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RESEARCH ON MODEL OF 6005A ALUMINUM ALLOY

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The deformation behavior of 6005A aluminum alloy at a strain rate of 0,01-10s^{-1}, a deformation temperature of 673-773K and a total strain of 0,8 was studied. Using the stress-strain data of 6005A aluminum alloy with a strain of 0,05-0,8, an Arrhenius-type constitutive model was established. And verified the accuracy of the model. The results show that: the flow stress of 6005A aluminum alloy increases with the increase of strain rate, and decreases with the increase of deformation temperature; Under different strains, the correlation coefficient (*R*) between the experimental value and the predicted value is as high as 98 %, and the average relative error (*AARE*) is less than 10 %, indicating that the established model has high predictability.

Keywords: 6005A aluminum alloy, extrusion, temperature, true stress-true strain curves, Arrhenius constitutive model

INTRODUCTION

6005A aluminum alloy is a medium-strength, low-density alloy. It is one of the most widely used alloys in the aviation and railway industries [1,2]. For the machining parameters related to the microstructure and mechanical properties of the product, it is very important to comprehensively study the hot deformation behavior of the alloy.

In recent years, many scholars have used various constitutive models to predict the constitutive behavior of different metals [3-4]. Among them, the Arrhenius constitutive model proposed by Sellers and Tegart [5] is suitable for different temperature ranges and is one of the widely used constitutive models under thermal working conditions. Cai et al. [6] established the Arrhenius constitutive equation of 3Cr23Ni8Mn3N strain compensation, and verified the accuracy of the constitutive model by calculating the correlation coefficient and relative error. Samantaray et al. [7] established the Arrhenius constitutive model of 9Cr-1Mo steel and used it to predict high temperature flow stress, and finally obtained good prediction results. However, the plastic compression deformation behavior of 6005A aluminum alloy under heat is still poorly understood and far from optimized.

In this paper, the effects of deformation temperature, strain rate and strain on the flow stress of 6005A aluminum alloy extrusions under isothermal compression are studied. The parameters of the 6005A aluminum alloy Arrhenius constitutive model were calculated with a strain of 0,05 – 0,8, and the Arrhenius constitutive model under different strain conditions was established to simulate the plastic flow behavior of 6005A aluminum alloy in a specific temperature range and strain rate. And verify its accuracy.

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EXPERIMENTAL MATERIALS AND PROCESSES

The experimental material is 6005A aluminum alloy, and its chemical composition (in wt.%) is 0,8 Si; 0,35 Fe; 0,1 Cu; 0,1 Mn; 0,6 Mg; 0,1 Cr; 0,1 Zn; 0,1 Ti; 97,75 Al; (bal.) Fe. The experiment was carried out on the Gleeble-1500D thermal simulation test machine, and the deformation temperature was set to 673, 723, 773 K respectively. The strain rate is 0,01, 0,1, 1, 10 s^{-1}. The total strain is set to 0,8. Before isothermal compression, the sample is preheated and kept at the deformation temperature for 5,0 min to achieve temperature equilibrium. According to the experimental results, the stress-strain curve of 6005 aluminum alloy is established, as shown in Figure 1.

ESTABLISHMENT OF ARRHENIUS MODLE

There are three expressions commonly used in the Arrhenius constitutive model, as follows:

$$\dot{\varepsilon} = A\sigma^{m} \exp\left(-Q/RT\right) \ (\alpha\sigma<0{,}8) \quad (1)$$

$$\dot{\varepsilon} = B\exp\left(\beta\sigma\right)\exp\left(-Q/RT\right) \ (\alpha\sigma>1{,}2) \quad (2)$$

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

Where α, β and m satisfy:

$$\alpha = \beta/m \quad (4)$$

In the equation, $\dot{\varepsilon}$ is the strain rate (s^{-1}); *A*, *B*, *C* represent material constant;σ is the true stress(MPa); *R* is the gas friction constant 8,3145 mol^{-1}·K^{-1}; *Q* is deformation activation energy (J. mol^{-1}); *T* is absolute temperature (K); *m*, *n* is the stress index; α, β are stress level parameters independent of temperature .

