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HIGH TEMPERATURE CONSTITUTIVE MODEL OF 6005A ALUMINUM ALLOY

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Use Gleeble-3800 thermal simulation test machine to conduct thermal tensile test on 6005A aluminum alloy at 623~723 K and 0,01~1 s^{-1} strain rate. Using the obtained true stress-strain curve, the modified Zerilli-Armstrong (m-Z-A) model considering strain compensation was used to construct the constitutive model of the alloy. The results show that the correlation coefficient and average absolute error of the m-Z-A model are 0,97311 and 4,1779 %, respectively. The experimental data is in good agreement with the predicted curve obtained by calculating the model, which verifies the feasibility of the model.

Keywords: aluminum alloy 6005A, constitutive model, tensile test, flow stress, Zerilli-Armstrong (Z-A) model

INTRODUCTION

6005A aluminum alloy has good formability, corrosion resistance, weldability, strong fatigue strength and medium static strength, so it is widely used in panel components in the aerospace industry and railway applications [1,2]. In order to accurately design the thermal mechanical processing parameters directly related to the microstructure and mechanical properties of the final product, it is very important to comprehensively study the thermal deformation behavior of the alloy. Most reports published so far have focused on the influence of friction, stirring and welding parameters on the flow behavior of 6005A aluminum alloy at different temperatures [3]. However, the plastic tensile deformation behavior of 6005A aluminum alloy under heat is still poorly understood and far from being optimized.

At present, scholars from various countries have carried out a lot of research on the constitutive model of materials during thermal deformation. For example, Li et al. [4] established peak constitutive equation of 21-4N heat-resistant steel, Ji et al. [5] established peak constitutive equation of TA15 titanium alloy, Cai et al. [6] established constitutive equation of 33Cr23Ni8Mn3N heat-resistant steel.

In this paper, based on the high temperature tensile test, the modified Z-A model of 6005A aluminum alloy is established using stress and strain data. Finally verified its accuracy.

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EXPERIMENTAL MATERIALS AND PROCESSES

The experimental material in this study is 6005A aluminum alloy, and its composition is:0,0~0,9 % Si,0,4~0,6 % Mg,0,0~3,5 % Fe,0,0~0,1 % Cu, 0,0~0,1 % Mn, 0,0~0,1 % Cr, 0,0~0,1 % Ti,0,15 Al.

The experiment was carried out on the Gleeble-3800 thermal simulation test machine, and the deformation temperature was set to 623, 673 and 723 K. The strain rate is 0,01, 0,1, 1 s^{-1}, and the sample is heated to the deformation temperature at a rate of 10 K/s and kept for 2 minutes. Then perform isothermal stretching.

RESULTS AND DISCUSSION

Figure 1 shows the true stress-true strain curve of 6005A aluminum alloy. It can be seen from Figure 1: The flow stress of the alloy is greatly affected by the deformation temperature and strain rate. At the same strain rate, as the temperature increases, the true stress decreases significantly. At the same deformation temperature, as the deformation rate increases, the stress level increases.

Samantaray D et al. [7] proposed a modified Zerilli-Armstrong model based on the physical concept of the Zerilli-Armstrong model. This model is widely used in the study of the constitutive relationship of alloys with FCC lattice structure., Its expression is shown in equation (1):

$$\sigma=\left(C_1+C_2\varepsilon^n\right)exp[-\left(C_3+C_4\varepsilon\right)T^* + \left(C_5+C_6T^*\right)ln\dot{\varepsilon}^*] \quad (1)$$

In the equation: $T^* = T - T_r$, T_r is the reference temperature; $\dot{\varepsilon}^* = \dot{\varepsilon} / \dot{\varepsilon}_r$, $\dot{\varepsilon}$ is the experimental strain rate, $\dot{\varepsilon}_r$ is the reference strain rate; C_1, C_2, C_3, C_4, C_5, C_6, n is a material parameter, characterize the hardening rate of a material with strain.

