Experimental Study on Deep Hole Drilling of TC18 Titanium Alloy Based on BTA

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Abstract. TC18 titanium alloy has problems such as difficult chip removal and chip removal, severe tool wear and skew of the hole axis during deep hole machining, which seriously affects the surface quality of the inner hole. Therefore, this test carried out the BTA deep hole drilling test for TC18 titanium alloy, and studied and analyzed the problems of chip shape change, tool wear and hole axis deflection during machining. The test results show that the chip shape is longer and more developed with the increase of the spindle speed, and the bending is longer and more curved with the decrease of the feed amount; the tool wear is serious during the drilling process, and the reasonable process parameters can reduce the wear of the tool; The cutting force, the rigidity of the drill pipe and the arrangement of the guide blocks are important factors affecting the deflection of the hole axis.

1. Introduction

Titanium alloy has high specific strength, good thermal strength and strong corrosion resistance. It is especially suitable for the production of instruments, sensors, aero engines and other components in aviation and spacecraft. Therefore, it has been widely used in the aerospace industry [1]. At the same time, titanium alloy has the characteristics of high chemical activity, small elastic modulus and low thermal conductivity, which leads to the processing difficulties of titanium alloy in cutting process, such as severe tool wear, large cutting force and high cutting temperature, especially in titanium alloy. Deep hole drilling process. Deep hole drilling is in a fully enclosed or semi-closed machining state, and the machining space is extremely narrow and it is difficult to directly observe the machining site. During the machining process, the chip removal path is long, too wide or too long chips will cause blockage of the chip removal channel; a large amount of cutting heat is generated during the cutting process, and it can not be effectively dissipated in a short time, heat accumulation generates high temperature, affecting the durability of the tool. Degree, causing tool wear, can not guarantee the quality of the processed inner hole; the processing system is poor in rigidity, easy to generate vibration, it is difficult to ensure the straightness of the inner hole. Therefore, deep hole processing of TC18 titanium alloy is more difficult. At present, the most widely used systems for deep hole machining mainly include gun drilling systems and BTA systems. The gun drill is mainly used for deep hole machining of small diameter (φ<20mm) holes. Considering that the processing aperture is large in this test, the BTA system is selected.

At home and abroad, the research on deep hole processing of titanium alloy is mainly for the deep hole processing of titanium alloys such as TC4 and TC11, but the deep hole processing of TC18 titanium alloy is less [1, 2]. In this test, deep hole drilling test of TC18 titanium alloy was carried out by using BTA deep chip drill in the BTA. The problem of chip shape change, tool wear and hole straightness deviation were studied and analyzed by changing the process parameters spindle speed n and feed rate.
$V_f$, to provide technical parameters and experience for the actual production and processing of TC18 titanium alloy.

2. Deep hole drilling test

2.1. Workpiece material

The material used in the test was TC18 titanium alloy ($\text{Ti-5Al-5Mo-5V-1Cr-1Fe}$) bar, and the external dimensions were $\varnothing 100\text{mm} \times 3300\text{mm}$. TC18 titanium alloy has the performance characteristics of $\alpha+\beta$ and $\beta$-type titanium alloys. It belongs to transitional $\alpha+\beta$ alloy and has the advantages of high strength, high temperature resistance, good plasticity, high hardenability and strong corrosion resistance. Table 1 shows the chemical composition of TC18 titanium alloy.

| Element | Mo    | Al    | V     | Fe   | Cr   |
|---------|-------|-------|-------|------|------|
| Content | 5.23  | 5.10  | 5.04  | 1.01 | 0.93 |

| Element | C | N | H | O | Ti |
|---------|---|---|---|---|----|
| Content | 0.021 | 0.02 | 0.002 | 0.15 | Margin |

2.2. Test equipment and tools

The test equipment used T2110 CNC deep hole drilling boring machine. The test equipment is shown in Figure 1. The maximum drilling diameter is $\varnothing 80\text{mm}$, the maximum machining depth is 4000mm, and the cooling system is rated at 2.5MPa. The workpiece is rotated during the machining process and the tool feed is drilled.

The drill bit adopts a multi-blade mis-toothed deep chip drill with a diameter of $\varnothing 70\text{mm}$. The actual bit is shown in Figure 2. According to the cutting characteristics of titanium alloy and the requirements of the tool material itself, YG8 is selected as the tooth material. The tool parameters are shown in Table 2. The drill pipe has a diameter of $\varnothing 65\text{mm}$ and a length of 4500mm.

![Figure 1. T2110 CNC deep hole drilling and boring machine](image)

![Figure 2. Internal chip removal deep hole drill](image)

| Table 2. deep chip drilling tool parameters and guide block position |
|---------------------------------------------------------------|
| Front angle | Back corner | Deflection angle |
| 8° | 12° | 18° |
| Drill tip eccentricity | Guide block 1 position | Guide block 2 position |
| 5mm | 80° | 182° |

2.3. Test process parameters

According to the deep hole machining experience of titanium alloy and the machine tool capability, the appropriate spindle speed $n$ and feed rate $V_f$ are selected. The test process parameters are shown in Table 3.
Table 3. Test process parameters

| Spindle speed $n$ | Drilling depth | Drilling diameter |
|------------------|----------------|-------------------|
| 98 r/min~174 r/min | 3300mm          | 70mm              |
| Feed rate $V_f$  | Coolant pressure | 2.5MPa            |
| 0.10 mm/r ~0.20 mm/r |               |                   |

3. Analysis of test results
According to the technological parameters, four deep hole drilling tests were carried out on TC18 titanium alloy to observe and analyze the chip morphology change, bit wear and hole axis deviation. The test results are shown in Table 4.

