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CONSTITUTIVE MODEL OF 7075 ALUMINUM AT HIGH TEMPERATURE

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In order to obtain the accurate mechanical properties of 7075 aluminum alloy, the Gleeble-1500D thermal simulation test machine was used to perform compression test on 7075 aluminum alloy. The deformation temperature range is 490 °C~560 °C, and the strain rate is 0,001 s^{-1}~1 s^{-1}.At present, for the high temperature thermal compression process, the Arrhenius constitutive model with strain compensation is usually used. The results show that the correlation coefficient of the Arrhenius constitutive model of 7075 aluminum alloy with strain compensation is 0,9894, and the average relative error is 5,6 %, realizing the fitting of flow stress and prediction, verified the feasibility of the model.

Keywords: 7075 aluminum alloy; hot compression test; stress-strain curves; temperature; constitutive model

INTRODUCTION

7075 aluminum alloy is the lightest and strongest aluminum material, and it has lightweight materials with moderate price, oxidation resistance, and low specific gravity [1] Make it not only an important lightweight material for aerospace, but also a basis for people's daily needs [2]. 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 [3], The strain-compensated Arrhenius constitutive model [4] has the highest accuracy, followed by the Hensel-Spittel model and the new Johnson-Cook model. In order to obtain higher accuracy, the Arrhenius constitutive model was constructed, Its main advantages also include that the relevant constitutive model can be obtained through a large amount of experimental data, which is more convenient for engineering applications and the results are more significant. Although 7075 aluminum alloy has been widely used, there is a lack of comprehensive internal structural analysis of the flow behavior of 7075 aluminum alloy after high temperature forming, and a constitutive model of 7075 aluminum alloy that can accurately predict the flow stress in the full stress range is required [5] , The Arrhenius model can meet this requirement. Its constitutive mainly contains four parameters. The constitutive model of 7075 aluminum alloy can be finally determined by finding the parameter values through linear fitting.

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In this article, 7075 aluminum alloy is subjected to a wide range of strain rate and temperature hot compression tests to study its flow behavior. On this basis, an Arrhenius constitutive model considering compensation is established, and the material constants are discussed in depth relation. Finally, the accuracy of the established inherent structure model was verified and analyzed.

EXPERIMENTAL MATERIALS AND TECHNOLOGY

7075 aluminum alloy is one of the most representative 7000 series aluminum alloys due to its small specific gravity, oxidation resistance and many other advantages The main chemical composition of 7075 aluminum alloy is 0,4 % Si, 0,5 % Fe, 1,2 % Cu, 0,3 % Mn, 2,1 % Mg, 0,18 % Cr, 5,1 % Zn, 0,2 % Ti, and the rest is Al. The experiment uses 7075 aluminum alloy extruded rods. The specific size of the test piece is φ10×15. This experiment is performed on the Gleeble-1500D thermal simulation test machine. The specific thermal deformation process is: heating to 10 °C·s^{-1} respectively 490 °C, 510 °C, 540 °C, 560 °C and then kept for 10 minutes, with strain rate of 0,001 s^{-1}, 0,01 s^{-1}, 0,1 s^{-1}, 1 s^{-1} for compression experiments.

ESTABLISHMENT OF CONSTITUTIVE MODEL

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.

