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ISSN 0543-5846
METABK 63(2) 237-240 (2024)
UDC – UDK 669.15.14.018:536.45-539.374:517.9:621.72=111

2209 DUPLEX STAINLESS STEEL HIGH TEMPERATURE PLASTIC DEFORMATION INTRINSIC MODELING

Received – Primljeno: 2023-08-22
Accepted – Prihvaćeno: 2023-11-02
Original Scientific Paper – Izvorni znanstveni rad

The high temperature compression experiments of 2209 duplex stainless steel were carried out by using Gleeble3800 thermal simulator, the rate was 0,01~10 s^{-1}, and the deformation temperature was 950~1 100°C. The strain rate and deformation temperature were analyzed and the effect of strain rate and deformation temperature were analyzed. The high-temperature rheological behavior of 2209 duplex stainless steel was investigated, and the effects of strain rate and deformation temperature on the two-phase relationship of 2209 duplex stainless steel were analyzed, the strain rate compensation factor Z was introduced, and the Arrhenius eigenmodel equation was established. The results show that the theoretical value of peak stress calculated numerically by this constitutive model fits well with the experimental results, and the correlation is 97,3 %, which verifies the feasibility of the model.

Keyword: 2209 duplex stainless steel; high temperature rheology; constitutive equation; Arrhenius model

INTRODUCTION

2209 duplex stainless steel has both ferrite and austenitic stainless steel, and its plasticity, weldability and toughness is better than ferrite strength, resistance to chloride stress corrosion and intergranular corrosion resistance than austenitic[1]. Chloride stress corrosion and intergranular corrosion resistance is stronger than austenitic[2]. However, in 2209 duplex stainless steel high temperature hot rolling process austenite phase and ferrite phase coexist, the steel deformation behavior is more complex than the single-phase organization, which leads to wire rod products in the hot processing process is prone to surface folding, microcracks and other defects[3].

In order to investigate the relationship between its relevant influencing factors and stress, the paper utilizes the Gleeble-3800 thermal simulator to carry out high-temperature compression experiments on 2209 stainless steel, to study the change characteristics of the rheological stress-strain curves, to establish the intrinsic model as well as the power dissipation diagrams and thermal processing diagrams under different strains, and to compare the experimental data with the model prediction data to verify the accuracy and feasibility of the intrinsic model[4].

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2209 duplex stainless steel hot compression test

The 2209 duplex stainless steel material is processed into ϕ 10 mm×15 mm specimens, which is composed of ferrite and austenite in a ratio of approximately 1:1. The specimens were subjected to compression tests on a Gleeble-3800 thermal/force simulator, which was heated to 1 200°C, held for 18 s, and then lowered to 950 °C~1 100°C (with 50°C intervals between experiments) and held for 30°C before being subjected to unidirectional compression tests. The experiments were carried out according to the strain rates of 0,01, 0,1, 1 and 10 s^{-1}, and the true strain in compression was 0,9, and the compression was completed by water quenching.

Experimental data and ontological modeling

After the test, 2209 duplex stainless steel should be changed at a rate of 0,01 ~ 10 s^{-1} under the real stress - really strain curve shown in Figure 1. From Figure 1, it can be concluded that the strain rate and deformation temperature have a greater impact on the flow stress change of 2209 duplex stainless steel. According to the curve graph analysis can be obtained, due to the emer-

