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Hot deformation behavior and Zener-Hollomon parameter constitutive model of Ti-22Al-26Nb-2Ta-0.5Y alloy

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Abstract. The thermal compression test of Ti-22Al-26Nb-2Ta-0.5Y alloy was performed using a Gleeble-3500 thermal simulator at deformation temperatures ranging from 900°C to 1150°C and strain rates ranging from $0.001s^{-1}$ to $10s^{-1}$. The results show that the flow stress of Ti-22Al-26Nb-2Ta-0.5Y alloy increases with the increase of deformation rate and decreases with the increase of deformation temperature. Based on the peak stress, the Arrhenius type constitutive model of Ti-22Al-26Nb-2Ta-0.5Y alloy was constructed using Zener-Hollomon parameters. The results show that this constitutive model has good prediction accuracy for peak stress. The correlation coefficient between the predicted value and the experimental value is R=0.9922, the average relative error E is 8.36%, and the deviation within 15% accounted for about 96.67% of the total validation data points. This study provided a reference for the formulation of the hot working processing scheme for Ti-22Al-26Nb-2Ta-0.5Y alloy and the application of the Z-parameter constitutive model.

1. Introduction

As a lightweight, high-temperature, high-strength structural material, Ti_2AlNb-based alloy has excellent mechanical properties and is a potential hot material[1-3] that can be used in aerospace engines. Many scholars at home and abroad have studied the prediction accuracy of various constitutive models, the Arrhenius type constitutive model is one of them which can accurately describe the hot deformation behavior of metallic materials[4-8] .

In this study, Arrhenius type constitutive model is used to describe the hot deformation behavior of Ti-22Al-26Nb-2Ta-0.5Y alloy. The thermal compression test of Ti-22Al-26Nb-2Ta-0.5Y alloy was performed using a Gleeble-3500 thermal simulator at deformation temperatures ranging from 900°C to 1150°C and strain rates ranging from $0.001s^{-1}$ to $10s^{-1}$ to study its hot deformation behavior. Based on the peak stress, the Arrhenius-type constitutive model of Ti-22Al-26Nb-2Ta-0.5Y alloy was constructed using Zener-Hollomon parameters[9] , and the prediction accuracy of the constitutive model was analyzed. This study provided a reference for the formulation of the hot working processing scheme for Ti-22Al-26Nb-2Ta-0.5Y alloy and the application of the Z-parameter constitutive model.

2. Experimental Scheme

The isothermal compression test scheme is: using a Gleeble-3500 thermal simulator with deformation temperatures of 900°C, 950°C, 1000°C, 1050°C, 1100°C and 1150°C, strain rates of $0.001s^{-1}$, $0.01s^{-1}$, $0.1s^{-1}$, $1s^{-1}$ and $10s^{-1}$. The test piece size is Φ8mm × 12mm . The sample was heated from room temperature to a deformation temperature at a heating rate of 5°C/s, and then retained for 300s to eliminate the temperature gradient. The compression amount was 70% and the compressed sample is water cooled. During the deformation process, the temperature and strain rate are kept constant by computer control, then the stress-strain data is directly output.

Based on the experimental data, the true stress-strain curve of the Ti-22Al-26Nb-2Ta-0.5Y alloy is plotted, as shown in Fig. 1. It can be seen from the figure that the hot deformation behavior of Ti-22Al-26Nb-2Ta-0.5Y alloy follows the deformation behavior of a typical rheological curve, and the flow stress increases with the increase of the deformation rate and decreases with the increase of the deformation temperature. It can be seen from the figure that when the strain reaches 0.1, the stress tends to peak stress.When the strain is 0.1 and the strain rates are $0.001s^{-1}$, $0.01s^{-1}$, $0.1s^{-1}$, $1s^{-1}$, and $10s^{-1}$, the stress at 950°C is 187.75 MPa, 429.33 MPa, 694.42 MPa, 797.53 MPa and 1082.95 MPa respectively. When the strain is 0.1 and the strain rates are $0.001s^{-1}$, $0.01s^{-1}$, $0.1s^{-1}$, $1s^{-1}$ and $10s^{-1}$, the stress at 1050°C is 77.05 MPa, 157.38 MPa, 280.67 MPa, 395.16 MPa and 610.93 MPa respectively.