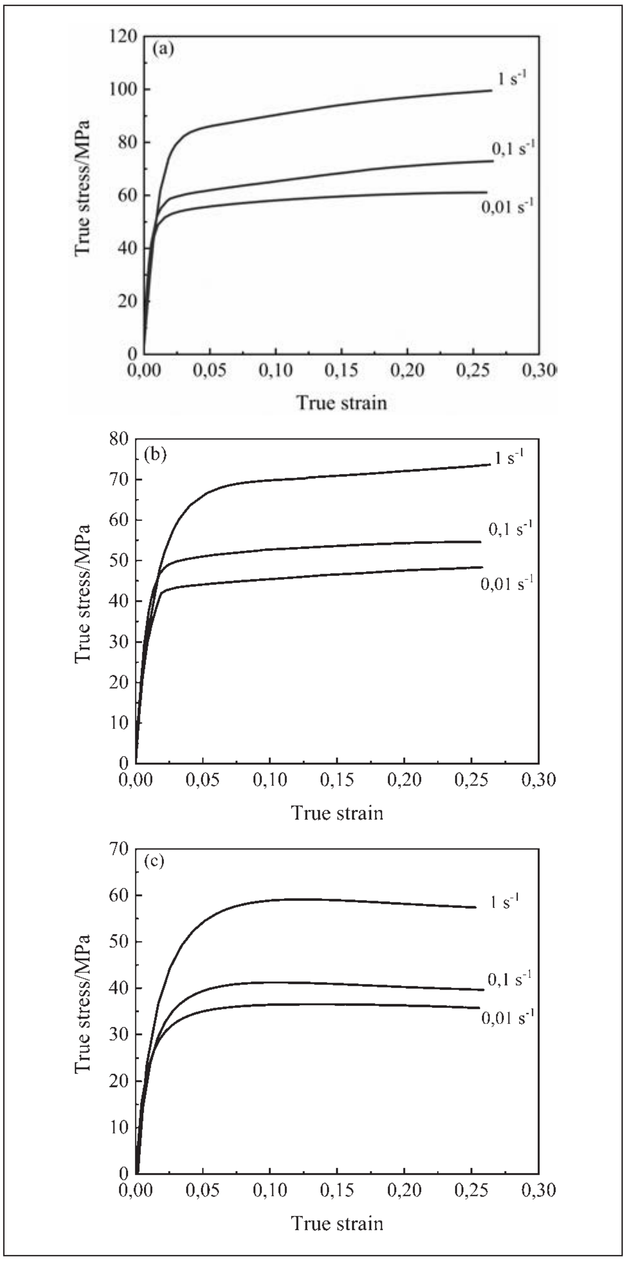

Figure 1 True stress-true strain curves at different temperatures: (a)623 K; (b)673 K; (c)723 K

Select the reference temperature as 623 K, the reference strain rate is 0,01 s^{-1}, under the reference temperature and reference strain rate, equation (1) can be rewritten as:

$$\sigma = \left(C_1+C_2\varepsilon^n\right)exp\left[-\left(C_3+C_4\varepsilon\right)T^*\right] \quad (2)$$

Taking the natural logarithm on both sides of the equal sign of equation (3), get:

$$ln\sigma = ln\left(C_1+C_2\varepsilon^n\right) - \left(C_3+C_4\varepsilon\right)T^* \quad (3)$$

Make $I = ln\left(C_1+C_2\varepsilon^n\right)$; $S_1 = -\left(C_3+C_4\varepsilon\right)$.Rewrite the formula equationas $I = ln\left(C_1+C_2\varepsilon^n\right)$:

$$ln\left(expI-C_1\right) = lnC_2+nln\varepsilon \quad (4)$$

At a reference strain rate of 0,01 s^{-1}, Take as 0,06, 0,08, 0,1, 0,12, 0,14, 0,16, 0,18, 0,2, 0,22, 0,24, 0,26, respectively, Make the relationship diagram under different temperature conditions, as shown in Figure 2, fit the points in the graph, to get the intercept and slope