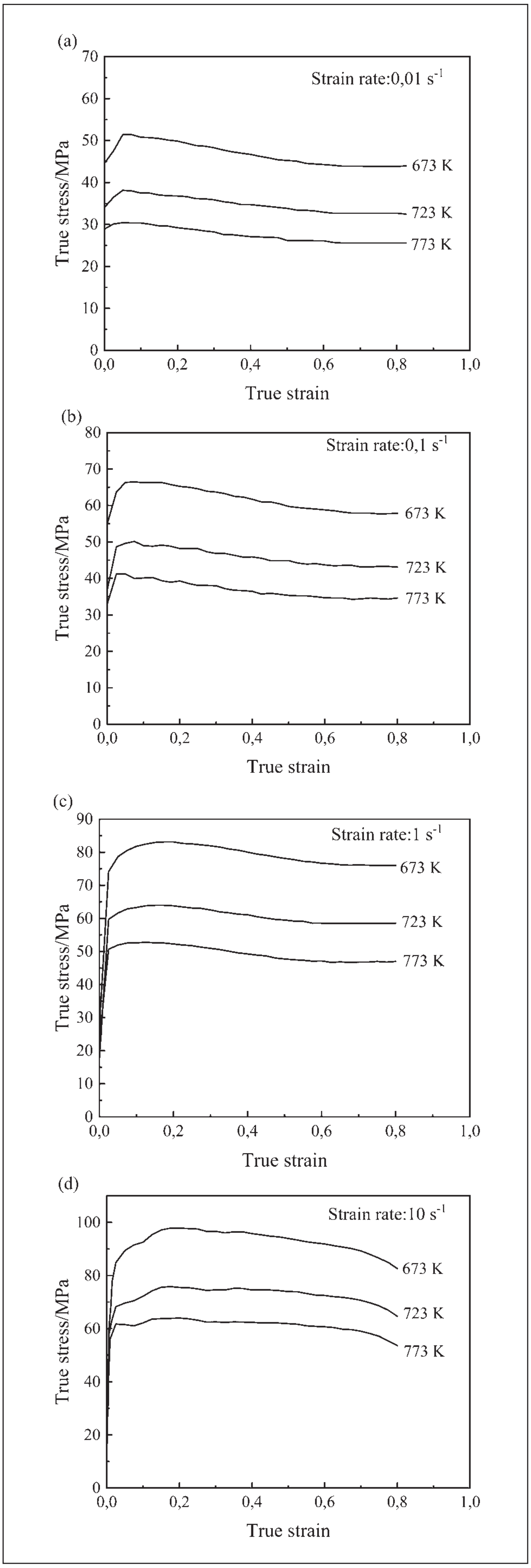

Figure 1 True stress – strain curves of 6005A aluminum alloy.

The parameter Z can be introduced, which indicates the relationship between deformation activation energy (Q), strain rate and deformation temperature during metal deformation.

$$Z = \dot{\varepsilon} \exp\left(Q/RT\right) \tag{5}$$

Combining equation (5):

$$\sigma = \frac{1}{\alpha} \ln \left\{ \left(\frac{Z}{C}\right)^{1/n} + \left[\left(\frac{Z}{C}\right)^{2/n} + 1 \right]^{1/2} \right\} \tag{6}$$

Take the stress under different deformation conditions when the strain is 0,4 as an example to calculate the material constant, Take the logarithm of equation (1) and equation (2):

$$\ln \dot{\varepsilon} = m \ln \sigma + \ln A - \frac{Q}{RT} \tag{7}$$

$$\ln \dot{\varepsilon} = \beta \ln \sigma + \ln B - \frac{Q}{RT} \tag{8}$$

Substitute the stress values of different strain rates (0,01, 0,1, 1, 10 s^{-1}) and different deformation temperatures (773 K, 723 K, 673 K) into equation (7) and equation (8). And equation (7) and equation (8) are fitted and calculated to obtain m = 8,826, β = 0,167.therefore, the value of α can be obtained by equation (4), that is, α = 0,0189.

Take the logarithm of equation (3):

$$\ln \dot{\varepsilon} = \ln C + n \ln\left[\sinh\left(\alpha\sigma\right)\right] - \frac{Q}{RT} \tag{9}$$

As shown in equation (9). When the deformation temperature and strain rate are determined, the following results can be obtained:

$$n = \frac{\partial \ln \dot{\varepsilon}}{\partial \ln\left[\sinh(\alpha\sigma)\right]} \tag{10}$$

$$\frac{Q}{Rn} = \frac{\partial \ln\left[\sinh\left(\alpha\sigma\right)\right]}{\partial(1/T)} \tag{11}$$

Substitute the above value α into equation (10) and equation (11), and fit equations (10) and (11) under different deformation conditions. The method of linear fitting calculation can get n = 6,590 and Q / (Rn) = 3521,437. Usually the R value is 8,3145 $mol^{-1} \cdot K^{-1}$. By calculation, when the strain is 0,4 and Q = 243,4401kJ/mol.

