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INFLUENCE OF PASS SPACING ON THE SPINNING PROCESS OF NICKEL-BASED ALLOY CONICAL CASING

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High temperature nickel-based alloys are prone to forming defects due to serious work hardening, and the pass spacing is an important parameter in multi-pass drawing and spinning. Using GH4169 superalloy as the material, a Finite Element Model (FEM) was established based on the Simufact platform, and the influence of the pass spacing on the spinning process was explored by using the concave curve and circular arc trajectory. The results show that the stress-strain increases with the increase of the pass spacing. Obtain the optimal pass spacing under specific conditions: blank wall thickness t = 2,5 mm, blank diameter d = 250 mm, feed ratio f = 1,2 mm/rad, mandrel speed n = 300 r/min, pass spacing p = 14 mm .

Key words: nickel-based alloys, wheel track, FEM, stress-strain, pass spacing

INTRODUCTION

As the main load-bearing external component of the entire engine, the conical casing of aero-engine has high requirements on its forming quality and mechanical properties[1]. The conical rotary part is a kind of aero-engine conical casing. This type of parts is usually formed by multi-pass stamping and drawing. The large spinning force is likely to cause serious uneven wall thickness. Spinning is a kind of plastic forming with the advantages of low material utilization, good product performance and high dimensional accuracy. Therefore, spinning forming is one of the effective methods for preparing high-precision superalloy conical casing. Most of the materials are high-temperature alloys, which are prone to forming defects due to their large deformation resistance and serious work hardening. In order to effectively control the precise forming of the conical parts and improve the forming quality, it is necessary to develop the influence of the process parameters on the forming quality of the superalloy conical casing.

At present, Wang Xingkun[2], based on the thermal strong spinning experimental platform, used range analysis, gray correlation analysis and other methods to explore the influence of process parameters on the forming quality of spinning parts. The results show that the thinning rate and the amount of axial misalignment have a significant effect on the forming accuracy of the spinning parts. Li et al.[3] established a multi-pass parameterized trajectory, and studied the influence of the wheel trajectory on the forming quality. The results show that for the forming of cylindrical sheet metal casings, the concave curve trajectory is better than the convex curve, and the second-order Bezier curve Formed workpieces have the most uniform wall thickness distribution. Ling Zeyu[4]established a finite element model for the drawing and spinning of nickel-based alloy conical and cylindrical parts based on the finite element software ABAQUS, obtained the multi-pass deep drawing and spinning forming law of GH3030 superalloy parts, and studied the key process parameters of the rotary wheel. The influence of feed ratio, first pass elevation angle and pass spacing on typical defects in spinning, and the criterion for instability and wrinkling of conical cylindrical parts in tensile spinning is proposed. At this stage, the influence of process parameters on the forming quality of superalloy conical casings by domestic and foreign scholars mostly focus on dimensional parameters such as billet thickness diameter, wheel diameter, wheel fillet radius, or wheel feed speed, mandrel speed, Process parameters such as thinning rate, and the research on the forming quality of superalloy conical casing by rotary wheel trajectory is still less.

In this paper, the GH4169 superalloy is used as the research material, and the Finite Element Model of the conical rotary part is established on the basis of the Simufact platform, and the parametric design of the motion trajectory of the concave curve and circular arc rotary wheel is carried out to explore the effect of the pass spacing on the spinning process of the conical rotary part.

THE ESTABLISHMENT OF FINITE ELEMENT MODEL

GH4169 nickel base superalloy is chosen as the model material, because it has good It has excellent comprehensive properties such as good fatigue resist-

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ance, thermal shock performance, processing performance, and high strength. Among the performance parameters of the GH4169 alloy material, the Young's modulus is 200 GPa, the Poisson's ratio is 0,3, and the density is 8,19×103 kg/m3.According to the research of Liu. X in the literature [5], the constitutive equation of the material is as followed:

$$\sigma_e = [650 + 809{,}16\varepsilon_e^{0,2754}]\times$$

$$\times[1+(-0{,}0067+6{,}35\times10^{-6}\dot{\varepsilon}_P)\ln\dot{\varepsilon}_e^{*}]\times(1-T^{*1,534}) \quad (1)$$

Where σ_e is the equivalent flow stress, ε_e is the equivalent plastic strain, $\dot{\varepsilon}_p$ is the equivalent plastic strain rate, $\dot{\varepsilon}_e$ is the dimensionless strain rate, T^* is the dimensionless temperature.

The spinning model consists of four parts: blank, mandrel, rotary wheel and tail top block. Since the rotary wheel, core mold and tail top block do not deform, the analytical rigid body is selected. The friction relationship between the roller and the blank is defined using a combined friction model, where the Coulomb friction and shear friction coefficients between the blank and the mandrel and the roller are 0,2 and 0,2, respectively. The Finite Element Model is shown in Figure 1.

