Experimental study on deep hole drilling of 17-4PH material

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Abstract: This paper uses 17-4PH material as the research object, according to the material characteristics of 17-4PH, designed and carried out deep hole drilling test. The purpose of the experiment is to study and discuss the three major problems of tool wear, chip shape and axial deviation of the hole in the process of deep hole drilling of 17-4PH materials. Through the deep hole drilling test of 17-4PH material, the variation of the chip shape and the deflection of the hole axis was obtained under different wear conditions.

1. Introduction

17-4PH, or 0Cr17Ni4Cu4Nb, is a martensitic precipitation hardened stainless steel. As a result of solid solution strengthening and aging treatment, this kind of stainless steel has better corrosion resistance and better strength, so it is widely used in the manufacture of Petroleum Instrument, chemical equipment, aircraft parts, nuclear reactor structure, etc. In the actual processing, its good mechanical properties cause great difficulties in machining, so the tool is prone to wear and tear and affect surface roughness and dimensional accuracy. In this paper, the wear of cemented carbide cutting tools in deep hole drilling is studied, and the influence of wear on chip morphology and hole straightness is discussed.

2. Analysis of Cutting Performance of 17-4PH Material

The test piece is a 17-4PH bar with a diameter of 850mm long and a hole with a diameter of 50mm is drilled on it. The chemical composition, mechanical and physical properties of 17-4PH are shown in Tables 1, 2, and 3.

| C   | Si   | Mn   | Cr   | Ni   | Cu   | Ni   | S   | P   |
|-----|------|------|------|------|------|------|-----|-----|
| ≦0.07 | ≦1.0 | ≦1.0 | 15.5~17.5 | 3.0~5.0 | 3.0~5.0 | 0.15~0.45 | ≦0.030 | ≦0.035 |

Tab. 2 performance comparison of 17-4PH material and steel 45

| Material | Tensile strength (MPa) | Yield Strength (MPa) | HBS |
|----------|------------------------|----------------------|-----|
17-4ph  $\geq$ 932  $\geq$ 726  363 
45 steel  $\geq$ 600  $\geq$ 336  229

|          | 0  | 100 | 200 | 300 | 400 | 500 |
|----------|----|-----|-----|-----|-----|-----|
| 17-4ph   | —  | 17  | 19  | 20  | 22  | 23  |
| 45 steel | 52.34 | 48.85 | 44.19 | 41.87 | 34.89 | — |

Tab.3 thermal conductivity of 17-4PH and 45 steels (W/mK)

the comparison of mechanical properties of 17-4PH and 45 steel are shown in Table two, it can be seen that the tensile strength and yield strength of the 17-4PH are much greater than those of the 45 steel, and the cutting force and the torque resistance during machining are also larger, the wear of cutting tool will be very serious, accuracy is difficult to be guaranteed. It can be seen from Table three that the thermal conductivity of 17-4PH is very small and less than half of the 45 steel at the same temperature, so heat dissipation is difficult. In addition, the carbon content of 17-4PH is low, the section stretch ratio reaches 40% - 50%, the toughness is larger, so the chip breaking is difficult during machining. In general, the cutting performance of a material is mainly determined by the cutting resistance, the service life of the tool, the surface roughness after cutting, and the chip breaking ability. Therefore, the cutting performance of this material is poor.

3. Deep hole drilling test of 17-4PH material

3.1. Test method

The testing machine is a deep hole machine converted from an ordinary lathe CW6140. The drilling system uses the system of BTA. The processing method is that the workpiece is rotating while the tool is feeding. The structure of tool is BTA deep hole drill, cutting gear material of drill is ZK30 carbide; the spindle speed is 195-225r/min, the feed is 0.14-0.26mm/r and the cooling fluid pressure is 2.5MPa. In order to ensure the machining accuracy, the vibration of the drill and morphology of chips is closely observed. After the drilling is completed, the cutting teeth should be observed by electron microscope. The thickness of the hole wall should be measured with the ultrasonic thickness gauge every 10cm, and the deflection of hole should be examined.

3.2 Analysis of test results

3.2.1. Tool wear analysis

Macroscopic tool wear as shown in Figure one, It can be seen from the figure that the tool's rake face and flank face have different degrees of wear and tear, even the phenomenon of chipping can be seen on the cutter tooth. This is mainly because 17-4PH itself is a kind materials difficultly to machine, its mechanical strength is high and plastic toughness is large, the cutting tool in the machining has a great cutting force and a large torque, there is a sharp friction between the tool and the workpiece surface, which causes wear; In addition, during the cutting process, the workpiece material had plastic deformation, the sliding and dislocation occur between the metal grains, and the cutting heat cause work hardening, all of these intensify the tool wear and make the cutting more difficult. Furthermore, it can seen that the wear occurred mainly in the cutting-edge outside, the blade has a certain degree of burning, the color near the blade was black; and the peeling part is mainly concentrated near the center teeth, which is due to the higher cutting speed of the external teeth, Long time
continuous cutting causes high temperature oxidation and wear of cutting tools. The cutting speed of center position of the tool is low, the cutting is mainly done by pressing, the torque of the tool is large, and the high temperature in the cutting reduces the tool strength, these cause the blade to crack.

