Tool Wear of Various Materials of Drills in Drilling CFRP Composite and Its Impacts on Drilling Quality

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Abstract: Drilling carbon fiber reinforced polymer (CFRP) composites is liable to generate serious defects including burrs, delamination, fiber pullouts and matrix cracking because of their inherent anisotropy in mechanical properties. Therefore, studies on drilling quality during composites processing is necessary. The thrust force of different material drill bits in composites drilling process was measured by the dynamometer and the surface quality of the hole wall was observed by scanning electron microscope (SEM), moreover, the tool wear and its effects on the hole wall quality were also taken into account.

Key words: composites; thrust force; hole quality; tool wear

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0 Introduction

Carbon fiber reinforced polymer (CFRP) composites have been extensively used in aircraft and aerospace due to their advantages in mechanical properties and structural functionalities. The demands for CFRP composites are considerably rising because of their superior properties, such as high specific strength and stiffness, superior fracture toughness, excellent corrosion resistance and satisfactory durability. To obtain desired geometrical shapes and tolerances for a final component, secondary machining operations, such as trimming, milling and drilling, are necessary[1-2]. Drilling is a major process in the hole making of fibrous composites required for riveting and fastening structural assemblies in the aerospace and aircraft industries[3-5].

However, the machinability of CFRP composites is extremely poor during drilling process owing to their inherent anisotropy/inhomogeneity, limited plastic deformation and abrasive characteristics[6]. Drilling CFRP composites is possible to produce serious damages surrounding the hole circumferences and inside the hole wall surfaces including burrs, tearing, delamination, matrix thermal damage, etc[7-8]. Theses flaws adversely affect the drilling quality and the fatigue life of the final composite joints and structures[9-10]. Furthermore, the highly abrasive carbon fiber reinforcement can cause rapid tool wear[11-13]. The rapid tool wear will induce the increase of thrust force which enlarges possibilities of delaminations[14-15], and also deteriorates hole surface qualities by generating uncut fibers, fiber pullouts, etc[16-19].

In recent years, characteristics of drilling force variations in terms of various tools and drilling parameters including spindle speed and feed rate have been widely investigated and published in Refs.[3-4, 20-26]. It is shown that the feed rate dominates the increase of thrust force, and different drill geometries may cause a variation in the thrust force evolution and hence influence the value of the maximum force in the composite drilling process. It is also concluded that the drilling parameters influence the tool wear behaviors and lifetime of drill bits during the composites drilling.

However, the influences of tool materials on

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tool wear and drilling quality is rarely reported. In this paper, effects of various materials that are extensively utilized in drill bits of tools on tool wear and hole quality are studied. Thrust force during drilling process is surveyed and hole wall surface is observed under scanning electron microscope (SEM). Wear conditions and damage modes of holes drilled by different tools are investigated. Moreover, merits and demerits of different tools are also analyzed.

1 Experiment

1.1 Specimen and drill bit

Since the high strength and extensibility, T800 CFRP composites are widely applied to the aircraft. In this study, the composite used was a carbon/epoxy with lamination sequence $[45/0/-45/90]_{3s}$, which was provided by Commercial Aircraft Corporation of China and applied to C919. The nominal ply thickness was 0.188 mm, yielding a nominal laminate thickness of 4.512 mm. Moreover, the dimension of the workpiece is 300 mm×200 mm, and three pieces of such laminated workpiece panels are used in the experiment. Different materials including HSS (high speed steel), YG8, Y330 (without coating) and Y330 (with 0.002 mm diamond coating) of twist drills are utilized in the whole drilling process, and their chemical composition is shown in Tables 1, 2. Every type of drills is a standard twist drill and all of them have the same diameter of 3.5 mm.

