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ISSN 0543-5846
METABK 64(1-2) 49-52 (2025)
UDC:669.71.5.721.3:7.024:621.72:620.16:539.37=111

RESEARCH ON CONSTITUTIVE MODEL OF RHEOLOGICAL BEHAVIOR OF 7050 ALUMINUM ALLOY BASED ON METAL MATERIAL OF BADMINTON RACKET FRAME

Received – Primljeno: 2024-05-12
Accepted – Prihvaćeno: 2024-08-10
Original Scientific Paper – Izvorni znanstveni rad

In order to improve people ‘s experience of badminton and improve the performance of badminton rackets. The flow stress behavior of 7050 aluminum alloy for badminton racket frame metal material was studied under the conditions of strain rate range of 0,01 ~ 10 s^{-1} and deformation temperature of 573 ~ 723 K. The true stress-strain curve of 7050 aluminum alloy was obtained. According to the real stress-strain curve, the Arrhenius constitutive model of 7050 aluminum alloy was constructed. The results show that obvious dynamic recovery and dynamic recrystallization occur in the hot compression deformation of 7050 aluminum alloy. The flow stress increases with the increase of strain rate and decreases with the increase of temperature. The theoretical stress value predicted by the constitutive model is fitted with the experimental value, and the correlation is 97,3 %. The constitutive model has high prediction accuracy.

Keyword: 7050 aluminum alloy, badminton racket frame, Arrhenius constitutive model, stress, strain

INTRODUCTION

Nowadays, badminton has entered people‘s daily life. How to improve people ‘s experience of badminton has become a new research direction[1]. The grip of the badminton racket directly affects the experience, thus affecting the development of badminton. Therefore, it is of great significance to study the thermal deformation of 7050 aluminum alloy used in badminton rackets[2].

7050 aluminum alloy belongs to Al-Zn-Mg-Cu ultra-high strength aluminum alloy[3]. Because of its high room temperature strength and light weight, it is widely used in sports equipment, air transportation and other industries[4]. In order to meet the characteristics of light weight and high strength of badminton rackets in badminton, 7050 aluminum alloy is mostly used as the processing material in the modern processing technology of badminton rackets[5]. Due to the low plasticity of ultra-high strength aluminum alloy at room temperature, it is generally necessary to improve its metal properties by high temperature plastic forming. In order to study its high temperature deformation characteristics, it is necessary to study the rheological behavior of the metal during processing.

In this paper, the hot compression tests of 7050 aluminum alloy under different conditions were carried out by using Gleeble-3500 thermal simulation testing machine. The high temperature flow stress behavior was studied, and the constitutive model which can accurately describe the flow characteristics of the material was established. It provides a theoretical basis for the development of plastic forming process of 7050 aluminum alloy.

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Hot compression test of 7050 aluminum alloy

The experimental material 7050 aluminum alloy, whose main chemical composition is Zn, Mg, Cu, Mn and Cr, belongs to Al-Zn-Mg-Cu series aluminum alloy. It has good strength and machinability, and can be strengthened by heat treatment. The hot compression test was carried out on the Gleeble-3500 thermal simulation testing machine. The deformation temperatures of the metal were set to 573,623,673 and 723 K, and the strain rates were set to 0,01,0,1,1 and 10 s^{-1}. After heating to the predetermined temperature and holding for 5 min, the compression experiment was carried out, and the deformation was 50 %. The compressed sample was immediately subjected to water quenching treatment to retain the deformed structure. The true stress-strain curves of 7050 aluminum alloy under different deformation conditions were drawn by analyzing the original test data recorded on the hot die machine.

