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BASED ON THE CONSTITUTIVE MODEL OF HIGH TEMPERATURE PLASTIC DEFORMATION OF TC17 TITANIUM ALLOY FOR UNDERWATER ROBOT METAL MATERIAL

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The hot compression tests of underwater vehicle metal material TC17 titanium alloy at deformation temperature of 800 ~ 950 °C and strain rate of 0,01 ~ 10 s^{-1} were carried out by Thermecmaster-Z thermal simulator. The hot deformation behavior of TC17 ferroalloy was studied. The effects of strain rate and deformation temperature on the high temperature forming of TC17 titanium alloy were analyzed. The multiple linear regression constitutive model of TC17 titanium alloy was established. The results show that the flow stress of TC17 alloy decreases with the increase of deformation temperature and increases with the increase of strain rate. The theoretical value of peak stress obtained by the multiple linear regression constitutive model of TC17 alloy is in good agreement with the experimental results, and the correlation is 97,25%. The model has high prediction accuracy.

Keyword: TC17 titanium alloy; stress; strain; underwater robot; constitutive model

INTRODUCTION

Titanium alloys are often used in the lightweight design and manufacture of underwater robots due to their low density, good strength and toughness, and low corrosion resistance. However, the hot working process of TC17 titanium alloy is complex, and the microstructure uniformity after forging is poor, which seriously affects its mechanical properties. The hot deformation behavior of the material is the basis for formulating its hot processing technology[1]. The microstructure and properties of the material after hot deformation depend on the interaction of work hardening and dynamic softening during the hot deformation process[2]. The hardening and softening processes are affected by many factors, among which the deformation temperature and strain have the greatest influence. In addition, studies have shown that the flow stress of TC17 alloy during hot deformation has a complex relationship with strain rate and deformation temperature[3]. Therefore, understanding the relationship between flow stress and strain rate, deformation temperature and strain during hot deformation of TC17 alloy has important guiding significance for improving its hot processing technology[4].

In order to explore the relationship between its related influencing factors and stress, the high temperature compression experiment of TC17 titanium alloy was carried out by Thermecmaster-Z thermal simulator. The variation characteristics of flow stress-strain curve were studied, and the constitutive model was established. The experimental data were compared with the model prediction data to verify the accuracy and feasibility of the constitutive model.

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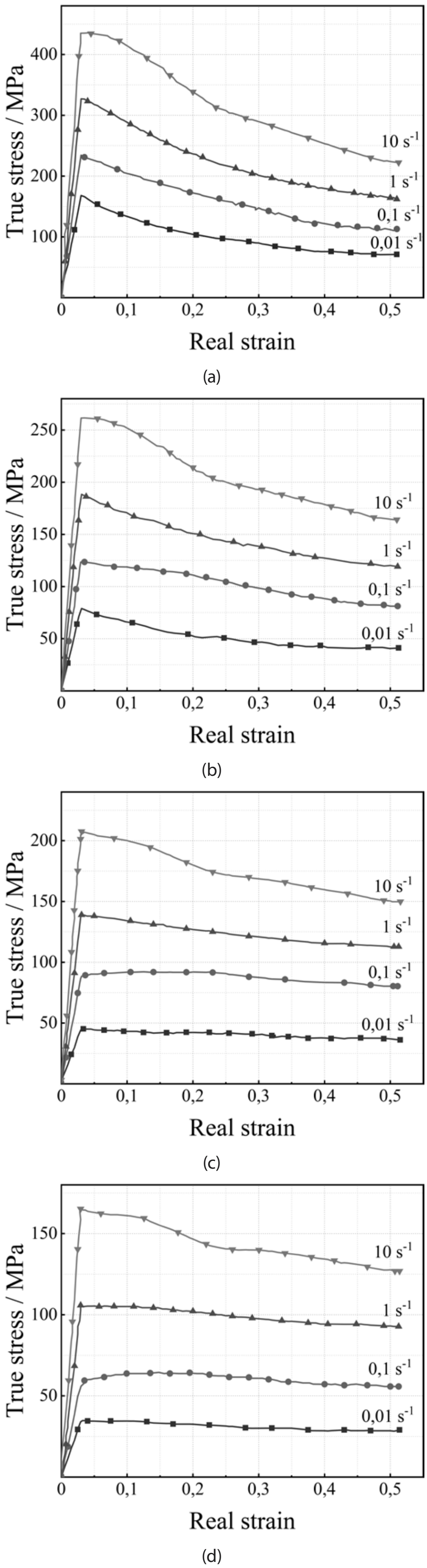
Hot compression test of TC17 titanium alloy

