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ARRHENIUS CONSTITUTIVE MODEL OF FV520B STEEL

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To investigate the thermoplastic deformation behavior of FV520B steel, the Gleeble-3800 thermal simulation test machine is used to perform hot compression test on FV520B steel. Select a deformation temperature of 900 °C - 1 050 °C, set the strain rate to 0,005 s^{-1} - 5 s^{-1}. The results indicate that the Arrhenius constitutive model of FV520B steel with strain compensation correlation coefficient value is 0,99601, and the average relative error is 3,061 %, realizing the fitting of flow stress and prediction, verified the feasibility of the model.

Keywords: FV520B steel, hot compression test, strain rate, constitutive model

INTRODUCTION

FV520B steel is a new type of martensite precipitation hardening acid resistant and heat resistant stainless steel developed on the basis of the original FV520 [1]. Due to its excellent corrosion resistance, it is widely used in fields such as chemical engineering, aviation, petroleum, machinery, and medical treatment [2]. In the study of material constitutive models, hyperbolic sine constitutive models are widely used in the study of various metal materials such as steel, titanium alloys, aluminum alloys, magnesium alloys, and nickel based alloys. The Arrhenius equation and the Zener Hollomon parameter proposed by Zener and Hollomon in 1944 are commonly used to characterize the response relationship between flow stress and deformation parameters such as temperature, strain rate, and strain [3].At present, the determination of specific parameters in the constitutive relationship requires a large amount of data obtained through experiments, and the specific parameters of the material constitutive model are finally obtained through the fitting of a large amount of data. Foreign scholars have established a variety of constitutive models [4], The strain-compensated Arrhenius constitutive model has the highest accuracy[5], followed by the Hensel-Spittel model and the new Johnson-Cook model.

In this article, FV520B steel underwent extensive strain rate and temperature hot compression tests to study its flow behavior. On this basis, a compensated Arrhenius constitutive model is established to deeply explore the material constants. Verify the accuracy of the established constitutive model.

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EXPERIMENTAL MATERIALS AND TECHNOLOGY

The main chemical composition of FV520B steel is 0,05 % C, 14,05 % Cr, 5,32 % Ni, 1,58 % Mo, 2,1 % Cu, 0,18 % Mn, 0,38 % Si, 0,03 % S / P, and the rest is Fe. The experiment used FV520B steel extruded bars, with specific dimensions of φ8×12. This experiment is performed on the Gleeble - 3800 thermal simulation test machine. The specific thermal deformation process is: heating to 10 °C·s^{-1} respectively 900 °C, 950 °C, 1 000 °C, 1 050 °C and then kept for 6 minutes, with strain rate of 0,005 s^{-1}, 0,05 s^{-1}, 0,5 s^{-1}, 5 s^{-1} for compression experiments.

ESTABLISHMENT OF CONSTITUTIVE MODEL

Through hot compression experiments, stress-strain data of FV520B steel compression specimens were obtained under different thermal deformation parameters. Figure 1 shows the nonlinear relationship curve between the true stress and strain of FV520B steel in the range of 900 - 1 050 °C / 0,005 - 5 s^{-1}. Figure 1 shows the influence of strain rate on flow behavior. Under the condition of constant temperature, it can be seen that the flow stress is increasing with the increase of strain rate; under the condition of the same strain rate, the flow stress is increasing with the increase of true strain until the peak stress drops slightly to a stable state.

The Arrhenius constitutive equation is used to characterize the response relationship between flow stress of high-temperature metals and deformation parameters such as temperature, strain rate and strain. Their mathematical expressions are as follows:

1) Under low stress $(\alpha\sigma < 0,8)$ is:

$$\dot{\varepsilon}=A_1\sigma^{n_1}\exp\left[-Q/(RT)\right] \tag{1}$$

2) Under high stress $(\alpha\sigma > 1,2)$ is:

