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Strain rate dependence of microstructural evolution in β titanium alloy during subtransus superplastic deformation

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ABSTRACT

The aim of this study is to investigate the strain rate dependence of microstructural evolution in β titanium alloy during subtransus superplastic deformation. Results show that the α phase plays a vital effect on β titanium alloy during subtransus superplastic deformation, such as that the limiting of β grain growth and the hindering of dislocations sliding. The higher strain rate resulting in elongating and cracking of α phase, while the lower strain rate leads to the growth of α phase. The β phase was also elongated at the higher strain rate and the low strain rate is in favor of the spheroidizing. EBSD results show that the texture component moves from $\Phi = 90°$ to $\Phi = 0°$ along the α-fiber with the strain rates decrease from 2.78×10^{-3} s^{-1} to 2.78×10^{-4} s^{-1}.

1. Introduction

β titanium alloys have become attractive to structural components owing to the excellent strength, corrosion resistance and cold deformability [1–3]. As well known, a prior hot deformation should be performed on β titanium alloys due to the inferior strength and ductility resulting from coarse grain in as-cast condition. The hot deformation of β titanium alloys was usually conducted in single β field due to the good workability [4]. However, deformation of β titanium alloys in single β field will leads to the lower match of strength and ductility than deformation in α+β field [5]. Meanwhile, some previous works have also pointed out that the desired properties of titanium alloys are dependent on the final thermomechanical processing [6–8]. It means that the deformation of β titanium alloys in α+β field should be an ideal choice to receive high strength and high ductility.

Superplastic forming technique of titanium alloys has a widely application due to the significant saving in weight and costs of metal structures [9]. A great deal of works have been done to study the superplastic deformation behavior of the α+β titanium alloy [10–14]. Regretfully, only a few works has been done on the superplastic forming of β titanium alloys. Research done by Salam et al. [15] shown that the Ti–3Al–8V–6Cr–4Zr–4Mo β titanium alloy is superplastic in a narrow temperature range 850–865 °C above the β transition temperature. Sheikhali et al. [16] also found the superplasticity of Ti–13V–11Cr–3Al titanium alloy in a narrow high temperature range 1030–1080 °C at a relatively low strain rate of 0.1 s^{-1}. As previously mentioned, the α+β field deformation should be conducted on β titanium alloys if a good combination of strength and ductility is desired after superplastic deformation. However, there almost no researches about superplastic deformation of β titanium alloys in α+β field. Therefore, it is necessary to investigate the superplastic deformation of β titanium alloys in α+β field. The purpose of the present study is to investigate the microstructural evolution during superplastic deformation of β titanium alloy in α+β field at different strain rates conditions.

2. Experimental

The material used in present study is Ti–3.5Al–5Mo–6V–3Cr–2Sn–0.5Fe (wt. %) alloy. The alloy was remelted and forged in α+β field to a round bars with the diameter of 80 mm. The β transition temperature was measured by metallographic method is about 815 °C. Flat tensile test specimens with a gauge section of 4.5 × 2 × 10 mm were then prepared by means of electro discharge machining from the forged ingot. The specimens

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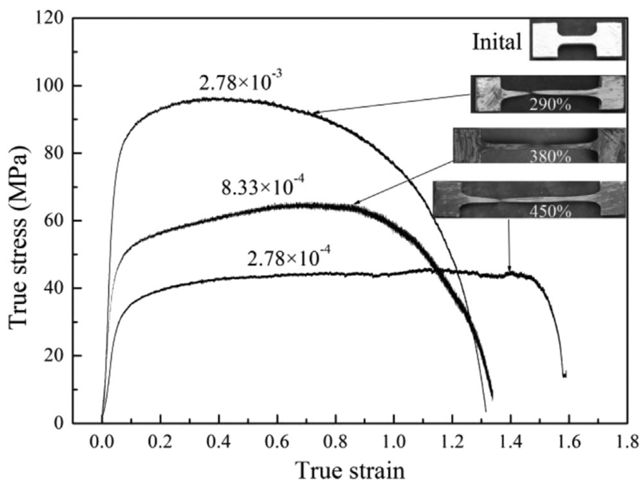

Fig. 1. True stress–strain curves of the alloy deformed at different strain rates.

were hold for 5 min at 800 °C and then tensile tested at strain rates of 2.78×10^{-3} s^{-1}, 8.33×10^{-4} s^{-1} and 2.78×10^{-4} s^{-1} respectively on an Instron 5569 testing machine respectively. Microstructure observation was characterized by scanning electron microscopy (SEM) and electron backscattered diffraction (EBSD) by using field emission gun scanning electron microscopy Quanta 200FEG, and transmission electron microscopy (TEM) by using Tecnai G2 F30 machine. Specimens for SEM and EBSD observations were prepared by electrochemical polishing using the electrolyte with the composition including 10% perchloric acid, 30% butyl alcohol and 60% methanol solution.