The deformation activation energy of 6005A aluminum alloy can be obtained. Substitute Q into equation (5), and when the strain is 0,4, the parameters Z of different strain rates and deformation temperatures can be obtained. Convert equation (3) to equation (5), and take the logarithm of both sides of the equation:

$$\ln \dot{\varepsilon} = \ln C + n \ln\left[\sinh\left(\alpha\sigma\right)\right] - \frac{Q}{RT} \tag{12}$$

Due to ln$Z$ and ln[sinh($\alpha\sigma$)] are linear relationships, ln$C$ is the intersection of the curve. ln$Z$ and ln[sinh($\alpha\sigma$)] linear fitting calculations in different deformation conditions can be obtained by ln$C$ = 38,014, $C = 3{,}232\times10^{16}$.

Substituting A, C, n, and Q into equation (6), the Arrhenius constitutive model of 6005A aluminum alloy at 0,4 strain can be obtained.

Table 1 **Values of *m*, *β*, *α*, *n*, *Q* and ln*C***

p	Strain		
	0,05	0,1	0,2
m	10,925	10,353	9,375
β	0,2042	0,1917	0,1714
α	0,01869	0,01852	0,01828
n	8,184	7,752	7,004
Q	219972,13	229013,74	238334,51
ln*C*	33,6897	35,2725	37,0204
p	0,3	0,4	0,5
m	9,135	8,826	8,647
β	0,1707	0,1670	0,1668
α	0,01869	0,01892	0,01929
n	6,821	6.590	6,459
Q	242560,79	243440,15	242334,22
ln*C*	37,7512	38,0144	37,9198
p	0,6	0,7	0,8
m	8,677	8,758	9,426
β	0,1705	0,1764	0,2010
α	0,01965	0,02014	0,02132
n	6,487	6,543	7,079
Q	240114,36	240174,26	244736,79
ln*C*	37,5353	37,4450	37,8006

$$\sigma = \frac{1}{0,01892}\ln\left\{\begin{array}{c}\left(\dfrac{Z}{3,23\times10^{16}}\right)^{\frac{1}{6,59004}}+\\ \left[\left(\dfrac{Z}{3,23\times10^{16}}\right)^{\frac{2}{6,59004}}+1\right]^{\frac{1}{2}}\end{array}\right\} \tag{13}$$

Similarly, the values of *m*, *β*, *α*, *n*, *Q* and strain 0,05-0,8 can be calculated by the same method, as shown in Table 1.

VERIFY THE ACCURACY OF THE MODEL

The Arrhenius constitutive model is used to predict the flow stress of 6005A aluminum alloy, and the predicted results are compared with experimental data. The result obtained is shown in Figure 5 In order to more accurately illustrate the accuracy of the equation prediction, according to equation (14) and equation (15), the standard statistical parameter (*R*) and the average absolute relative error *AARE* (%) are used.

$$R = \frac{\sum_{i=1}^{n}(E_i-\overline{E})(P_i-\overline{P})}{\sqrt{\sum_{i=1}^{n}(E_i-\overline{E})^2(P_i-\overline{P})^2}} \tag{14}$$

$$AARE(\%) = \frac{1}{N}\sum_{i=1}^{N}\left|\frac{E_i-P_i}{E_i}\right|\times 100\ \% \tag{15}$$

In the equation, *E* is the experimental stress, *P* is the predicted stress, $\overline{E}$, $\overline{P}$ is the average of the experimental and predicted values, and *N* is the total number of experimental data. Figure 2 shows the comparison between experimental and predicted values under the Ar-

