Research on The Deep Hole Processing of Aramid Fiber Reinforced Composites

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Abstract. Aramid fiber reinforced composite is a new material with high strength and low density, which is widely used in weapon, automobile, aerospace and other fields. The material is difficult to process, drilling is the main processing method of the material. In the drilling process, it is easy to appear fluff, ablation, stratification and so on. As a result, it is difficult to guarantee the quality of traditional processing and seriously affects its performance. In this paper, the drilling force and temperature in the drilling process are studied, and the influence of temperature and force on the processing quality is analyzed, so as to provide reference for the low-damage processing of aramid fiber reinforced composites.

1. Introduction
Aramid fiber reinforced composites have the advantages of high specific stiffness, low density, large strength and excellent electromagnetic properties [1],[2], which is widely used in weapon armor, automobile manufacturing, aerospace and other fields. Especially in the field of aerospace, the proportion of the composite material has become an important index to measure the advancement of military equipment [3] and become a development trend. It has become a development trend that the aramid fiber reinforced composite has non-uniformity, multiphase structure and anisotropy, which leads to the complexity of material removal in traditional machining [4], [5]. In view of the difficult processing nature of this material and the various defects in the process, such as fluffing, ablation, stratification, etc., it is difficult to obtain the idealized surface by traditional machining, which seriously affects the application of this material in relevant models.

At present, the research on the defect formation mechanism and the low damage processing technology of the material has become a hotspot. Bunsell A R et al. found that the fibers of Kevlar araftron fiber composites fracture after plastic deformation under the action of tension in the process of processing, so the fracture mode is mainly tensile fracture or bending fracture, which is the main reason for the formation of burr [6].

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Kim S C et al. studied the interlaminar fracture toughness of Kevlar aramid fiber composite material during mechanical processing, and found that the bonding performance between the layers of Kevlar aramid fiber composite material was poor, and the cutting heat in processing led to further deterioration of interlaminar bonding performance, leading to burr and layering [7].
Because in the actual processing, the traditional mechanical processing still occupies the dominant position. In this paper, the relationship between machining parameters, cutting force and cutting temperature was analyzed, and the defects caused by heat/force were discussed, which laid a foundation for the low damage machining of aramid fiber.

2. Experimental

2.1. Materials
The test sample was made of kevlar-49 fiber and aramid fiber composite reinforced with epoxy resin matrix. The material size was a rectangle of 50 mm×50 mm×35 mm.

2.2. Processing equipment and parameters
The drill adopted by the experimental drilling institute is the alloy twist drill produced by SANDVIK. The drill diameter 6mm; The test machine is a three-axis vertical machining center with the maximum spindle speed of 20000r/min.

| No. | Mainshaft speed (r/min) | Feed speed (mm/min) | No. | Mainshaft speed (r/min) | Feed speed (mm/min) |
|-----|------------------------|---------------------|-----|------------------------|---------------------|
| 1   | 2000                   | 30                  | 9   | 2000                   | 90                  |
| 2   | 4000                   | 30                  | 10  | 4000                   | 90                  |
| 3   | 6000                   | 30                  | 11  | 6000                   | 90                  |
| 4   | 8000                   | 30                  | 12  | 8000                   | 90                  |
| 5   | 2000                   | 60                  | 13  | 2000                   | 120                 |
| 6   | 4000                   | 60                  | 14  | 4000                   | 120                 |
| 7   | 6000                   | 60                  | 15  | 6000                   | 120                 |
| 8   | 8000                   | 60                  | 16  | 8000                   | 120                 |

2.3. Other analytical equipment
The A40 infrared thermal imager developed and produced by us company feryl is used to measure the temperature of the borehole. The temperature measurement range is -40 ℃ ~ 2000 ℃, and the temperature difference of 0.08 ℃ can be distinguished. The generated high-definition infrared heat map can reach 320X240 pixels.

The pore morphology of the sample was measured by ultra-deep microscope (KEYENCE vhx-600, Japan) with a resolution of 54 million pixels.

Kistler 9257B (Swiss) was used to measure the borehole axial force.

3. Results and Discussion

3.1. The influence of machining parameters on axial force
The variation curve of axial force of aramid fiber composite with feed speed and spindle speed, as shown in Fig.1. The axial force is the mean value of the three experiments.
It can be seen that when the feed speed increases from 30mm/min to 120mm/min, the axial force increases accordingly. This is due to the increase of the feed speed, the corresponding increase of the cutting depth, the increase of the cutting amount in the same time, the work done by the cutting tool to remove the material increased, so the axial cutting force increased. When the feed speed is 30–60mm/min, the axial force decreases linearly with the increase of the rotating speed. When the feed speed increases to 120mm/min, the maximum axial force increases greatly and decreases in a curve with the increase of the rotational speed. When the feed speed increased to 120mm/min, the maximum axial force increased greatly, and decreased in a curve with the increase of the rotational speed, indicating that the parameter selection of high rotational speed and low feed was needed to obtain the lower axial force in the machining process.

3.2. The influence of machining parameters on cutting temperature

3.2.1. Burr defect

As can be seen above, the effect of feed speed and spindle speed on axial force and cutting temperature is opposite. When the feed speed is small, the axial force is small but the machining temperature is large, and the burr area is mainly affected by the cutting temperature. The increase of cutting temperature leads to the decrease of elastic modulus and tensile strength of resin base. When the cutting temperature exceeds the glass transition temperature, the physical properties of epoxy resin decrease sharply. The instant softening of resin matrix loses the support and binding of fiber. The fibers with weak constraints could not form neat fracture, presenting a state of tension and serious burr. Therefore, the cutting temperature should be controlled not to exceed the conversion temperature of epoxy resin based glass, so as to increase the processing efficiency.

Fig. 1 Influence of cutting parameters on temperature

![Influence of cutting parameters on temperature](image)

When the spindle speed is low, the cutting temperature is relatively low. The feed speed is controlled to make the temperature change less and lower than the glass transition temperature of epoxy resin matrix. But the increase of axial cutting force is very obvious. Because the in-layer bonding capacity between aramid fiber and resin matrix is low, too much axial force will lead to the
phenomenon of resin and fiber debonding in AFRP. Most fibers cannot be effectively cut beyond the maximum yield strength of the knitting and tool bonding point, resulting in more burr.

3.2.2. The ablation defects
Due to the low thermal conductivity of AFRP and poor thermal conductivity, in addition, drilling is a semi-closed machining method, the heat generated by the rapid accumulation, cutting temperature rise after the obvious burn. Under the cutting parameters of "low feed, high speed", obvious ablation will occur.

As shown in FIG. 3, spindle speed n=6000r/min, feed speed Vf=60mm/min, cutting temperature 248.6 °c, serious ablation defect, accompanied by workpiece burning odor.

![Fig. 3 The burr at 248.6 °C with the speed 6000 r/min](image)

With the increase of spindle speed by 7000r/min, the friction between the cutter and the processed surface increases in unit time, and the cutting temperature reaches 279°C. With the increase of carbonization, the corresponding thermal damage becomes more serious.

![Fig. 4 The burr at 279°C with the speed 7000 r/min](image)

4. Conclusion
(1) When the feed velocity increases, the axial force increases; The axial force decreases linearly with the increase of rotational speed. Therefore, the parameters of high speed and low feed are selected in order to obtain lower axial force.

(2) The effect of cutting parameters on cutting temperature is opposite to that of cutting force, that is, the smaller the spindle speed and the larger the feed, the lower the cutting temperature.

(3) Axial force and cutting temperature will cause machining defects.

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