be carefully chosen or use finer diamond grits such as 80/100 mesh. But the measurement indicated that the accuracy to size of drilling holes is able to be guaranteed according to the demand of parts.

With the increase of hole number, the diameter of hole with the brazed core drill hardly changed. However, the diameter of hole with twist drill changed greatly due to the serious wear of twist drill.

3.2 Delamination Analysis

From the observation of the delamination images, the delamination mainly occurred at the first layer and/or second layer on the top or bottom of the hole. There was seldom delamintion in the middle layers.

Fig.4 (a) and (b) showed the results of calculated delamination factor at entrance and exit of hole respectively. From the evaluated results, the delamination factor increased with the increase of feed rate and the decrease of spindle speed in spite of drill styles. From the observation of delamination at entrance the delamination factor used twist drill was bigger than that used brazed diamond core drill. At exit, the delamination factor used twist drill was smaller than that used brazed diamond core drill when the fade rate was above 400mm/min, and the delamination factors with two different drills were alike when the fade rate was less than 400mm/min. The delamination at the entry side of the tool was peel-up style and delamination at the exit side was push-out style (see Fig. 5) used twist drill[9]. But the direction of axial force was down, so the peel-up delamintion used brazed diamond core drill at the entry side seldom occurred (see Fig. 6 (a)). Therefore, the delamination factor was smaller. On the other side, at the exit side, the direction of axial force was also down, so the push-out delamintion used brazed diamond core drill at the exit side occurred like twist drill. Furthermore, the axial force changed abruptly at the exit (see Fig. 6 (b)). The delamintion factors were alike when the fade rate was less than 400mm/min used two different style drills, because the axial force was so small that the change of axial force was too small. But the change of axial force was so abrupt used brazed diamond core drill that the delamintion factor was bigger than that used twist drill when the fade rate was above 400mm/min.

From the fig. 4, the delamintion factor used brazed core drill was small when the fade rate was less than 400mm/min, so the delamination could be avoided by selected the proper machining parameter.

3.3 Roughness of Hole Wall Measurement

The measured roughness results of hole wall were shown in table 2. It showed the roughness value used twist drill was smaller than that used brazed diamond core drill. And the roughness value of hole wall used brazed diamond core drill increases with the increase of feed rate. The smaller roughness used twist drill was attributed to something of the hole surface due to the formation of a recast layer of the matrix as shown in fig. 7 (a). On the other hand, the surface topography used brazed diamond core drill was generated by the traces of the individual abrasive particles on the machined surface as shown in fig. 7 (b). Therefore, surface roughness in abrasive machining was critically dependent on grit size and not highly dependent on feed rate. And each abrasive grit on the brazed diamond core drill acted as a single point cutting edge with a large negative rake angle and a wide edge angle, so the carbon fiber was compressed. Because the size of the diamond grits was big in this paper and the rupture style of carbon fiber was different from the twist drill, the roughness value used twist drill was smaller than

that used brazed diamond core drill. But that don't indicate the quality used twist drill is higher than that used brazed diamond core drill. Because the swarf removal using twist drill is more difficult than using brazed diamond core drill during drill process, the swarf was squeezed into the resin matrix. That may result in the decrease of CFRP performance.
To reduce the value of roughness, the finer diamond grits should be applied and the fade rate should be decreased.

4 Conclusions

Based on the experimental results obtained from the machining quality after drilling CFRP, the following conclusions can be extracted.
(1) The diameter tolerance of hole with the brazed core drill was bigger than that of twist drill. But the size stability of with the brazed core drill was better than that of twist drill.
(2) At entrance the delamination factor used twist drill was bigger than that used brazed diamond core drill. At exit, the delamination factor used twist drill was smaller than that used brazed diamond core drill when the fade rate was big, and the delamination factors with two different drills were alike when the fade rate was small.
(3) The roughness value used twist drill was smaller than that used brazed diamond core drill.

Table 1 the diameters of holes

Process parameter	spindle speed: 8000 rpm feed rate: 100mm/min	
Drill variety	Twist drill	Diamond core drill
Diameter (mm)	6.0154	6.0643

Table 2 the roughness of hole wall

Drill variety	Fade rate	Roughness Ra
Twist drill	150 mm/min	1.67μm
	300 mm/min	1.83μm
	500 mm/min	1.95μm
Core drill	150 mm/min	4.53μm
	300 mm/min	6.75μm
	500 mm/min	8.34μm