Analysis of test data and establishment of constitutive model

As shown in Figure 1, the true stress of 7050 aluminum alloy is significantly affected by temperature and strain rate. The flow stress curve experienced a transition deformation stage and a steady-state deformation stage. In the transition deformation stage, the softening mechanism in the early stage of deformation is mainly cross slip, and the work hardening is dominant before the peak stress. With the further increase of deformation, the deformation storage energy becomes the driving force of the recrystallization after exceeding

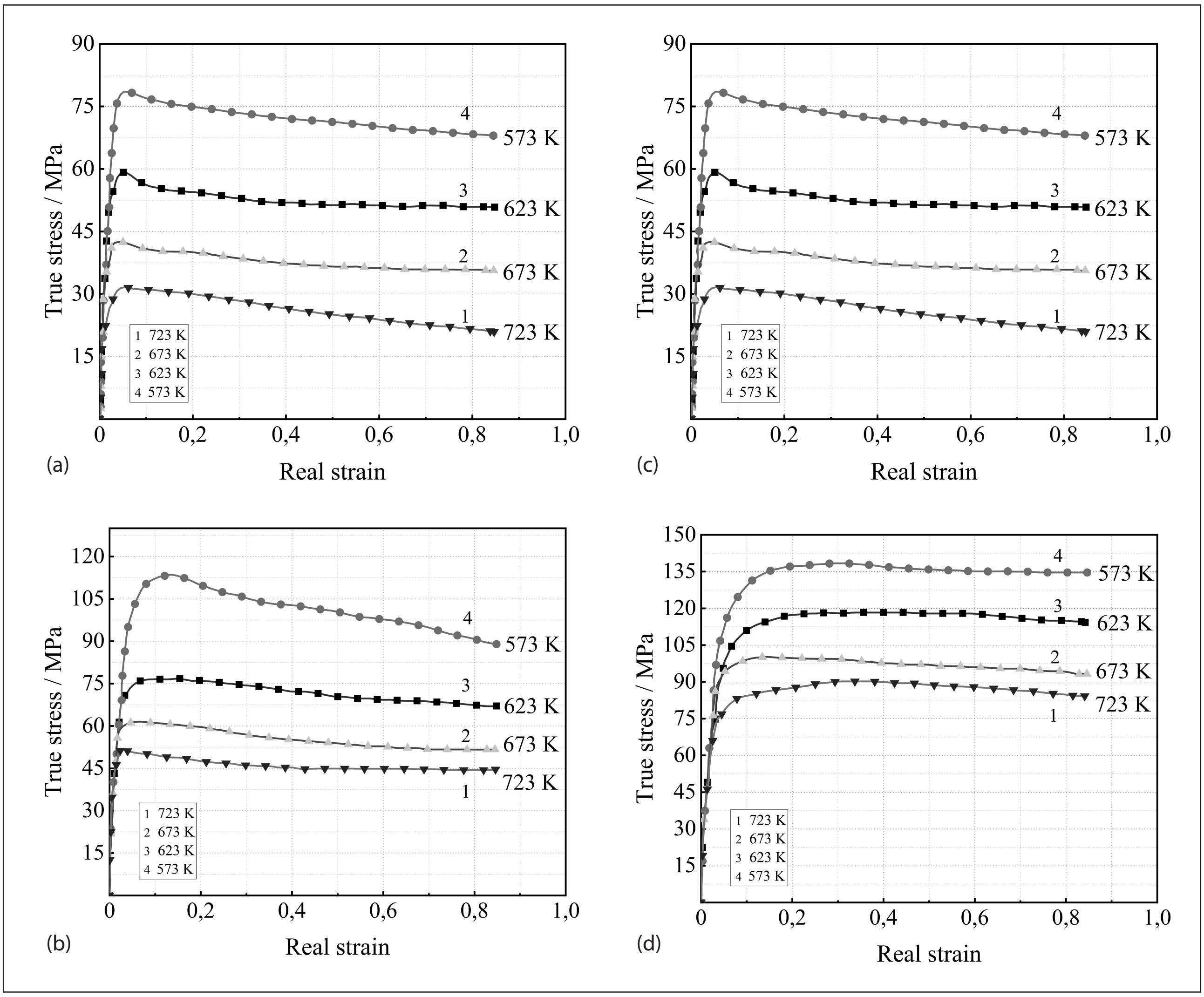

Figure 1 The true stress-true strain curves of 7050 aluminum alloy at different strain rates (a) 0,01 s^{-1} (b) 0,1 s^{-1} (c) 1 s^{-1} (d) 10 s^{-1}

a certain amount of deformation. Recrystallization can eliminate or change the original deformation texture, and dynamic recrystallization softening occurs. When the softening rate and the hardening rate are balanced, the flow stress reaches the maximum value. As the softening rate of dynamic recrystallization is greater than the hardening rate, the stress gradually decreases. When complete dynamic recrystallization occurs, the grain structure and flow stress do not change with the deformation and enter the steady-state deformation stage.