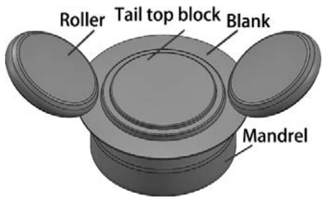


Figure 1 Finite Element Model of conical casing spinning

The simulation parameters are that the radius of the rounded wheel is 6 mm, the installation angle of the wheel is 45°, the thickness of the blank is 2,5 mm, and the diameter is 250 mm. The simulation parameters of the conical rotary parts are shown in Table 1.

Table 1 **Technological parameters of conical casing**

Parameter	Value
Black thickness / mm	2,5
Blank diameter / mm	250
Mandrel speed / r/min	300
Rotary wheel feed ratio / mm/r	1,2
Rotary wheel fillet radius / mm	12
Wheel diameter / mm	150
Wheel installation / °	45

PARAMETRIC DESIGN OF ROTARY WHEEL MOTION TRAJECTORY

The wheel track has a straight line and a curve, and the curve includes an arc curve, an involute curve, and a Bezier curve. In this paper, the concave curve and circular arc-shaped rotary wheel trajectory of the die-attached push is adopted, which has the advantages of simple design and good forming performance, as shown in Figure 2.

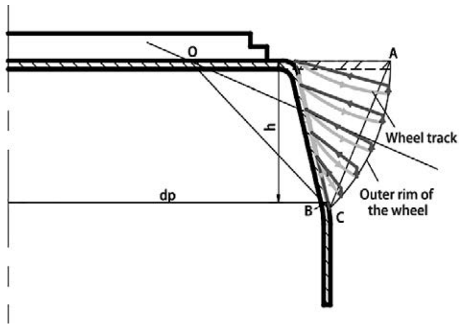


Figure 2 Concave curve circular arc wheel track

The design of the wheel track first determines the outer edge of the wheel track, which is the finish line of the wheel's forward journey. The wheel track curve cannot be too short or too long. If it is too short, the wheel and the blank will not be able to fully carry out each cycle. If the plastic deformation of the pass is too long, it will increase the time of the spinning process and reduce the efficiency. Therefore, the outer edge of the spinning wheel movement track should be designed reasonably. In the process of billet stretching and spinning, the contour of the outer edge of the track of the rotary wheel can be represented by a circular equation:

$$(x-a)^2 + (y-b)^2 = r^2 \quad (2)$$

Where x is the abscissa of the outer edge, y is the ordinate of the outer edge, a is the abscissa of the center o, b is the ordinate of the center o, r is the radius.

In Figure 2, O is the center of the arc, A and C are the two ends of the outer edge of the wheel, and the coordinates of point A, point B, point C, and point O are (D_0/2,0), (d_p/2,- h),(d_p/2+Δl,-h-Δh),(D_0/2-r,0), where D is the diameter of the blank, dp is the mouth diameter of the formed part after spinning according to the principle of equal volume, Δl and Δh It is the wheel track length compensation. The equation of the vertical line in the AC line segment is established by the coordinates of the AC two points, and the AO line is simultaneously combined to obtain the outer edge line equation of the wheel motion trajectory.

The wheel motion trajectory curve of each pass is determined by the starting point, the end point and the radius of curvature. The starting point is determined according to the pass spacing, the end point is determined

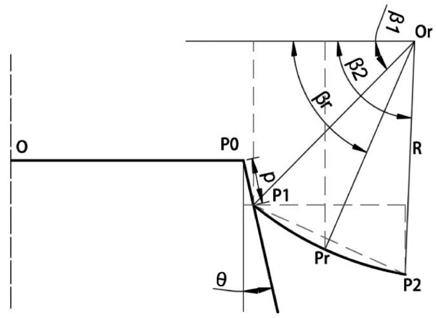


Figure 3 Schematic diagram of coordinates of concave curve arc curve

according to the outer edge of the rotary wheel, and the radius of curvature is selected to be a larger value under the condition that the forming conditions can be met.

As shown in Figure 3, P_1 and P_2 are the known points on the motion track of the rotating wheel, P_r is any point on the arc curve, R is the radius of curvature, θ is the angle of the mandrel cone angle, β_1 is the starting angle, and β_2 is the Termination angle, β_r is the angle corresponding to any point of P_r, and p is the pass spacing.Suppose n represents the number of passes. From this, the coordinate formula of the concave curve circular arc rotary wheel motion trajectory can be obtained as follows:

$$P_{rx} = OP_0 + np\sin\theta + R\cos\beta_1 - R\cos\beta_r \quad (3)$$

$$P_{ry} = np\cos\theta + r\sin\beta_r - R\sin\beta_1 \quad (4)$$

As shown in Figure 4, because the blank has two states of loading and unloading, the billet springs back in the forward and return clearances of the rotary wheel. The return path adopts a linear trajectory, because the billet will spring back at the end of each pass, and the direct linear wheel return trajectory is easy to interfere with the billet. shown, red is the return trajectory.

