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CONSTITUTIVE RELATIONSHIP OF 7075 ALUMINUM ALLOY BASED ON MODIFIED ZERILLI-ARMSTRONG (M - ZA) MODEL

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The Gleeble – 3500 thermal simulation testing machine was used to perform isothermal tensile test on 7075 aluminum alloy at a deformation temperature of 300 – 450 °C and a strain rate of 0,01 – 1 s^{-1}, and the true stress-strain curve of the alloy was obtained. Based on the true stress-strain data, the modified Zerilli-Armstrong (M-ZA) model was used to construct the constitutive model of the alloy, and the fitting accuracy of the model was analyzed.

Keyword: 7075 aluminum alloy, isothermal tensile, flow stress, temperature, modified Zerilli-Armstrong model

INTRODUCTION

7075 aluminum alloy has the characteristics of low density, high strength and hardness and good processing performance. It is an important lightweight and high-strength structural material. 7075 aluminum alloy is an Al-Zn-Mg-Cu series heat-treatable high-strength deformed aluminum alloy. In practical engineering applications, the Finite element method (FEM) is a powerful tool to simulate the thermoplastic forming process of materials and determine the optimal forming process conditions for metals and the accuracy of the finite element simulation results is closely related to the accuracy of the constitutive model [1, 2]. Therefore, in order to obtain high-quality 7075 aluminum alloy components during the thermoplastic forming process, it is necessary to construct a more accurate constitutive model based on the thermal deformation behavior of 7075 aluminum alloy.

Currently, researchers have conducted many studies on high-temperature intrinsic constitutive models of alloys. He [3] used the modified Zerilli-Armstrong model to predict the high temperature deformation behavior of 20CrMo alloy steel. Cai [4] used the strain-compensated Arrhenius constitutive equation to predict the high temperature deformation behavior of 3Cr23Ni8Mn3N alloy steel. Ji[5] used the modified Johnson – Cook constitutive equation to predict the high temperature deformation behavior of TA15 alloy.

In this study, The Gleeble – 3500 thermal simulation testing machine was used to perform isothermal tensile test on 7075 aluminum alloy at a deformation temperature of 300 – 450 °C and a strain rate of 0,01 – 1 s^{-1}, and the true stress-strain curve of the alloy was obtained. Based on the true stress-strain data, the modified Zerilli-Armstrong (M-ZA) model [6] is used to construct the constitutive model of the alloy and analyze the fitting accuracy of the model.

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EXPERIMENTAL MATERIALS AND PROCESSES

The material used in the test is a rolled 2 mm thick 7075 aluminum alloy sheet, and its chemical composition is shown in Table 1.

Table 1 **Chemical composition of 7075 aluminum alloy sheet/wt.%**

Si	Fe	Cu	Mn	Mg
0,07	0,22	1,4	0,04	2,2
Cr	Zn	Ti	Al	
0,19	5,4	0,02	Bal,	

In order to study the thermal deformation behavior of 7075 aluminum alloy, a Gleeble – 3500 thermal simulation testing machine was used to perform uniaxial hot tensile test on 7075 aluminum alloy. The geometry and dimensions of the uniaxial hot tensile specimen are shown in Figure 1 (unit: mm). First, the specimen was heated to 450 °C at a rate of 20 °C/s, and then heated to a solid solution temperature of 480 °C at a rate of 5 °C/s, and kept for 10 minutes. The specimen is lowered to the deformation temperature at a rate of 50 °C/s, and the temperature of the specimen is kept uniform for 10 seconds. Stretching is carried out at a constant temperature and strain rate, and the specimen is rapidly cooled after being stretched to preserve its microstructure at high temperature. The deformation temperature is 300 °C, 350 °C, 400 °C, and 450 °C, and the strain rate is 0,01 s^{-1},0,1 s^{-1},1 s^{-1}. The stress-strain curve of 7075 aluminum alloy is shown in Figure 2.

