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EFFECTS OF MOLD PARAMETERS ON MICROSCOPIC PROPERTIES OF CROSS WEDGE ROLLING (CWR) GH4169 ALLOY SHAFT PARTS

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Shaft grain size and uniformity play an important role in improving its mechanical properties. Using DEFORM-3D finite element software, the effects of broadening angle and forming angle on the micro performance of the GH4169 alloy shaft parts were studied systematically. The results show that grain refinement is mainly completed in the stretching section. As the broadening angle increases, the grain size expands constantly, and the fluctuation value decreases and then increases, while as the forming angle increases, the grain size and the fluctuation value decrease and then increase. The accuracy of the finite element model was verified through cross wedge rolling experiments.

Key words: GH4169 material; mold parameters; CWR; shaft; metallographic analysis

INTRODUCTION

Featuring good qualities such as fatigue resistance and corrosion resistance, GH4169 alloy, a kind of superalloy, is widely used in aerospace, nuclear power, petroleum and other fields. However, it is difficult for GH4169 alloy to refine the grain by heat treatment due to its low processing plasticity and large deformation resistance, and after hot processing, there often appears the coarse grain and mixed crystal [1]. Therefore, it is very necessary to study the influence of die parameters of cross wedge rolling on the internal grain size and uniformity of the GH4169 alloy shaft.

Some scholars worked hard in researches on forming of GH4169 alloy. Qi et al. researched the material model of GH4169 mainly through compression experiments [2], Zhang et al. studied the influence of three process parameters of cross wedge rolling on the micro grain size [3], and Wang et al. analyzed the effect of forging parameters on the hot die forging of GH4169 alloy turbine disk [4], but there were few studies on the influence of the die parameters of cross wedge rolling on its micro properties. The broadening angle and the forming angle are the most fundamental and important process parameters for the cross wedge rolling die design, therefore, in this article, the forming mechanism of GH4169 shaft and the variation of the grain size are obtained by DEFORM-3D finite element software simulation and rolling experiments. The research results provide theoretical guidance for selecting reasonable mold parameters.

Material modeling

Since there is no material model of GH4169 alloy in the DEFORM-3D finite element material library, it is necessary to establish a material model of GH4169 alloy in DEFORM-3D.

The constitutive equation of GH4169 alloy selected in this paper is as follows[4]:

$$\dot{\varepsilon} = 4,51\times 10^{16}\left[\sinh\left(0,0024\ \overline{\sigma}\right)\right]^{5,05} \bullet \exp\left(-413\ 118 / RT\right) \quad (1)$$

$$R = 8,314\ \mathrm{J{*}mol^{-1}K^{-1}}$$

In the above formula, $\dot{\varepsilon}$ is the strain rate; $\overline{\sigma}$ is the flow stress; R, T are gas and temperature constants.

In this article, Avrami equations constructed in the material model are from the reference [5]. The Young's modulus E of the GH4169 alloy is 202,7 GPa, the density is $8,24\times 10^3$ kg*m^{-3}, and the Poisson's ratio is 0,37.

Determination of finite element model and process parameters

As shown in Figure 1, the CWR model established in Pro/E software was imported into DEFORM-3D software in STL format. Considering the symmetry of the structure, when a half of the geometric model was established, symmetric constraints would be set on its symmetry plane. The process parameters are shown in Table 1.

Table 1 **Process parameter list**

Temperature T / °C	1 050 °C
Area reduction ψ / %	50
Forming angle α / °	26 / 28 / 30 / 32
Broadening angle β / °	6 / 8 / 10 / 12

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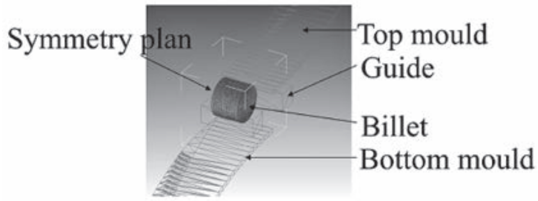


Figure 1 Finite element model of rolling

The related parameters of the simulation software were as follows: the ambient temperature was 20 °C, the rotation speed around the Z axis was 0,42 rad/s, the heat exchange coefficient between the blank and the environment was 200 $W^*m^{-2*}K^{-1}$, the heat exchange coefficient between the blank and the die is $2{,}5\times10^4$ $W^*m^{-2*}K^{-1}$, and the blank was divided by a tetrahedral mesh into 50 000 meshes.

