ISSN (Online) 2393-8021
ISSN (Print) 2394-1588
International Advanced Research Journal in Science, Engineering and Technology
Vol. 2, Issue 6, June 2015

Research on Rolling Process and Prediction of Microstructure and Mechanical Properties

Wang Zexuan

College of Mechanical Engineering, Shanghai University of Engineering Science, Shanghai, China

Abstract: Heat resistant steel is a new type of martensite heat-resistant steel which has the very high temperature comprehensive performance and wide application. Now integrating practical experiments with the simulation of finite element analysis software DEFORM-3D. Research on the forming process of heat resistant steel by cross wedge rolling. Obtained the distribution laws of microstructure in cross-longitudinal planes of after rolling steel, and the influence law of different technology parameters affects steel dynamic recrystallization volume fraction and austenite average grain size. Finally, combining the experiment of metallographic structure, and validate the validity、feasibility of the simulation.

Key words: Heat-resistant steel; Deform 3D; Dynamic recrystallization.

I. INTRODUCTION:

Heat resistant steel is refers to the metal material working in a high temperature environment[1-3], and the development is closely related to the power industry. Heat resistant steel is used in the power plant boiler and high temperature pressure parts. There are other austenitic heat resistant steel, ferritic heat resistant steel and martensitic steel. T91 heat resistant steel with high resistance to oxidation and corrosion resistance to high temperature steam. High and stable temperature enduring strength, creep tolerance and long-lasting plasticity. The rolling production of T91 steel pipe can be used to manufacture the high pressure boiler reheater which pipe wall temperature is lower than 650℃. Superheater and the boiler header that wall temperature is less than or equal to 600℃, steam piping and so on.

As yet, there are a great deal of investigation about the T91 heat-resistant steel. But most of the studies on creep properties of new heat-resistant steel, welding processes and methods for the steam pipe of T / P91. Zhang Yanhong[4] discussed the causes of P91 steel main steam pipe weld microstructure defect state. A.H.Yaghi， T.H.Hyde，A.A.Becker[5] explored the P91 pipe welding parts for the numerical simulation of residual stress, presented the pipe diameter influence on residual stress. Ajit K.Roy, Pankaj Kumar[6] had researched on the different silicon content of T91 grade steel dynamic strain aging. However, few researches have been done to analyze the law of P91 alloy microstructure evolution and rule of grain growth during the rolling process.

In the process of high temperature forming, the metal will occur dynamic and static recrystallization, form new grain. This microstructure evolution largely determine the macroscopic mechanical properties of the product. Through the hot-working process controlling grain size, refining microstructure is an important means to improve the mechanical properties of the product[7-10]. Consequently, investigation on the material change in the hot-forming process of macroscopic mechanical behavior and microstructure. To reveal the relationship between them, and based on this to optimize the process parameters. Designing the technology of plastic forming, would be very significant for solving the current technology problems and improving product quality. But also a frontier subject about comprehensive simulation of deformation process.

II. FINITE ELEMENT MODELING

A. *Finite element model*

Fig.1 is the cross wedge rolling system model, the roller was defined as a rigid body, workpiece was defined as the plastic body. Given the symmetry on baffler, roller and workpiece, modeled with 1/2 length, 1/2 width, 1/2 thickness of the way. Hot-rolled three-dimensional finite element model, the roller diameter was 1000mm. The geometric assembly model of roller, baffler and workpiece which established in the Pro/E, were saved in STL format.