MODIFIED ZERILLI-ARMSTRONG MODEL

The modified ZA model (M-ZA) is expressed as follows:

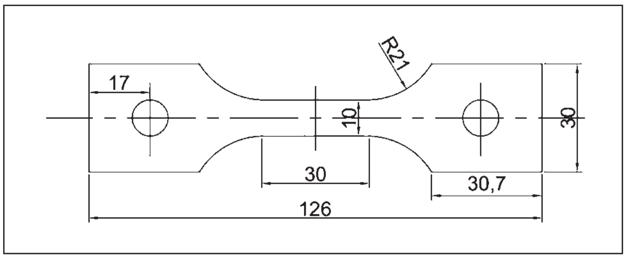

Figure 1 Shape and size of high temperature tensile specimen

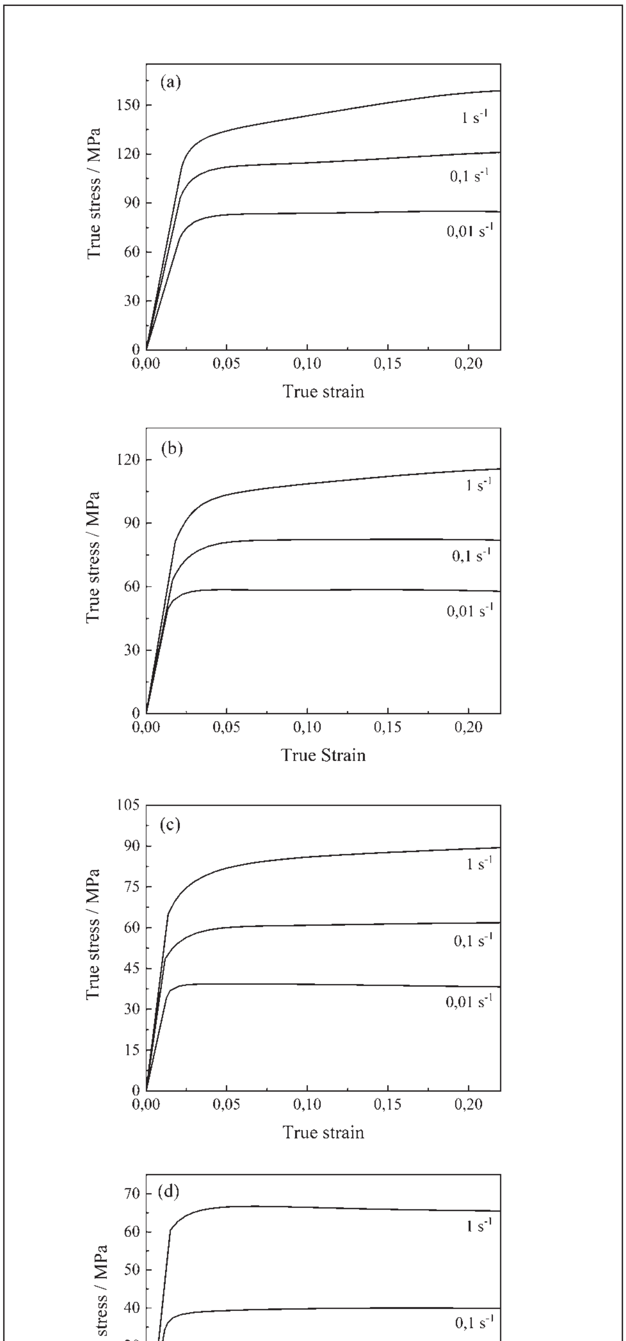

Figure 2 Stress-strain curve of 707 5 aluminum alloy. (a) T = 300 °C; (b) T = 350 °C; (c) T = 400 °C; (d) T = 450 °C

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

Where: C_1, C_2, C_3, C_4, C_5, C_6 and m are the material constants; $\dot{\varepsilon}$ is the strain rate (s^{-1}); $\dot{\varepsilon}^* = \dot{\varepsilon}/\dot{\varepsilon}_{ref}$, $T^* = T - T_{ref}$, $\dot{\varepsilon}_{ref}$ and T_{ref} are the reference strain rate and reference temperature, respectively.

Choose temperature 350 °C and strain rate 0,01 s^{-1} as reference values to calculate the material constants in the model. When the reference strain rate is 0,01 s^{-1}, Equation (1) can be transformed into Equation (2):

$$\ln\sigma = \ln\left(C_1 + C_2\varepsilon^m\right) - \left(C_3 + C_4\varepsilon\right)T^* \quad (2)$$

At a reference strain rate of 0,01 s^{-1} and 4 deformation temperatures, 7 groups of stress and strain data points with strains ranging from 0,05 to 0,2 with an interval of 0,025 are substituted into Equation (2). The values of $I_1 = \ln(C_1+C_2\varepsilon^m)$ and $S_1 = -(C_3+C_4\varepsilon)$ can be obtained by linear fitting of the relationship of (as shown in Figure3). I_1 is the intercept of the fitted straight line, and S_1 is the slope of the fitted straight line.