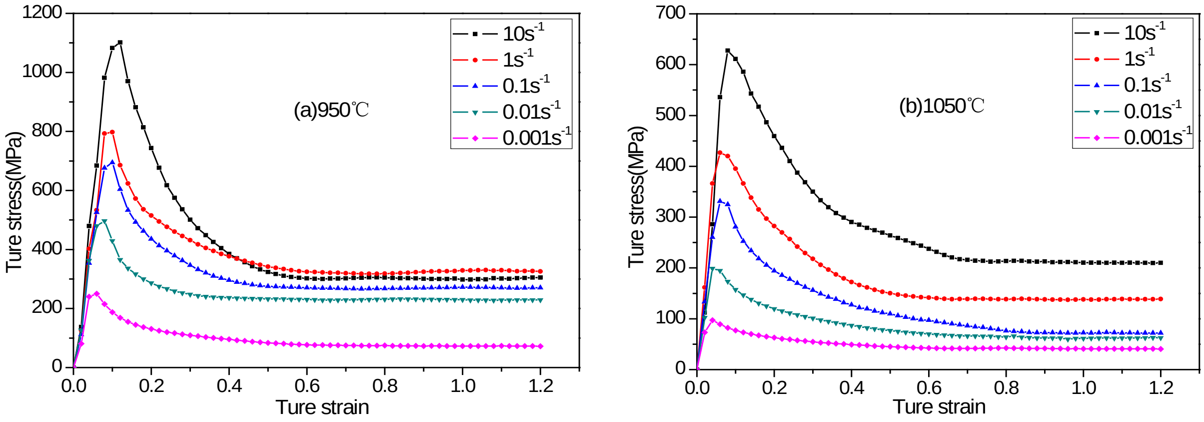


Figure 1. True stress-strain curves of Ti-22Al-26Nb-2Ta-0.5Y alloys with strain rates of $0.001s^{-1}$, $0.01s^{-1}$, $0.1s^{-1}$, $1s^{-1}$, and $10s^{-1}$ respectively deformed at temperature of (a)950°C; (b)1050°C.

3. Arrhenius Type Constitutive Model

The expression of the Arrhenius type constitutive model containing the Z parameter[10] is:

$$\dot{\varepsilon} = AF(\sigma)\exp(-Q/RT) \tag{1}$$

$$F(\sigma) = \begin{cases} \sigma^{n_1} & \alpha\sigma < 0.8 \\ \exp(\beta\sigma) & \alpha\sigma > 1.2 \\ [\sinh(\alpha\sigma)]^n & for\ all\ \sigma \end{cases} \tag{2}$$

$$Z = \dot{\varepsilon}\exp(Q/RT) \tag{3}$$

Among them, $\dot{\varepsilon}$ is the strain rate(s^{-1}); σ is the ture stress(MPa); Q is the deformation activation energy($kJ \cdot mol^{-1}$); R is the gas constant($8.314 \cdot mol^{-1} \cdot K^{-1}$); T is the absolute temperature; A, n_1, α, n and β ($\beta=\alpha n_1$) is the material constant.

From equation (1) to equation (3), the mathematical expression for real stress can be derived as:

$$\sigma = \frac{1}{\alpha}\ln\left\{\left(\frac{Z}{A}\right)^{1/n} + \left[\left(\frac{Z}{A}\right)^{2/n} + 1\right]^{1/2}\right\} \tag{4}$$