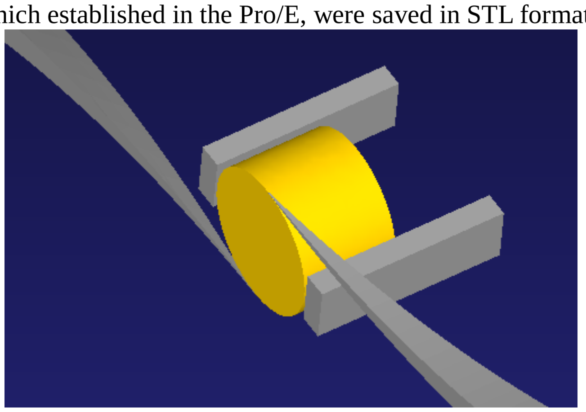


Fig.1 Finite element model of cross wedge rolling

B. *Dynamic recrystallization model of T91 steel in hot deformation*

Due to the material library of Deform-3D finite element software without thermal deformation dynamic recrystallization model on T91 steel. To analyze the billet (T91 steel) microstructure evolution during the forming process of cross wedge rolling, we needed to create a dynamic recrystallization model for T91 steel thermal deformation. As the formula (1) to (7) were shown.

ISSN (Online) 2393-8021
ISSN (Print) 2394-1588

International Advanced Research Journal in Science, Engineering and Technology
Vol. 2, Issue 6, June 2015

Flow stress mathematical model and Zener-Holloman parameter expressions :

$$\dot{\varepsilon} = A[\sin h(\alpha\sigma)]^n exp(-Q/RT) = 2.023 \times 10^{16}[\sin h(\alpha\sigma)]^{4.6176} exp\left(-\frac{484000}{RT}\right) \quad (1)$$

$$Z = \dot{\varepsilon} exp(Q/RT) = A[\sinh(\alpha\sigma)]^n \quad (2)$$

Critical strain formula :

$$\varepsilon_p = 0.02Z^{0.12} \quad (3)$$

$$\varepsilon_c = 0.833\varepsilon_p \quad (4)$$

Where, Z is Zener-Holloman parameter; $\dot{\varepsilon}$ is the strain rate; σ is the flow stress; ε_p is dynamic recrystallization peak strain; A and α are material constants; ε_c dynamic recrystallization critical strain; R is the gas constant, R=8.31J / (K/mol); T is the deformation temperature.

A.

Kinematics equation of dynamic recrystallization and grain size equation :

$$X_{drex} = 1 - \exp[-0.693(\frac{\varepsilon-\varepsilon_c}{\varepsilon_{0.5}})^2] \quad (5)$$

$$\varepsilon_{0.5} = 0.133Z^{0.0274} \quad (6)$$

Where, X_{drex} is Dynamic recrystallization volume fraction; ε is the dynamic strain; $\varepsilon_{0.5}$ is the value of strain while dynamic recrystallization volume fraction reached 50%.

Grain size model of dynamic recrystallization:

$$d_{rex} = 3446Z^{-0.147} \quad (7)$$

Where, d_{rex} is dynamic recrystallization grain size.

C. *Founded the coupled finite element model about deformation-heat-microstructure evolution*

During T91 steel rolling deformation process, temperature and deformation were the main factors affected the forming precision and the product performance; Forming angle and spreading angle were the most important and basic technology parameters on the mold design of cross wedge rolling. And especially, both had a significant impact for the workpiece rotation conditions, the loosen conditions and necking conditions. Therefore this paper mainly considered the effects of rolling temperature T, forming angle α and spreading angle β. The specific rolling parameters were shown in Table 1.

Rolling temperature T(℃)	Forming angle α(°)	Spreading angle β(°)	area reduction ψ(%)	angular velocity of roller w（rad/s）
900/（1000）/1200	20/25/（30）	5/（7.5）/9	75	0.48

Table 1 Rolling process parameters of the T91 steel

First of all, the model of T91 steel thermal deformation dynamic recrystallization was imported into the Deform-3D finite element software. The corresponding assumptions and associated boundary conditions for finite element modeling of cross wedge rolling with reference to the relevant literature. In addition to the boundary conditions should be set as follows : the environmental temperatures was 20 ℃ ; the contact heat transfer coefficient of roller and billet was 15 N/sec/mm/C; the air convective heat transfer coefficient was 0.02 N/sec/mm/C; Billet, roller and the surrounding air radiant heat transfer coefficient was 0.06 N/sec/mm/C. Tetrahedral meshes were used to divide the billet, and the number of meshes was 30000. The diameter of workpiece was 30mm, and the roller diameter was 1000mm. The billet initial grain size was 200um.