(a) Frontal wear  (b) Flank wear

In Figure one (b) the flank has obvious scratches, on one hand the reason for this is the friction between the flank and the rough machined surface. On the other hand because of abrasive grains wear. Carbon and Niobium of 17-4PH material and carbon combine to form hard spots of Cr3C2 and NbC, own to the hard spots with high hardness rubbed with the tool, which results in scratches.

Figure two is the tool wear area of the topography, Figure three is the wear area of the EDS element analysis chart, in Figure two it can be seen in the cutting process the tool surface coating has been peeled off. This is due to the continuous cutting process of the tool by the alternating contact stress and thermal stress resulted in stress fatigue, After a period of time, the accumulation of stress make the tool coating produce cracks, which are gradually worn and peeled off under the effect of friction and cutting forces. In addition the blade is blunt and wavy, near the blade there are some crater wear. This is due to adhesive wear and diffusion wear, the tool surface coating due to friction gradually peeling off, the tool surface directly contact with workpiece surface, Mutual adsorption and mutual penetration of atoms diffusion take place under the promotion of high temperature and pressure, The diffusion of atoms between the material to reduce the strength of the tool, so the tool turns blunt, when the tool and the processing of the surface are separated by a part of each other was taken away, and then the tool produces crater wear, Figure 3 Cr, Ni, and Cu elements indicate diffusion wear and adhesion abrasion.

Fig. 2 tool wear under electron microscope
3.2.2. Analysis of chip morphology

Stainless steel material has a strong toughness, so chip is much difficult to break. Usually in order to facilitate chip breaking, the tool breakers are ground to increase the deformation of the chip and to promote its fracture. During the cutting process, a lot of chip heat will be produced, so the chip has a high temperature. When the hot cutting chips encounter cold cutting fluid, the hardness and brittleness increase, which is beneficial to chip breaking. On the other hand, as the length of the chip increases, the area affected by the impact increases accordingly, the impact of the corresponding increase. When the force of impact exceeds the chip bearing force, the chip breaks.

In the beginning of the cutting depth set 0.14mm, the chip obtained as shown in Figure four (a), the chip is elongated spiral, this is because the tool is not worn, the drilling process is smooth, so the chip surface is also smooth and has little burrs. According to the theory of metal cutting, on the premise of the feed rate and cutting depth remain unchanged, As the cutting speed of external teeth is lager than other, so usually the edge of the external teeth firstly wear and the chip edge has obvious burrs, as shown in Figure four (b). And when the cutting teeth and guide blocks are worn, the wear of tool is more serious, the drill pipe will have a more obvious vibration, The chip is not only burr, but also shorter in length, as shown in Figure four (c); Figure four (d) shows the length of the chip is long and full of wrinkles with burrs, the reason for this situation is that when the cutting depth is 0.24mm, the chips are thick and tough, it is difficult to break the chip. In addition, the tool wears and the drill pipe is vibrant violently. Especially in the test, a serious crushing phenomenon occurred, the cutting teeth were significantly cracked, the chip is fine at this time, as shown in Figure four (e), because the tool has completely lost the cutting capacity, drilling must be stopped immediately.
The curve of hole straightness is shown in Figure five, it can be seen that the deviation of the straightness of the hole increases with the increase of the hole depth, and then the deviation decreases. At the beginning, in order to allow the drill bit to enter the guide hole smoothly, the cutting speed is set at 145 m/s and the cutting depth is set to 0.14 mm. At this point the tool is not almost wear, the deviation of the hole is small; After the drill enter the guide hole completely, the cutting speed is raised to 255 m/s, and the cutting depth is 0.2 mm, at this time, cutting force become larger, the cutting-edge and guide block began to appear obvious wear and tear, hole deflection is also intensified, the crash of tool causes the hole's deviation to increase rapidly. After the replacement of the bit, the deflection of the hole has been corrected, so the deflection becomes smaller.

3.2.3. analysis of the deflection of the hole axis

In practice, there are many reasons for the deviation of the hole, such as uneven material composition and clamping errors. However, the factor that determines the deflection of the hole is the force in the drilling. One of the factors that affect the drill force is the wear of the drill bit. During the drilling process, the tool will inevitably cause wear and wear, which will cause the change of the force balance, with the continuous development of wear and tear, the tool will continue to change the force, which causes vibration, the axis of the tool machining will deviate from the correct axis of the hole. When the tool is broken, the tool will be violent vibration, which aggravate the deflection of the hole, then we must stop drilling, replace the tool to prevent serious deviation.

3. Conclusions

![Fig.4 Chip morphology in different degree of wear of tool](image)

![Fig.5 Variation of hole axis deviation with hole depth](image)
The guide block in the drilling will also wear, and the guide block directly guide the direction of the drill bit, if the wear of guide block is very serious, the degree of hole deflection will be particularly serious.

(1) In the drilling process of 17-4PH material, the wear of the cemented carbide tool is mainly manifested as the wear of the rake face, the flank face and the guide block. The wear mechanism includes abrasive wear, bond wear and diffusion wear. Bonding wear is dominant.

(2) Tool wear directly affect the shape of the chip, with the tool wear increases, the chip shape will change accordingly, the actual processing can be observed by cutting the chip shape to determine the tool wear.

(3) After the tool wears, the force balance system of the tool is changed and the force of tool is changed. The feed direction deviates from the hole axis, so it has a great influence on the deflection of hole.

4. References

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