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EFFECT OF PROCESS PARAMETERS ON MICROSTRUCTURE OF 42CrMo STEEL BALL HOT SKEW ROLLING

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Microstructure grain refinement is an effective way to improve the quality of 42CrMo steel ball. A three-dimensional thermal-mechanical-microstructure coupled Finite element model (FEM) of steel ball skew rolling is established in the finite element simulation software. Simufact software was used to simulate the effects of process parameters on the microstructure of steel balls, and the effects of roll Angle, roll temperature and roll speed on the average grain size of rolled pieces were analyzed by single factor variable method.The research results provide some reference for the improvement of 42CrMo steel ball quality.

Key words: skew rolling, steel ball,microstructure, process parameters, FEM

INTRODUCTION

Skew rolling, viz. helical-groove rolling ,is a technology has many advantages. Such as high efficiency, material saving and environmental protection, so it is widely used in ball parts forming. Steel grinding ball is the medium of ball mill abrasive, widely used in mineral processing, power generation, cement, chemical and other industries [1] . The working nature of ball grinding steel ball inevitably leads to easy wear and large consumption. The working nature of ball grinding steel ball inevitably leads to easy wear and large consumption. In the hot cross rolling process of ball milled steel balls, the rolling temperature is an important technological parameter affecting the degree of grain refinement, and increasing the degree of grain refinement is the key to improve the service life of ball milled steel balls. Zbigniew Pater [2] carried out finite element analysis and experimental study on the diagonal rolled steel ball, and obtained the distribution law of stress, strain and temperature as well as the changes of rolling force and rolling moment in the rolling process; J.M.Shang [3] found that heating temper ature plays a leading role in the degree and uniformity of spheroidized tissue; D. Y. Tian [4] to eliminate internal void and improve the mechanical properties of steel ball formed by skew rolling, the floating pressure method (FPM) using high-pressure gas to compact void is applied in this paper. Therefore, it is necessary to study the influence of temperature of ball mill steel ball on microstructure.

Due to the great influence of temperature on the microstructure of rolling process, the related research has not been reported. Therefore, the finite element model of thermo-mechanic-microstructure coupling of steel ball hot cross rolling was established in Simufact. Forming15.0 with 42CrMo steel as the research material.The effect of rolling temperature on microstructure of hot cross rolling steel ball was studied by single factor test method, in order to provide reference for improving service life of ball mill steel ball.

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MODELING OF MATERIALS AND MICROSTRUCTURE

42CrMo alloy structural steel is chosen as the model material, because 42CrMo steel has good toughness and strength, and high hardenability. According to the research of Y. C. Lin in the literature [5], the constitutive equation of the material is as followed:

$$\dot{\varepsilon} = 1,34\times10^{18}\left[\sinh\left(8,198\times10^{-3}\sigma\right)\right]^{8,1434}\bullet$$
$$\bullet\exp\left(-4,6334\times10^{5}/\left(RT\right)\right) \quad (1)$$

Critical strain of dynamic recrystallization ε_c can from peak strain of the stress-strain curve ε_p estimate it. Dynamic recrystallization occurs before the stress reaches its peak,When the stress reaches the peak stress, Its corresponding dependent variable ε_p can reflect the deformation state of the material.

Dynamic recrystallization activation criterion are as follows:

$$\varepsilon_p = 7,28\times10^{-4} d_0^{0,31}\left[\dot{\varepsilon}\exp\left(247\ 000/\left(RT\right)\right)\right]^{0,21} \quad (2)$$

$$\varepsilon_c = 0,696\varepsilon_p \quad (3)$$

Where d_0 is initial grain size; $\dot{\varepsilon}$ is strain rate; R is gas constant (8,31/J·K-1·mol-1); T is deformation temperature.