III. SIMULATION RESULTS AND DISSCUSSION

A. *Influence of process parameters on the microstructure of the T91 steel*

To completely demonstrate distributions of the average grain size and its variety, six tracking points were selected uniformly along the radial direction in the axial symmetry cross-section A-A, B-B. Points 3,5 are at the center of the cross-section A-A, B-B; Point 2 is at half radius of cross-section A-A; Points 1,4,6 are on the surface A-A, B-B.

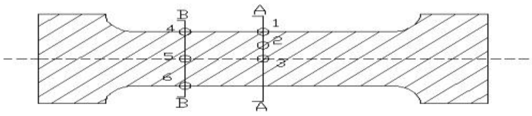
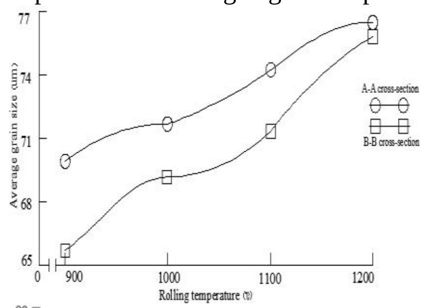


Fig 3 Location of tracking points in cross sections

For the simulation results, according to Fig.3 selected the sections A-A、B-B, average values of grain size were calculated for each sections dependant upon these points. Obtained the average grain size of two sections under different temperatures、forming angle and spreading angle.



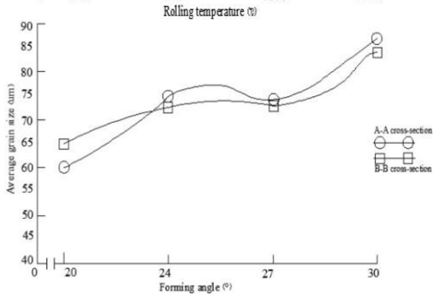


Fig 4 Variation curves of average grain size with the rolling temperature

Fig 5 Variation curves of average grain size with the forming angle

 DOI 10.17148/IARJSET.2015.2602

ISSN (Online) 2393-8021
ISSN (Print) 2394-1588
International Advanced Research Journal in Science, Engineering and Technology
Vol. 2, Issue 6, June 2015

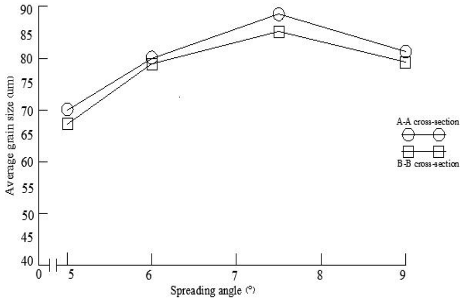


Fig 6 Variation curves of average grain size with the spreading angle

1. Temperatures

As can be seen from Fig.4, the average grain size of workpiece increases obviously with increases of temperature; The average grain size of cross-section A-A is greater than B-B. And with the change of temperature, the average grain size in central cross-section changed relatively slow. This was mainly because in the deformation process, as temperature rose, and the recrystallized grains grew faster.

2. Forming angle

Fig.5, it is revealed that with increasing forming angle, the average grain size of workpiece increases; When the forming angle between 20°～24°, the average grain size of the workpiece increases rapidly; 24°～27°, the average grain size of billet changes slowly; 27°～30°, the average grain size of workpiece increases quickly again; And the average grain size of the central cross-section A-A is larger than B-B.

Fig.7, the instantaneous radial direction rolling reduction of cross wedge rolling; Where α is forming angle of roller; d_0 is the original diameter of workpiece; d_1 is the after rolling diameter of workpiece; S is the value of spreading; Z_0 is the maximum amount of workpiece radial direction compression.

