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EFFECT OF PROCESS PARAMETERS ON AVERAGE GRAIN SIZE AND MICROSCOPIC UNIFORMITY OF THE THREE-ROLL SKEW ROLLING FORMING OF THE RAILWAY HOLLOW SHAFT

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The average grain size and microstructure uniformity are the key factors determining the mechanical properties of the hollow shaft. In order to obtain a fine and uniform microstructure, a finite element model of three-roll skew rolling hollow shaft for the coupling of heat, force and microstructure was established. The influence of process parameters on the average grain size and microstructure uniformity of the rolled product was analyzed by using the single factor research method. The results show that the grain size is remarkably refined and the distribution is relatively uniform. The optimum rolling temperature is 1 050 °C; the optimum feed angle is 9 °; the optimum roll rotate speed is 90 rad/min.

Key words: three-roll skew rolling, hollow shaft, average grain size, microscopic uniformity, process parameters

INTRODUCTION

As a newly proposed hollow shaft production method, three-roll skew rolling has the advantages of high production efficiency and low cost [1]. Xu Chang et al. studied the influence of process parameters on the three-roll skew rolling force parameters, and based on the study of stress and strain distribution, analyzed the mechanism and law of the process deformation [2]. During the operation, it will be subjected to fatigue loads, various complicated environments and other accidental damages [3]. Many of these damages are caused by the unreasonable internal microstructure of the rolled parts. Therefore, in addition to meeting the basic size and shape requirements, the railway hollow shaft must pay attention to the micro-structure inside the rolled pieces, and its reasonable microstructure will greatly improve the safety and service life of the shaft.

ESTABLISHMENT OF FINITE ELEMENT MODEL

To reduce the simulation time, a 1:5 scale shaft was used for the simulation. A three-dimensional finite element model was built using pro/E software and imported into Simufact14.0 software.

The rolled pieces material was selected as 43CrMo4, and the MATILDA microstructure model was used, assuming an initial grain size of 150 μm [4-5]. The blank mesh is divided by a hexahedral free mesh with a grid cell size of 3,3 mm and initial mesh number is 23 444. In addition, the mesh is refined on the part with large radial reduction, and the grid size is set to 1/8 of normal. Rolls, clamp, and mandrel are defined as rigid bodies, while rolled pieces are defined as rigid plastomers. The initial mold temperature was set to 50 °C. The rolled product and the rolls were selected to be in contact friction with a coefficient of 0,9. The rolled piece and the clamp are placed in a bonded state.

MICROSCOPIC RESEARCH METHODS

In order to obtain the average grain size after rolling, take the point as shown in Figure 1.

The average grain size of each section was counted as follows:

$$d_{\mathrm{xave}} = \frac{\sum_{i=1}^{n} d_{xi}}{84} \tag{1}$$

where: X is the number of each section, a total of five cross sections of ABCDE; n is the number of statistical points of each section, here is 84.

The uniformity of the average grain size of each section of the rolled product directly determines the uniformity of the microstructure. For this reason, the uniformity coefficient S is introduced as the uniformity evaluation index:

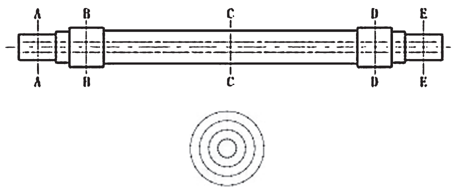

Figure 1 Node location map

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$$\Delta_d = d_{int} - d_{fin} \tag{2}$$

$$\Delta d_{ave} = \frac{\Delta d_A + \Delta d_B + \Delta d_C + \Delta d_D + \Delta d_E}{5} \tag{3}$$

$$S = \sqrt{\frac{\left(\Delta d_A - \Delta d_{ave}\right)^2 + ... + \left(\Delta d_E - \Delta d_{ave}\right)^2}{5}} \tag{4}$$

where: Δd is the change of the average grain size of the section during the rolling process, d_{int} is the initial average grain size value, d_{fin} is the average grain size at the end of rolling, and Δd_{ave} is the average variation of each section.