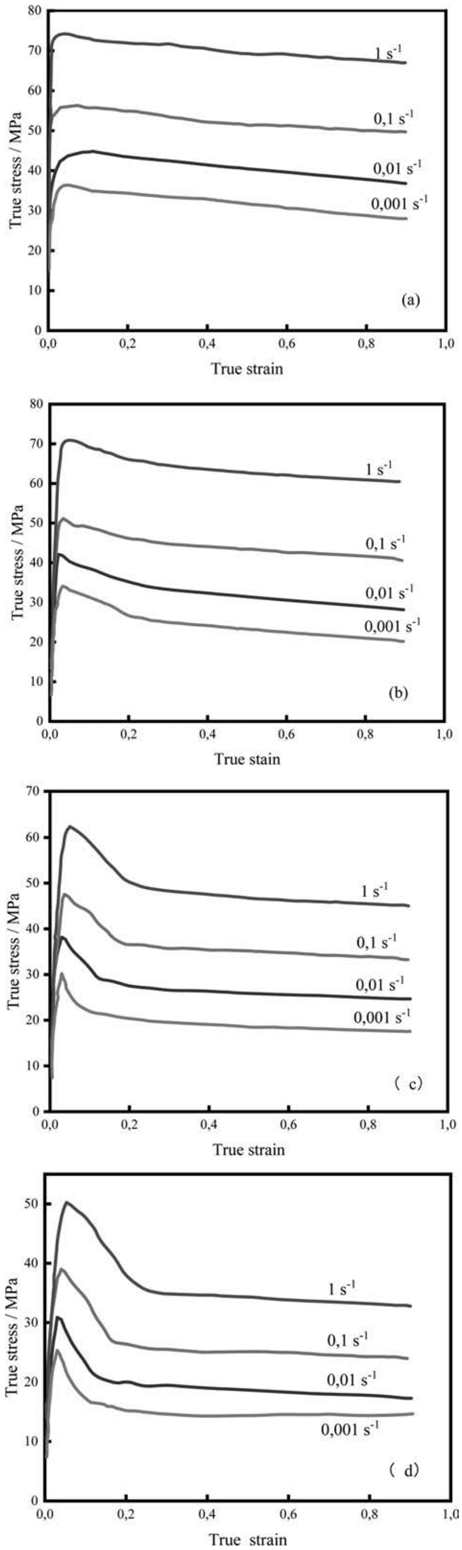

Figure 1 Stress-strain curves of 7075 aluminum alloy at different temperatures: (a)T=490 °C; (b)T=520 °C; (c)T=540 °C; (d)T=560 °C

The Arrhenius constitutive equation is more suitable for high-temperature metals, and it mainly contains constitutive equations of three stress levels.

1) The constitutive equation under low stress ($\alpha\sigma < 0,8$) is:

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

2) The constitutive equation under high stress ($\alpha\sigma < 1,2$) is:

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

3) The constitutive equation under full stress is:

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

Where-strain rate/s^{-1}; A_1, A_2, A-structure factor is related to the material; flow stress /MPa; n, n_1-stress index; α, β-stress level parameter /MPa^{-1}; R -Molar gas constant and R = 8,314J/(mol·K); Q-deformation activation energy (J/mol); T-deformation temperature /K;

Respectively taking the natural logarithm of both sides of the equations (1) and (2):

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

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

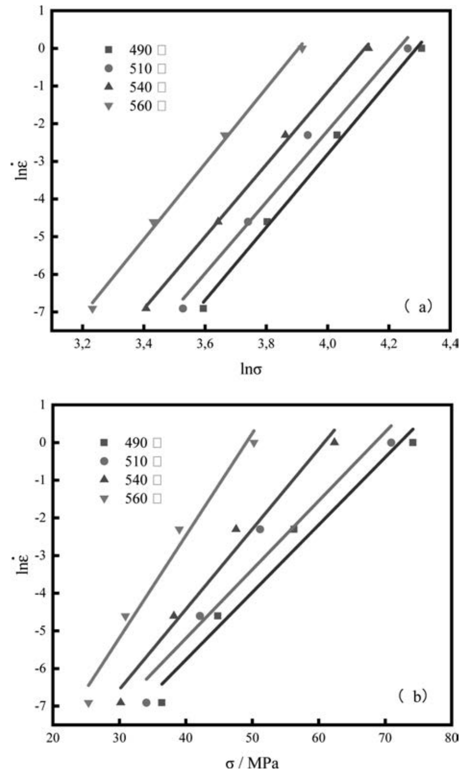

Figure 2 The relationship between strain rate and peak stress at different temperatures: (a) $\ln\dot{\varepsilon} - \ln\sigma$ (b) $\ln\dot{\varepsilon} - \sigma$

It can be seen that when the temperature is constant, the two ends of the equation show a certain linear relationship. The fitting result is shown in Figure 2, so that the parameters n_1 = 9,702525 and β = 0,211545 are obtained, and α = 0,021803 is obtained by formula (6).

$$\alpha = \frac{\beta}{n_1} \quad (6)$$

Equation (7) can be obtained from equation (3), as shown in Figure 3 through linear fitting, the parameter n = 7,292203 can be obtained.

$$\ln\dot{\varepsilon} = n\ln\left[\sinh(\alpha\sigma)\right] - Q/(RT) + \ln A \quad (7)$$