(Under the condition of high temperature plastic deformation of 7050 aluminum alloy, the relationship between flow stress, strain rate and temperature can be described by Arrhenius model. The Arrhenius model is expressed as follows:

$$\dot{\varepsilon} = A_1 \sigma^{n_1} \exp(\frac{-Q}{RT}), \quad \alpha\sigma \le 0,8 \tag{1}$$

$$\dot{\varepsilon} = A_2 \exp(\beta\sigma) \exp(\frac{-Q}{RT}), \quad \alpha\sigma \ge 1,2 \tag{2}$$

$$\dot{\varepsilon} = A[\sinh(\alpha\sigma)]^n \exp(\frac{-Q}{RT}), \quad \text{for all } \sigma \tag{3}$$

where R is the molar gas constant, the value is 8,314 J·(mol/K)$^{-1}$, σ is stress/MPa and Q/J/mol is the apparent activation energy of hot deformation. 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.

According to the characteristics of Arrhenius model, the strain rate is controlled by the thermal activation process during high temperature plastic deformation. The relationship between strain rate and temperature can be expressed by Z parameter:

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

When the temperature T is a fixed value, Q, A, R, T are constants, so the value of and can be calculated by combining Eq. (1) and Eq. (2). The specific calculation formula is :

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

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

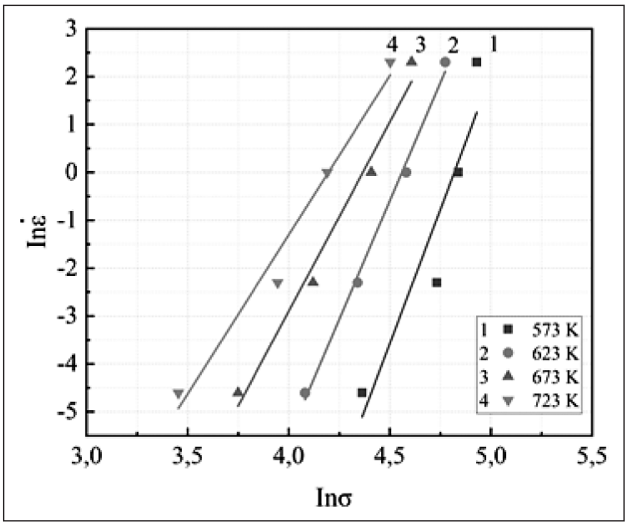

Figure 2 Relation curves of $\ln\dot{\varepsilon}$ and $\ln\sigma$

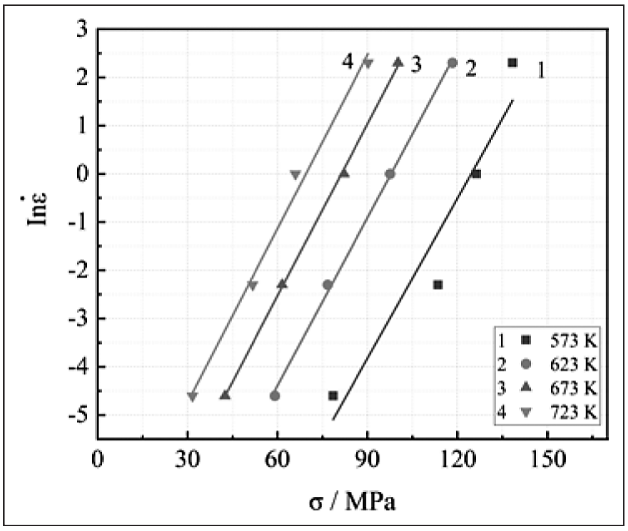

Figure 3 Relation curves of $\ln\dot{\varepsilon}$ and σ

As shown in Figure 2 and Figure 3, the test data are substituted into Eq. (5) and Eq. (6). By fitting the slopes of $\ln\dot{\varepsilon}-\ln\sigma$ and $\ln\dot{\varepsilon}-\sigma$, $n_1 = 8{,}91327$ and $\beta = 0{,}116325$ are obtained. According to the relationship between n_1, β and α, α = 0,01305076588 MPa^{-1} is obtained.