Dynamic recrystallization volume fraction equation is as follows:

$$\varepsilon_{0,5} = 3,0 \times 10^{-3} d_0^{0,4} \dot{\varepsilon}^{0,086} \exp(4\ 089 / T) \quad (4)$$

$$X_{drex} = 1 - \exp\left[-0,693\left(\left(\varepsilon - \varepsilon_c\right) / \left(\varepsilon_{0,5} - \varepsilon_c\right)\right)^{1,8}\right] \quad (5)$$

Grain size equation are as follows:

$$d_{\mathrm{drex}} = 38 d_0^{0,8} \dot{\varepsilon}^{-0,234} \exp\left[-42\ 327,5 / \left(RT\right)\right] \quad (6)$$

$$d = \left[d_0^{3,55} + 2,90 \times 10^{25} \exp\left(-64\ 273,96 / T\right) t\right]^{\frac{1}{3,55}} \quad (7)$$

Where X_{drex} is dynamic recrystallization volume fraction; ε is dynamic strain value; $\varepsilon_{0.5}$ is dynamic recrystallization volume fraction of strain at 50 %; d_{drex} is dynamic grain size.

FEM AND SIMULATION PROGRAM

In this paper, 12 groups of single factor finite element simulation are designed, and the single factor test analysis method is used to explore the influence of process parameters on the average grain size. The main parameters affecting the microstructure of steel ball are: rolling temperature *T*, roll speed *r* and roll inclination *α*.

According to the above process parameters, the assembly model is established in SolidWorks 3D software, and the established model is imported into Simufact.Forming15.0 software.In the simulation, the hexahedral element type is used to mesh the blank, and the mesh size is 12 mm. In advanced settings, the grid type selects the cylindrical rotation axis division method, and the rotation axis is *X_c*.The friction value between the workpiece and the roll is set to 0,9, and the contact between the workpiece and the baffle also produces friction, but the value is small, so it is set to 0,2. The initial grain size is set to 145μm. The heat conduction coefficient of the rolling piece to the environment is set to 0,39*KW* / (*m·K*), the heat conduction coefficient of the die to the environment is set to 0,02*KW* / (*m·K*), and the heat conduction coefficient between the die and the rolling piece is 10*KW* / (*m·K*).The thermal emissivity of the mold and billet to the environment is set to 0,7.

The accuracy and reliability of the three-dimensional solid model of the pass cross rolling die is an important prerequisite for establishing a reliable finite element simulation model of skew rolling. The pass hot skew rolling model established in this paper mainly includes three parts: roller, guide and sleeve. The roller is the main die for cross rolling, driven by two rolls with the same rotation direction at a constant rotation speed, The round bar is rotated and bitten into the ball billet gradually; The sleeve not only supports the bar before it is completely bitten into the roll, but also stabilizes the bar; The function of guide is to ensure that the bar is rolled stably in the cavity after biting into the roll, which can not only balance the transverse force, but also effectively avoid product defects such as drilling, product scratch and so on. The finite element model is shown in Figure 1.

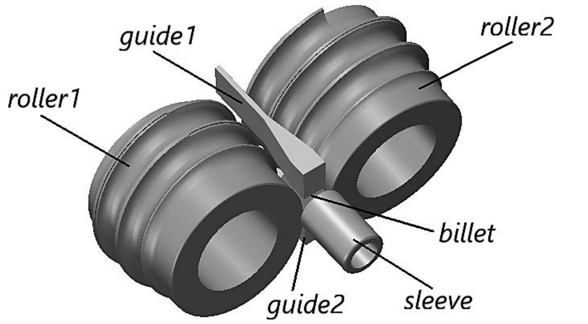

Figure 1 FEM of skew rolling steel ball

In this paper, 12 groups of single-factor finite element simulations were designed, and the effect of temperature on average grain size was investigated by single-factor experimental analysis. As shown in Table 1, the effects of three process parameters of skew rolling steel ball on the microstructure of steel ball are studied, including rolling temperature *T*, rotation speed r and roll inclination α.

