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Low-temperature superplastic behavior of beta titanium alloy

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ABSTRACT

The low temperature superplastic deformation behavior of Ti–3.5Al–5Mo–6V–3Cr–2Sn–0.5Fe alloy were investigated. Results show that the elongation of the alloy exceeds 100% when deformation at the temperature ranging from of 650 °C to 800 °C and the initial strain rates ranging from $2.78\times10^{-4}\ s^{-1}$ to $8.33\times10^{-3}\ s^{-1}$, and the elongation of the alloy increases with the decrease of initial strain rates and the increase of temperature. The true strain–stress curves show that the peak flow stress decreases with the decrease of initial strain rates and the increase of temperatures, and the peak flow stress shows much sensitivity to the initial strain rates as well as the temperatures. During superplastic deformation, the α phase was elongated and the size grows up with the decrease of initial strain rates. The superplastic mechanism of the alloy is grain boundary sliding accommodated by dislocation movement and dynamic recrystallization.

1. Introduction

Superplastic forming technique of titanium alloys has a widely application in titanium alloys due to the significant saving in weight and costs of metal structures [1–6]. Many works have been done to study the superplastic properties of titanium alloys, especially Ti–6Al–4V alloy. Unfortunately, there has been limited works reported on superplasticity in β titanium alloys. The superplastic properties of Ti–3Al–8V–6Cr–4Mo–4Zr β titanium alloy have been studied with the temperature ranging from 830 °C to 925 °C and the strain rates ranging $5\times10^{-5}\ s^{-1}$ to $3\times10^{-3}\ s^{-1}$ respectively, and it exhibited superplasticity only in a narrow temperature range that 850–865 °C [7]. The superplastic of another β titanium alloy Ti–15V–3Cr–3Sn–3Al has been studied in the temperature ranges 650–950 °C and the strain rate ranging from $10^{-1}\ s^{-1}$ to $10^{-4}\ s^{-1}$, the results shown that the elongation of the alloy first increased and then decreased with the strain rates rising [8]. Sheikhali et al. researched the superplasticity of coarse-grained Ti–13V–11Cr–3Al alloy, it was found that the elongation of 200% can be achieved at the temperature ranges 1030–1080 °C and at a strain rate of $0.1\ s^{-1}$[9].

The above mentioned studies are mainly focus on the superplasticity of β titanium alloys in β region. The α+β titanium alloys have shown good superplasticity during deformation in α+β region [10–12], even the titanium alloys were suggested to hot deform in the β region due to the good workability [13]. However, the systematic research on the superplasticity of β titanium alloys in α+β region has not reported yet. Therefore, the purpose of this paper is to study the superplasticity of β titanium alloy in α+β region. The experiment carried on a β titanium alloy Ti–3.5Al–5Mo–6V–3Cr–2Sn–0.5Fe, which exhibited the excellent mechanical properties [14].

2. Experimental

The material used in the experiments is forged β titanium alloy with the diameter of 80 mm, and its nominal composition is Ti–3.5Al–5Mo–6V–3Cr–2Sn–0.5Fe. The β transition temperature of the alloy is about 815 °C obtained by metallographic method. Tensile specimens with a gauge length with gauge section of $4.5\times2\times10\ mm^3$ were then prepared by means of electro discharge machining from the forged alloy, as shown in Fig. 1. Uniaxial tensile experiments at high temperature were taken in Instron 5569 electronic universal material testing machine. Tensile testing temperatures ranged from 650 °C to 800 °C and the initial strain rates were from $2.78\times10^{-4}\ s^{-1}$ to $8.33\times10^{-3}\ s^{-1}$, respectively. The specimens were hold for 5 min at the furnace before tensile testing.

The microstructure of the alloy after superplastic deformation was observed by scanning electron microscopy (SEM) and electron backscattered diffraction (EBSD) by using field emission gun

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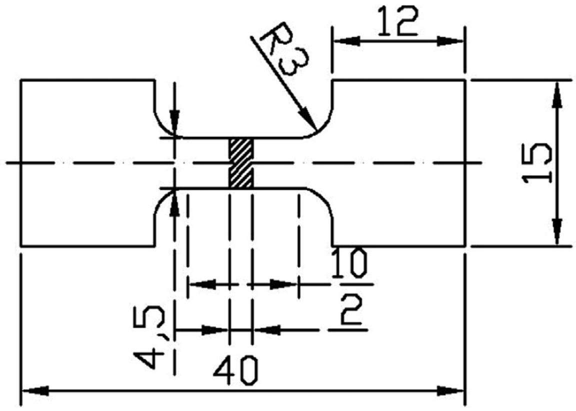

Fig. 1. Schematic diagram of specimens for superplastic tensile test (unit: mm).