When the strain rate is constant, R, n, A and α are constants, and the thermal deformation activation energy Q will change with temperature. Combined with Eq. (3), Q and lnA can be calculated. The specific calculation formula is:

$$Q = Rn\left[\frac{\partial \ln[\sinh(\alpha\sigma)]}{\partial(1/T)}\right]_{\dot{\varepsilon}=constant} \quad (7)$$

$$\ln A = \ln\dot{\varepsilon} + \frac{Q}{RT} - n\ln[\sinh(\alpha\sigma)] \quad (8)$$

As shown in Figure 4 and Figure 5, through linear regression, the average value of the slope of the regression line is calculated by n = 6,614805 and K = 2 584,71 respectively, and Q = 156 996,1717466067 J/mol is calculated according to $K = Q/nR$.

Combining Eq. (3) with Eq. (4), the logarithm is obtained:

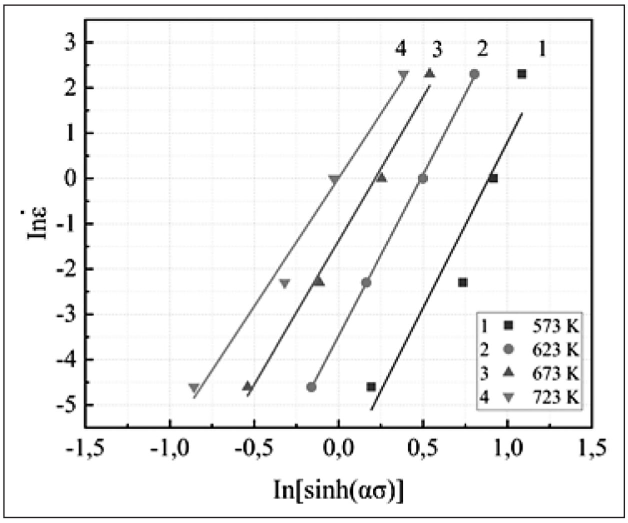

Figure 4 Relation curves of $\ln\dot{\varepsilon}$ and $\ln[\sinh(\alpha\sigma)]$