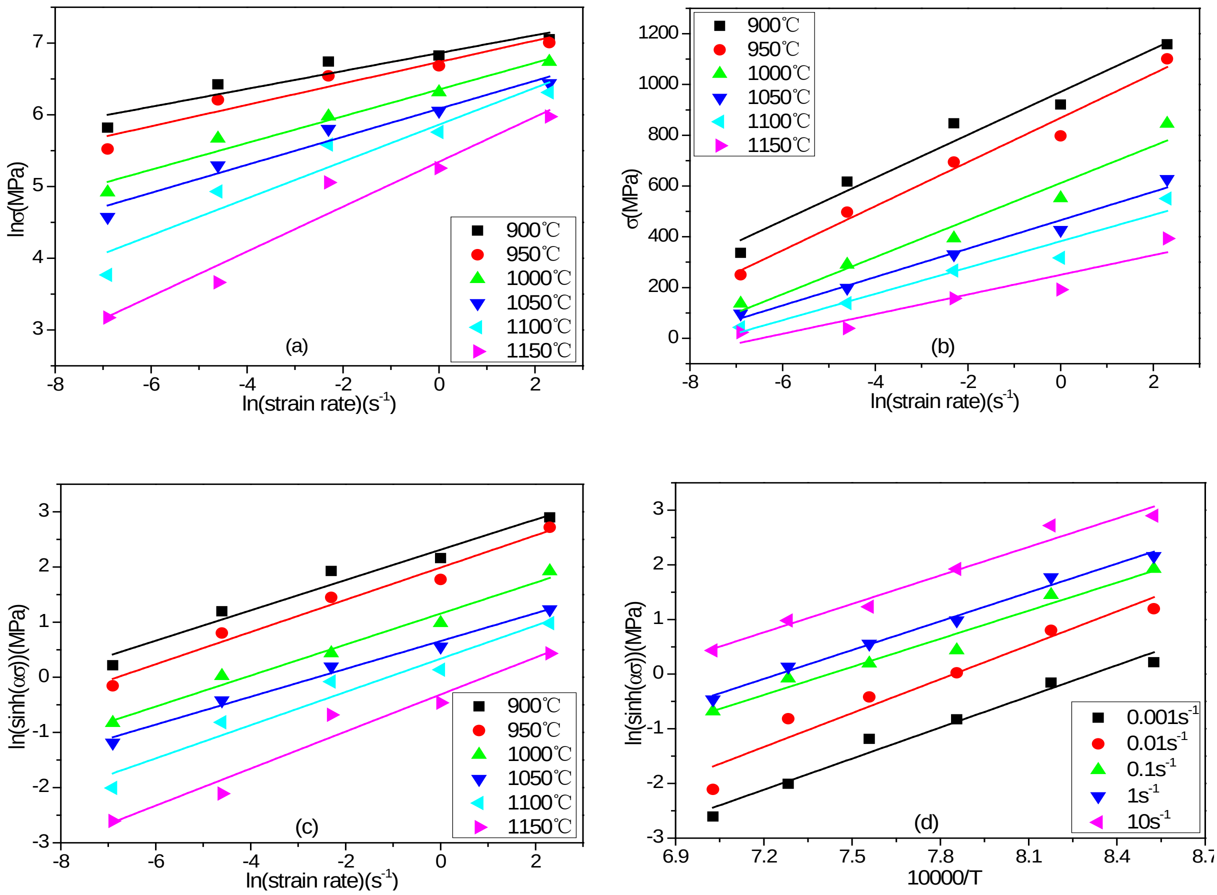
4. Z parameter Constitutive Model

The characterization parameters are based on experimental data obtained by a linear regression method. At different deformation temperatures, the average slope of the $\ln\dot{\varepsilon} - \ln\sigma$ fitting curve is taken as the reciprocal n_1=5.3828; At different deformation temperatures, the average slope of the $\ln\dot{\varepsilon}-\sigma$ fitting curve is taken as the reciprocal β=0.0167, then find the material constant α=β/n_1=0.0031; At different deformation temperatures, the average slope of the $\ln\dot{\varepsilon}-\ln(\sinh(\alpha\sigma))$ fitting curve is taken as the reciprocal n=3.4828; At different deformation temperatures, the average slope of the $10000/T-\ln(\sinh(\alpha\sigma))$ fitting curve is 1.83431, then find the deformation activation energy Q=531.14; The intercept of the fitting curve is lnA=45.922, then find the material constant A=8.784×10^{19}.