Table 1 **The process parameters selected in simulation**

Parameters \ Section	Reference	Change
T/°C	1 000	900 / 950 / 1 050 / 1 100
r/rpm	50	30 / 70 / 90 / 110
α/°	3	2,5 / 3,5 / 4 / 4,5

INFLUENCE OF PROCESS PARAMETERS ON AVERAGE GRAIN SIZE

The process parameters include billet temperature T and roll inclination α, roll speed r, which is the main factor affecting the average grain size of skew rolled steel ball. From Figure 2, in order to accurately track the changes of grain size inside and outside the steel ball during skew rolling, 5 characteristic points after rolling are selected.

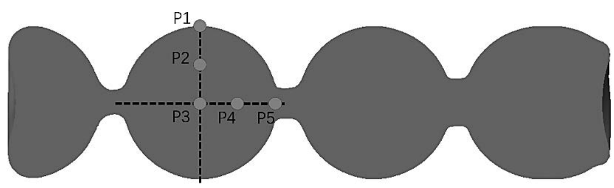

Figure 2 Longitudinal section tracking point selection

The average grain size decreases with the increase of inclination α. This is because the axial force brought by the roll to the rolled piece increases with the increase of the inclination angle, and the axial deformation increases, resulting in an increase in the axial dislocation density, resulting in an increase in the activation energy of recrystallization, so the grain refinement is more obvious. From Figure 3. The average grain size of P1 and

P5 decreases gradually with the increase of inclination α, but the change is not obvious, and the fluctuation value is less than 10 μm. This is due to the large radial reduction of P1 and P5, the deformation of the rolled area provides enough activation energy, the dynamic recrystallization is carried out fully, and the grains are basically refined to a great extent, so it is not obviously affected by the inclination angle. The P2 point is located at the 1/2 radius of the radial middle plane, and the deformation of axial tension and radial compression is very small, so the degree of grain size refinement is not great. The P3 point is located in the core of the rolled piece, but the material flow is from P5 to P3, so the grain refinement of the P3 point is higher than that of P2. Because the deformation of P5 position is very large, and the material flows from P5 to P4, the axial deformation of P4 point is larger with the increase of inclination angle, and the grain size refinement is especially obvious.

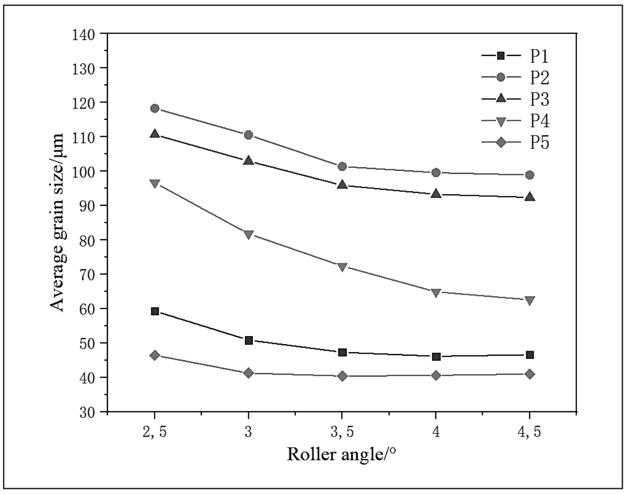

Figure 3 Effect of roller angle on average grain size

From Figure 4 , the average grain size decreases at first and then increases with the increase of temperature, this is because the degree of dynamic recrystallization increases with the increase of temperature, but as the temperature continues to increase, the average grain size grows. Due to the larger deformation of P1 and P5 under radial compression, the activation energy is more and the average grain size is smaller, and the average grain size of P5 is the smallest because of the largest deformation due to the radial extrusion of roll convex edges. Because of the influence of material flow, the grain refinement of P3 is higher than that of P2. The position of P4 point is close to the connecting neck, so with the increase of rolling temperature, the degree of temperature increase is higher than that of P2 and P3, so the average grain size refinement is more intense. From the overall trend, the temperature reaches the highest degree of grain refinement at 1 050 °, the phenomenon of grain growth will occur when the temperature continues to rise, and the high temperature will increase the cost, so the best temperature is 1 050 °C.