$$\dot{\varepsilon}=A_2\exp(\beta\sigma)\exp\left[-Q/(RT)\right] \tag{2}$$

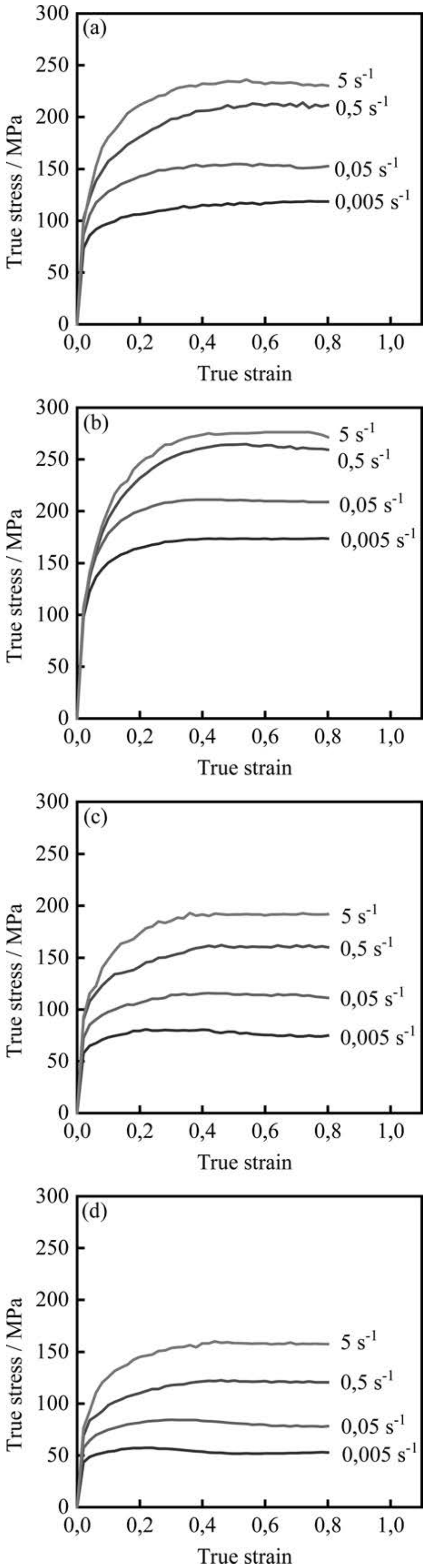

Figure 1 Stress-strain curves of FV520B steel at different temperatures: (a) T=900 °C; (b) T=950 °C; (c) T=1 000 °C; (d) T=1 050 °C

3) Under full stress is:

$$\dot{\varepsilon}=A\left[\sinh\left(\alpha\sigma\right)\right]^{n}\exp\left[-Q/\left(RT\right)\right] \qquad (3)$$

Where-strain rate / s^{-1}; A_1, A_2, A - structure factor is related to the material; flow stress /MPa; n, n_1 - stress in-