Fig. 2 shows the fitting straight lines obtained by linear regression based on the peak stress under each deformation condition. The Arrhenius type constitutive model for the characterization parameters of Ti-22Al-26Nb-2Ta-0.5Y alloy is:

$$\sigma=\frac{1}{3.1\times10^{-3}}\ln\left\{\left(\frac{Z}{8.784\times10^{19}}\right)^{1/3.4828}+\left[\left(\frac{Z}{8.784\times10^{19}}\right)^{2/3.4828}+1\right]^{1/2}\right\} \quad (5)$$

$$Z=\dot{\varepsilon}\exp\left(\frac{531.14\times10^{3}}{8.314T}\right)$$



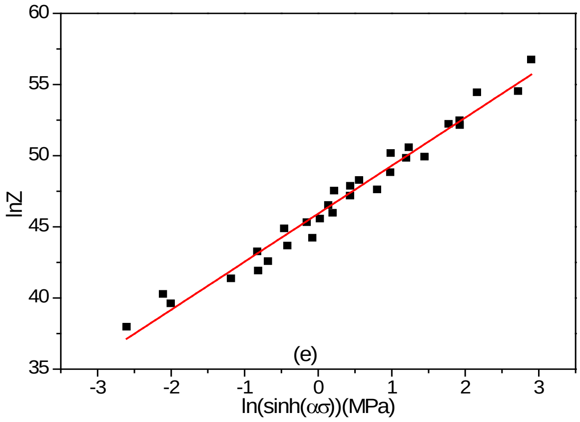


Figure 2. Characterization parameter fitting curve: (a)ln$\dot{\varepsilon}$-lnσ; (b)ln$\dot{\varepsilon}$-σ; (c)ln$\dot{\varepsilon}$-ln(sinh(ασ)); (d)10000/T-ln(sinh(ασ)); (e)ln(sinh(ασ))-lnZ.

The constitutive equations were used to calculate the experimental parameter points and the calculated values of the flow stress were compared with the experimental values. Fig. 3 shows the error accuracy of the constructed constitutive equations. The error analysis shows that the deviation within 15% of all data points account for about 96.67% of the total. The above shows that the constitutive equation can accurately describe the influence of the hot working processing parameters of Ti-22Al-26Nb-2Ta-0.5Y alloy on its flow stress.

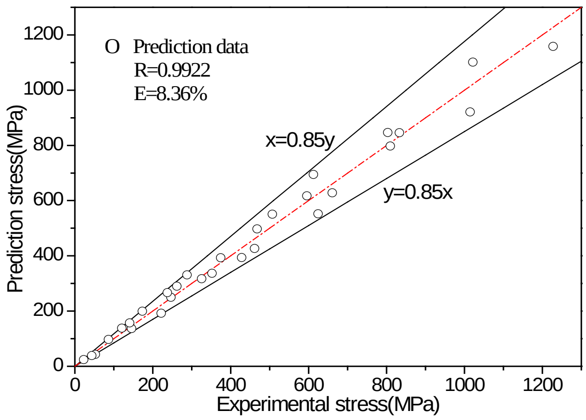


Figure 3. Curve of the calculated and actual values

5. Conclusion

(1)The hot deformation behavior of Ti-22Al-26Nb-2Ta-0.5Y alloy follows the deformation behavior of a typical rheological curve. The flow stress increases with the increase of deformation rate and decreases with the increase of deformation temperature.

(2)The Z-parameter Arrhenius type constitutive model of Ti-22Al-26Nb-2Ta-0.5Y alloy based on peak stress has good prediction accuracy. The predicted value of this constitutive model is fitted to the measured value of the isothermal compression test. The correlation coefficient between the predicted value and the experimental value is R=0.9922, the average relative error E is 8.36%, and the deviation within 15% accounted for about 96.67% of the total validation data points.

Acknowledgements

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