Among them, Z_0=Stan α (8)

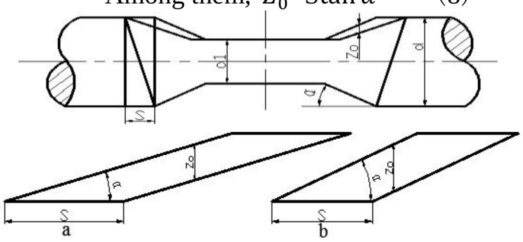


Fig 7 The instantaneous radial direction rolling reduction of cross wedge rolling

As you can see from equation (8), the amount of radial compression associated with forming angle and spreading. When other factors without changing, Z is proportional to α. The value of radial compression increases with the increases of forming angle. Then compares graph a and b, the forming angle in graph a is larger than graph b, and the value of Z also changes accordingly. Because Z become larger with the increase of forming angle, led to any moment the plastic work generate heat become greater. The value of grain size on T91 steel increases as the temperatures rises.

3. Spreading angle

It is evident from fig.6, with the increases of spreading angle, the average grain size of after-rolling T91 steel as a whole is a upward trend; When spreadinging angle between 5°～8°, the average grain size becoming larger; As spreading angle is above 8° and the average grain size decreases; the average grain size of the central cross-section A-A is larger than B-B.

Fig.8, the instantaneous broadening chart of cross wedge rolling; And α is forming angle of roller, β is spreading angle of roller, d_k is rolling diameter of workpiece, S is the spreading value of workpiece.

Among them, $S={}^{1}/_{m}\ \pi d_k \tan\beta$ (9)

Where m is the number of roller; d_k is the rolling diameter.

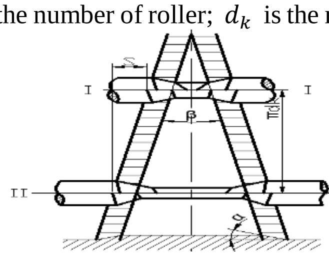


Fig 8 The instantaneous spreading of cross wedge rolling

For equation (9), spreading value related to spreading angle. when other factors without changing, S is proportional to β. The spreading value becomes larger as spreading angle increases. Resulting in any moment the plastic work generates heat increases. The temperatures rises, the value of the grain size of T91 steel becomes larger.

IV. EXPERIMENTAL

In view of the above simulation condition, we did the rolling experiment of T91 steel on the two-roll cross wedge rolling machine. And the below picture shows the microstructure of after-rolling T91 steel under three different temperatures.

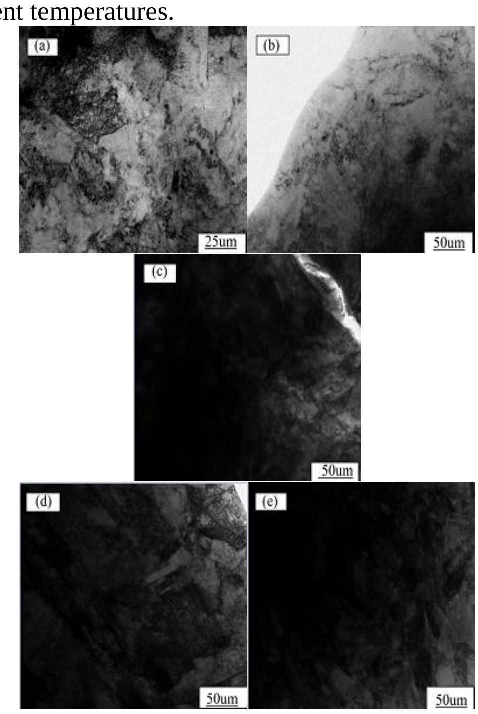


Fig 9 The microstructure of after rolling T91 steel at different temperatures:

ISSN (Online) 2393-8021
ISSN (Print) 2394-1588
International Advanced Research Journal in Science, Engineering and Technology
Vol. 2, Issue 6, June 2015