Table 1 Chemical composition percentage of HSS tool

C	Si	Mn	Cr	W	Mo	V	S	P
0.80	0.40	0.40	4.10	18.0	0.30	1.20	0.03	0.03

Table 2 Chemical composition percentage of YG8 tool

WC	Co
92	8

1.2 Experimental setup and drilling parameter

Indeed, thrust force is one of the most significant factors which have influence on drilling quality in drilling process. Thus, Kistler piezoelectric crystal dynamometer, Kistler charge amplifier and oscilloscope are accepted for measuring thrust force, and the drilling experiment is carried out on VMC-850 CNC machine tool with the maximum spindle speed of 10 000 r/min, as shown in Fig.1. Furthermore, the spindle speed is set four levels from 1 370 r/min to 10 000 r/min, and the feed rate is also set at four levels from 0.005 mm/r to 0.05 mm/r.

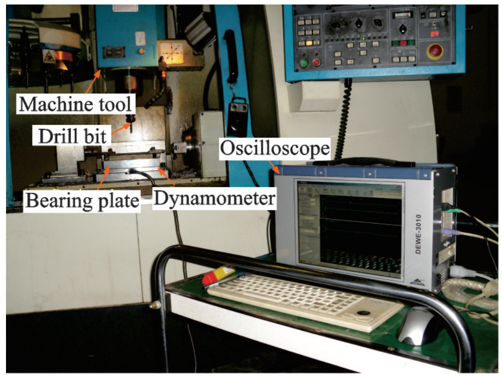


Fig.1 Experimental setup

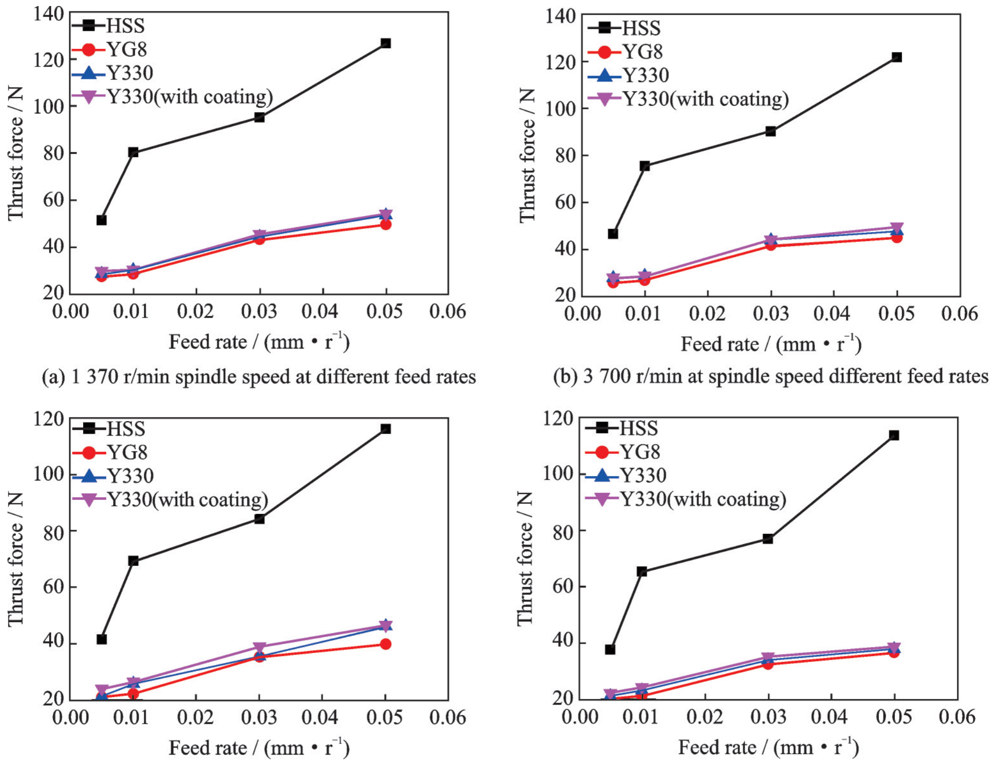
2 Drilling Quality

To test the drilling quality, two main parameters including thrust force and surface integrity of holes are investigated in this work.

