Research on Super-long Deep Hole Drilling Technology Based on 0Cr17Ni4Cu4Nb Stainless Steel

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Abstract. 0Cr17Ni4Cu4Nb stainless steel has problems such as severe work hardening, serious tool wear and difficulty in heat dissipation in deep hole processing. Thus the super-long deep hole drilling of 0Cr17Ni4Cu4Nb stainless steel was studied. The material and geometric parameters of drilling bit were selected reasonably. The super-long deep hole drilling test of 0Cr17Ni4Cu4Nb material was designed and carried out. The drilling process and reason for the axis deviation were investigated. The experimental results show that reasonable parameters of drilling bit and drilling process can better control the hole axis deviation. It provides technical parameters and experience for actual production.

1. Introduction
In the mechanical manufacturing industry, a hole having a length to diameter ratio of more than 50 (L is a hole depth and d is a diameter) is generally referred to as a super-long hole [1]. Deep hole machining is an important branch of machining, and deep hole machining technology theory is also an important topic in machining research. With the advancement of technology and the development of industry, the application of deep hole processing is more and more widely used in almost all machine manufacturing departments such as petroleum machinery [2], aviation industry [3], shipbuilding, metallurgy, power generation equipment, mold manufacturing and other departments. Therefore, it has become a commonly used processing method and has an increasingly important position. Meanwhile, with the advent of new materials, the processing requirements for deep holes are getting higher and higher. The super-long deep hole processing of difficult-to-machine material gradually appears in the mechanical manufacturing industry, and it occupies an increasing important position. Compared with general machining, it has the following characteristics.

(1) Deep hole drilling is in a fully enclosed or semi-closed machining state, and the operator cannot directly observe the cutting state, the cutting condition and the degree of wear of the tool [4].

(2) Since the hole is relatively deep, the path of the chip passing through the deep hole is relatively long, which is inconvenient for the chip to be discharged, and the chipping phenomenon is liable to occur, which causes the tool tipping [5].

(3) Due to the large length-diameter ratio, the drill pipe is slender and its rigidity is poor. The drill pipe is prone to deflection and vibration during the process which increases as drilling depth increase. So the precision and surface roughness of the hole to be machined are difficult to guarantee.

(4) The heat of cutting is not easy to dissipate in the cutting zone. The drill pipe works in an approximately closed state, and the heat is easily accumulated to cause serious wear of the tool.
When processing super-long tubes, the stability requirements for deep-hole drilling machines are very high, especially the stability of the drill pipe. In order to meet the processing quality requirements, the cost input is invisibly increased.

0Cr17Ni4Cu4Nb is a martensitic precipitation hardening stainless steel, which is a typical difficult-to-machine material [6]. It possesses high strength and wear resistance, good hardenability and corrosion resistance. Therefore, it is widely used in aerospace, petrochemical and marine development industries. However, the finished bar of this kind of material has high toughness and low thermal conductivity. There are problems such as large plastic deformation, severe work hardening, and high cutting heat and difficulty heat dissipation. So the chips adhere to the cutting edge seriously, and it is easy to produce built-up edge, and the chips are not easy to discharge. Therefore it is difficult to cut the 0Cr17Ni4Cu4Nb using the super-long deep hole drilling.

The super-long deep hole drilling of 0Cr17Ni4Cu4Nb stainless steel was studied. The tool material and tool geometry parameters were selected reasonably. The super-long deep hole drilling test of 0Cr17Ni4Cu4Nb material was designed and carried out. The drilling process and reason for the axis deviation were investigated. It provides technical parameters and experience for actual production.

2. Processability of 0Cr17Ni4Cu4Nb stainless steel

0Cr17Ni4Cu4Nb stainless steel has a low carbon content, high content of Cr and Ni, good welding performance and corrosion resistance, and high content of alloying elements such as Nb and Cu. These alloying elements can precipitate age hardening phase during heat treatment, so that the material has high strength and hardness. Because of this, the work hardening of 0Cr17Ni4Cu4Nb stainless steel is severe, the cutting force is sharply increased, the cutting temperature is rapidly increased, and the tool wear is severe in the cold working process. So 0Cr17Ni4Cu4Nb stainless steel is the most difficult to process in stainless steel.

