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Research on Simulation Model of Ultra Deep Hole Machining of Nickel Base 718 Alloy

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Abstract: Deep hole machining technology is widely used in aerospace, military and other fields, but for difficult to cut materials such as nickel base 718 alloy, there are bottlenecks such as poor machining accuracy and low efficiency in deep hole machining with large depth to diameter ratio. In order to improve the processing quality and efficiency of deep hole machining of nickel base 718 alloy, this paper establishes a finite element model for ultra deep hole machining of nickel base 718 alloy workpiece by gun drilling and a calculation model for straightness deviation of deep hole based on gun drilling theory and finite element method, studies the influence of tools and drilling parameters on straightness deviation of deep hole, and quotes some test data of others to verify the rationality of gun drilling model, Compared with the model in this paper at different speeds and feed rates, the adaptability of the model at different apertures was discussed. The results show that the finite element model for deep hole machining of nickel base 718 alloy established in this paper has good adaptability.

Keywords: Deep hole processing Nickel base 718 alloy, Tool angle, Process parameters.

1. Introduction

According to statistics, in 29 manufacturing industries in China, at least half of them have direct demand for deep hole processing technology, and 1/3 have urgent demand. Deep hole processing technology is widely used [1]. However, as the deep hole processing process is in a semi closed or fully closed state, it is impossible to directly observe, and only sound and vibration can be used to judge whether the processing is normal. Therefore, it is difficult to ensure the quality and efficiency ratio of deep hole processing with large depth diameter ratio for gun drilling nickel base 718 alloy and other difficult cutting materials: on the one hand, nickel base 718 alloy has the characteristics of high strength, high density, low heat conductivity and work hardening during processing; On the other hand, with the increase of drilling depth, the straightness deviation of deep holes is larger.

Many scholars at home and abroad have studied the cutting performance of nickel base 718 alloy: Li [2] studied the grooving wear and chip wear of coated carbide tools during high-speed cutting of nickel base 718 alloy through experiments, and found that adhesive wear and abrasive wear play a dominant role in the processing of nickel base 718 alloy; Ezugwu [3], Zhu [4] and others studied the cutting test of nickel base 718 alloy, and found that the low thermal conductivity of the alloy led to significant thermal tool load and the formation of stacking edges.

The research on deep hole machining of superalloy workpiece includes: Liu Jingjing [5] and others conducted a Ti6Al4V titanium alloy gun drilling test (depth diameter ratio 25), tested the axis deviation, hole diameter error and machining surface integrity of gun drilling deep holes, and believed that the main reason for the deviation was the vibration of drill pipe; Imran [6] carried out a deep hole machining experiment of Ni base 718 alloy with a depth to diameter ratio of 17 mm (depth to diameter ratio of 10), studied the relationship between tool life and machining parameters, and found that when the feed rate was 0.01 mm, the maximum tool life of lf=400 mm was reached; K. S. Woon [7] and others analyzed the reasons for the instability of gun drill processing nickel base 718 alloy through processing tests, and found that the improper grinding angle of the gun drill end face would cause the twist bending of the drill pipe and cause great axis deviation error. It was concluded that the vibration caused by the wear of the gun drill cutting edge would seriously affect the accuracy and surface quality of the hole; Zhang [8] studied the problem of inconsistent vertex offset during gun drill regrinding and its relationship with hole straightness during deep hole machining of nickel base superalloy thin-walled parts through finite element method, and verified the model through experiments.

Up to now, the research on the cutting performance of nickel base 718 alloy is mainly limited to turning (milling) and deep hole machining with small depth diameter ratio in the field of deep hole machining, while the research on deep hole machining with large depth diameter ratio of nickel base 718 alloy is less.

In this paper, based on gun drilling theory and finite element method, the model of gun drilling nickel base 718 alloy and the calculation model of straightness deviation of deep holes are established: the influence of internal angle, external angle, rotational speed and feed rate on the drilling force of gun drilling and the influence of straightness deviation of deep holes are studied. This research provides a method for simulation calculation of straightness of deep hole machining, and has a certain reference significance for the research on straightness deviation control of deep hole machining.

2. Deep Hole Drilling Model

2.1. Physical properties of drilling model parts

This paper takes the ultra deep hole with a depth of 11.8 mm, a depth of 1200 mm, and a depth diameter ratio of more than 90 as an example. The parts in the model are made of nickel base 718 alloy, the drill bit is made of YG-6X cemented carbide, and the drill pipe is made of 45 steel. The simulation model is established. Table 1 shows the physical property parameters of the selected materials.