2.1 Thrust force

In the drilling process, the thrust force collected by the dynamometer is amplified by the charge amplifier and collected by the oscilloscope. Force measuring software DEWE soft 6.5 is utilized to obtain the force curve during the drilling process and the mean force in the stable cutting state is calculated. In order to eliminate the error caused by tool wear, the mean thrust force of first hole drilled by a new tool is taken as the objects under every different drill parameter, as demonstrated in Fig.2.

It is can be seen that the thrust force of all type bits increases with the feed rate rising. Particularly, this phenomenon is the most obvious for the HSS tool. Moreover, under different feed rate levels, the thrust force of HSS bit is always much higher than that of any other bits. This is due to that the Rockwell hardness of ordinary high speed steel is 63 HRC, which is almost as much as that of T800 CFRP composite (53—65HRC). Conversely, the



(a) 1 370 r/min spindle speed at different feed rates

(b) 3 700 r/min at spindle speed different feed rates

(c) 6 900 r/min spindle speed at different feed rates

(d) 10 000 r/min spindle speed at different feed rates

Fig.2 Thrust force under different feed rates and spindle speeds

thrust force of other tools which are fabricated of hard alloy steel is much lower than that of HSS tool and less affected by the feed rate.

2.2 Surface integrity of holes

Typically, the hole wall quality is an important factor which directly affects the fatigue behaviors of the composite joints and structures. However, due to the difficult processing of T800 CFRP composite, various damage modes, such as matrix cracking, delamination layer bending, and fiber debonding, often occur during drilling. In order to investigate the internal damage of the hole wall surfaces, specimens processed by different tools are examined by scanning electron microscope (SEM), as demonstrated in Fig.3. All workpieces are fabricated under the same drilling parameters 6 900 r/min spindle speed and 0.01 mm/r feed rate.

3 Tool Wear

In the drilling process, the flank face, chisel edge, rake face, and edge of the tool are the main wear regions, as shown in Fig.4. In this paper, drilling parameters are set at 6 900 r/min spindle rate and the 0.01 mm/r feed rate, and the drilling quality is utilized as a criterion to evaluate tool wear. When burrs, delamination, splitting, and other obvious damages occur at the inlet or outlet of the five holes of continuous drilling, it is concluded that the tool has been severely worn and its life is exhausted, as illustrated in Fig.5. According to this criterion, HSS, YG8, Y330, and Y330 (with diamond coating) can process 3, 49, 42 and 80 holes, respectively. HSS tool wears badly after drilling three holes and the hole qualities processed by it reduce seriously. However, the other three tools wear obviously only after drilling dozens of holes, especially Y330 tool with diamond coating. To have a better view of wear condition, different tools after drilling 60 holes (HSS tool is after drilling 3 holes) are observed by microscope, as illustrated in Fig.6. Moreover, thrust force of four tools after drilling different number holes is demonstrated in Fig.7.

Thrust force of the four tools rises sharply with the increase of numbers of drilling holes, especially HSS tools. However, thrust force of Y330 (with diamond coating) increases the most slowly and it even becomes lower than that of Y330 tool after