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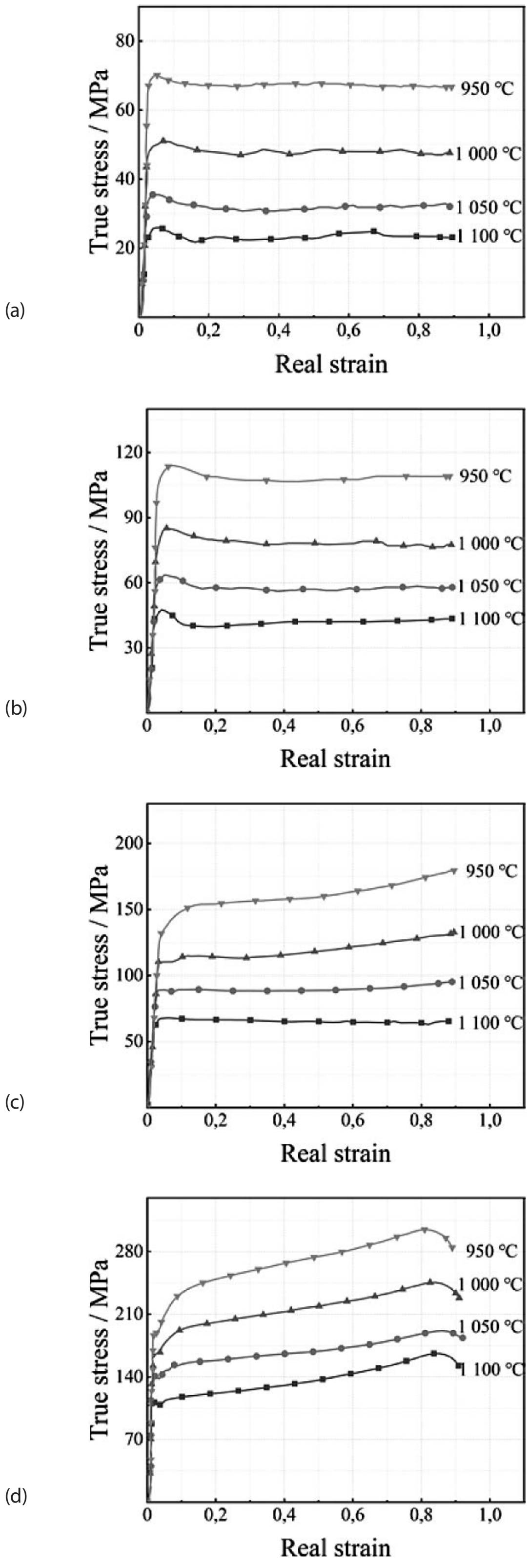

(a) 0,01 s^{-1} (b) 0,1 s^{-1} (c) 1 s^{-1} (d) 10 s^{-1}

Figure 1 2209 duplex stainless steel true stress-true strain curve

gence of work hardening phenomenon at the beginning of processing, the flow stress climbs rapidly. When the stress rate is small, the flow stress grows to the peak value with the increase of the true strain decreases and finally stabilizes; when the strain rate is large, the flow stress increases to the peak value and finally stabilizes. Along with the increase of strain rate, the steady state zone at the same temperature is extended, the work hardening effect is weakened, the dynamic softening effect is enhanced, and the curve type is gradually transformed from dynamic recrystallization type to dynamic recovery type.

In order to investigate the influence of processing parameters on the rheological stress during the deformation of 2209 duplex stainless steel, an Arrhenius-type ontological model that quantitatively describes the interrelationships between the rheological stress σ and the temperature T and the strain rate $\dot{\varepsilon}$ is established Introduction of temperature-compensated strain rates Strain rate compensation is performed by the Zener-Hollomon parameter Z, which is a temperature-independent function of the rheological stress and the degree of deformation.

$$Z = \dot{\varepsilon} \exp\left(\frac{Q}{RT}\right) \tag{1}$$

In the formula: Z parameter is the strain compensation factor, R is the molar gas constant, the value is 8,314 J $(mol/K)^{-1}$, and Q is the apparent activation energy (J/mol) of hot deformation.

The relationship between flow stress σ, temperature T and strain rate $\dot{\varepsilon}$ during high temperature hot deformation can be expressed as:

$$\dot{\varepsilon} = A_1 \sigma^{n_1} \exp(\frac{-Q}{RT}) , \quad \alpha\sigma \leq 0,8 \tag{2}$$

$$\dot{\varepsilon} = A_2 \exp(\beta\sigma) \exp(\frac{-Q}{RT}) , \quad \alpha\sigma \geq 1,2 \tag{3}$$

$$\dot{\varepsilon} = A\left[\sinh(\alpha\sigma)\right]^n \exp(\frac{-Q}{RT}) , \quad \text{Any stress level} \tag{4}$$

where σ is stress, MPa; A; A_1; A_2; α, β, n and n_1 are temperature-independent material constants, and $\alpha = \beta/n_1$; T is the deformation temperature, K.