Microstructure distribution during rolling

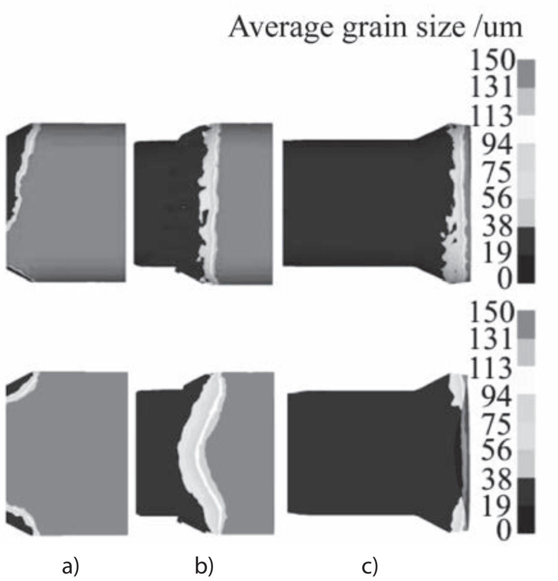
In order to illustrate the microstructure variation during rolling forming, the process conditions at ψ = 50 %, T = 1 050 °C, α = 28 °, β = 8 ° were selected. The average grain size distribution of GH4169 alloy shaft at different stages during rolling is shown in Figure 2.

From Figure 2, in the wedging section, the wedge begins to contact the shaft, and plastic deformation and grain refinement occur in contact area. In the stretching section, the internal grains are gradually refined because the rolling force is gradually transmitted from the surface of the rolling stock to the center area. In the finishing section, the area of grain refinement tends to be stable due to the small amount of shaft deformation. The grain refinement process is mainly completed in the stretching section.

Selection of feature points

As shown in Figure 3 a, the shaft size was φ 40 × 60. To facilitate the study of the average grain size and uniformity inside the shaft, A, B, C, and D sections were selected. As shown in Figure 3 b, each section was 8 mm apart, in which A was middle section. Each section had 21 tracking points, which was shown in Figure 3 c.

$$C_{\mathrm{Xave}} = \frac{\sum_{\mathrm{i=1}}^{n} d_{X_i}}{n} \tag{2}$$



a) wedging section b) stretching section
c) finishing section

Figure 2 Shaft surface and internal grain size distribution

$$C_{\mathrm{zave}} = \frac{C_{A_{\mathrm{ave}}} + 2(C_{B_{\mathrm{ave}}} + C_{C_{\mathrm{ave}}} + C_{D_{\mathrm{ave}}})}{7} \tag{3}$$

$$C_{\mathrm{zflu}} = \frac{\sum_{i=1}^{n}(C_{A_i} - C_{A_{ave}})^2 + 2\left(\sum_{X=B}^{D}\sum_{i=1}^{n}(C_{X_i} - C_{X_{ave}})^2\right)}{7n} \tag{4}$$

C_{Xave} was the average grain size at the X cross section; C_{zave} was the average grain size of the shaft; C_{zflu} was the variance formula of the shaft, indicating the grain fluctuation value of the shaft.

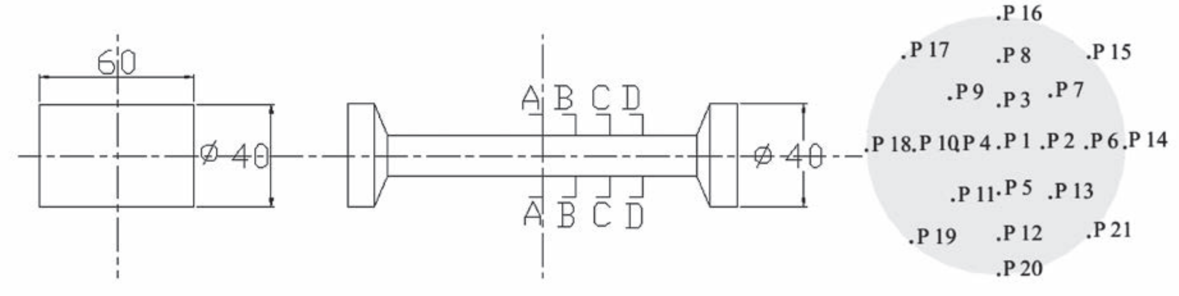
In the above formula, X represented one of A, B, C, and D cross sections; n was the number of selected points on the cross section and n here was 21; d was the grain size value of the selected points; C_{Xi} meant grain size value of the i-th point on X cross section.