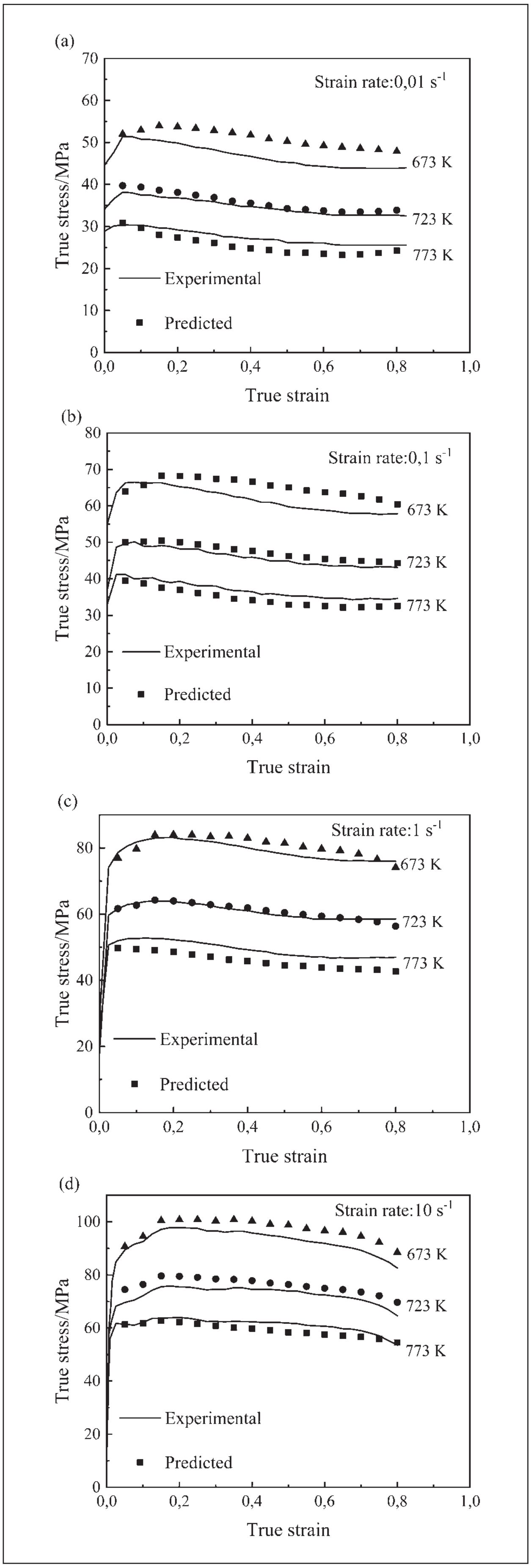

Figure 2 Comparison of predicted and experimental values of flow stress

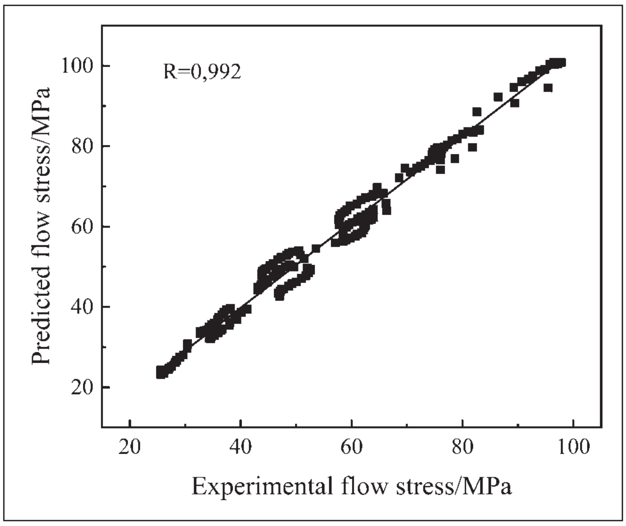

Figure 3 Correlation between experimental flow stress and predicted flow stress of 6005A aluminum alloy

rhenius constitutive model. As can be seen from the figure, the predicted values of each point are almost consistent with the experimental values. This shows that the Arrhenius constitutive model has a higher prediction accuracy for the prediction of the flow stress of 6005A aluminum alloy.

Figure 3 shows the correlation between experimental values and predicted data. As can be seen from the figure, the prediction results are usually highly correlated. The correlation coefficient is R = 0,992, *AARE* (%) = 4,828 % and less than 10 %.

CONCLUSION

The true stress-true strain curve under the same conditions is consistent. It increases suddenly, then slowly decreases after reaching a peak, and finally becomes stable. Deformation temperature and strain rate have a significant effect on the stress and strain curve of 6005A aluminum alloy. The value of flow stress increases with the increase of strain rate, and decreases with the increase of deformation temperature.

The Arrhenius constitutive model of 6005A aluminum alloy was obtained at a strain of 0,05 to 0,8. After calculation, the correlation coefficient is R = 0,992, *AARE* (%) = 4,828 % is less than 10 %. The forecast meets the expected accuracy.

Acknowledgments

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