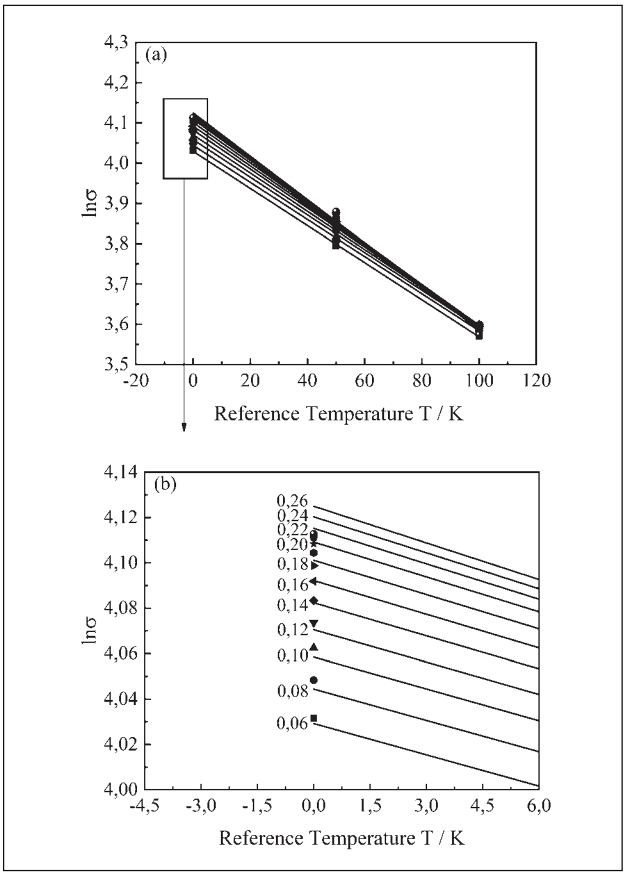

Figure 2 Relationship diagram: (a)fitting; (b) local amplification

values at different values of , It corresponds to I and S respectively.

Take the value of $R_{p0.2}$ corresponding to the 0,2 % residual strain in and as the value of C_1, which is C_1 = 49,86 MPa. According to the obtained I and S_1 values, make $ln(expI-C_1)$ and S_1-ε diagrams, as shown in Figure (3a) and Figure (3b), it can be found that there is a relatively good linear relationship between the two. Fit the points in the graph, according to the intercept and slope values obtained by fitting, according to the intercept and slope values obtained by fitting, C_2 = 22,32395 and n = 0,44413, C_3 = 0,00428 and C_4 = 0,00422.

Make $S_2 = C_5 + C_6T^*$, equation (1) can be written in the form of equation (5) under specified strain conditions, S_2 can be obtained by linear fitting of a polynomial of ln -$ln\dot{}$, the relationship diagram is shown in Figure (4a), C_5, C_6 can be obtained by calculating the linear relationship of S_2 - T*, as shown in Figure (4b). Find C_5 = 0,09266 and $C_6 = 7{,}82\times10^{-5}$.

$$ln\sigma = ln\left(C_1+C_2\varepsilon^n\right)-\left(C_3+C_4\varepsilon\right)T^*+S_2ln\dot{\varepsilon}^* \quad (5)$$

Through the above steps, the relevant material parameters of the Modified Zerilli-Armstrong (Z-A) model are shown in Table 1.

MODEL ACCURACY ANALYSIS

In order to verify the selected constitutive model's ability to predict flow stress of 6005A aluminum alloy, bring different temperature and strain values into the

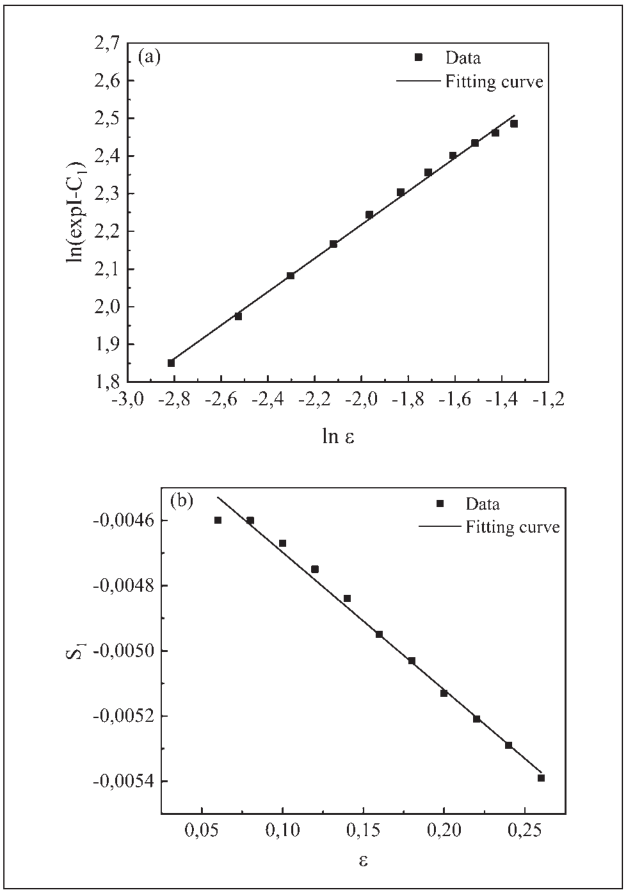

Figure 3 Fitting relationship between deformation parameters: (a) $ln\left(exp\text{I-C}_1\right) - ln\varepsilon$; (b) S_1-ε