Fig.1. Experimental setup

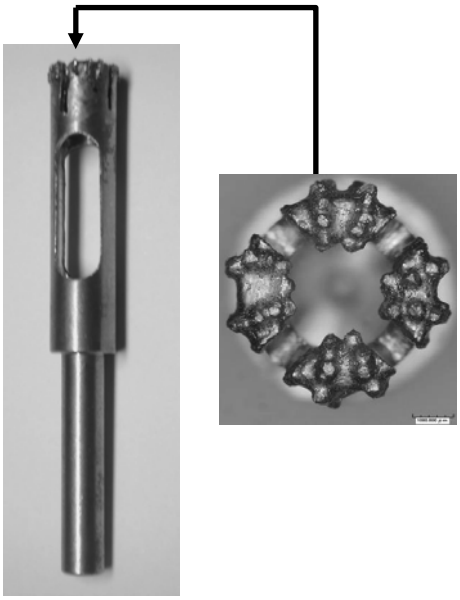


Fig. 2 Brazed diamond core drill

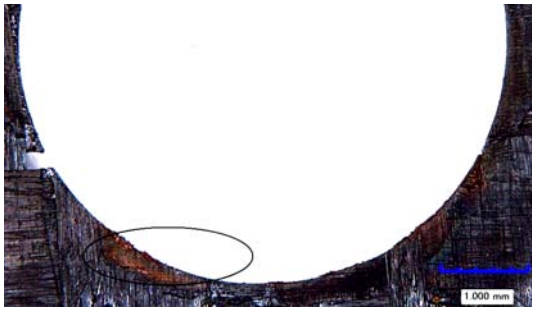
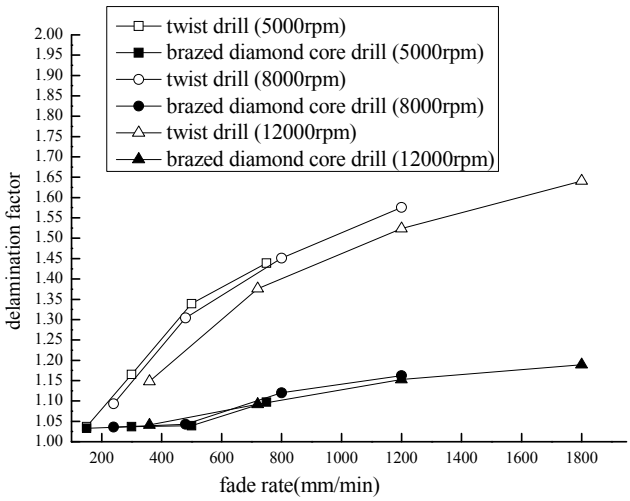
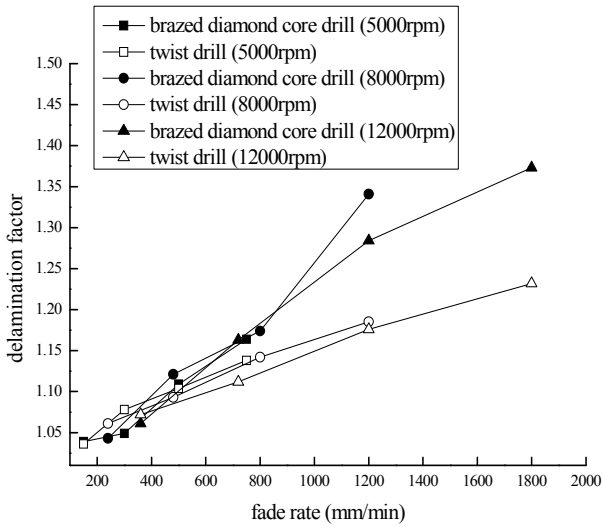


Fig. 3 Image of delamination



(a) entrance of hole



(b) exit of hole

Fig. 4 Delamination factor

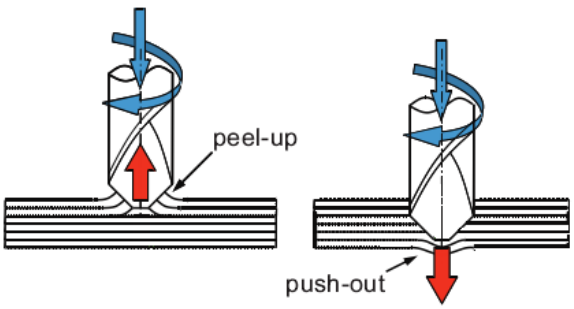
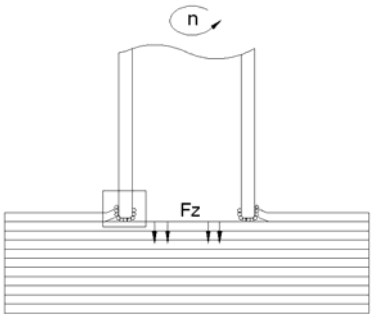
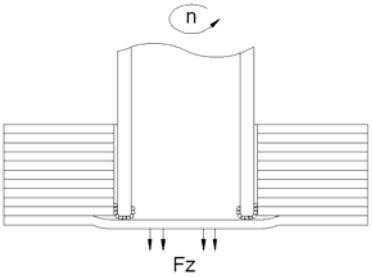


Fig. 5. Schematic of delamination mechanisms (peel-up and push-out)[9]

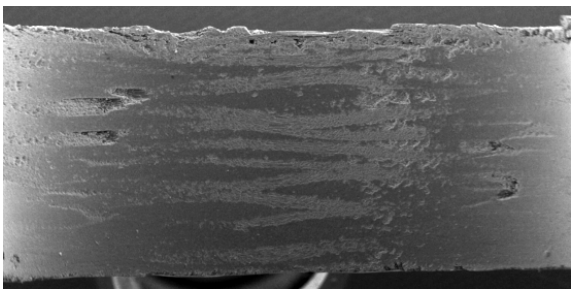


(a) entrance of hole

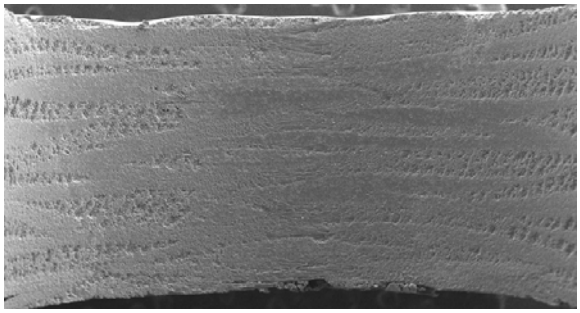


(b) exit of hole

Fig. 6. Schematic of delamination mechanisms with core drill



(a) Image of hole wall used twist drill



(b) Image of hole wall used brazed core drill

Fig. 7 Images of hole wall

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