Although the material has good strength, its thermal conductivity is low and can withstand high temperature and high pressure. Therefore, when cutting the material, the cutting force is sharply increased, the cutting temperature is rapidly increased, the tool wear is severe, and the durability is low. The main aspects of its cutting performance should be as follows:

1. The cutting force is large and the work hardening is serious [7]. Since 0Cr17Ni4Cu4Nb has high strength and large plastic deformation, the cutting force is large and work hardening is likely to occur.

2. The cutting temperature is high and the tool is prone to wear [8]. Plastic deformation and friction between the tool and the workpiece will generate a large amount of cutting heat, and the bonding between the tool and the chip will usually occur, accompanied by the mutual diffusion of chemical elements between the tool and the workpiece contact surface. It is easy to produce crater, which causes the tool to wear and diffuse, and the durability of the tool is greatly reduced.

3. Chip breaking is difficult. The plasticity and toughness of the 0Cr17Ni4Cu4Nb stainless steel are relatively large, and the chip breaking is difficult. Moreover, entanglement is easy to occur between the chips, causing serious processing accidents.

3. Processing system selection and tool design

1. Processing system selection

Common systems for deep hole drilling mainly include BTA systems, gun drilling systems, ejector drilling systems and DF systems [9, 10]. When the general hole diameter is less than 20mm, the gun drilling system is adopted; and the BTA system is adopted with the hole diameter larger than 20mm and has a wide range of use. Considering that the diameter of actual sample diameter is 40mm, the BTA deep hole drilling system is selected as the processing system.

2. Design of BTA drilling bit

According to the characteristics of super-long deep hole drilling, the designed structure of BTA drill bit is shown in Figure 1. The multi-edge staggering tooth is used [11]. Compared with the single-edge tool, the cutting force and torque can be reduced by almost 50%, and power consumption can be decreased and durability of the tool can be increased. In order to ensure chips can be discharged smoothly, the geometric parameters of the tool are shown in Table 1.
Figure 1. The structure of the BTA drilling bit

Table 1. Geometric parameters of BTA drilling bit

| Parameters                                      | Value  |
|-------------------------------------------------|--------|
| Rake angle of outside cutting edge \((\gamma_0)\) | 7°     |
| Relief angle of outside cutting edge \((\alpha_0)\) | 12°    |
| Rake angle of inside cutting edge \((\gamma_{se})\) | -6°    |
| Relief angle of outside cutting edge \((\alpha_{se})\) | 12°    |
| Eccentric magnitude \((e)\)                     | 5mm    |
| \(\delta_1\)                                   | -3°    |
| \(\delta_2\)                                   | 12°    |
| Inclination angle of outside cutting edge \((\lambda)\) | 0° |
| Working approach angle of outside cutting edge \((\psi_0)\) | 18° |
| Working approach angle of inside cutting edge \((\psi_{se})\) | 20° |

Due to the particularity of the 0Cr17Ni4Cu4Nb stainless steel, YG-type tools with high temperature hardness, high temperature strength and strong oxidation resistance were selected. This is because YG-type tools have better flexural strength and impact toughness, better thermal conductivity, and less chipping of tool. Although the hardness and heat resistance of the YT-type tool are higher than that of the YG type hard alloy, the bending strength and impact toughness are far worse than those of the YG-type hard alloy [12].

4. Super-long deep hole drilling tests of 0Cr17Ni4Cu4Nb stainless steel

4.1. Experiment and samples
The experiment sample is a bar of 0Cr17Ni4Cu4Nb with a length of 4600 mm and a diameter of Ф40 mm. The experimental equipment is shown in Figure 2, and Figure 3 is the experimental BTA drilling bit.

Figure 2. CW6163D type experimental equipment
4.2. Experimental process parameters

The experimental process parameters mainly include drilling diameter (D), workpiece length (L), rotation speed of workpiece (n), feed rate (f), cutting fluid pressure (P) and cutting fluid flow rate (Q.). The process parameters are shown in Table 2.