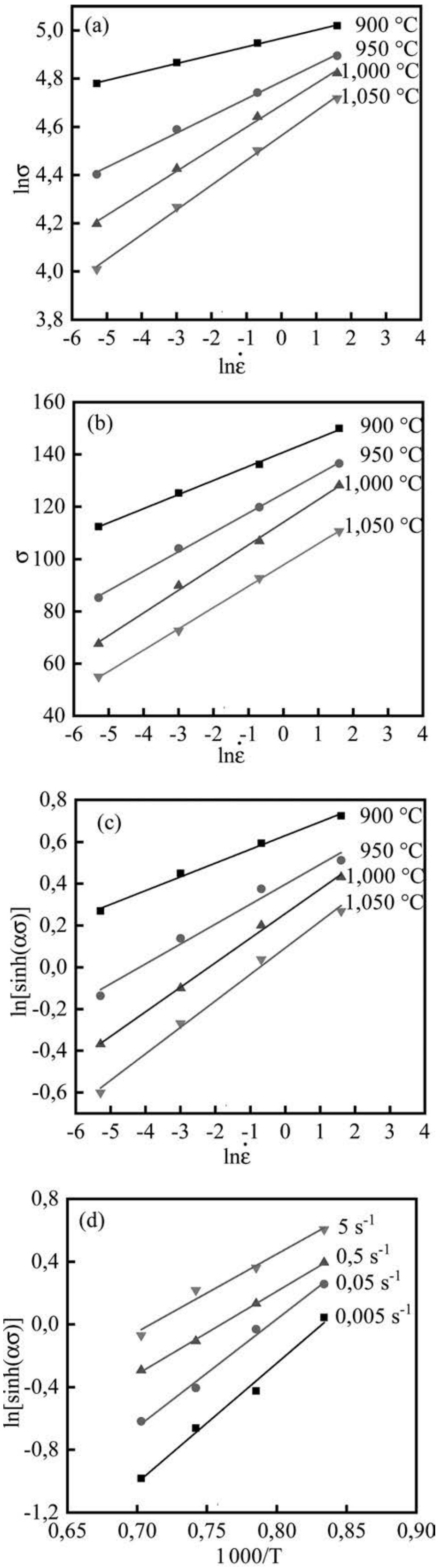

Figure 2 Linear fitting curve between different variables of FV520B steel: (a) $\ln\dot{\varepsilon}-\ln\sigma$; (b) $\ln\dot{\varepsilon}-\sigma$; (c) $\ln\dot{\varepsilon}-\ln[\sinh(\alpha\sigma)]$; (d) $1000/T-\ln[\sinh(\alpha\sigma)]$

dex; α, β - stress level parameter /MPa^{-1}; R - Molar gas constant and R = 8,314 J/(mol·K); Q-deformation activation energy (J/mol); T - deformation temperature /K;

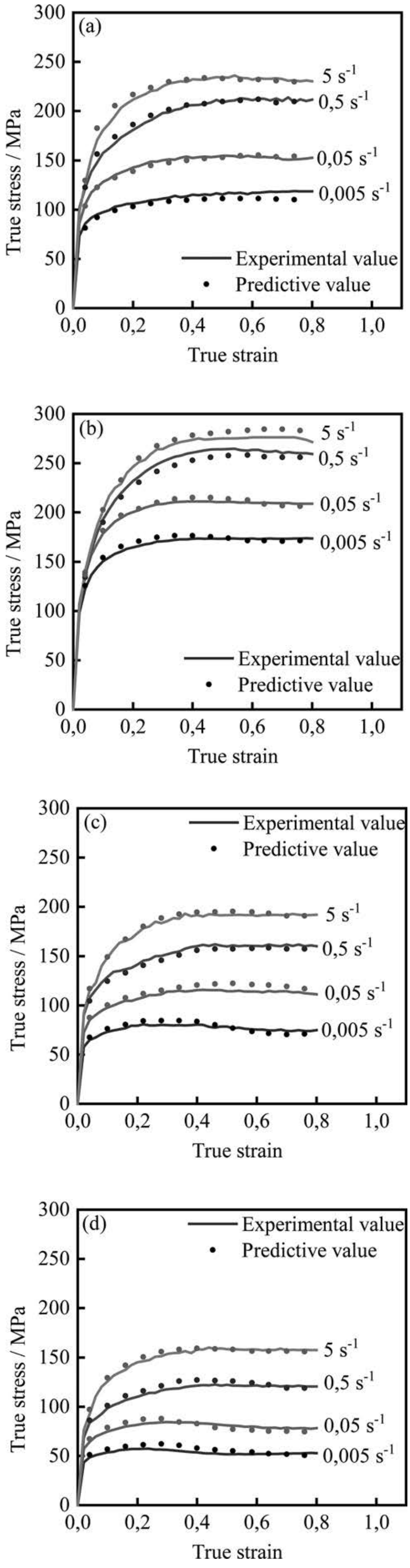

Figure 3 Comparison of experimental and predicted values of FV520B steel at different temperatures: (a)T=900 °C; (b)T=950 °C; (c)T=1 000 °C; (d)T=1 050 °C

Respectively taking the natural logarithm of both sides of the equations (1) and (2), we can get:

$$\ln\dot{\varepsilon} = n_1\ln\sigma + \ln A_1 - Q/(RT) \qquad (4)$$

$$\ln\dot{\varepsilon} = \beta\sigma + \ln A_2 - Q/(RT) \qquad (5)$$

Equation (6) can be obtained from equation (3).

$$\ln\dot{\varepsilon} = n\ln\left[\sinh(\alpha\sigma)\right] - Q/(RT) + \ln A \qquad (6)$$

After taking the logarithm of Equation (3) and deforming it, Equation (7) can be obtained to know, $M = \frac{Q}{1000Rn}$, $N = \left(\ln\dot{\varepsilon} - \ln A\right)/n$.

$$\ln\left[\sinh\left(\alpha\sigma\right)\right] = M\times\frac{1000}{T} + N \qquad (7)$$

According to Equations (4 - 7), the linear fitting curves between different variables of FV520B steel is shown in Figure 2.