The TC17 titanium alloy material after single-phase isothermal forging, solution treatment and aging treatment was processed into a cylindrical.The samples were placed on the Thermecmaster-Z thermal simulator for compression test. The strain rates were set to 0,01, 0,1, 1, 10 s^{-1}, the deformation temperatures were 800, 850, 900, 950 °C, and the heating rate was 10 °C· s^{-1}. After reaching the deformation temperature, the samples were kept for 5 min for compression. The maximum height reduction rate is 40 %, and the corresponding true strain is about 0,51. During the test, the temperature of the sample was measured in real time by a thermocouple installed in the middle of the side of the sample, and the temperature of the sample was controlled within the range of ±1°C of the deformation temperature. The compressed sample was immediately cooled to room temperature in fluorine gas.

Experimental data and ontological modeling

The true stress-true strain curve of TC17 alloy under the strain change rate of 0,01 ~ 10 s^{-1} is shown in Figure 1.

In order to explore the transformation of flow stress during the deformation of TC17 titanium alloy, an Arrhenius constitutive model was established based on the



(a) 800 °C (b) 850 °C (c) 900 °C (d) 950 °C

Figure 1 The true stress-true strain curves of TC17 alloy during compression at different deformation temperatures and strain rates were obtained.

Arrhenius equation proposed by Sellar et al., and the temperature-compensated strain rate Zener-Hollomon parameter was introduced to compensate the strain rate. The Arrhenius constitutive model quantitatively describes the relationship between flow stress σ and temperature T and strain rate $\dot{\varepsilon}$. The expression is as follows.

$$Z = \dot{\varepsilon}\exp\left(\frac{Q}{RT}\right) = A\sinh\left(\alpha\sigma\right)^{n} \tag{1}$$

In the formula: Z parameter is the strain compensation factor, R is the molar gas constant, the value is 8,314J·(mol/K)$^{-1}$, σ is stress/MPa and Q/J/mol is the apparent activation energy of hot deformation.

In the low stress region, when $\alpha\sigma \leq 0{,}8$, the Arrhenius equation is

$$\dot{\varepsilon} = A_1\sigma^{n_1}\exp(\frac{-Q}{RT}) \tag{2}$$

In the low stress region, when $\alpha\sigma \geq 1{,}2$, the Arrhenius equation is

$$\dot{\varepsilon} = A_2\exp(\beta\sigma)\exp(\frac{-Q}{RT}) \tag{3}$$

The relationship between flow stress σ, temperature T and strain rate $\dot{\varepsilon}$ can be expressed as

$$\dot{\varepsilon} = A\left[\sinh(\alpha\sigma)\right]^{n}\exp(\frac{-Q}{RT}) \tag{4}$$

where A, A_1, A_2, α, β, n, and n_1 are temperature-independent material constants, and $\alpha = \beta / n_1$; T is the deformation temperature, K.

$$In\dot{\varepsilon} = InA_1 + n_1 In\sigma - \frac{Q}{RT} \tag{5}$$

$$In\dot{\varepsilon} = InA_2 + \beta\sigma - \frac{Q}{RT} \tag{6}$$

Under the condition of constant temperature, the logarithmic processing of the test peak data is substituted into Formula (5) and Formula (6), and the linear regression curves of $\ln\dot{\varepsilon} - \ln\sigma$ and $\ln\dot{\varepsilon} - \sigma$ are obtained, as shown in Figures 2, 3.

