Performance Analysis of Drilling Test of Aramid Fiber Composite

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Abstract. Aramid fiber-reinforced polymer (AFRP) is a typical difficult material to machine. It is easy to occur defects such as ablation and burr in the drilling process due to the serious non-uniformity and heterotrophy of these material properties, as well as low heat transfer coefficient and high fibre toughness of the aramid fibre, which remarkable affects the machining quality and assembly accuracy. In this paper, three types of drills with different cutting edge shapes were compared to analyse the influence of drilling on cutting force, cutting temperature and machining quality. The results showed that the tool geometry has a great influence on the drilling performance of AFRP. Due to poor drilling quality, 8-face drill and twist drill are not suitable for drilling AFRP drilling tools. The machining quality of Brad & Spur drill is relatively good, which can meet the drilling requirements of AFRP.

1. Introduction
Aramid fiber-reinforced polymer (AFRP) is an advanced materials with typical high difficult, specific strength material, specific stiffness, low density and designability [1,2]. For its exceptional shock resistance and low density, the materials are widely applicated in aerospace, armored weapons, electronic vehicles and human body protection and other fields [3-5]. However, due to the characteristics of low inter laminar strength and low thermal conductivity of aramid fiber composite materials, under the coupling action of cutting force and cutting heat, defects such as burr, tear and layering are easy to occur in machining process, which will affect the geometric error of workpiece and assembly accuracy. Especially, drilling is a semi-closed machining mode, and the cutting area temperature is extremely high during machining, which makes it difficult to dissipate the processing heat in time, easily causing ablation on the hole wall [6,7].

In particular, drilling is a semi-closed machining mode, and the cutting area temperature is extremely high during machining, which makes it difficult to dissipate the processing heat in time, easily causing ablation on the hole wall. studied The experimental study on the perforation of the kevlar fiber was operated by Hemant C using laser processing. The result showed that the AFRP can significantly inhibit burrs and tears on the inlet and outlet surfaces, but ablative defects occur in the inlet and outlet holes due to the high-energy heat generated by the highly focused laser beam [8]. A.Díaz-Álvarez analyzed effect of standard twist bit and three-point bit on drilling of Arlington composite material. The empirical formulas of the damage area and axial force at the inlet and outlet of the material are established through variable parameter experiments [9]. Sinan L et al, compared the effects of feed velocity on borehole axial force with and without support ring, as the upper and lower support ring is added when the twist drill machining AFRP plate. It was found that the lamination, tear
and burr defects on the inlet and outlet surfaces were the least when the support ring size was larger bit diameter [10].

In this paper, the three-point drill bit, eight-face drill bit and twist drill bit are used as drilling tools to study the influence on the processing performance of AFRP, providing some references for the high quality and efficient processing technology of arrayon composite materials.

2. Experiments

2.1. Test materials and cutting tools

The experimental composite material was f12/602 arrayon fiber reinforced epoxy resin base composite plate material, F12 the fiber model, the weaving direction was 0/90°, and the single-layer fiber thickness was 0.13mm. The curing temperature of epoxy resin was 130℃, and the glass conversion Tg was 150℃. The laminates were 5.8±0.1mm thick and the fiber mass fraction was 62±2wt%. After molding, it is cut into 150mm×100mm specification for convenient testing. The specific physical properties are shown in table 1.

In this experiment, three kinds of drills with the same blade diameter of 6mm were used for drilling research, the maford-207 diamond-coated three-point drill, the kyocera-120 diamond-coated octahedral drill and the kyocera-101 titanium nitride coated standard twist drill, as Figure 1 shown. In the test, cutting parameters were adopted as spindle rotation speed of 4000r/min and feeding speed of 40mm/min.

| Table 1. Mechanical properties of AFRP laminates |
|--------------------------------------------------|
| Materials | Volume density (g.cm⁻³) | Compression strength (MPa) | Extension strength (MPa) | Bending strength (MPa) | Shear strength (MPa) | Heat conductivity coefficient (W/(m·K)) | Weaving direction |
|-----------|---------------------|--------------------------|-------------------------|----------------------|-------------------|-----------------------------------|------------------|
| F12/602   | 1.44                | 171                      | 726                     | 398                  | 38.4              | 0.35                              | 0/90°            |

![Drills in experiment.](image)

2.2. Experiment devices

The machine tool used in the drilling test of AFRP was KVC850M of the long march three-axis vertical machining center. The cutting force was collected by piezoelectric dynamometer, LN5861 charge amplifier and ADLINK usb-1901 acquisition card. Drilling temperature is completed by manual thermocouple and data acquisition card. The thermocouple adopts OMEGA-K thermocouple, measuring range -200~500℃, accuracy 0.1℃. Before the test, a 1mm micro drill bit was used to conduct embedded hole processing of AFRP. The location of embedded hole was 0.2mm away from the wall of the processed hole. The thermocouple was encapsulated in the material with cryogen.
3. Result and analysis

3.1. Cutting force

The axial force of the three types of bits routinely process AFRP laminated platesc were shown as Figure 2. During drilling, because the drill is composed of two symmetrical cutting edges, the radial force generated by the cutting edges can cancel each other under normal circumstances, resulting in a small torque generated by drills. In the direction of feed, the axial force is larger due to the extrusion of the transverse edge and the cutting and friction of the main cutting edge. A raft of studies suggest that axial force during mechanical drilling of laminated composite materials is the main factor affecting lamination, tear and burr defect [11-12]. Therefore, only three kinds of axial forces generated by bit cutting are discussed.