After taking the logarithm of equation (3) and deforming it, equation (8) can be obtained to know

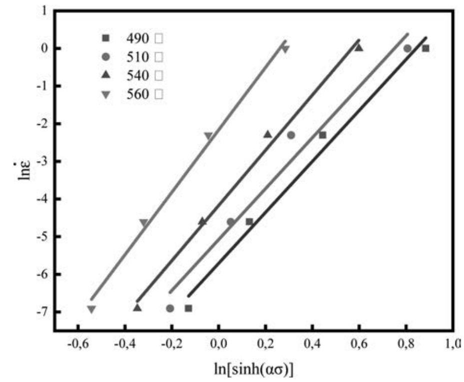

Figure 3 Relation curves of $\ln\left[\sinh(\alpha\sigma)\right]$ and $\ln\dot{\varepsilon}$

$M = \dfrac{Q}{1000Rn}$, $N = (\ln\dot{\varepsilon} - \ln A)/n$, and draw its scatter diagram and fit it as shown in Figure 4, and deduce $Q = 1\ 000Rn\times k_{均} = 254\ 242,25J/mol$.

$$\ln\left[\sinh(\alpha\sigma)\right] = M\times\frac{1000}{T} + N \tag{8}$$

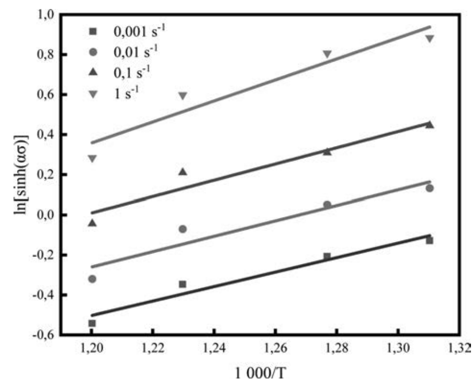

Figure 4 Relation curves of $\ln\left[\sinh(\alpha\sigma)\right]$ and $\dfrac{1000}{T}$

From the transformation of equation (3), equation (9) can be obtained by taking the logarithms of both sides of the equation to obtain equation (10), and then the scatter diagram is drawn and linear fitting is performed as shown in Figure 5, so that A = $5,765\times10^{14}$.

$$Z = \dot{\varepsilon}\exp\left[Q/(RT)\right] = A\left[\sinh(\alpha\sigma)\right]^n \tag{9}$$

$$\ln Z = n\ln\left[\sinh(\alpha\sigma)\right] + \ln A \tag{10}$$

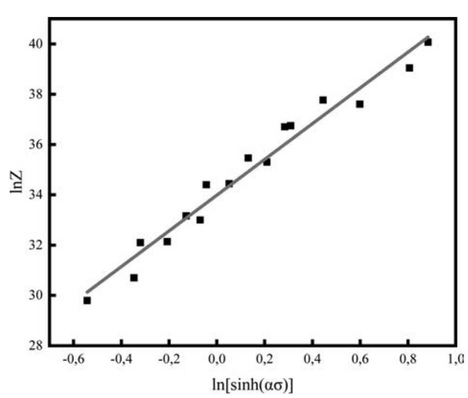

Figure 5 Relation curves of $\ln Z$ and $\ln\left[\sinh(\alpha\sigma)\right]$

So far, all the parameters of the full stress constitutive equation can be obtained. The peak stress equation of 7075 aluminum alloy at a deformation temperature of 490 °C to 560 °C and a strain rate of 0,001 s^{-1}~1 s^{-1} is shown in (11).

$$\dot{\varepsilon} = 5,765\times10^{14}\left[\sinh(0,021803\sigma)\right]^{7,292203}\exp\left(\frac{-254\,242,25}{RT}\right) \tag{11}$$