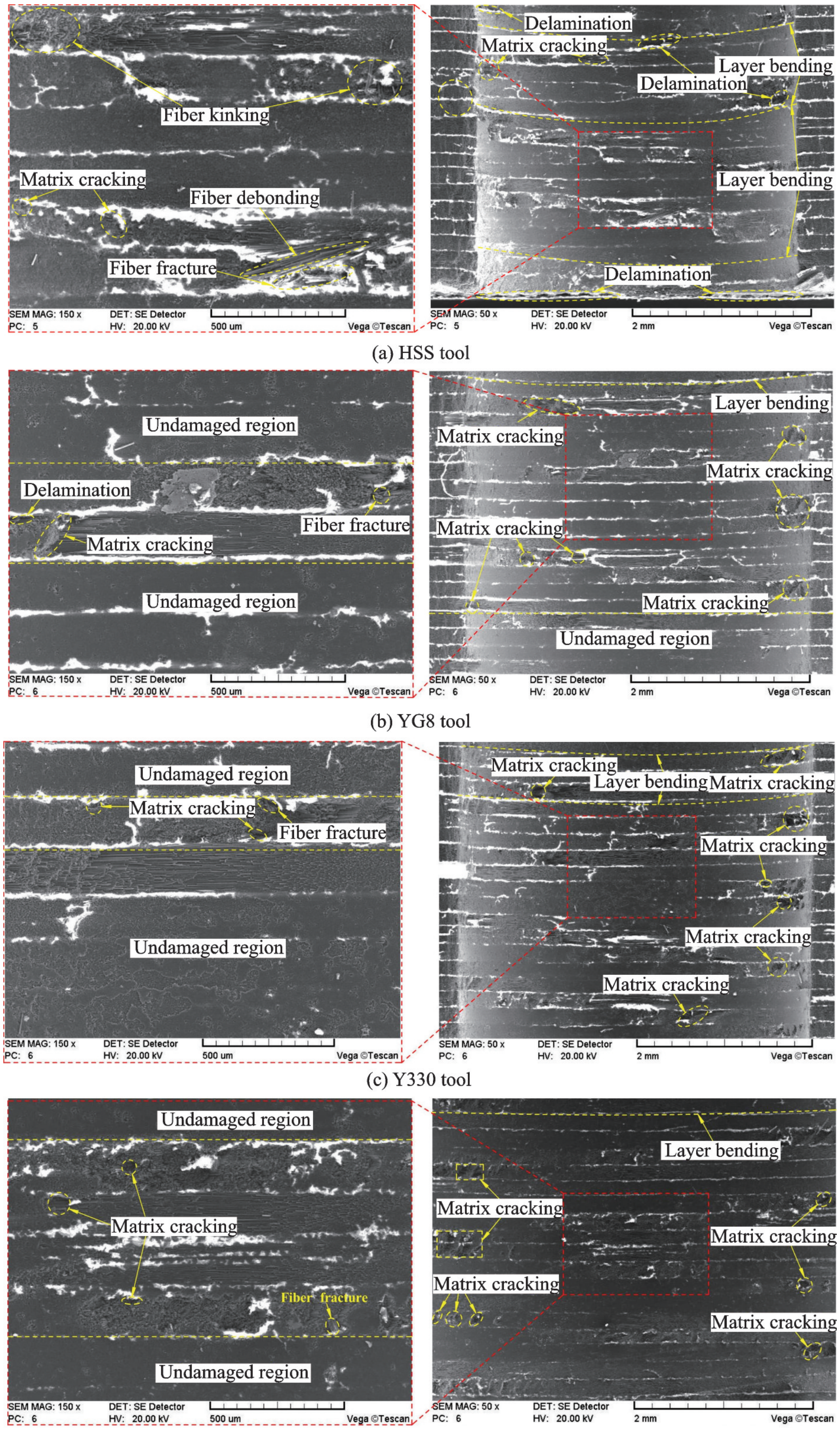


Fig.3 Hole wall surface damages of workpieces drilled by different tools under SEM at 6 900 r/min spindle speed and 0.01 mm/r feed speed

drilling 20 holes and begins to be almost the same as that of YG8 after drilling 50 holes. Through Fig.6, it can be visually seen the wear conditions of different tools. After drilling only three holes, HSS tool wears seriously, and the flank face and chisel edge of it have become very smooth. YG8 and Y330 tools can also see significant wear after drilling 60 holes, while Y330 (with diamond coating) tool