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$$In\dot{\varepsilon} = InA_1 + n_1 In\sigma - \frac{Q}{RT} \tag{5}$$

$$In\dot{\varepsilon} = InA_2 + \beta\sigma - \frac{Q}{RT} \tag{6}$$

Under the condition of constant temperature, the logarithmic processing of the test peak data is substituted into Formula (5) and Formula (6), and the linear regression curves of $\ln\dot{\varepsilon} - \ln\sigma$ and $\ln\dot{\varepsilon} - \sigma$ are obtained, as shown in Figures 2, 3.

The slopes of the linear regression curves of $\ln\dot{\varepsilon} - \ln\sigma$ and $\ln\dot{\varepsilon} - \sigma$ can be obtained from the figure, and the average values of the slopes are taken to obtain n_1 = 3,833 and β = 0,03846698, respectively. According to the relationship of $\alpha = \beta/n_1$, α = 0,009965 MPa^{-1} is obtained.

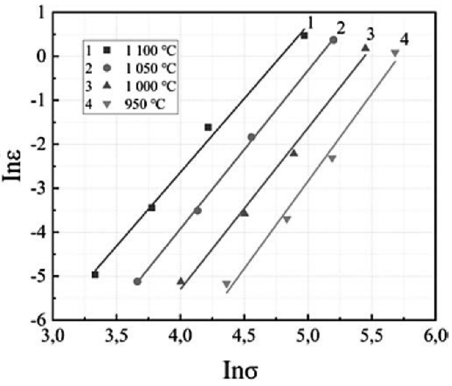

Figure 2 Relation curves of $\ln\dot{\varepsilon}$ and ln σ

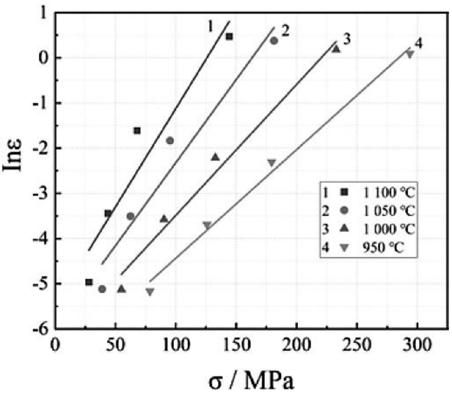

Figure 3 Relation curves of $\ln\dot{\varepsilon}$ and σ

Taking logarithm of pair (4), the following result is obtained:

$$In\dot{\varepsilon} = InA + nIn\left[\sinh(\alpha\sigma)\right] - \frac{Q}{RT} \tag{7}$$

The partial derivative transformation of Eq. (4) is obtained respectively :

$$n = \frac{\partial In\dot{\varepsilon}}{\partial In\left[\sinh\left(\alpha\sigma\right)\right]} \tag{8}$$

$$K = \frac{Q}{nR} = \frac{\partial In\left[\sinh\left(\alpha\sigma\right)\right]}{\partial\left(1/T\right)} \tag{9}$$

Where K is the material constant.

Finally, the thermal activation energy Q is obtained, and the expression is:

$$Q = R\frac{\partial In\left[\sinh\left(\alpha\sigma\right)\right]}{\partial\left(1/T\right)} \cdot \frac{\partial In\dot{\varepsilon}}{\partial In\left[\sinh\left(\alpha\sigma\right)\right]} = nRK \tag{10}$$

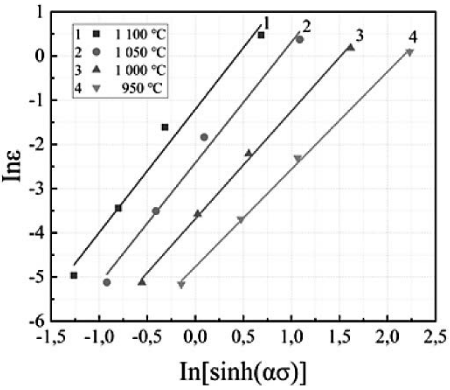

Figure 4 Relation curves of $\ln\dot{\varepsilon}$ and ln[sinh(ασ)]