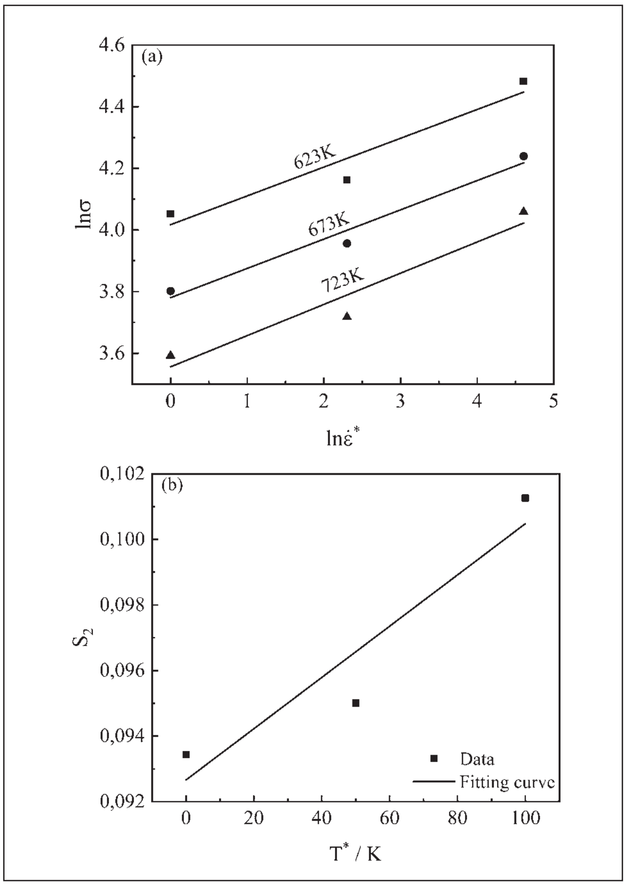

Figure 4 Fitting relationship between deformation parameters: (a) $ln\sigma - ln\dot{\varepsilon}^*$; (b) S_2-T*

