Drilling technology and experimental research of ultra-high strength steel A100

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Abstract. In order to study the influence of different drilling parameters on the cutting force during the drilling process of A100 ultra high strength steel, the simulation analysis and drilling test of A100 high strength steel were carried out by single factor test method. Firstly, the dynamic simulation software AdvantEdge cutting simulation software is used to build the A100 steel drilling model, and the cutting force of the A100 steel under different drilling parameters is simulated and analyzed. Secondly, the cutting force is measured in the process of drilling A100 steel by three direction dynamometer and the cutting force is analyzed, and the simulation results are compared with the test results. The results show that the size of drilling force decreases with the increase of spindle speed, and increases obviously with the increase of feed rate, while drilling step depth and feed are the main factors affecting the drilling. Therefore, in the drilling of A100 steel, higher spindle speed, smaller feed and moderate drilling step depth should be selected.

1. Introduction

High strength steel A-100 (23Co14Ni12Cr3MoE), which has the best performance and the highest technical content in the aircraft landing gear, has the comprehensive properties of high alloy, high strength, high toughness and so on [1]. Because of its poor cutting performance and sensitivity to stress concentration, it belongstoa refractory material [2]. In the machining industry, drilling technology accounts for about 40%-50% of the machining industry [3]. On the landing gear of the aircraft, there are more parts to be drilled, such as outer cylinder, wheel shaft and so on [4]. Drilling is a semi closed machining [5]. In the process of processing, the geometric parameters of the drill, the material of the tool and the cutting amount are the main factors that affect the quality of the drilling [6]. The drilling force, the drilling temperature and the tool wear are the important basis to reflect the drilling performance and the processing process [7-10].

AdvantEdgesoftwareas a finite element metal cutting simulation software, the simulation results are reliable, and can avoid the defects of the quality of the controlled parts in the traditional processing [11].
It has been widely used in the cutting, milling, drilling and other different types of cutting simulation research [12,13]. In this paper, the effects of different drilling parameters on the cutting force in the drilling process of A100 steel are analyzed by the simulation analysis and experimental research. The problems in the drilling process of hard working material A100 steel are solved, the efficiency and quality of drilling are improved, and the reference is provided for the drilling hard drilling in the future.

2. Finite element simulation and analysis

2.1. The establishment of finite element model
At present, the methods of cutting numerical simulation are mainly Euler method and Lagrange method. As a solid analysis method, the Lagrange method changes the mesh of the workpiece along with the deformation of the workpiece during the cutting process. Therefore, this paper chooses Lagrange method to establish the finite element model, and uses the adaptive mesh technology in AdvantEdge to improve the accuracy of calculation. The material of the workpiece is A100 steel with a size of 12mm*12mm*3mm. Its chemical composition is shown in Table 1, and its mechanical properties are shown in Table 2. The cutting tool chooses cemented carbide and the tool diameter is 5.5mm.

| Table 1. Chemical composition |
|-------------------------------|
| C   | Mn | Si   | Cr   | Ni   | Mo  | Co   | P    | S    | Fe  |
| 0.21-0.27 | ≤0.10 | ≤0.002 | 2.8-3.3 | 11.0-12.0 | 1.0-1.3 | 13.3-13.5 | ≤0.003 | 0.0008 | Bal |

| Table 2. Mechanical properties |
|--------------------------------|
| strength of extension $\sigma_b$/MPa | yield strength $\sigma_0.2$/MPa | percentage reduction of area $\psi/%$ | elongation $\delta/%$ | fracture toughness $K_C$ (MPa$\cdot$mm$^{1/2}$) |
| ≥1930 | 1765 | ≥55 | ≥10 | ≥120 |

2.2. Test content and method
In order to study the change law of cutting force in the process of drilling A100 steel by n (r/min), feed f (mm/min) and near depth P (mm), this paper uses a single factor test method and the cutting test parameters, as shown in Table 3.

| Table 3. Single factor test parameters |
|---------------------------------------|
| Parameter Name | Parameter values |
| Spindle speed(n/min) | 300 | 350 | 400 (f=30mm/min, p=1.2mm) |
| Feed rate(f(mm/min)) | 20 | 25 | 30 (n=350r/min, p=1.2mm) |
| Drilling depth(mm) | 1 | 1.5 | 1.2 (n=350r/min, f=30mm/min) |

2.3. Analysis of simulation results
In the simulation test, the influence of the drilling parameters on the cutting force is mainly focused on the cutting force, and the cutting edge, the cuttings and the tool wear are not taken into account, so the simulation analysis is not carried out for the near depth. Fig. 1 is a simulation diagram of drilling force for A100 steel. Table 4 is the result of cutting force obtained under different drilling parameters.
Fig. 1 is a simulation curve of drilling force for A100 steel at spindle speed $n=350\text{r/min}$ and feed $f=30\text{mm/min}$. From Figure 1, it can be seen that the cutting force is divided into three stages: the first stage, because the bit has just contacted the workpiece material, the blade has not yet processed the workpiece and collided with the workpiece, resulting in a sharp increase in the drilling force; the second stage bit began to process the workpiece, and the drilling force was slowly rising; the third stage of drilling force gradually stabilized. The data in Table 4 can be obtained. The size of the drilling force varies with the feed and the spindle speed. The drilling force increases with the increase of the feed, and the drilling force increases with the increase of the spindle speed.