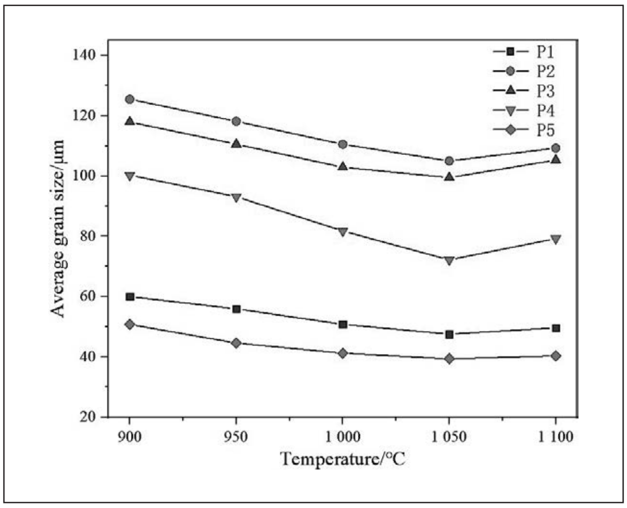

Figure 4 Effect of temperature on average grain size

From Figure. 5 , the grain size decreases with the increase of roll speed from 30 rpm to 110 rpm. This is because with the acceleration of roll speed, the metal flow speed on the rolled piece is accelerated, and the more activation energy is provided for recrystallization, the more obvious the grain refinement is. Among them, P2 and P3 are obviously affected by roll speed, From the average grain size of 130 μm in 30 rpm to less than 105 μm in 50 rpm, the average grain size decreases greatly. And the grain size tends to be stable after 50 rpm. The position of P4 point is next to the connecting neck. with the increase of roll speed, it is greatly affected by metal flow speed, and the degree of grain refinement is also obvious. The position of P1 and P5 is not greatly affected by the roll speed because of the large deformation itself. The average grain size is refined from 30 rpm to 50 rpm, but with the increase of roll speed, the average grain size does not change obviously. To sum up, the continuous increase of roll speed in 50 rpm has little effect on the average grain size, and selection of large roll speed will increase the power consumption of the equipment, so the best roll speed is 50 rpm.

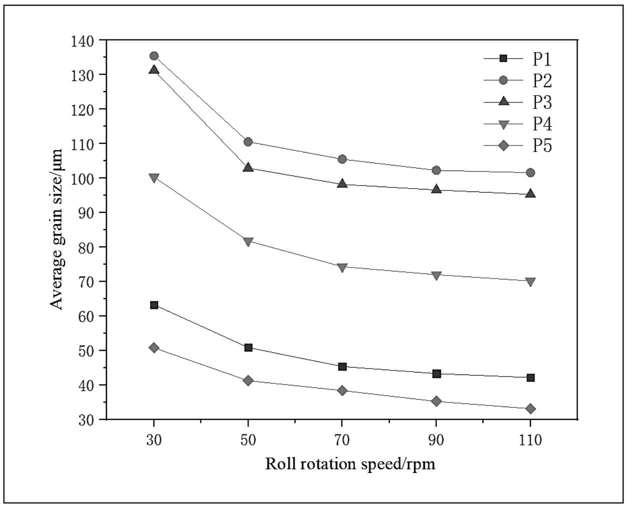

Figure 5 Effect of roll rotation speed on average grain size

CONCLUSIONS

Through the comparison of 12 groups of simulation results, the influence of different process parameters on the average grain size of steel ball was obtained. It was found that the smaller average grain size could be obtained by selecting the rolling temperature, increasing the Angle and increasing the roll speed reasonably.The microstructure and properties of steel ball can be improved by selecting reasonable process parameters.This paper provides a reference for reasonably selecting the influence of technological parameters on the average grain size of steel balls.

Acknowledgments

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Note: The responsible translator for English language is X. S. Gao, Ningbo, China