Simulation results and discussion

Broadening angle

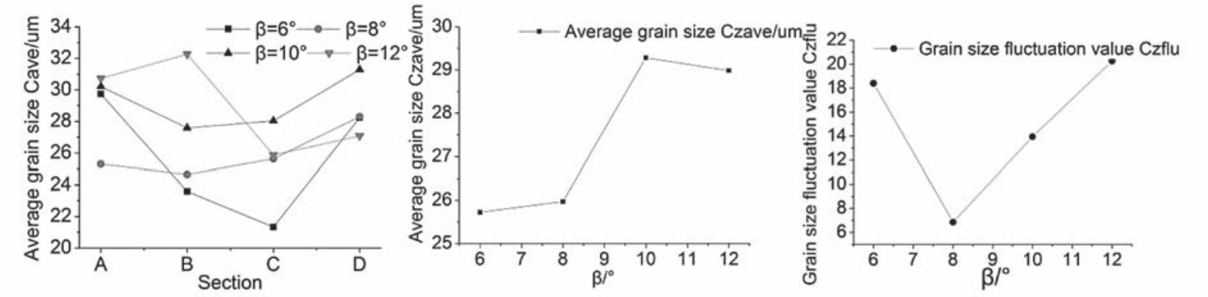
The distribution of grain size and fluctuation value is shown in Figure 4.

From Figure 4 a, as β is 8 °, the cross-section grain size is about 25 μm. As β is 6 ° and 12 °, there is a large



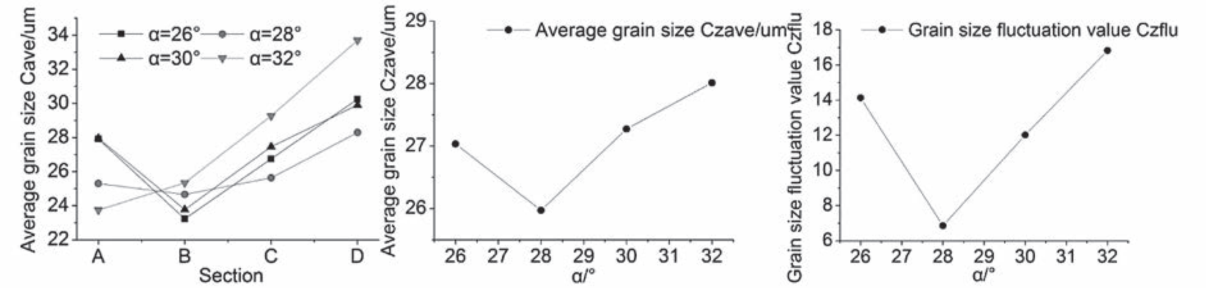
a) Blank b) Forming parts c) Selection of data points

Figure 3 Determination of shaft section and data points



a) Average grain size of section b) Shaft average grain size c) Shaft grain size fluctuation

Figure 4 Influence of broadening angle on average grain and distribution uniformity



a) Average grain size of section b) Shaft average grain size c) Shaft grain size fluctuation

Figure 5 Influence of forming angle on average grain and distribution uniformity

difference in grain size between each sections, while at β = 6 °, 8 °, and 10 °, the average grain size of A and D sections are larger than that of B and C sections. This is because A section is the wedge section which abrupt changes of radial and tangential force take place during plastic forming, leading to uneven loading of internal wedge shaft and the grain not fully recrystallized on A section. As its axial and radial force work together to promote plastic forming of the shaft, D section at the end of the stretching section makes the crystal grains here not fully recrystallized and grain distribution here uneven.

Figure 4 b and 4 c show that the fluctuation value decreases and then increases with the broadening angle expanding, and the grain size value tends to increase as the broadening angle expands, which is because under the conditions of the same reduction of area and end rolling length of the shaft, larger widening angle accelerates the strain rate, shortens the rolling time, and makes dynamic recrystallization insufficient. The optimum forming condition is β = 8 °.