3. Results and discussions

Fig. 1 shows the true stress–strain curves of the alloy deformed at 800 °C with different strain rates. The peak stress at strain rate of 2.78×10^{-3} s^{-1} is more than two times larger than at strain rate of 2.78×10^{-4} s^{-1}, that indicating a sharp sensitivity of the flow stress to the strain rate at this temperature. After reaching the peak value, the flow stress decreases trend at high strain rate of 2.78×10^{-3} s^{-1} due to softening behavior [17]. In contrast, the flow stress is steady at strain rate of 2.78×10^{-4} s^{-1}, that indicating a balance of hardening and softening [18].

In order to investigate the effect of strain rate on microstructural evolution of the alloy, the SEM images on the grip section and gauge section of tensile specimens were studied, and the microstructure analysis of the gauge section was carried on the uniform deformation region, as shown in Fig. 2. Fig. 2 (a) shows the microstructure of the grip section on tensile specimen deformed at 800 °C with the strain rate of 2.78×10^{-4} s^{-1}. In fact, the microstructure of grip section has no associate with the deformation strain rate, which only influenced by the temperature. It can be seen that the α phase with a large size exhibits spherical and elongated shape on the grip section. Fig. 2 (b)–(d) exhibits the microstructures of the uniform deformation sections of the tensile specimens with different strain rates. It is clear to observe that the α phase is significantly influenced by deformation. At the strain rate of 2.78×10^{-3} s^{-1}, some α grains with a clubbed shape near in a line parallel to the load direction (as indicated by un-directional arrow) indicates that the α phase elongated and cracked during deformation process at the higher strain rate. When the strain rate decreases, the α phase shows a larger size and exhibits a weak directionality parallel to the load direction, as shown in Fig. 2 (b) and (c). The size of α phase in gauge section of the tensile specimens increases with the decrease of deformation strain rates is relevant to the strain rate, which provides more time to growth of α phase.

Fig. 3 (a) and (b) show the phase and grain boundary EBSD maps on the uniform deformation section of tensile specimen at the strain rate of 2.78×10^{-4} s^{-1}. As can be seen it from Fig. 3 (a), the α phase distributes in subgrain and grain boundaries, it means that the α phase can limit the growth of β grains during superplastic deformation in α+β field. Meanwhile, as shown in Fig. 3 (b), there is

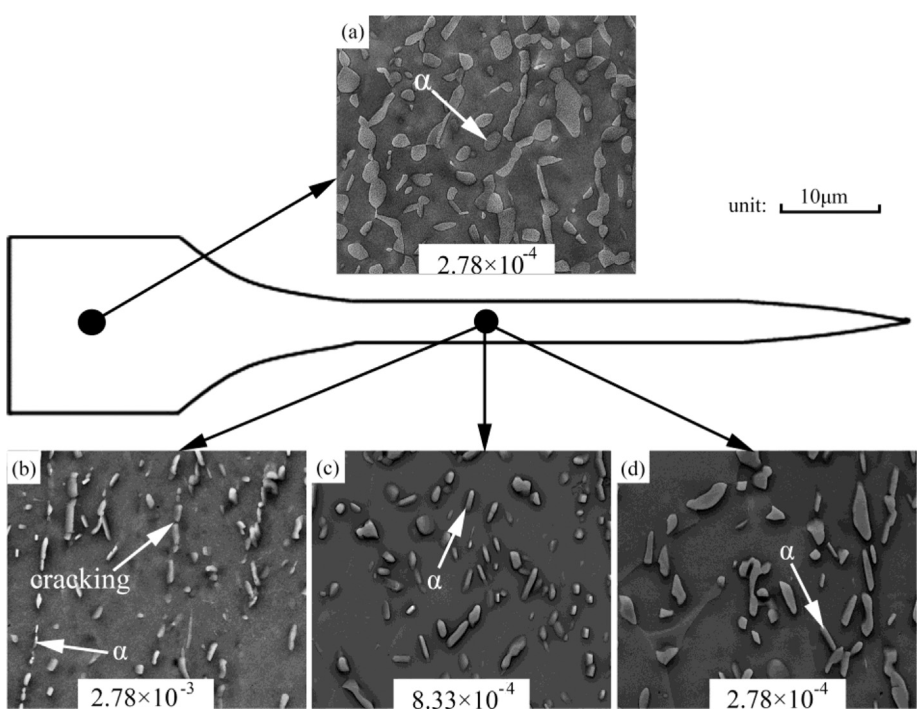

Fig. 2. Microstructure of the alloy on grip section deformed at strain rate of 2.78×10^{-4} s^{-1} (a) and on uniform deformation section at strain rate of 2.78×10^{-3} s^{-1} (b), 8.33×10^{-4} s^{-1} (c), 2.78×10^{-4} s^{-1} (d).