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Effect of gradient temperature rolling on microstructure of initial pass of ultra-heavy plates

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Abstract: In this paper, the gradient temperature rolling (GTR) method is used to establish the rolling model of the first two passes by using the deform-3D finite element software. The variation of temperature field, stress field, static recrystallization and average grain size of ultra-heavy plate slab under different conditions is systematically studied. Test result shows that the water cooling between the passes can form a temperature gradient layer (about 30mm) of a certain thickness on the surface of the rolled blank, the deformation of the core can be effectively improved during the rolling process, the static recrystallized grain size and average grain size of the surface of the rolled part are more obvious than the uniform temperature rolling; in addition, since the surface temperature of the water-cooled product is low, the amount of deformation is small, and metastable dynamic recrystallization does not occur.

1. Introduction

In the process of deformation of metal, there is not only the flow of metal inside the metal, but also the change of the organizational structure, which includes work hardening, dynamic recovery, dynamic recrystallization, grain growth, and has essential effect on the microstructure and flow stress of metals. During the rolling process of metal, due to the simultaneous action of temperature and deformation, the macroscopic behavior interacts with the evolution of microstructure, therefore, understanding the evolution of microstructure and its influencing factors is very important for controlling the performance of metals. With the development of simulation technology, numerical simulation of microstructure has become one of the main hotspots of current research.

At present, the simulation of organizational evolution mostly focuses on extrusion, hot forging and hot rolling, as an illustration, study on plastic damage distribution and fracture of 316L austenitic stainless steel by finite element method [1]; predicting the nanostructure mechanical properties of quasi-static axially extruded aluminum profiles and optimizing the design of hot forging dies and selecting suitable materials and production processes[2]; investigating the influence of blanking force and friction force of 22MnB5 steel on the damage evolution and impact force of the forming process, and predicting the possible area of cracks during hot forging[3]. Recently, systematic research on microscopic defects such as core shrinkage, crack and grain coarseness due to low rolling permeability and low core deformation during ultra-heavy plate rolling has been carried out[4-7], and a new ultra-heavy plate



temperature difference rolling process has been proposed to improve the core structure and improve the rolling permeability, which makes some progress. Li Gaosheng et al, performed differential temperature rolling on E40, C-Mn-Nb-V, C-Mn, EH47 super-thick sheet steel and found that the core deformation was significantly higher than that of isothermal rolling, and the heart structure improved significantly [7-13], however, the changes in microstructure in ultra-thick plate differential temperature rolling have rarely been reported [14-16].

In this paper, Deform 3D finite element software was used to simulate the temperature field and microstructure evolution of C-Mn steel [8] after single-pass water-cooling rolling of ultra-thick plates. Predict the temperature change and microstructure evolution during the rolling process to provide a theoretical basis for actual production.

2. Experimental procedure

In this article, the three-dimensional model of rolling stock, roll and push plate is established by Creo 3.0 software, and the STL file is imported into deform-3D software. The roll size is $\phi 1100\text{mm}$, and the rolling stock and roll are symmetric models. For reducing the amount of calculation, the roll is modeled by 1/2 and the rolled piece is modeled by 1/4. The diameter of the roll is $\phi 1100\text{mm}$, the slab is $150 \times 130 \times 300\text{mm}$, and the simulation network is divided as shown in Fig.1. The simulated mesh is automatically re-divided by grid to ensure the simulation is correct. The roll is set as rigid material during the simulation; the rolled piece is made of plastic E40 material.

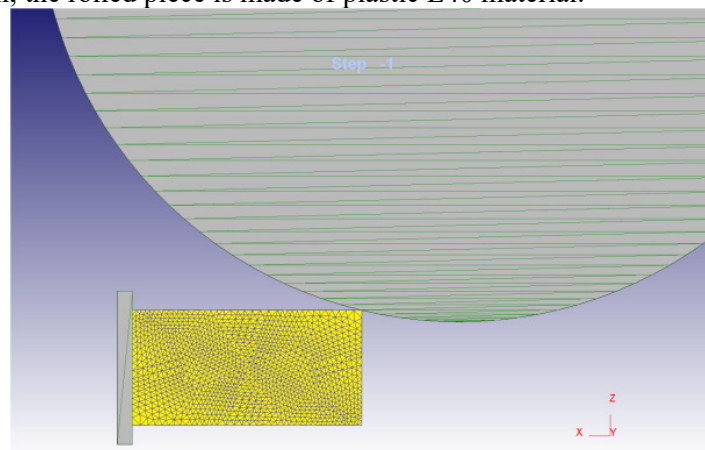


Figure1. the mesh of model.