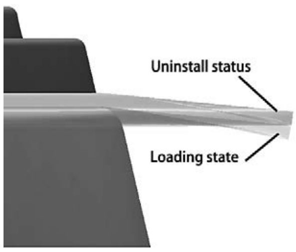


Figure 4 Billet springback

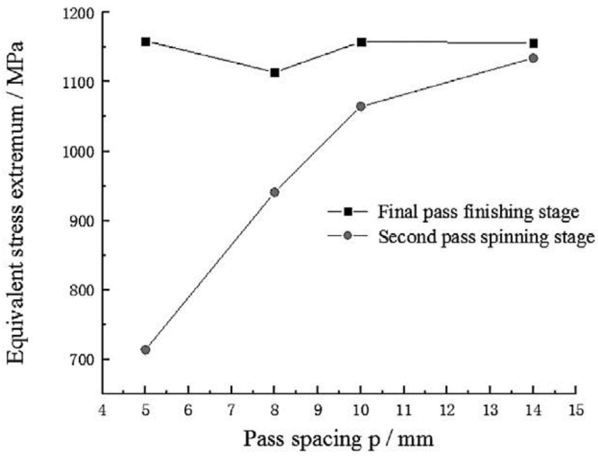
INFLUENCE OF PASS SPACING ON SPINNING PROCESS

The influence of the wheel movement trajectory on the multi-pass spinning process is extremely significant. The factors affecting the wheel movement trajectory include: billet diameter, billet wall thickness, wheel fillet radius, first pass elevation angle and pass spacing. When the blank and equipment dimensions are determined, most parameter values are determined, except for the first pass elevation and the pass spacing. The pass spacing represents the distance from the starting point of each pass's outgoing trajectory, and its numerical value determines the number of passes. Table 2 shows the number of outgoing passes under different pass spacings.

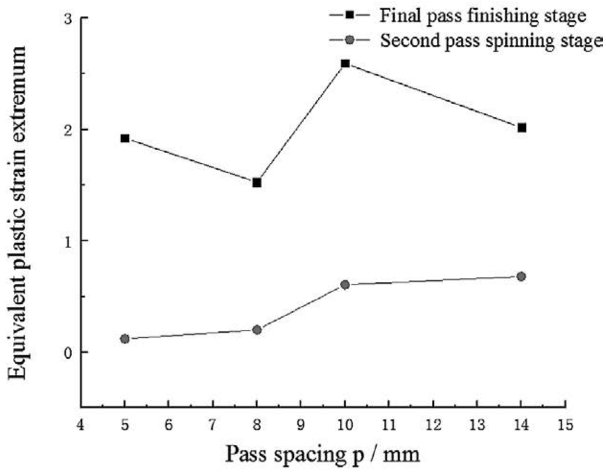
Figure 5 shows the variation law of equivalent strain. and the equivalent stress in the spinning process at different pass intervals p when the feed ratio f = 1,2 mm/r, n = 300 rad/min and the first pass elevation angle θ_0 = 50 °,taking the second and last pass as an example.

Table 2 **Corresponding number of passes under different pass spacing**

Pass spacing p/mm	5	8	10	14
Number of passes	9	6	5	4



(a) Influence of different pass spacing on equivalent stress extreme



(b) Influence of different pass spacing on equivalent plastic strain

Figure 5 Influence of different pass spacing on equivalent stress-strain

It can be seen from Figure 5(a) that in the second pass spinning stage, the extreme value of the equivalent stress increases with the increase of the pass spacing, because the increase of the pass spacing leads to the large deformation of the blank and the corresponding increase in tensile stress and the compressive stress. In addition, there is a springback phenomenon in the formed area, the deformation of the billet is large, the springback phenomenon is serious, and the yield stress increases. The pass spacing has little effect on the equivalent stress extrema of the last pass.It can be seen from Figure 5(b) that in general, the extreme value of equivalent strain increases with the increase of the pass spacing, because the pass spacing increases, the number of passes decreases, and the deformation of the billet increases in each pass, etc. The efficacious plastic strain extreme value also increases accordingly.The effect of the pass spacing on the extreme value of the equivalent plastic strain in the last pass shows a wavy trend, which is because the equivalent plastic strain increases with the increase of the pass number due to the influence of the pass number and work hardening.And when the pass spacing is small, the more passes will increase the work hardening degree of the billet mouth in the last few passes, which is easy to increase the rupture tendency. Therefore, an appropriate pass spacing should be selected for deep spinning.Under the conditions of specific selected process parameters and on the premise of satisfying the blank forming quality, considering the production efficiency, the pass spacing p = 14 is selected.

CONCLUSIONS

Using superalloy as the material, a spinning finite element model was established, and the parametric design of the circular arc motion trajectory of the gyratory concave curve was carried out. According to the simulation results of the influence of the pass spacing on the spinning process, the equivalent stress and equivalent The extreme value of plastic strain increases with the increase of the pass spacing. On the premise of satisfying the forming quality of the blank, a larger pass spacing can be selected.

Acknowledgments

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Note: The responsible translator for English language is L. Ding, Ningbo, China