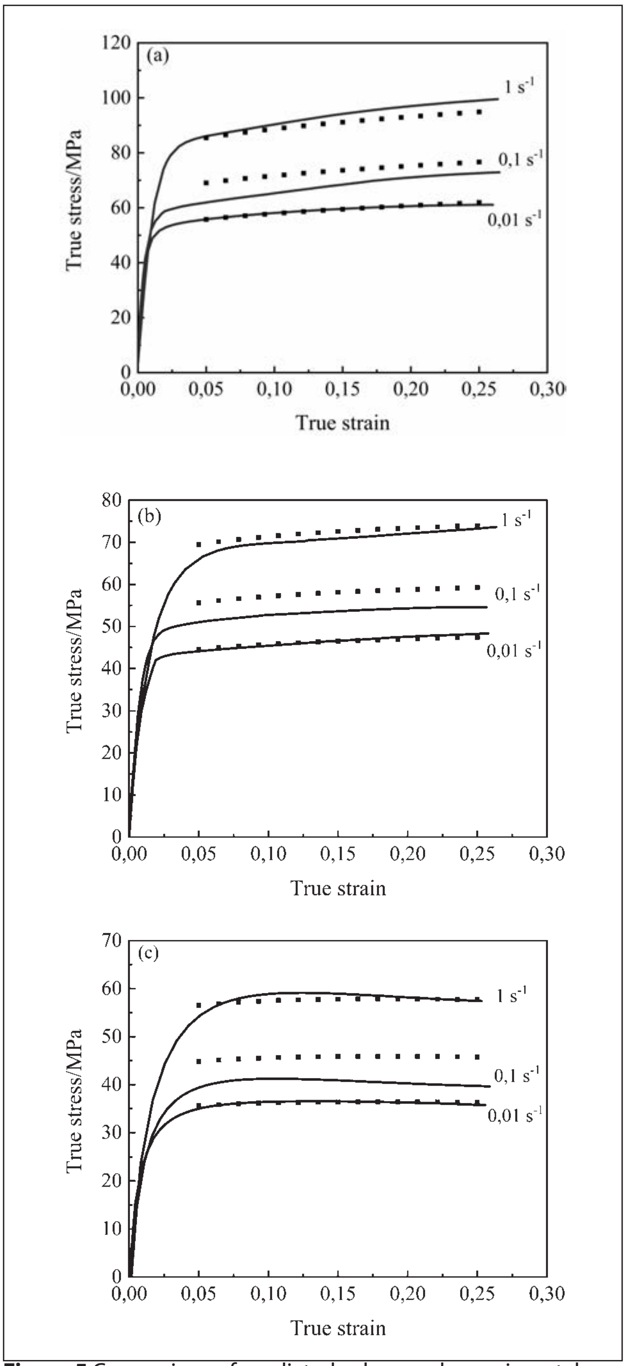

Figure 5 Comparison of predicted values and experimental values of different models: (a)623 K; (b)673 K; (c)723 K

Table 1 **Parameters for the modified Z-A model**

Constants	n	C_1	C_2
Value	0,44413	49,86	22,32395
Constants	C_3	C_4	C_5
Value	0,00428	0,00422	0,09266
Constants	C_6		
Value	$7{,}82\times10^{-5}$		

above constitutive model, and compare the experimental value of flow stress with the predicted value, as shown in Figure 5. It can be seen that when the deformation temperature is the same, the calculation results are more consistent with the test results in the uniform deformation stage and different strain rates. In summary, the constitutive model constructed in this paper has high accuracy

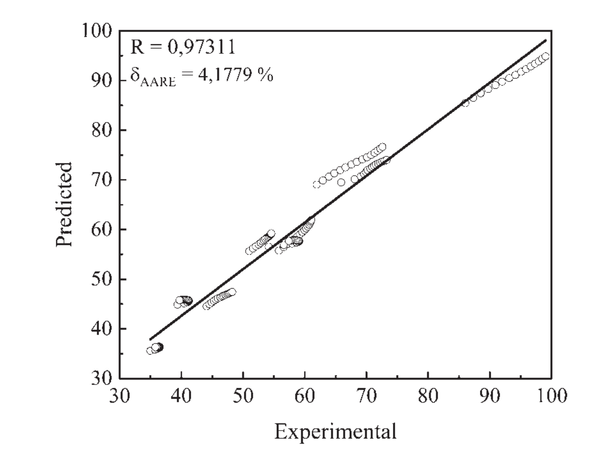

Figure 6 Correlation test between predicted value and experimental value

and can be used to predict the rheological behavior of 6005A aluminum alloy during warm forming.

In order to more accurately quantify and compare the prediction accuracy of the two constitutive equations established, it is necessary to perform statistical error analysis on the prediction data and experimental data, Introduce two statistical parameters, the correlation coefficient (R) and the average absolute error (δ_{AARE}), to further evaluate the predictive ability of the model, as can be seen from Figure 6. A good correlation (R = 0,97311) between the experimental and the predicted data is obtained, while the mean regular residual was found to be 4,1779 %.

$$R = \frac{\sum_{i=1}^{N}\left(E_i - \bar{E}\right)\left(P_i - \bar{P}\right)}{\sqrt{\sum_{i=1}^{N}\left(E_i - \bar{E}\right)^2 \times \left(P_i - \bar{P}\right)^2}} \quad (7)$$

$$\delta_{AARE} = \frac{1}{N}\sum_{i=1}^{N}\left|\frac{E_i - P_i}{E_i}\right| \times 100\ \% \quad (8)$$

In the equation, E is the experimental stress, P is the predicted stress, $\bar{E}$, $\bar{P}$ is the average of the experimental and predicted values, and N is the total number of experimental data.

CONCLUSION

The flow stress of 6005A aluminum alloy during hot deformation is more sensitive to deformation temperature and strain rate, and increases with the decrease of deformation temperature and the increase of strain rate.

The established constitutive model of 6005A aluminum alloy has high accuracy. The modified (Z-A) model can be used to predict the rheological behavior of 6005A aluminum alloy during warm forming.

Acknowledgments

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