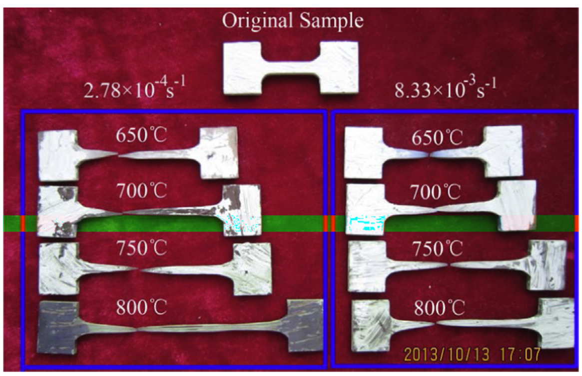

Fig. 2. The specimens of the alloy before and after deformation.

scanning electron microscopy Quanta 200FEG. The specimens for SEM and EBSD analysis were polished with 400–2000 grid SiC paper in water, and then electrolytic polished in reagent of 60% methanol, 30% butyl alcohol and 10% perchlorate. Moreover, the specimens for SEM analysis were etched by the Kroll agent (10 ml HF, 30 ml HNO_3 and 200 ml H_2O) followed by electrolytic polishing.

3. Results and discussion

3.1. Mechanical properties

Fig. 2 shows stretched samples of the alloy which shows that the alloy exhibits good superplasticity in all deformation conditions. The fracture of the specimen exhibits needlepoint shape. Fig. 3 shows the effect of the temperatures and the initial strain rates on the elongation of the alloy, it can be seen that the elongation of the alloy increases with the decrease of the initial strain rates and the increase of the temperatures. The maximum elongation of 455% was obtained at 800 °C and $2.78 \times 10^{-4}\ s^{-1}$, and the minimum elongation of 109% was obtained at 650 °C and $8.33 \times 10^{-3}\ s^{-1}$.

The true stress–strain curves of Ti–3.5Al–5Mo–6V–3Cr–2Sn–0.5Fe alloy deformed at the different temperatures and the initial strain rates conditions are shown in Fig. 4. The curves exhibit a rapid increase of flow stress in the beginning of deformation and followed by a significant softening behavior at lower temperatures or higher initial strain rates. In the higher temperatures or the lower initial strain rates conditions, the curves show a steady state due to the balance of work hardening and dynamic softening. The alloy shows the maximum peak flow stress of 356 MPa at the lowest temperature of 650 °C with the highest initial strain rate of $8.33 \times 10^{-3}\ s^{-1}$, and the lowest peak flow stress of 46 MPa was obtained at the highest temperature of 800 °C with the lowest initial strain rate of $2.78 \times 10^{-4}\ s^{-1}$.

Fig. 5 shows the effect of the deformation temperatures and the initial strain rates on the peak flow stress of the alloy. As can be seen from Fig. 3, the peaks flow stress decreases with strain rates decreasing and temperatures increasing. It can also be seen from Fig. 5 that the peak flow stress of the alloy is strongly sensitive to the temperature and the initial strain rate. At a constant initial strain rate, the peak flow stress increases faster as the temperature decreases. For example, at an initial strain rate of $8.33 \times 10^{-3}\ s^{-1}$, the peak flow stress at 650 °C is higher about 72 MPa than at 700 °C, and the decrease value of peak flow stress is about 55.5 MPa with the temperature increases from 700 °C to 750 °C. That is to say that the peak flow stress shows more sensitive to the lower temperature. The significantly reduced of flow stress at higher temperatures is mainly due to easier dislocation movement, grain growth, and possibly also grain boundary slip at the higher temperatures [15]. The same with the temperature, the peak flow stress decreases with the decrease of the initial strain rates, and the peak flow stress shows much sensitivity to the initial strain rate as well as the temperature, as shown in Fig. 5(b).

The relationship between the flow stress and the strain rate $\dot{\varepsilon}$ is often described by Arrhenius equation [16]:

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

where $\dot{\varepsilon}$ is the strain rate, A is a material constant, σ is the flow stress, n is the stress exponent which is the inverse of the strain

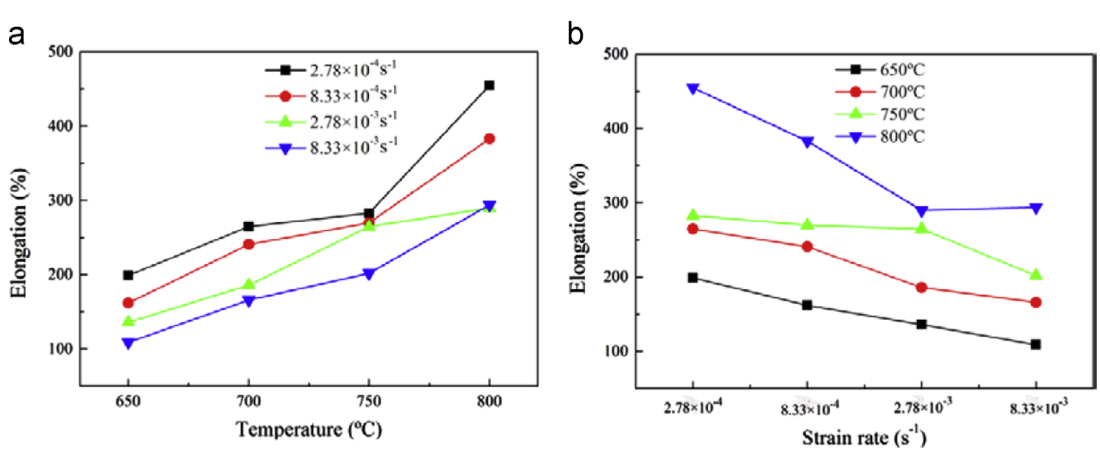

Fig. 3. The tensile elongation of the alloy as function of the: (a) initial strain rate, (b) temperature.