After reconverting I_1, find the logarithm of both sides of the equation:

$$\ln\left(\exp I_1 - C_1\right) = \ln C_2 + m\ln\varepsilon \quad (3)$$

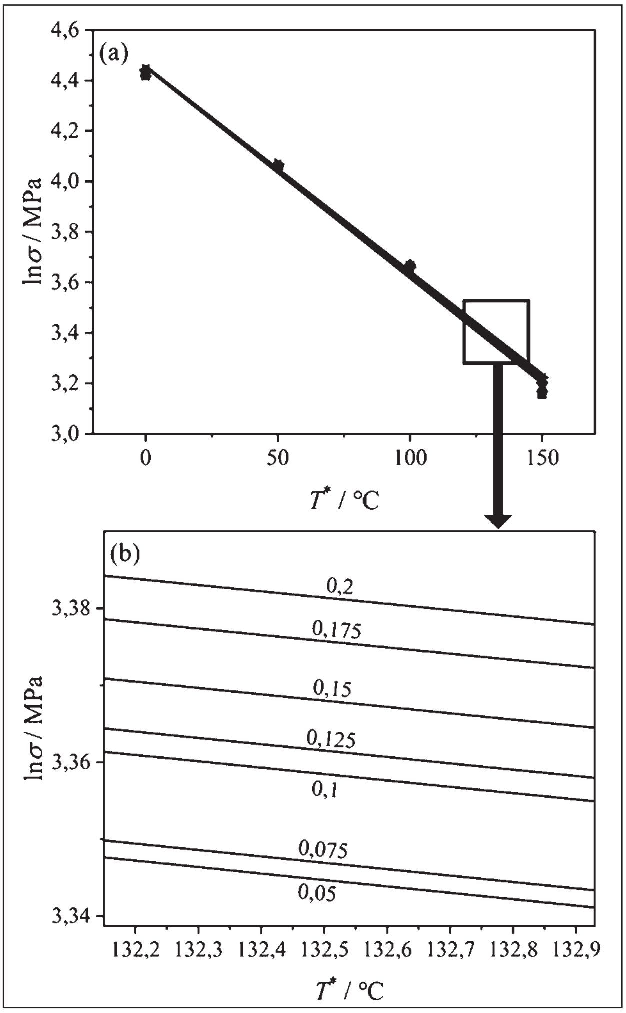

Figure 3 Fitting relationship between T* and lnσ. (a) fitting; (b) local amplification

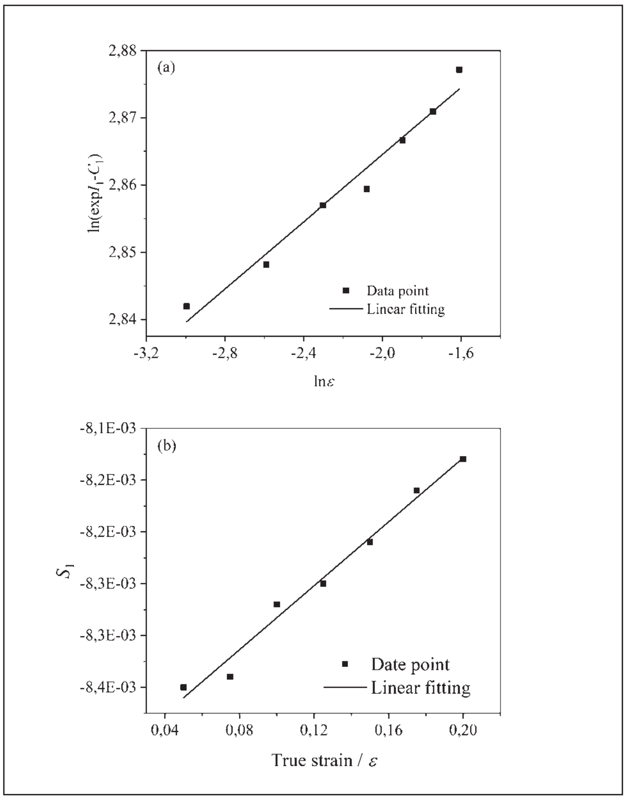

Figure 4 Fitting relationship between deformation parameters. (a) lnε and ln(expI_1-C_1); (b) true strain and S_1