S > 0, S represents the degree of microstructure uniformity of the rolled piece. The smaller the S value, the higher the degree of microstructure uniformity of the rolled piece; the larger the S value, the lower the degree of microstructure uniformity of the rolled piece.

Table 1 **Process parameter setting**

parameter / group	Rolling temperature T / °C	Roll rotation speed n/rad · min^{-1}	Feed angle α / °
1	950	60	
2	1 050		
3	1 150		
4	1 250		
5	1 150	30	
6		60	
7		90	
8		120	
9		60	5
10			7
11			9
12			11

INFLUENCE OF PROCESS PARAMETWRS ON MICROSTRUCTURE AND UNIFORMITY

In this paper, 12 groups of simulations were designed. The effects of three process parameters, temperature T, feed angle α and roll rotation speed n, on the average grain size of the five cross-sections along the axial direction were studied, as shown in Table 1.

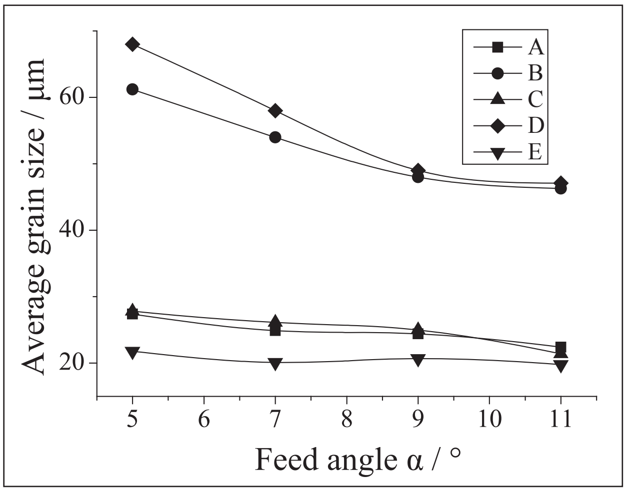

Figure 2 The average grain size varies with the feed angle

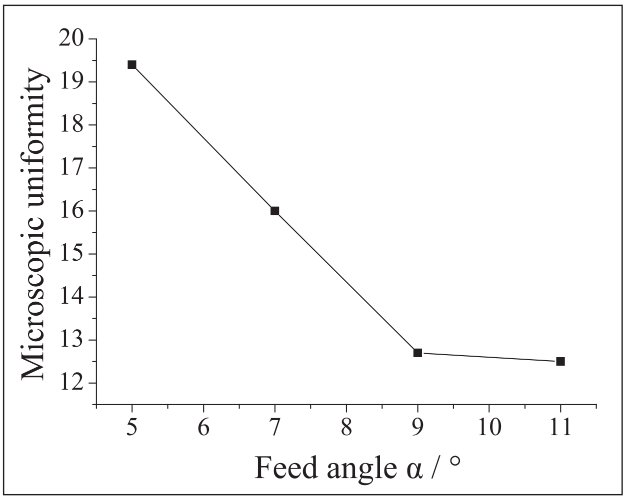

Figure 3 Axial microscopic uniformity varies with feed angle

As can be seen from the Figure 2, as the feed angle α increases, the average grain size gradually decreases. This is because as the feed angle increases, the axial force of the roll to the rolled piece increases, the axial deformation of the rolled piece increases, and the axial dislocation density increases, and the activation energy for recrystallization is increased. So the grain refinement is more obvious. The average grain size of the three cross sections A, C and E increases with the increase of the feed angle α, but the change is not obvious, and the upper and lower fluctuation values are within 5 µm. This is because the radial reduction of the three cross sections of A, C and E is large, and the deformation amount of the rolled region provides sufficient activation energy, and dynamic recrystallization is more sufficient, and the crystal grains are basically obtained to a large extent. The refinement is not obvious because of the feeding angle. The two sections B and D are not subject to the radial force of the rolls, but the inclined rolls will drive the axial flow of the metal on the surface of the rolled piece, so that the two sections B and D are largely refined due to the axial metal flow deformation. As the feed angle increases, the axial flow of the metal becomes more pronounced, so the average grain size of