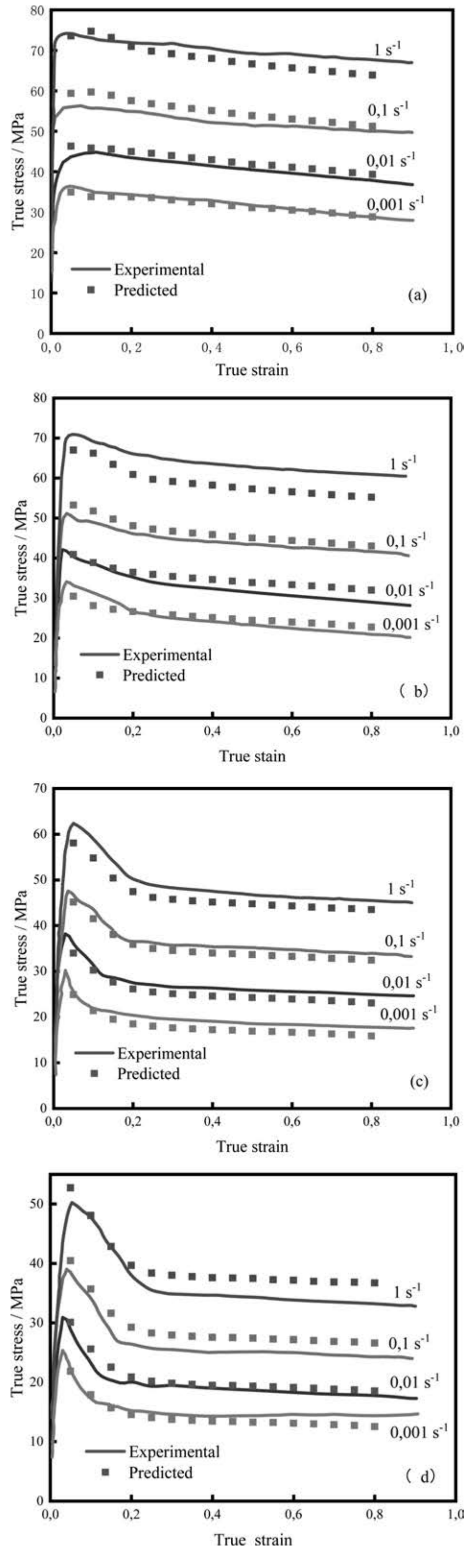

Figure 6 Comparison of experimental and predicted values of 7075 aluminum alloy at different temperatures: (a) T=490 °C; (b)T=520 °C; (c)T=540 °C; (d)T=560 °C

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 7075 aluminum alloy.

Putting the obtained parameters into equation (12) can obtain the flow stress at different temperatures. Figure 6 shows that the obtained constitutive equation has high accuracy.

$$\sigma = \frac{1}{\alpha}\ln\left\{\left(\frac{Z}{A}\right)^{\frac{1}{n}} + \left[\left(\frac{Z}{A}\right)^{\frac{2}{n}} + 1\right]^{\frac{1}{2}}\right\} \qquad (12)$$

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.

$$R = \frac{\sum_{i=1}^{n}(E_i - \bar{E})(P_i - \bar{P})}{\sqrt{\sum_{i=1}^{n}(E_i - \bar{E})^2 (P_i - \bar{P})}} \qquad (13)$$

$$\delta_{AARE} = \frac{1}{N}\sum_{i=1}^{N}\left|\frac{E_i - P_i}{E_i}\right| \times 100\,\% \qquad (14)$$

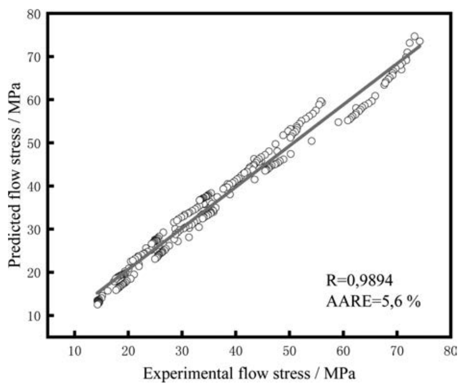

Figure 7 Correlation detection between predicted value and experimental value

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 7 shows good data correlation, with a correlation coefficient (R) value of 0,9894 and a value of 5,6 %.

CONCLUSION

7075 aluminum alloy is very sensitive to changes in temperature and strain rate. As the deformation temperature increases and the strain rate decreases, and the smaller the corresponding flow stress value. At the deformation temperature of 490 °C ~ 560 °C, The Arrhenius constitutive model was constructed within the strain rate range of 0,001 s^{-1}~1 s^{-1}. By comparing the calculated and experimental values, it was proved that the established constitutive model had high accuracy.

Acknowledgments

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