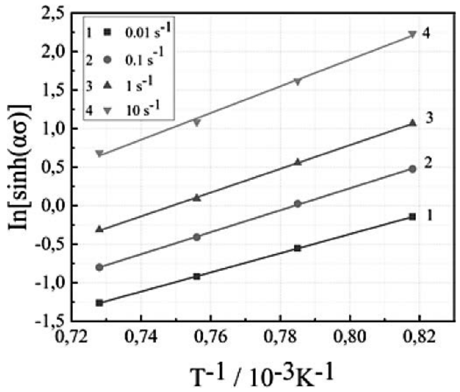

Figure 5 Relation curves of ln[sinh(ασ)] and 1/T

As shown in Figure 4 and Figure 5, n = 2,694323 and K = 15136,09 are obtained by linear regression by calculating the average value of the slope of the regression line respectively. According to $K = Q/nR$, Q = 339057,5 J/mol is calculated.

Bring Formula (4) into Formula 1, and take the logarithm to get :

$$\ln Z = n\ln[\sinh(\alpha\sigma)] + \ln A \tag{11}$$

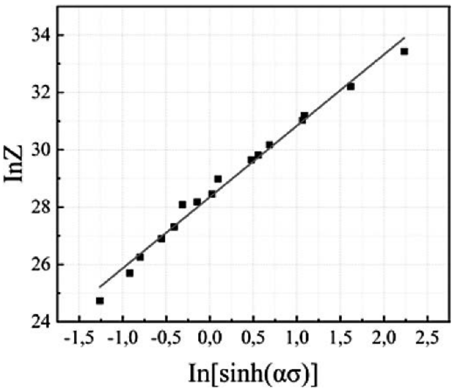

Figure 6 Relation curves of ln Z and ln[sinh(ασ)]

According to Formula (11), the relationship equation between ln Z and ln[sinh($\alpha\sigma$)] is made and linear regression processing is carried out. Finally, the intercept ln A = 28,92308 is obtained, and then the experimental alloy structure factor $A = 3{,}64027\times10^{12}$ is obtained.

The calculated A, α, Q and n are brought into Formula (4) to obtain the peak stress constitutive equation of 2209 duplex stainless steel.

$$\dot{\varepsilon} = 3{,}64027\times10^{12}\left[\sinh(0{,}009965\sigma)\right]^{2{,}694323}\exp\left(\frac{-339\ 057{,}5}{8{,}314T}\right) \tag{12}$$

Simulation prediction and verification of constitutive model

The predicted stress values of 2209 duplex stainless steel at different strain rates and different deformation temperatures were compared with the experimental values, as shown in Figure 7. The correlation coefficient between the calculated results of the constitutive model of 2209 duplex stainless steel and the experimental values is 0,973, the maximum relative error is 9,43 %, and the average relative error is 5,46 %. The established model can well predict the macroscopic stress of the material.

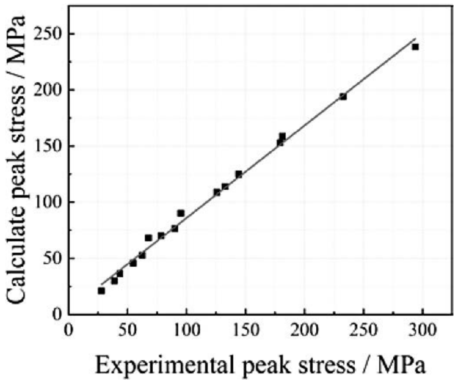

Figure 7 The peak stress calculation results are compared with the measured values

CONCLUSION

In this paper, the constitutive relationship of 2209 duplex stainless steel at different temperatures and different strain rates was studied. The Arrhenius constitutive model of 2209 duplex stainless steel in the expected strain range was established by introducing the temperature-compensated strain rate factor Zener-Hollomon parameter. The accuracy and feasibility of the model for predicting flow stress were analyzed and verified. The results show that the constitutive model of 2209 duplex stainless steel established in this paper has certain accuracy, which can provide a strong basis and reference for the study of plastic deformation of duplex stainless steel.

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Note: The responsible translator for English language is W. LI-North China University of Science and Technology, China