Table 2. Super-long deep hole drilling process parameters

| D    | L     | n (r/min) | f (mm/r) | P    | Q  |
|------|-------|-----------|----------|------|----|
| 40mm | 4600mm| 145~335   | 0.22~0.3 | 1Mpa | 100~200L/min |

4.3. Experimental results and analysis

(1) Drilling process

According to the cutting parameters, the drilling process is divided into two groups. The rotation speed is 335 r/min and 145 r/min. the feed rate is 0.22 mm/r and 0.3 mm/r. The results of the drilling process are shown in Table 3. It main includes the chip morphology, drilling bit wear and drilling bit breakage.

Table 3. The results of the different drilling process

| Number | n (r/min) | f (mm/r) | Chip morphology | Drilling bit wear | Drilling bit breakage |
|--------|-----------|----------|-----------------|-------------------|-----------------------|
| 1      | 335       | 0.3      | normal          | severe            | tipping               |
| 2      | 335       | 0.22     | normal          | severe            | none                  |
|        | 145       | 0.3      | normal          | severe            | none                  |
|        | 145       | 0.22     | normal          | slight            | none                  |

(2) Drilling bit wear

The tool wear condition is shown in Figure 4, in which Figure 4(a) is a 200-times SEM photograph of the rake face of intermediate tooth, and Figure4 (b) is a 500-times SEM photograph of the rake face of intermediate tooth. It can be seen that the peeling of the surface layer and the drilling bit wear can be clearly observed at the cutting edge of the multi-edge staggering tooth. During the cutting process, the main cutting edge is subjected to repeated thermal stresses, frictional stresses and contact stresses, and with a strong thermal shock and mechanical shock, a large amount of heat is generated during the machining process. As the machining depth increases, the heat generated is less and less likely to be discharged, thereby accelerating the wear of the tool. When these wears reach a certain amount, the tool point is tipped.
In the super-long deep hole drilling process, the drill pipe has a large length-diameter ratio and is sensitive to the change of the force. When the hardness of the workpiece is not uniform, the drill pipe is easily twisted, which causes the initial deflection of the drill bit. The amount of deflection will increase with the increase of the drilling depth, eventually leading to the drilling direction of the drill bit. This makes the drill bit to move more and more away from the workpiece axis of rotation. However, all of this is due to the harsh working environment of deep hole drilling, which is caused by the inconsistency of the direction and processing of the tool during the machining process. If the axis of the hole is excessively offset, the guide block is pressed against the wall of the hole to cause friction, which causes the frictional force and torque of the guide block to increase sharply, thereby increasing the probability of the tool and seriously damaging the surface of the machined surface roughness. Therefore, it is necessary to reduce the axial offset of the hole by reasonable parameters of tool and cutting process to meet the processing requirements.

The wall thickness value was measured with an ultrasonic wall thickness meter every 500 mm during drilling, and the eccentricity (e) at the center of the hole at each position was calculated. The hole axial deflection tendency under this cutting condition can be obtained, as shown in Figure 5.

5. Conclusion
Through the deep hole processing test of the 0Cr17Ni4Cu4Nb stainless steel, the following conclusions can be drawn:

1. For super-long deep hole machining with diameter of Ф40mm, it can be processed by BTA drilling system with multi-edge staggering tooth. The drill bit is made of hard alloy, which can better control the problem of hole axis deviation.
(2) The geometric parameters of the drill bit are: $\gamma_0=7^\circ$, $\alpha_0=12^\circ$, $e=5\text{mm}$, $\delta_1=-3^\circ$, $\delta_2=12^\circ$, and $\lambda_s=0^\circ$; the optimum cutting parameters are $n=145\text{r/mm}$, and $f=0.22\text{ m/r}$.

(3) The cutting parameters have a great influence on the axial deflection of BTA deep hole drilling. Specifically, the increase in the cutting parameters causes an increase in the cutting amount, which affects the amount of cutting force, which in turn causes the axis of the hole to be deflected.

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