3. Drilling test of A100 steel

3.1. Test conditions

The test machine tool adopts the vertical CNC machining center, the model is CY-VMC-850C, the workpiece material is super high strength A100 steel, the size is $100\text{mm} \times 100\text{mm} \times 60\text{mm}$, the cutting tool is made of hard alloy twist drill, and the diameter is 5.5mm. Drilling force measurement consists of kistler-9255B three-way dynamometer, charge amplifier, data acquisition card and other equipment, the principle of which is shown in Figure 2. Figure 3 is a field map for processing drilling.
3.2. Test scheme
For drilling, the main factors affecting the drilling are the amount of drilling, and the drilling force of the bit is mainly the axial force because of the structure of the drill bit itself. In order to study the change law of cutting force in the process of drilling A100 steel by \( n \) (r/min), feed \( f \) (mm/min) and near cutting depth \( p \) (mm), the single factor method was used to fix other factors, which only changed one of the factors. The drilling test parameters are shown in Table 5.

Table 5. The numerical value of drilling force is measured by spindle speed test

| No. | Test parameters | n(r/min) | f(mm/min) | p(mm) |
|-----|----------------|----------|-----------|-------|
| 1   |                | 300      | 30        | 1.2   |
| 2   |                | 350      | 30        | 1.2   |
| 3   |                | 400      | 30        | 1.2   |
| 4   |                | 350      | 20        | 1.2   |
| 5   |                | 350      | 25        | 1.2   |
| 6   |                | 350      | 30        | 1.2   |
| 7   |                | 350      | 30        | 1   |
| 8   |                | 350      | 30        | 1.5   |
| 9   |                | 350      | 30        | 2     |

3.3. Result analysis

3.3.1. Research on the influence of spindle speed on drilling. The feed rate is \( f=30\text{mm/min} \) and the drilling step depth is \( p=1.2\text{mm} \). Considering the material performance of high strength steel A100, the large spindle speed may accelerate the wear of the bit and shorten the service life of the bit, so the rotation speed is taken respectively by 300r/min, 350r/min and 400r/min.

Figure 4(a) is the impact of the spindle speed on the drilling force. From Figure 4(a), it can be seen that the \( F_x \) and \( F_y \) are almost the same due to the cutting edge of the drill, and are not affected by the spindle speed. \( F_x \) and \( F_y \) may be caused by the vibration of the bit and the workpiece during the processing. The axial force of \( F_z \) decreases with the increase of spindle speed, but has little effect.

3.3.2. Study on the influence of feed on drilling. The spindle speed of the test is \( n=350\text{r/min} \), and the step depth is \( p=1.2\text{mm} \). Considering the mechanical properties of high strength steel A100, the feed is selected by 20mm/min, 25mm/min and 30mm/min respectively.

Figure 4(b) is the impact of feed on drilling force. It can be seen from the drawing that the influence of different feed rates on drilling force is different in the drilling process. The axial force of \( F_z \) increases obviously with the increase of feed, and increases greatly.

3.3.3. Study on the influence of drilling step depth on drilling. Select spindle speed \( n = 350\text{r} / \text{min} \), feed \( f = 30\text{mm} / \text{min} \), drilling step depth of 1 mm, 1.5mm and 2 mm respectively to drill test.

Figure 4(c) is a diagram of the influence of drilling step depth on the drilling force. It can be seen from the diagram that the axial force of \( F_z \) increases slowly first and then drops. When the drilling step depth is increased from 1mm to 1.5mm, the axial force of the \( F_z \) increases, but the axial force of \( F_z \) decreases gradually when the drilling step depth is increased from 1.5mm to 2.0mm. Therefore, when drilling depth reaches a certain value, increasing drilling depth may reduce drilling force.
Figure 4. Visual analysis of test results. (a) The influence of the spindle speed on the drilling force; (b) Influence of feed on drilling force; (c) Effect of drill depth on drilling force

4. Comparison of test results

The simulation analysis and experimental study on drilling of high strength steel A100 are carried out respectively. The results are compared and analyzed.

From Figure 5, it can be found that the cutting force of the simulation results is similar to that of the experimental results. The drilling force decreases with the increase of the spindle speed, and increases with the increase of the feed rate, and the feed amount has a great influence on the drilling force and the spindle speed is relatively small. Therefore, feed rate is the most important factor affecting drilling. As can be seen from Figure 5, the simulation value is smaller than the test value. The reason for the analysis is that there is a difference between the properties set by the material in the simulation analysis and the material properties of the sample used in the actual processing, and the hardness of the material is lower than that of the test sample. Therefore, the simulation value is less than the test value.

Figure 5. Results comparison diagram (a) Effect of spindle speed on drilling force; (b) Effect of feed rate on drilling force

5. Conclusion

In this paper, the influence of drilling parameters on drilling force in A100 ultra high strength steel drilling process is analyzed by finite element simulation analysis and experimental research, and the following conclusions are obtained.

(1) The AdvantEdge simulation software is used to simulate the drilling of A100 steel with different drilling parameters. Through the analysis of the results, the drilling force increases with the increase of the feed rate. With the increase of spindle speed, the feed rate is the biggest factor affecting drilling force when the drilling step depth is constant.

(2) Through the test of high strength steel A100 drilling, and comparison and analysis of the measured drilling force data and simulation results, the results are similar. It is more determined that the main factors affecting the drilling process are feed and the spindle speed is less affected.
(3) After analyzing the drilling force, it can be concluded that Fx and Fy are small and almost equal in the process of drilling, and the drilling force is mainly axial force Fz. Therefore, in drilling process, Fx and Fy may be caused by vibration of bit and workpiece during machining.

Acknowledgments
This work was supported by the National Natural Science Foundation of China (Grant Nos. 51505268).

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