Table 4. TC18 Deep Hole Drilling Test

| Test No. | Spindle speed $n$ | Feed rate $V_f$ | Chip condition | Bit wear |
|----------|------------------|-----------------|----------------|---------|
| 1        | 98 r/min         | 0.10 mm/r       | Blocking       | Severe  |
| 2        | 98 r/min         | 0.20 mm/r       | Normal         | Slight  |
| 3        | 174 r/min        | 0.10 mm/r       | Blocking       | Severe  |
| 4        | 174 r/min        | 0.20 mm/r       | Normal         | Severe  |

3.1. Chip morphology
The shape of chip curl and the length of chip directly affect the chip removal in deep hole processing. When the cutting volume factor $R < 50$, the chip can be removed smoothly. In this study, a multi-edged staggered-tooth deep hole drill is used to remove chips. The width of chips is determined by the distance between the cutting teeth. In the process of processing, the chip shape will be affected by changing the spindle speed and feed rate. As shown in Figure 3, the chip morphology will expand longer and more with the increase of spindle speed when the feed rate is constant. When spindle speed increases, cutting temperature increases, chip plasticity increases, material elongation increases, fracture strain increases, chip thickness decreases, which is not conducive to chip breaking, and chips are longer and more expanded. When spindle speed is constant, chip shape will become longer and more curved with the decrease of feed. When the feed rate decreases, the chip thickness becomes thinner, the bending deformation energy of the chip breaking groove decreases, the strain of the chip decreases, and the chip is more difficult to break [3].

![Chip morphology images](a)n=98r/min $V_f$=0.10mm/r  (b)n=98 r/min $V_f$=0.20 mm/r
3.2. Tool wear

In TC18 titanium alloy deep hole drilling process, the cutting force is large, the cutting temperature is high, and the work hardening phenomenon is serious, which leads to tool breakage, diffusion wear, front and rear tool face wear and guide block wear easily under such harsh conditions. As shown in Fig. 4a, the cutting edge is continuously cut during the processing, resulting in wear and tear, resulting in a reduction in the strength of the cutting edge. When the cutting force on the cutting edge is greater than the fracture strength limit of the tool material, the tool edge will collapse. As shown in figs. 4B and 4c, the elastic deformation of titanium alloy is large and the chemical affinity of titanium element to the cutting tool is strong. When cutting, a large amount of cutting heat is generated by friction with the workpiece, resulting in the adhesive wear of the cutting tool, affecting the durability of the cutting tool, and then leading to the wear of the front and rear cutter surfaces. As shown in Fig. 4d, the guide block not only plays a guiding role, but also needs to offset the radial force generated during cutting. During the cutting process, the guide block is constantly squeezed and sliding friction with the hole wall, resulting in massive spalling and fragmentation of the guide block.
3.3. Hole axis deflection

Due to the particularity of deep hole processing technology, the deviation of drill pipe is easy to occur during drilling, which leads to the excessive deviation of the axis of deep hole [4]. Axis deviation is one of the evaluation indexes for evaluating axial deviation of deep holes. In this experiment, the wall thickness of holes with different cross-sections was measured by ultrasonic thickness gauge, and the wall thickness of four-point holes was measured at 300 mm interval, so the axis offset of holes was calculated. As shown in Figure 5, the deviation of hole axis increases with the increase of hole depth.

The deviation of drill pipe is one of the reasons that affect the deviation of deep hole axis. In the process of drilling, when the axial force on the bit exceeds the buckling limit of the drill pipe or the drilling depth is large, the rigidity of the drill pipe is poor and there is no auxiliary support inside the workpiece, which results in the bending of the drill pipe and the deviation of the hole axis during drilling, as shown in Figure 6a. The relative position of the guide block and the tool will also have a greater impact on the hole axis deviation. During the processing, the guide block will bear the radial force generated by drilling. When the radial cutting force can not be completely offset by the guide block, the tool will deviate, resulting in the hole axis deviation, as shown in Figure 6b. The deviation of the hole axis is the result of a combination of many factors, and there are other factors that affect the hole straightness, such as: machine tool fixture error, uneven workpiece material, workpiece end-face inclination, wear of guide block and cooling hydraulic pressure, etc. [5]. Reasonable control of the above factors can reduce the deviation of the hole axis.
4. Conclusion
In this paper, deep-hole drilling experiments of TC18 titanium alloy were carried out. By changing feed $V_f$ and spindle speed $n$, the chip morphology, bit wear and hole axis deviation were studied. The following conclusions are drawn:

- When the feed rate is constant, the chip morphology will expand longer and more with the increase of spindle speed. When the spindle speed is fixed, the chip shape will be longer and more bent with the decrease of feed.
- In TC18 titanium alloy deep hole drilling, reasonable selection of process parameters can effectively reduce tool wear and vibration and improve processing stability. The test results show that the spindle speed $n=98$ r/min and feed $V_f=0.20$ mm/r are the most stable.
- High rigidity drill pipe and reasonable tool parameters can reduce the deviation of hole axis, and the deviation of hole axis increases with the increase of deep hole drilling depth.

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