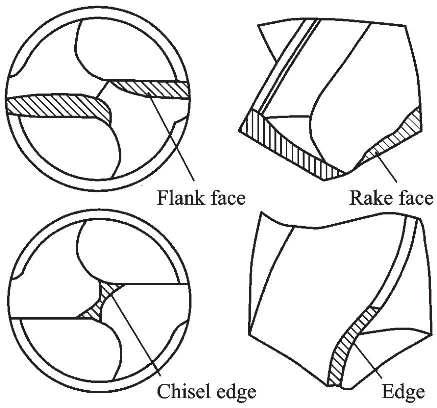
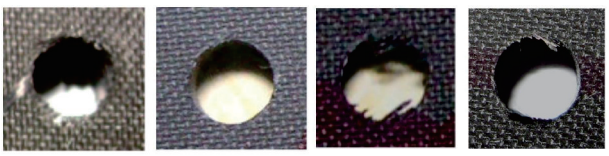
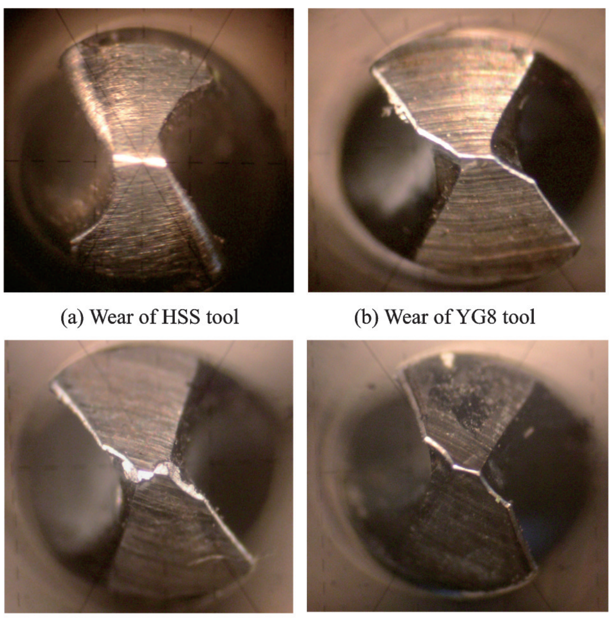


Fig.4 Main wear regions of the tool



(a) HSS tool (b) YG8 tool (c) Y330 tool (d) Y330 tool (with diamond coating)

Fig.5 Some holes with flaws



(a) Wear of HSS tool (b) Wear of YG8 tool

(c) Wear of Y330 tool (d) Wear of Y330 tool (with diamond coating)

Fig.6 Wear of different tools under microscope

wear is not obvious, which can explain the phenomenon of Fig.7 well.

4 Results and Discussion

According to Fig.3, greater damages at hole wall surfaces obtained by the HSS tool are observed than these of other three tools, which contributes to the roughness increase of surfaces and lifetime reduce of final composite joints and structures. Microscopically, matrix cracking and layer bending during drilling process exhibits in the hole wall surfaces machined by all four kinds of tools under SEM. However, layer bending occurs at the whole hole wall surfaces processed by the HSS tool while it only appears at the entrance of the holes drilled by other three tools. Moreover, many fiber damages, such as fiber fracture, fiber kinking, and fiber debonding, can be seen at the hole wall surfaces drilled by the HSS bit and serious delaminations are observed at the drilling inlet and outlet, especially at the outlet. On the contrary, there are few fiber damages and delaminations at the hole wall drilled by other three tools and their main areas are undamaged regions.