Material composition is shown in Table 1.

Table 1. The Chemical composition of tested steel (mass,%)

C	Si	Mn	P	S	Cu	Cr	Ni	Nb	Ti
0.08	0.35	1.50	0.018	0.003	0.25	—	0.36	0.04	0.012

Plate1: After the first pass, the air is cooled for 20s and then subjected to the second pass rolling, and the air is cooled for 20s after rolling;

Plate2: After the first pass rolling, the water was cooled for 8 s and then subjected to the second pass rolling. After rolling, the air was cooled for 12 s.

3. The setting of model boundary condition

The boundary conditions of the model include velocity boundary conditions, friction boundary conditions and thermal boundary conditions. Owing to the high contact stress at the interface between the rolls and the rolling stock, the shear model is more accurate than the Coulomb model. The heat transfer boundary mainly considers the convection and radiation heat transfer between the free surface of the rolling stock and the surrounding environment. The exchange coefficient between the roll and the rolled piece is $2000 \text{ w/m}^2 \cdot ^\circ\text{C}$; the deformation of the metal will produce deformation heat, and the conversion coefficient of thermal power is taken as (0.9).

3.1 Effect of gradient temperature rolling(GTR) on temperature field

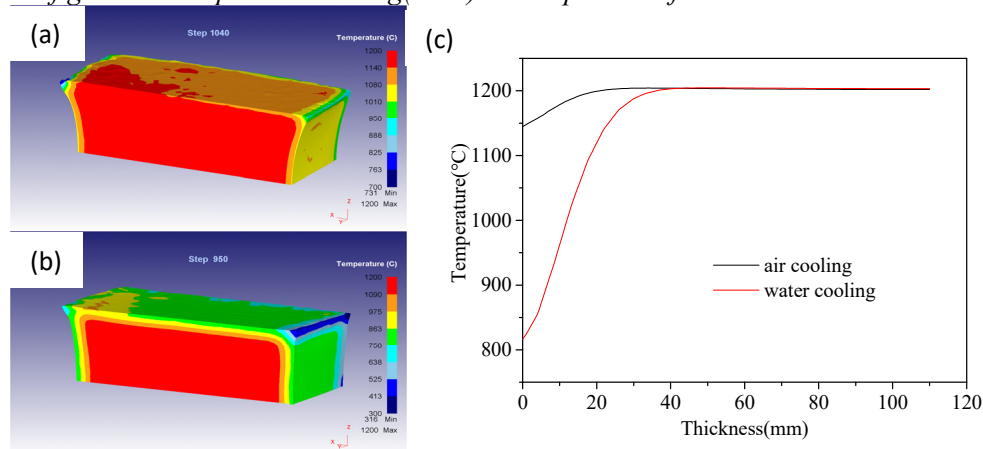


Figure 2. Temperature field after second pass (a)Cloud pattern of air cooling (b)Cloud pattern of water cooling (c)Curve of temperature field in thickness direction.

It can be seen from Fig. 2(a)(b) that the rolled piece is rolled under air-cooling conditions. At the end of the first rolling, the surface temperature rises due to the deformation, and the temperature rise is about 40°C , reaching 1240°C . After 10 seconds of water cooling and after the second pass rolling, the surface temperature drops to about 825°C (except for the side), and a temperature gradient layer of a certain thickness is formed along the thickness direction. Fig. 2(c) is the curve of the temperature field of the rolled product along the thickness direction after the second pass, so that the temperature gradient on the surface of the differential rolled steel is significantly higher than that of the isothermal rolling. The temperature gradient layer has a thickness of about 40 mm.