The axial force values of conventional machining of brad & spur drill, 8-face drill and twist drill are respectively 41.8N, 104.7N and 51.8N, as shown in Figure 2. The axial force of each cutter will rise sharply, when it is just cut into the material axial. The maximum value of the force appears after cutting a certain distance inside the material. And then, the axial force decreases gradually during the cutting process. According to the characteristics of drilling, the axial force can be divided into three stages.

(1) A~B Drill transverse edge, main cutting edge and secondary cutting edge cut into the material stage
Each cutting edge of the drill bit gradually extrudes the cut material, and the axial force increases sharply. As the cutting edge of the twist drill and the eight-sided drill continuously ACTS on the material surface, the axial force in this stage presents an increased state.

(2) B~C Drill transverse edge, main cutting edge and secondary cutting edge all work together stage
Each cutting edge of the drill is fully involved in cutting, and the axial force continues to increase and then reaches the peak. Due to the U-shaped groove structure between the middle sharp Angle and the outer edge sharp Angle of the three-pointed drill, the axial force at this stage increases for a period of time and then reaches the peak. After the peak value, the axial force presents a steady downward trend due to the screw Angle of the drill.

(3) C~D Drill cutting edge, main cutting edge and secondary cutting edge cutting material stage
Each cutting edge of the drill gradually moves away from the material and the force acting on the workpiece decreases sharply until it no longer exerts force on the workpiece, and the value of axial force returns to 0. Due to the lack of support at the outlet, the axial force fluctuates slightly at that time.

3.2. Cutting temperature

The maximum temperature value of hole wall during AFRP machining is shown in Figure 3. The temperature of brad & spur drill, 8-face drill and twist drill are respectively 234.7℃, 285.4℃ and 195.7℃. Due to the low thermal conductivity of aramid fiber composites (0.35W/m*K), a large amount of cutting heat generated during drilling could not be diffused in time. When the cutting zone temperature exceeds the resin base glass conversion temperature Tg, the resin base softened, degraded
and even completely carbonized, causing serious ablative defects in the inlet and outlet and pore wall. Cutting heat energy reduces the bond strength of resin, which will lead to the fiber being easily pulled out from the resin matrix under the action of cutting force, leading to the emergence of burr defects. On the one hand, the reduction of resin bond strength will reduce the export stiffness of composite workpiece, and make the uncut material heave to the exit direction during the cutting out of the material, so as to inhibit the emergence of export layering. On the other hand, the reduction of resin bond strength will reduce the bonding strength between layers, easy to produce stratification.

The twist drill bore the lowest temperature as shown in Figure 3. The main source of cutting heat is the work done by material resisting cutting force. The 8-face drill produces the most cutting force and thus the most heat and temperiment. The brad & spur drill has the smallest cutting force, but because of the U-groove shape of the cutting edge, the area of contact between the tool and the workpiece material is larger, the material produces more friction, generates more heat, resulting in a high cutting temperature.

3.3. Surface quality of machined holes
AFRP is a highly heterogeneous material with obvious anisotropy. As the characteristics of high toughness aramid fiber and low affinity with resin base, it is easy to form such phenomena as fiber pulling out and matrix and fiber defusing under the action of thermal/force coupling. During mechanical drilling, the fibers on the surface of material inlet and outlet are difficult to be cut due to lack of support, resulting in burr defects, as shown in Figure 4. In the dry cutting state of the 8-facene drill, there are a lot of fibers on the inlet and outlet surface that have not been cut off. At the same time, the excessive cutting temperature caused obvious burns on the fibers on the material surface, and almost all the resins at the hole wall have been heavily carbonized.

According to the observation of hole wall, resin ablative phenomenon increases obviously with the increase of bit axial feed. Significant carbonization has been observed at the outlet. The reason is the cutting edge of the drill bit continuously cuts the material, under the semi-closed environment, the cutting heat is continuously low and accumulates and increases, resulting in the cutting temperature increasing with the feed of the drill hole, resulting in more serious material burns at the outlet than at the inlet.

Compare the other two drills, under the dry cutting condition of the brad & spur drill, the burrs at the inlet and outlet are greatly reduced, and there are almost no long burrs at the inlet and only a few remaining burrs at the outlet. The reason is the special external geometric edge shape of the three-point drill, as shown in Figure 5. Different from the extruded cutting from the center of the hole to both sides of the Fh produced by the twist drill and the 8-face drill, the brad & spur drill, due to the existence of external edge, first cuts the outer fiber of the hole, and applies the horizontal component
force $F_{h}'$ on the material to the center of the circle, thus forming a cutting state from the edge of the hole to the center of the hole.

No force is produced to extrude the fiber on the edge of the hole, reducing the burr caused by the fiber on the edge of the hole due to lack of support. And in the hole wall observation can be, three-pointed drill will also produce ablative resin base, resin base is heavily carbonized, at the same time in the hole wall produced serious fiber pulling defects.

![Figure 5. Model of the drilling force.](a) Brad & Spur drill (b) 8-face drill and (c) Twist drill]

4. Conclusion
The influence of cutting tool geometry on the drilling performance of array on fiber composites is obvious. The 8-face drills, which have multiple cutting edges, will generate greater cutting force and cutting heat when drilling, and the quality after drilling is poor, which is not suitable for AFRP. The twist drills produce less cutting heat, less burrs at the cutting inlet than the 8-face drills,, and less surface burns. The cutting force produced by the brad & spur drill is small, and the hole wall may have defects such as fiber pulling out, but the import and export quality is relatively good.

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