Table 1. Physical properties of machined parts, drill bits and drill pipes

Material Science	Young's modulus MPA	Poisson's ratio	Coefficient of thermal expansion K	thermal conductivity W/m/℃	Specific heat capacity J/kg/℃	density kg/m3
Alloy 718	205000	0.3	1.18e-5	11.4	534	8190
Hard alloy	534000	0.22	4.9e-6	50	400	11900
45 steel	209000	0.269	7890	—	—	—

The simulation model for gun drilling of nickel base 718 alloy workpiece has the following assumptions:

According to literature [9], the temperature variation range of deep hole processing is small, and the Young's modulus, thermal expansion coefficient, thermal conductivity and other parameters of the workpiece material change little with temperature, so they are set as constant values.

The workpiece material model is described by J-C damage model.

The gun drill bit has a complex structure. After being simplified, its main cutting features, namely the external and internal angles of the drill bit and the structure of the coolant hole, are retained.

In this paper, the diameter of deep hole is small, which can be directly processed by gun drilling without pre drilling.

The straightness of the deep hole is required to be 0.254 mm. Due to the thermal expansion reaction of the drill bit, the actual straightness value is 0.25 mm.

2.2. Gun drill drilling model

In this paper, a simplified drilling model is used to simplify the ultra deep hole on the machining parts, and a gun drill bit is used to drill a certain circle in the deep hole processing. In the model, the machining workpiece and drill bit are respectively established, as shown in Figure 1.

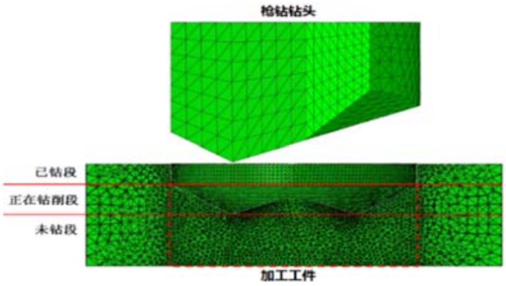


Figure 1. Ø 11.8 mm Gun drill drilling model

2.3. Deep hole straightness calculation model

Therefore, during deep hole processing, the gun drill bit mainly bears the drilling resistance during drilling and the load generated by the drill pipe compression torsion on the drill bit. As shown in Figure 2, according to the load direction, the load is divided into tangential force (F cutting), radial force (F diameter) and axial force (F axis).

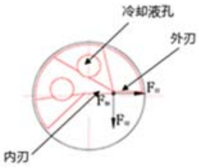


Figure 2. Load of Gun Drill Bit on Hole Wall

The drill pipe is simplified as a simply supported beam model [9] under the action of coolant load (q), axial force, radial force and other loads, as shown in Figure 3.

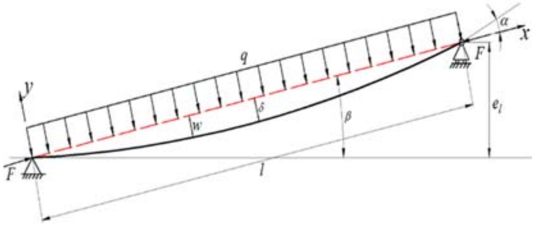


Figure 3. Schematic Diagram of Bit Offset at Different Drilling Depth

Then the torque of drill pipe is:

$$M(x)=F\omega+\frac{qx^2}{2}-\frac{qlx}{2} \tag{1}$$

Where: M - torque; F - Axial force; ω - Coolant load; l - Drilling depth.

The approximate differential equation of deflection curve is:

$$EI\omega''=\frac{qx^2}{2}-F\omega-\frac{qlx}{2} \tag{2}$$

Where, EI - bending stiffness.

Let, the general solution of equation (3) is: $K^2=F_{轴}/EI$

$$\omega=A\sin(kx)-Bk\cos(kx)+\frac{Fq(2x-l)}{2} \tag{3}$$

When,, B=0, When, $x=0$ $\omega=0$ $x=l/2$ $\omega=\delta$, $A=\delta+Fql^2/8/\sin(kl/2)$; When,,there is=0. $x=l$ $\omega=0$ $\frac{\delta+Fql^2/8}{\sin(kl/2)}\cdot\sin(kl)=\frac{\delta+Fql^2/8}{2}\cdot\cos(kl/2)$ $kl=\pi$