3.2 Effect of gradient temperature rolling(GTR) on strain effective field

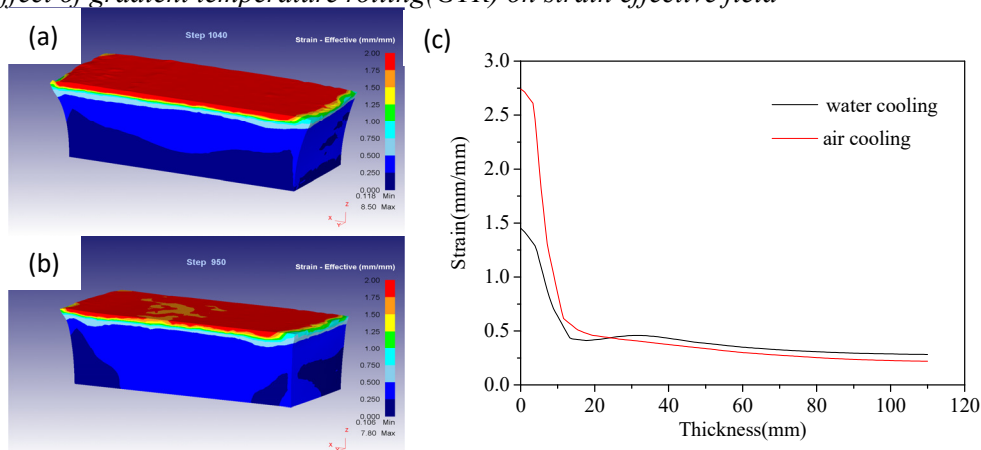


Figure 3. Strain effective field after second pass (a)Cloud pattern of air cooling (b)Cloud pattern of water cooling (c)Curve of strain effective field in thickness direction.

From Fig. 3(a)(b), cloud patterns after second pass rolling, which are air cooling and water cooling before rolling, show that the effective strain value of the water-cooled rolled piece in the thickness direction is less than 0.25 (dark blue part in the figure 3), and the effective strain value of the core of the rolled piece after water cooling exceeds 0.25 (except for the side and light blue part). Obviously, water cooling can significantly increase the deformation of the core of the rolled piece. Fig. 3(c) is the curve of strain effective field in thickness direction. It can be seen from the figure that the deformation of the surface layer during rolling is significantly lower than that of uniform temperature rolling due to the lower surface temperature of GTR. The heart deformation is slightly higher than the uniform temperature rolling. This is beneficial to improve the texture of the core of the rolled piece.

3.3 Effect of GTR on average grain size

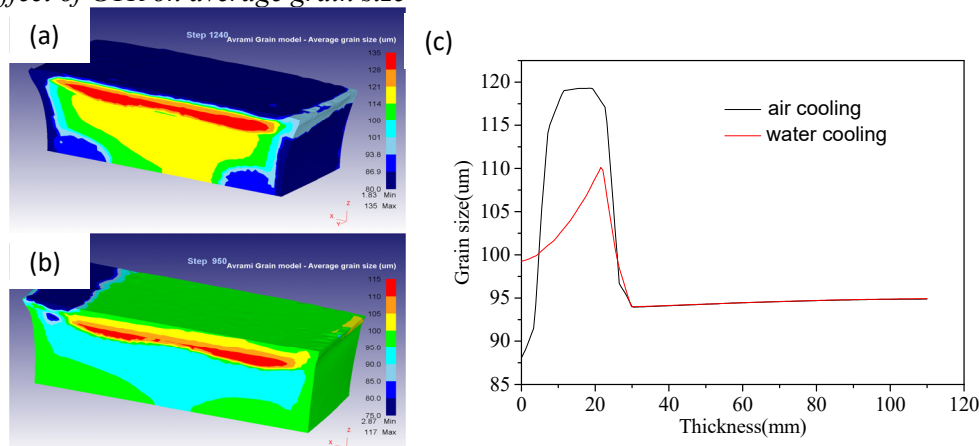


Figure 4. Average grain size field after second pass (a) Cloud pattern of air cooling (b) Cloud pattern of water cooling (c) Curve of average grain size field in thickness direction.

As can be seen from Fig. 4(a)(b), regardless of whether the second pass is water-cooled or air-cooled, the change of grain size is significantly different from the surface in the thickness direction of about 30 mm. For GTR, the grain size increases first and then decreases rapidly with increasing thickness, which increases rapidly from 87 μm on the surface, increases the grain size to 120 μm at a thickness of 15-20 mm, and increases the grain size after the thickness exceeds 20 mm, the size drops rapidly. But, in the case of water-cooling 2 seconds and then air-cooling 12 seconds, the grain size is mainly concentrated in 98~110 μm, and the distribution is relatively uniform. When the thickness exceeds 20 mm, the grain size decreases rapidly. When the thickness exceeds 30 mm, the air-cooled and water-cooled crystals, The particle size is exactly the same, about 95 μm. It can be seen that water cooling is beneficial to reduce the surface grain size and reduce the difference in grain size between the surface layer and the core, which is beneficial to the uniformity of material properties.

4. Conclusion

The surface of the rolled piece is water-cooled to form a temperature gradient layer (about 30 mm) of a certain thickness, which can effectively improve the deep penetration of the rolling and increase the deformation of the core.

- (1) Temperature difference rolling can significantly reduce the average grain size (<50 μm) of the surface layer.
- (2) When the thickness of the surface layer exceeds the thickness of the temperature gradient layer, the gradient temperature rolling (GTR) and the uniform temperature rolling (UTR) have the same average grain size change.

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