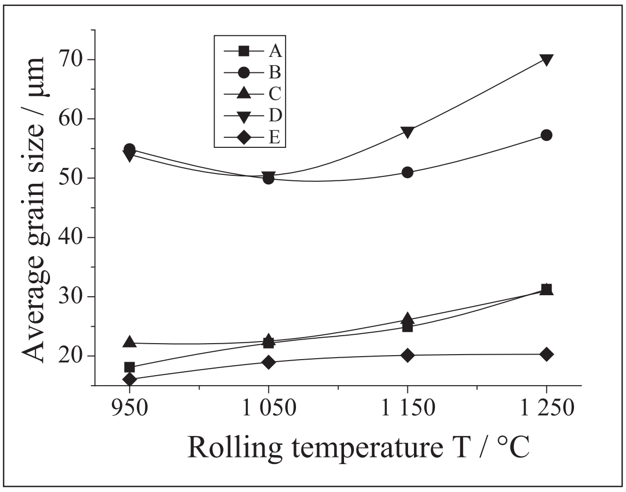

Figure 4 Average grain size varies with rolling temperature

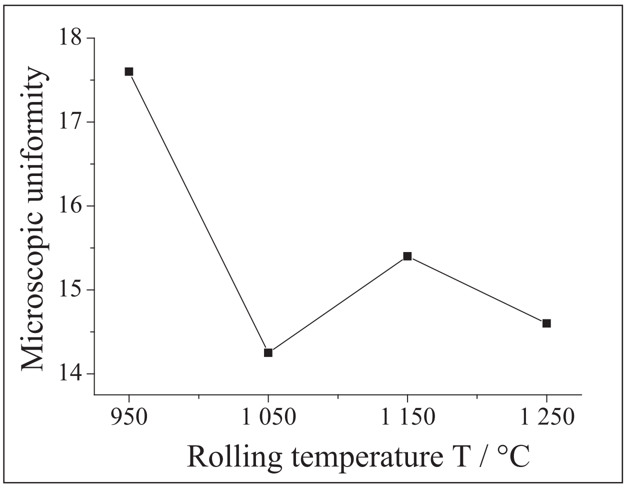

Figure 5 Axial microscopic uniformity varies with rolling temperature

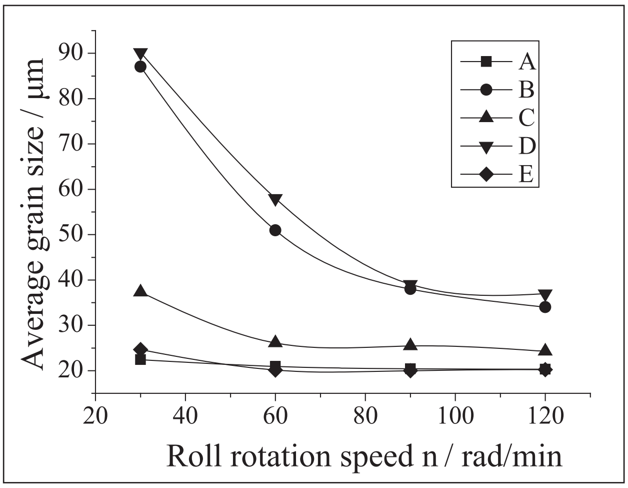

Figure 6 Average grain size varies with roll rotation speed

the two sections B and D is relatively affected by the feed angle. It can be seen from Figures 2 and 3 that when the feed angle is 9 °, the grain size of each cross section is basically refined to the greatest extent, and the uniformity is good.As the feed angle continues to increase, the average grain size and microscopic uniformity change is not obvious, and there are a series of problems due to the excessive feed angle, such as increased energy consumption and increased tool wear . Therefore, when the feed angle is 9 °, the effect is the best, and the average grain sizes of the A section, the B section, the C section, the D section, and the E section are 24,4 μm, 48 μm, 25 μm, 49,2 μm, and 20,7 μm, respectively.