(a) 900℃,edge of the cross-section (b) 900℃,1/2 radius of the cross-section (c) 900℃,center of the cross-section (d) 1000℃ (e) 1200℃

To divide into thin slices with 3mm diameter and 1mm thickness in A-A, B-B of after rolling workpieces. Analysis on TEM metallographic structure and observed grain morphology as shown fig.9. By study of metallographic structure, the results of the experiment on average grain size of the billet under different temperatures were in accordance with the simulation results. In the contact area between billet and roller, the outer surface of the workpiece, grain size distributed from 15um to 25um. So the grain was obviously refined. And in the center zone of the billet, the refining effect of grain was not obvious, the size was 85um～95um..

V. CONCLUSION

（1）In the cross wedge rolling forming process of T91 steel, the workpiece grain gradually refined from the surface to the core, and carried out with the deformation. From the workpiece forming area to the two ends unforming area, the degree of refinement of the grain decreased. In addition, when the core of workpiece strain reached the value that dynamic recrystallization happened, dynamic recrystallization could occur entirely. Workpiece microstructure from inside to outside could be completely refined, grain size was small and uniform. As demonstrated by TEM metallographic experiment, grain size was about 100um in the central part of workpiece, and the size of outer surface was around 30um.

（2）Rolling in T91 steel. In order to improve the mechanical properties, process performance and physical properties of the after-rolling workpiece, rolling temperature should be around 900 ℃; The forming angle of roller is 20º ~ 24º, spreading angle is 5º～6º. Meanwhile, the grain of T91 steel is better refined, and enhance the strength, hardness, plasticity and toughness of T91 steel. Thereby providing a certain reference value for the development of process parameters in rolling T91 steel.

（3） Rolling experiments show that, by using DEFORM-3D finite element analysis software to study on T91 steel microstructure evolution of cross wedge rolling is reliable and precise.

REFERENCES

[1] Thomas Paul V, Saroja S, Vijayalakshmi M. Microstructural stability of modified 9Cr–1Mo steel during long term exposures at elevated temperatures. J Nucl Mater 2008;378:273–81.

[2] Ning B Q, Shi Q Z, Yan Z S, et al. Variation of martensite phase transformation mechanism in minor-stresses T91 ferritic steel. J Nucl Master, 2009, 339 (1) : 54

[3] Haney E M, Dalle F, Sauzay M, et al. Macroscopic results of long-term creep on a modified 9Cr-1Mo steel (T91). Mater Sci Eng A, 2009, 510/511: 99

[4] Zhang Yanhong, Li Hongqiang, Xuyun. Reasons for metallography defect form and the formation of P91 steel main steam pipe welding seam. Northeast Electyic Power Technology. 2009(7): 1～5

[5] A.H. Yaghi, T.H. Hyde, A.A. Becker, J.A. Williams, W. Sun. Residual stress simulation in welded section of P91 pipes. Journal of Materials Processing Technology. 167(2005)480～487

[6] Ajit K. Roy, Pankaj Kumar, Debajyoti Maitra. Dynamic strain ageing of P91 grade steels of varied silicon content.

[7] Fu G S, Chen W Z, Qian K W. Characteristics of flow stress-strain curves of aluminum sheet used for pressyre can during compression at elevated temperature. Chin J Nonferrous Met, 2002, 12 (Al Spec): 140

[8] Zhang C L, Sun R X, Cai D Y, et al. Dynamic recrystallization of elevated temperature deforming austenite of Cu-P-Cr-Ni-Mo weathering stell. Spec Stell, 2010, 31 (4) : 43

[9] Yazdipour N, Davies C H J, Hodgson P D. Microstructural modeling of dynamic recrystallization using irregular cellular automata. Comput Master Sci, 2008, 44 (2) : 566

[10] Huang G S, Wang L Y, Chen H, et al. Hot deformation and processing maps of 2618 aluminum alloy. Chin J Nonferrous Met, 2005, 15 (5) : 763