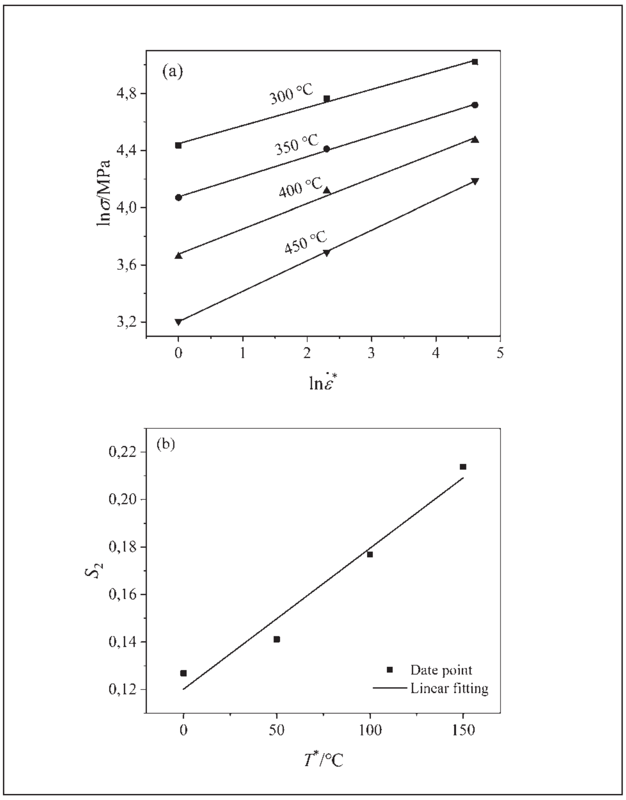

Figure 5 Fitting relationship between deformation parameters. (a) $\ln\dot{\varepsilon}^*$ and lnσ; (b) $T^*$and S_2

In the above equation, C_1 is the yield stress value under reference conditions (C_1 = 68,55). Substituting C_1 into Equation (3), the value of C_2 and *m* can be obtained by linear fitting of the relationship of (Figure 4(a)). Similarly, C_3 and C_4 can be obtained by linear fitting of the relationship between S_1-ε (Figure 4(b)).

Obtain C_2 = 18,36, m = 0,025, C_3 = 0,008, C_4 = -1,54×10^{-3}.

Let $S_2 = C_5+C_6T^*$, Equation (1) can be written as Equation (4). Under the specified strain conditions, S_2 can be obtained by linear fitting of relationship (Figure 5(a)), and C_5 and C_6 can be obtained by calculating the linear relationship between S_2 (as shown in Figure 5(b)).

$$\ln\sigma = \ln\left(C_1 + C_2\varepsilon^m\right) - \left(C_3 + C_4\varepsilon\right)T^* + S_2\ln\dot{\varepsilon}^* \quad (4)$$

Obtain C_5 = 0,12, C_6 = 5,93×10^{-4}.

The relevant material parameters obtained according to the above steps are summarized in Table 2, and the modified ZA model is as follows

$$\sigma = \left(68,55 + 18.36\varepsilon^{0,025}\right)\exp[-(0,008 - 1,54\times10^{-3}\varepsilon) + (0,12 + 5,93\times10^{-4}T^*)\ \ln\dot{\varepsilon}^*] \quad (5)$$

Table 2 **Material parameter table of Modified ZA model**

Constants	C_1	C_2	C_3	C_4
Value	68,55	18,36	0,008	-6,32×10^{-4}
Constants	C_5	C_6	m	
Value	0,12	5,93×10^{-4}	0,025	

SIMULATION PREDICTION AND VERIFICATION OF CONSTITUTIVE MODEL

According to the M-ZA model, the predicted value of flow stress can be obtained. The comparison result of the predicted value based on the M-ZA model and the experimental value is shown in Figure 6.

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: correlation coefficient (R) and average absolute error (δ_{AARE}) to further evaluate the predictive ability of the model:

$$R = \frac{\sum_{i=1}^{N}\left(E_i - \overline{E}\right)\left(P_i - \overline{P}\right)}{\sqrt{\sum_{i=1}^{N}\left(E_i - \overline{E}\right)^2 \times \left(P_i - \overline{P}\right)^2}} \quad (6)$$

$$\delta_{\mathrm{AARE}} = \frac{1}{N}\sum_{i=1}^{N}\left|\frac{E_i - P_i}{E_i}\right| \times 100\% \quad (7)$$

Where: E_i is the experimental value; P_i is the predicted value; $\overline{E}$ and $\overline{P}$ are the average of the experimental value and the predicted value; N is the number of samples.