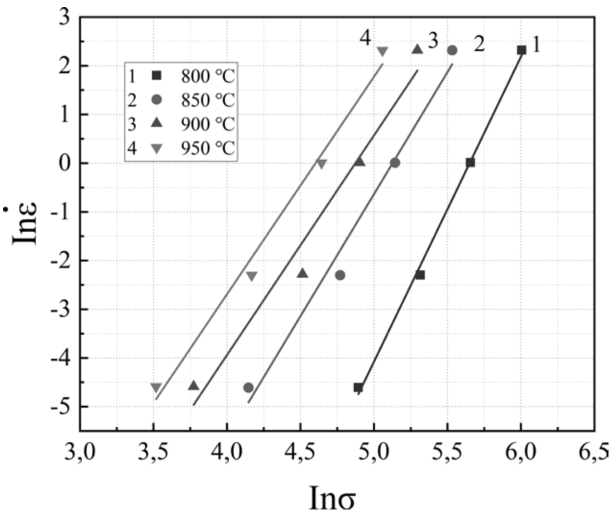


Figure 2 Relation curves of $\ln\dot{\varepsilon}$ and $\ln\sigma$

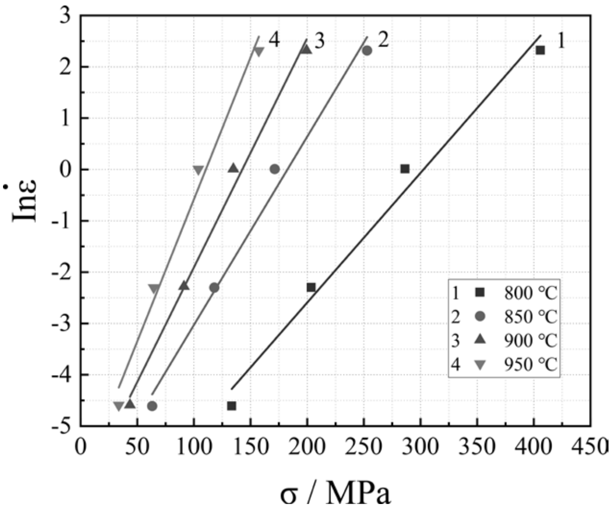


Figure 3 Relation curves of $\ln\dot{\varepsilon}$ and σ

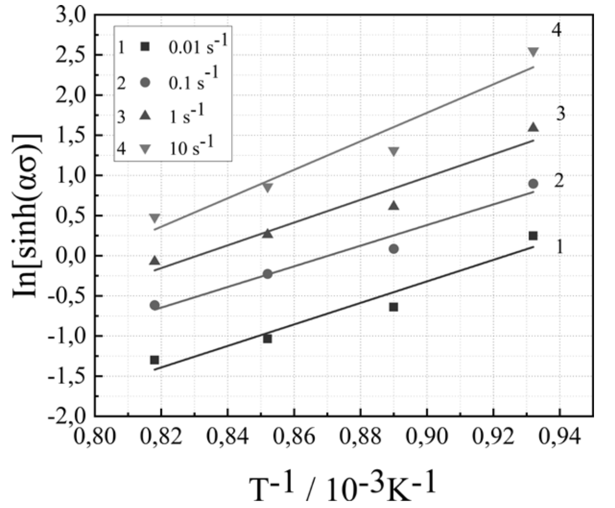


Figure 5 Relation curves of ln[sinh($\alpha\sigma$)] and 1/T

The slopes of the linear regression curves of $\ln\dot{\varepsilon}-\ln\sigma$ and $\ln\dot{\varepsilon}-\sigma$ can be obtained from the figure, and the average values of the slopes are taken to obtain n_1 = 5,0622825 and β = 0,040485, respectively. According to the relationship of $\alpha = \beta / n_1$, α = 0,00799738MPa^{-1} is obtained.

Taking logarithm of pair (4), the following result is obtained:

$$In\dot{\varepsilon} = InA + nIn\left[\sinh(\alpha\sigma)\right] - \frac{Q}{RT} \tag{7}$$

The partial derivative transformation of Eq. (4) is obtained respectively :

$$n = \frac{\partial In\dot{\varepsilon}}{\partial In\left[\sinh\left(\alpha\sigma\right)\right]} \tag{8}$$

$$K = \frac{Q}{nR} = \frac{\partial In\left[\sinh\left(\alpha\sigma\right)\right]}{\partial\left(1/T\right)} \tag{9}$$

Where K is the material constant.

Finally, the thermal activation energy Q is obtained, and the expression is:

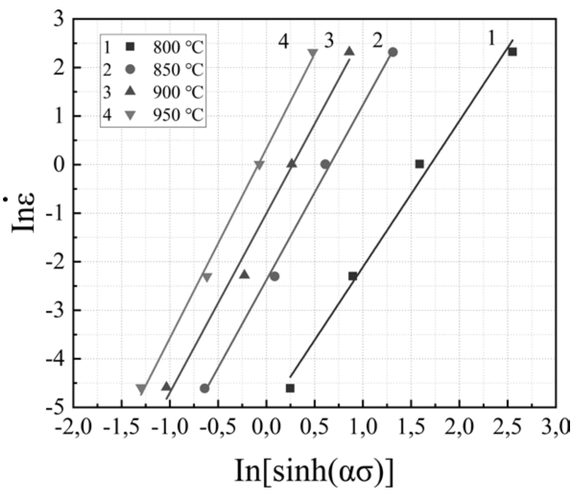


Figure 4 Relation curves of $\ln\dot{\varepsilon}$ and ln[sinh($\alpha\sigma$)]

$$Q = R\frac{\partial In\left[\sinh\left(\alpha\sigma\right)\right]}{\partial\left(1/T\right)} \bullet \frac{\partial In\dot{\varepsilon}}{\partial In\left[\sinh\left(\alpha\sigma\right)\right]} \tag{10}$$

As shown in Figure 4 and Figure 5, n = 3,5522875 and K = 14538,225 are obtained by linear regression by calculating the average value of the slope of the regression line respectively. According to $K = Q/nR$, Q = 429367,8 J/mol is calculated.