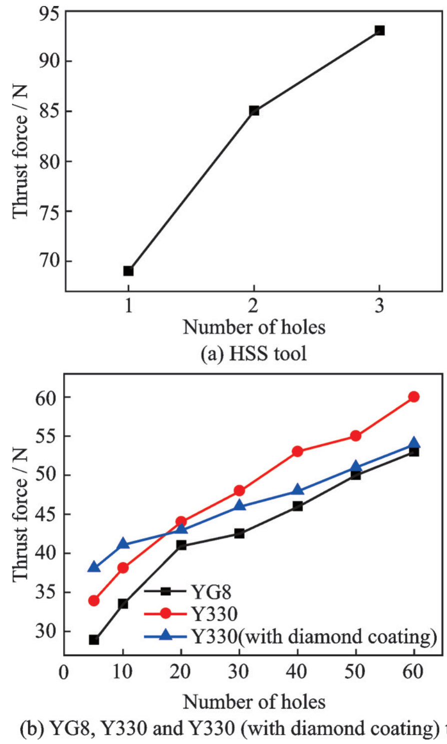


Fig.7 Thrust force of four tools after drilling different numbers of holes

Through Fig.2, it is simple to understand the above phenomenon because thrust force obtained by the HSS tool is much higher than that obtained by other three tools at any drilling parameters. Furthermore, among three hard alloy steel tools, thrust force of YG8 tool is the lowest and that of Y330 (with diamond coating) tool is the largest. This is a intriguing phenomenon as the Rockwell hardness of YG8 (HRA74.5) is lower than that of Y330 (HRA 90.5). Therefore, Rockwell hardness of drill bits is not the only factor that affects hole quality during composites drilling machining. It may be a result combing various factors, such as strength and stiffness.

Likewise, tool wear can see the similar phenomenon that lifetime of YG8 drill bit is a little larger than that of the Y330 tool. According to Fig.6, after drilling 60 holes, although the flank and rake face wears of both of them are at similar levels, the chisel edge of Y330 wears more serious than that of YG8. Fig.7 can prove this quantitatively as the thrust force of YG8 tool is about 10 N lower than that of Y330 tool after processing 60 holes. However, diamond can improve the durability as well as lifetime of drill bits obviously. By adding diamond coating, the lifetime of Y330 tools increases twice.

5 Conclusions

Effects of various tool materials on drilling quality and tool wear during drilling process are investigated. Dynamometer are utilized to measure thrust force and SEM are used to observe the hole wall surfaces, moreover, tool wear conditions are also surveyed by microscope. According to the results obtained in this paper, the following conclusions can be seen.

(1) Thrust force of high speed steel tool is much higher than that of hard alloy steel tools, which contributes to the more serious damages at the hole wall surfaces. Among the hard alloy steel tools, YG8 drill bit has the lower thrust force than that of Y330 drill bit during composites drilling.

(2) The main damage modes of hole wall surfaces drilled by hard alloy steel tools are layer bending and matrix cracking, while ordinary speed steel tools will lead to more serious damages, such as delamination, fiber debonding, fiber kinking, and fiber fracture.

(3) Durability of the HSS tool is extremely poor in composites drilling. Moreover, Y330 (with diamond coating) tool has the longest lifetime, which is twice as much as that of Y330 tools. This is due to that the coating can protect the drill bits thereby improving their durability. Interestingly, YG8 tools exhibit higher durability than Y330 tools, which may be a complex process that demands more studies.

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Author contributions Mr. **ZHENG Guo** designed the study, completed the experiments and wrote the manuscript. Prof. **CAO Zengqiang** contributed to the design, background and discussion of the study. All authors commented on the manuscript draft and approved the submission.

Competing interests The authors declare no competing interests.

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CFRP复合材料钻削中钻头材料及刀具磨损对钻削质量的影响

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摘要：由于碳纤维增强复合材料（Carbon fiber reinforced polymer，CFRP）固有力学性能的各向异性，在进行钻削加工时容易产生毛刺、分层、纤维拔出和基体开裂等严重缺陷。因此，对复合材料加工过程中的钻孔质量进行研究是非常必要的。本文利用压力传感器测量了不同材料钻头在复合材料钻孔过程中的进给力，并使用扫描电镜（Scanning electron microscope，SEM）观察了钻孔过后的孔壁表面质量，同时还考虑了刀具磨损及其对孔壁质量的影响。

关键词：复合材料；进给力；孔壁质量；刀具磨损