Figure 7 shows the correlation between the predicted value of flow stress of the M-ZA model and the experimental value. The 45° straight line represents the best regression line between the predicted value and the experimental value. Most of the data points of the M-ZA model are distributed on a straight line. The model's R

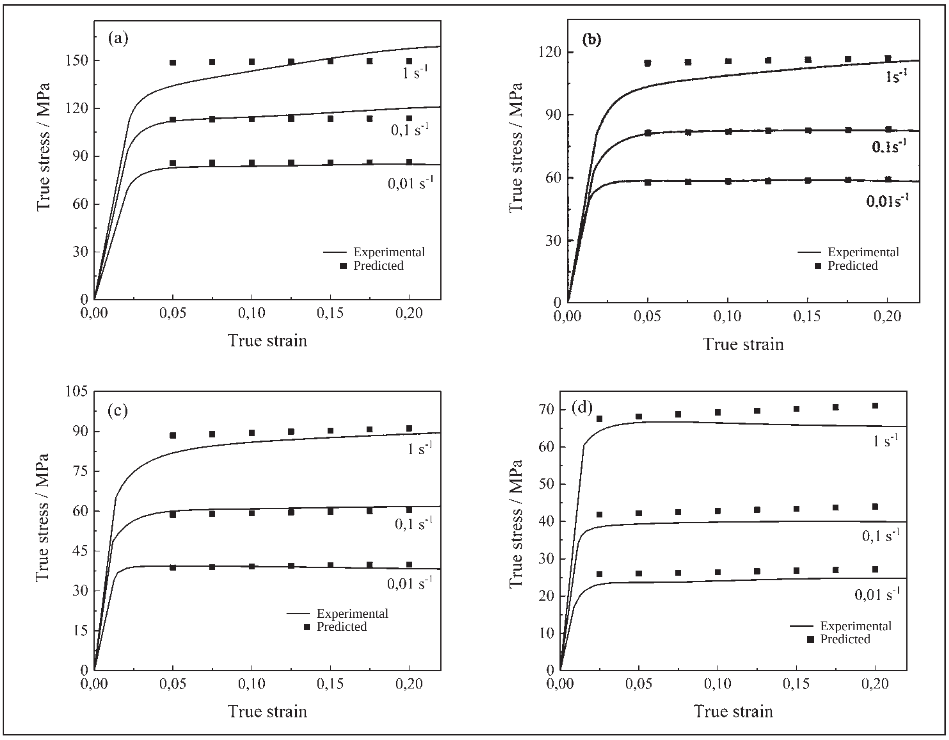

Figure 6 Comparison of predicted value and experimental value. (a) T = 300 °C; (b) T = 350 °C; (c) T = 400 °C; (d) T = 450 °C

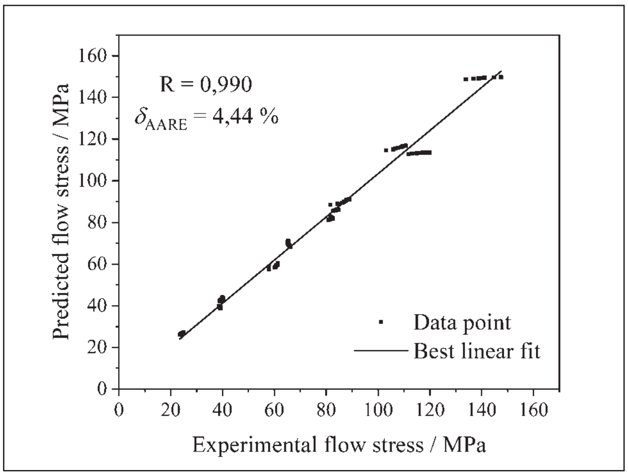

Figure 7 Correlation test between predicted value and experimental value

= 0,990 and δ_{AARE} = 4,44 %. It shows that the predicted value of the model has a very close relationship with the experimental value. The M-ZA model can accurately reflect the high temperature plastic flow behavior of 7075 aluminum alloy.

CONCLUSION

Deformation temperature and strain rate have a significant effect on the flow stress and strain curve of 7075 aluminum alloy. The value of flow stress increases with the increase of strain rate and decreases with the increase of deformation temperature.

The constructed M-ZA constitutive model of 7075 aluminum alloy can highly predict its flow stress. R = 0,990, δ_{AARE} = 4,44 %.

Acknowledgments

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