Forming angle

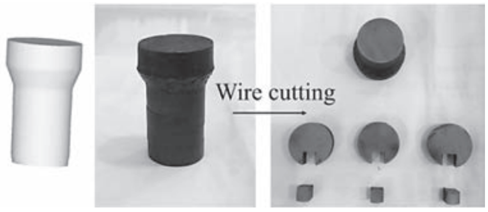
The distribution of grain size and fluctuation value is shown in Figure 5.

From Figure 5 a, when α is 26 °, 28 °, and 30 °, the average grain size of the cross-section is about 25 μm, indicating that grain refinement on the cross section is better, When α is 32 °, the average grain size from A to D cross section increases all the time with an increase of 42 %, indicating that there is a large difference in grain size among the cross sections. This is because in the forming process of GH4169 alloy, as the forming angle increases, the radial force becomes smaller and the axial force keeps growing, which is not conducive to grain refinement of the shaft part for the forming shaft. When α is 28 °, the best forming effect is achieved and the average grain size is the smallest.

From Figure 5 b and 5 c, the effect of the forming angle on the shaft is that the average grain size value and the fluctuation value decrease and then increase with the increase of the forming angle.

EXPERIMENTS

In order to verify the accuracy of finite element simulation, cross wedge rolling experiments and metallographic experiments were performed. The experimental parameters were as follows: ψ = 40 %, α = 28 °, β = 8 °, T = 1 050 °C. Simulation results and 1/2 axis comparison chart is shown in Figure 6 a, the metallographic specimen obtained by wire cutting is shown in Figure 6 b.



a) b)

a) Comparison chart b) Metallographic specimen

Figure 6 Simulation and experimental comparison and metallographic specimens

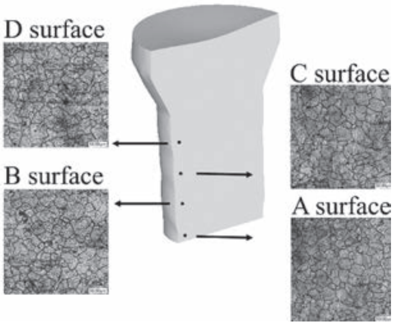


Figure 7 Microscopic Metallography

The microscopic metallography obtained by the digital three-dimensional electron microscope is shown in Figure 7.

The average value of the experimental results for the four cross-sections obtained by the linear intercept method is 28,12 um. The simulation data obtained by the point tracking method is 28,70 um, and the error value is 2,1 %, which show that the microscopic simulation model of GH4169 shaft is reliable.

CONCLUSIONS

(1) In the wedge section, grain refinement takes place only in the contact area with the wedge; grain refinement is mainly done in the stretching section; in the finishing section, refinement area becomes steady.

(2) The effect of die process parameters on the microscopic properties of GH4169 alloy is that the grain size decreases and then increases as the forming angle increases, and increases as the broadening angle increases. The fluctuation value decreases and then increases with the increase of the broadening angle and the forming angle. The smaller forming angle and broadening angle should be selected under the condition that the shaft can be shaped.

(3) Through the cross wedge rolling experiments, the error of average grain size is 2,1 %, indicating that the model in this paper is reliable. The research results in this paper provide the theoretical basis for choosing die process parameters and improving the microstructure and properties of the cross wedge rolling GH4169 alloy shaft.

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REFERENCES

[1] N. Zhang, B. Y. Wang, Z. H. Hu, Thermomechanical coupled numerical simulation of GH4169 alloy for cross wedge rolling, Journal of University of Science and Technology Beijing 33(2011)11,1396-1401.

[2] G. X. Qi, R. B. Mei, N. Cao, Study on Microstructure Evolution in GH4169 Alloy Blade during Finish Forging, Applied Mechanics and Materials 217-219(2012),1671-1675.

[3] N. Zhang, B. Y. Wang, J. G. Lin, Effect of cross wedge rolling on the microstructure of GH4169 alloy, International Journal of Minerals Metallurgy and Materials 19(2012)9,836-842.

[4] H. Y. Wang, W Zhao, J. X. Dong, M. C. Zhang, Z. H. Yao, Research on optimization of GH4169 turbine disc hot die forging technique based on Deform-3D and orthogonal experimental method, Forging & Stamping Technology 38(2013)5,13-19.

[5] G. X. Qi, J. J. Wan, X. F. Chen, T. Z. Ji, Numerical simulation of microstructure evolution during GH4169 alloy blade making, Forging & Stamping Technology 34(2009)1, 161-165.

Note: The responsible translator for the English language is Q. Q. Yan, Ningbo, China