It can be seen from the Figure 4 that the average grain size of the three cross sections of A, C and E gradually increases with the increase of temperature. A and E are the cross sections with the largest reduction, so the deformation is large, and the more activation energy is generated, the smaller the average grain size is. Since the recrystallization time is earlier than the E, the grain size grows on the section A, so the grain size is slightly larger than the E surface.The C surface reduction is less than A and E, and the deformation is relatively small, so the grain size is slightly larger than A and E. On both sides of B and D, when the temperature changes from 950 °C to 1 250 °C, the grain size of the B and D first decreases and then increases.When the temperature is 1 050 °C, the grain size is the smallest. When the temperature is lower than 1 050 °C, the degree of dynamic recrystallization occurs relatively small because the temperature is too low. When the temperature is greater than 1 050 °C, the average grain size grows as the temperature increases. It can be seen from Figure 5 that the axial grain size distribution of the rolled product is also the most uniform when the temperature is 1 050 °C. It can be seen that when the temperature is 1 050 ° C, the average grain size of the rolled piece is the smallest and the microstructure is the most uniform.

As can be seen from the Figure 6, as the roll rotation speed increases from 30 rad/min to 120 rad/min, the grain size gradually decreases. This is because as the rotation speed of the rolls increased, the speed of metal flow on the rolled part is accelerated, and the more recrystallization activation energy is supplied, and the grain refinement is more pronounced. Among them, B and D are particularly affected by the roll rotation speed. The average grain size is 90 μm from 30 rad/min,and the average grain size is less than 40 μm at 120 rad/min, and the average grain size is more than doubled. The grain size refinement of 30 - 90 rad/min is more obvious, and the grain size tends to be stable after 90 rad/min. The grain sizes of A, C and E are larger at 30 rad/min, and the grain size is gradually reduced from 30 rad/min to 60 rad/min. When the rotation speed is greater than 60 rad/min, the grain size changes are not obvious. When the roll rotation speed is greater than 90 rad/min, the average grain size is less affected by the it. At this time, the average grain size has been refined to the limit value, and as shown in Figure 7, the axial microscopic uniformity has also reached the peak value. The use of a large roll rotation speed increases the power consumption of the equipment, so the optimum roll rotation speed is 90 rad/min.

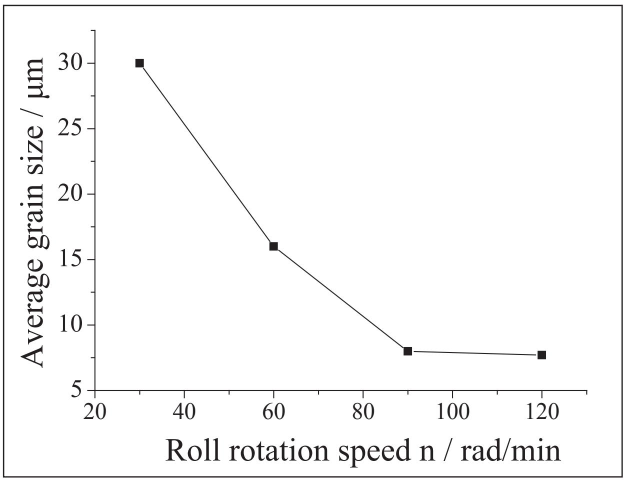

Figure 7 Axial microscopic uniformity varies with roll rotation speed

CONCLUSION

1) The average grain size change of the three-roll skew rolling hollow shaft is characterized by significant grain refinement in the forming zone, followed by grain refining effect in other areas, and the average grain size of the rolled piece gradually increases from the deformed zone to the undeformed zone. The overall grain size distribution of the rolled products is uniform.

2) The influence of the process parameters on the average grain size of each section is basically the same as that of the microscopic uniformity coefficient S. Specifically, the average grain size and axial microscopic uniformity decrease with the increase of the feed angle α, and decrease with the increase of the roll rotation speed n.As the rolling temperature T increases, it first decreases and then increases; finally, the optimum rolling temperature is 1 050 °C; the optimum feeding angle is 9 °; the optimum roll rotation speed is 90 rad/min.

Acknowledgements

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Note: The responsible translator for the English language is J. Wang, Ningbo, China