Bring Formula (4) into Formula 1, and take the logarithm to get :

$$\ln Z = n\ln[\sinh(\alpha\sigma)] + \ln A \tag{11}$$

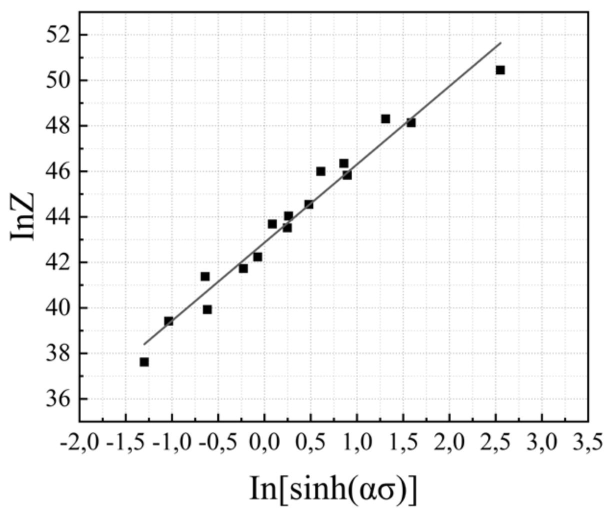


Figure 6 Relation curves of lnZ and ln[sinh($\alpha\sigma$)]

According to Formula (11), the relationship equation between ln Z and ln[sinh($\alpha\sigma$)] is made and linear regression processing is carried out. Finally, the intercept ln A = 42,86925 is obtained, and then the experimental alloy structure factor A = 4,14838×10^{18} is obtained from Figure 6.

The calculated A, α, Q and n are brought into Formula (4) to obtain the peak stress constitutive equation of TC17 titanium alloy.

$$\dot{\varepsilon} = 4{,}14838\times10^{18}\left[\sinh(0{,}00799738\sigma)\right]^{3{,}5522875}\exp\left(\frac{-429\ 367{,}8}{8{,}314T}\right) \quad (12)$$

Simulation prediction and verification of constitutive model

In order to test the applicability and accuracy of the Arrhenius constitutive model of TC17 titanium alloy, the calculated value of flow stress obtained by the constitutive model of TC17 titanium alloy is compared with the experimental value, as shown in Figure 7. The correlation coefficient between the calculated results of the established constitutive model of TC17 titanium alloy and the experimental values is 97,25 %, indicating that the established constitutive model of TC17 titanium alloy has high calculation accuracy for flow stress.

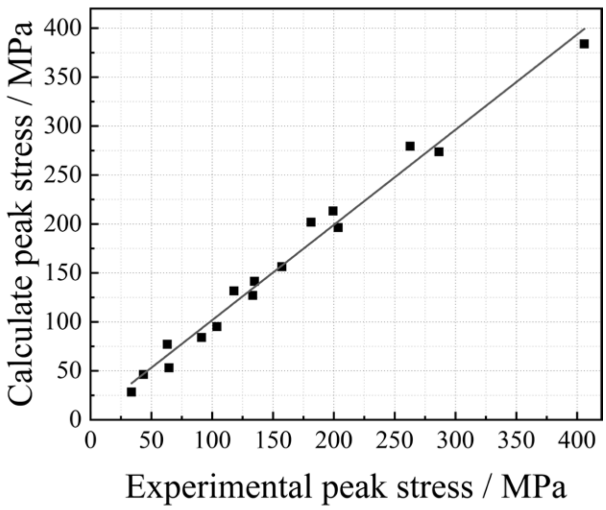


Figure 7 The peak stress calculation results are compared with the measured values

CONCLUSION

The flow stress of TC17 titanium alloy is highly sensitive to deformation temperature and strain rate. The flow stress decreases with the increase of deformation temperature and increases with the increase of strain rate. In this paper, the constitutive relationship of TC17 titanium alloy at different temperatures and different strain rates was studied. The Arrhenius constitutive model of TC17 titanium alloy was established by introducing the temperature-compensated strain rate factor Zener-Hollomon parameter. The accuracy and feasibility of the model for predicting flow stress were analyzed and verified. The results show that the error between the calculated value and the experimental value of the flow stress obtained by the constitutive model of TC17 titanium alloy established in this paper is small, and the prediction accuracy is high.

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Note: The responsible translator for English language P.F. Shuai- Harbin Engineering University, China