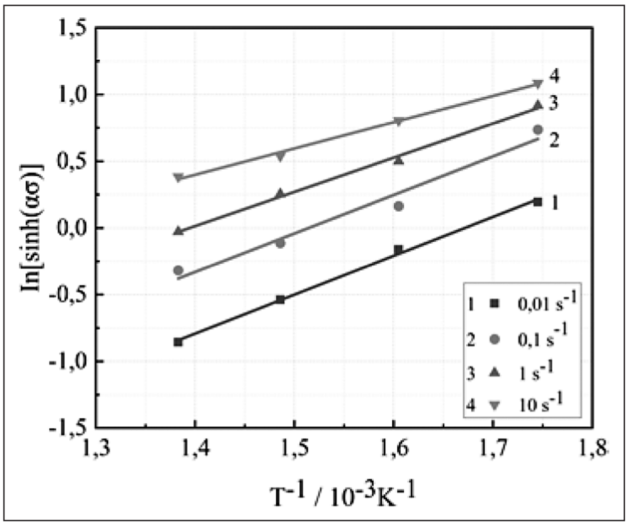

Figure 5 Relation curves of $\ln[\sinh(\alpha\sigma)]$ and $1/T$

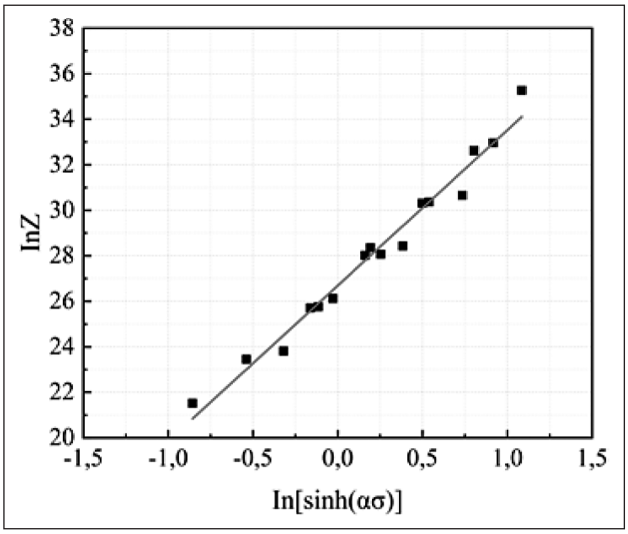

Figure 6 Relation curves of lnZ and $\ln[\sinh(\alpha\sigma)]$

$$\ln Z = n\ln[\sinh(\alpha\sigma)] + \ln A \quad (9)$$

According to Formula (9), by fitting the relationship between ln$Z$ and $\ln[\sinh(\alpha\sigma)]$, the intercept ln$A$ = 26,68958 is finally obtained, and then the structural factor A = 3,9007×10^{11} of the experimental alloy is obtained.

In summary, the constitutive model of 7050 aluminum alloy at deformation temperature of 573 ~ 723 K and strain rate of 0,01 ~ 10 s^{-1} is:

$$\dot{\varepsilon} = 3,9007 \times 10^{11} \left[\sinh(0,01305076588\sigma)\right]^{6,614805} \exp\left(\frac{-156\,996,1717466067}{8,314T}\right) \quad (10)$$

Prediction and verification of constitutive model

In order to test the applicability of the Arrhenius-type constitutive model of 7050 aluminum alloy, the flow stress data predicted by the constitutive model of 7050 aluminum alloy are compared with the experimental values. As shown in Figure. 7, the correlation coefficient R^2 = 0,97309 between the predicted value and the experimental value shows that the established 7050 constitutive model can accurately describe the flow behavior of 7050 aluminum alloy in high temperature plastic deformation.

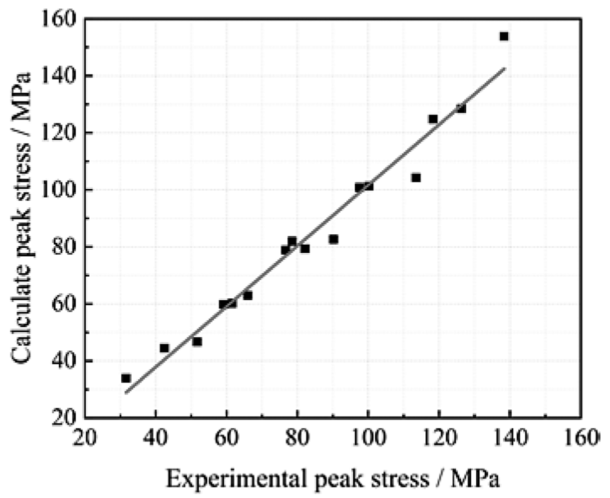

Figure 7 The peak stress calculation results are compared with the measured values

CONCLUSION

7050 aluminum alloy has obvious dynamic recovery and dynamic reunion phenomenon in the process of high temperature compression deformation. The flow stress experienced two stages of transition deformation and steady-state deformation. The flow stress increases with the increase of strain rate at the same deformation temperature, and decreases with the increase of temperature at the same strain rate. The Arrhenius constitutive model of 7050 aluminum alloy was established by introducing the parameter of temperature compensated strain rate factor. The results show that the error between the predicted value and the experimental value of 7050 aluminum alloy established in this paper is small, which can provide a theoretical basis for the prediction and control of the deformed microstructure of 7050 aluminum alloy and the formulation of thermal processing technology. It can provide some help and reference for the forming process of badminton racket.

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Note: The responsible translator for English language L. C. Sun - Harbin Sport University, China