ω' Is the slope of deflection curve, then there is, $\omega'_{(x=l)}=\tan\alpha$

Where: - maximum deflection. δ

$$\omega'=\frac{2\pi\delta+(1+\pi/4)Fql^2}{2l} \tag{4}$$

According to Formula (4), when the drilling depth increases, the deflection slope of the drill pipe increases from to, and the offset between the drill point and the axis at the drilling depth increases, that is, the bit offset at the top of the drill pipe increases. $l\ {}^{\alpha}\ \alpha+\beta\ \ e_f$

Considering the influence of processing parameters such as the number of support rings, sectional processing scheme, speed and feed rate, the drilling models with different depths are established, as shown in Figure 4. The bit offset of unit feed under different drilling depth is obtained. The real strain of the extrusion deformation of the workpiece hole wall is taken as the bit offset under the unit feed rate. Based on the simulation experiment data, the bit offset under these different drilling depths will be fitted to obtain the bit offset curve, as shown in Figure 5.

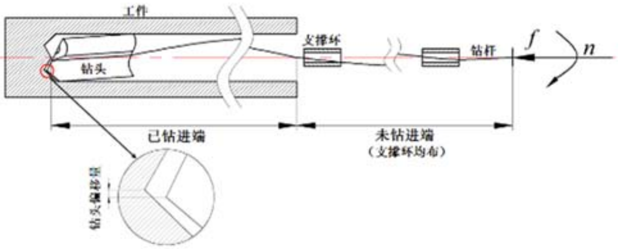
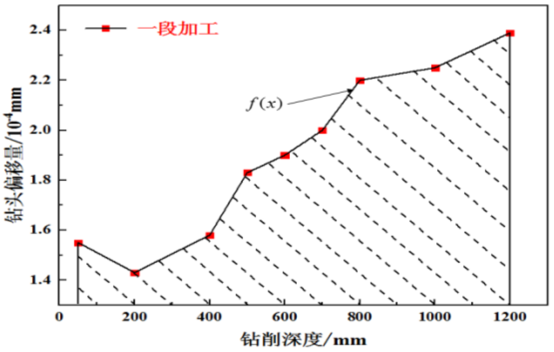


Figure 4. Schematic Diagram of Drilling Models with Different Depth

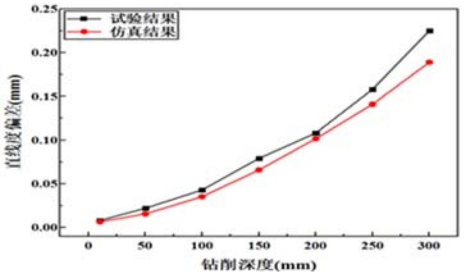


Calculate the straightness deviation (e_L) under different drilling depths according to Formula (5):

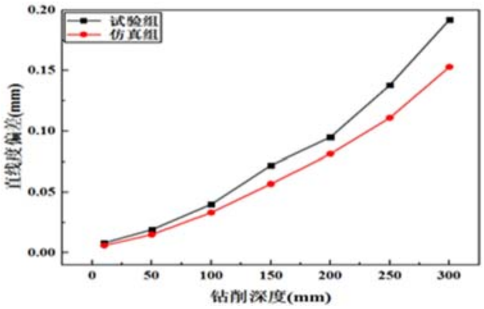
$$e_L = \int_0^L f(x)dx \tag{5}$$

3. Model Validation and Comparison

In order to verify the rationality of gun drilling model and position degree calculation model, part of the test data of Fu Kangkang [9] are cited to compare with the model in this paper at different speeds and feed rates, and discuss the adaptability of the model at different apertures. The test uses a Ø 13 mm cemented carbide gun drill, with a drilling depth of 300 mm, and the machined parts are 45 steel.



(a) Vf=25 mm/s



(b) Vf=20 mm/s

Figure 6. Comparison of test and model calculation results

It can be seen from Figure 6 that the reflection law of the finite element model calculation results in this paper is consistent with the test results. When Vf (feed speed) is 25 mm/s, the average error rate between the model calculation results and the test results is 19.06%; When Vf (feed speed) is 20mm/s, the average error rate between model calculation results and experimental results is 17.92%. All the models in this paper meet the engineering error.

4. Conclusion

In this paper, the finite element model and straightness deviation calculation model of gun drilling nickel base 718 alloy with a diameter of 11.8 mm are established, and the effects of drilling force and processing parameters on straightness deviation are studied. The conclusions are as follows:

(1) The comparison between the calculated results of the finite element model and the existing experimental results shows that the finite element model meets the requirements of engineering error under different hole diameters and drilling parameters, and has good applicability.

(2) According to the straightness calculation model of deep holes, the variation of straightness deviation of deep holes is mainly affected by tangential force (F tangent), radial force (F diameter), axial force (F axis) and drilling depth l.

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