So far, from Figures 2 (a), (b), (c) and (d), it can be concluded that n_1 = 0,07479 and β = 7,39365, α = β/ n_1 = 98,8588, n = 0,101325, M = 6,1836475, Q = 1,000$Rn\times M$ = 5,209,204 J/mol. The experimental results obtained $A = 3{,}915\times10^{11}$. The peak stress equation of FV520B steel at a deformation temperature of 900 °C to 1050 °C and a strain rate of 0,005 s^{-1}~5 s^{-1} is shown in Equation (8).

$$\dot{\varepsilon} = 3{,}915\times10^{11}\left[\sinh\left(98{,}8588\sigma\right)\right]^{0{,}101325}\exp\left(\frac{-5\,209{,}204}{RT}\right) \qquad (8)$$

SIMULATION PREDICTION AND VERIFICATION OF CONSTITUTIVE MODEL

In order to improve the accuracy of the equation prediction, strain factors are introduced into the Arrhenius equation, and Q, n, α and A under different strains are calculated based on the data obtained from the isothermal compression experiment of FV520B steel.

Putting the obtained parameters into Equation (9) can obtain the flow stress at different temperatures. Figure 3 shows that the obtained constitutive equation has high accuracy.

$$\sigma = \frac{1}{\alpha}\ln\left\{\left(\frac{Z}{A}\right)^{\frac{1}{n}} + \left[\left(\frac{Z}{A}\right)^{\frac{2}{n}} + 1\right]^{\frac{1}{2}}\right\} \qquad (9)$$

In order to quantify and compare the prediction accuracy of the two constitutive equations, it is necessary to carry out statistics and error analysis on the prediction data and experimental data further accurately. Introduce two parameters: the correlation coefficient (R) and the average relative error (δ_{AARE}) to further evaluate the model ability to predict.

$$R = \frac{\sum_{i=1}^{n}(E_i - \overline{E})(P_i - \overline{P})}{\sqrt{\sum_{i=1}^{n}(E_i - \overline{E})^2(P_i - \overline{P})}} \qquad (10)$$

$$\delta_{AARE}(\%) = \frac{1}{N}\sum_{i=1}^{N}\left|\frac{E_i - P_i}{E_i}\right| \times 100\ \% \tag{11}$$

In the formula, E_i is the experimental value; P_i is the predicted value; N is the number of samples. Correlation coefficient (R) is usually used to reflect the ability of experimental data and predictive data. Figure 4 shows good data correlation, with the correlation coefficient (R) value of 0,99601 and the average relative error of 3,061 %.

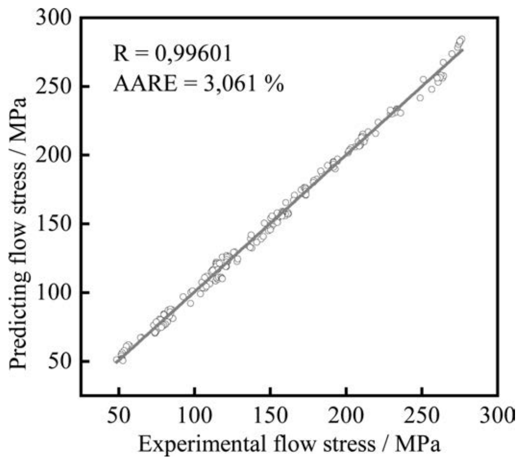

Figure 4 Correlation detection between predicted value and experimental value

CONCLUSION

As the deformation temperature increases and the strain rate decreases, the corresponding flow stress value of FV520B steel decreases. The Arrhenius constitutive model was constructed within the deformation temperature range of 900 ° C ~ 1 050 ° C and the strain rate range of 0,005 s^{-1} ~ 5 s^{-1}. By comparing the calculated and experimental values, it has been proven that the established constitutive model has high accuracy.

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Note: The responsible translator for English language is Jia Deng -North China University of Science and Technology, Hebei, China