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Superplastic behavior and deformation mechanism of Ti600 alloy

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ABSTRACT

The superplastic deformation behavior and mechanism of Ti600 alloy at elevated temperature were investigated. Results show that Ti600 alloy exhibits excellent superplastic behavior in the temperature range of 840–960 °C at $5\times10^{-4}\,s^{-1}$ and all of the tensile elongations exceed 220%. Optical microstructure shows that the grains still remain equiaxed and refined after deformation. However, primary α phase increases with the increasing of temperature. TEM observation indicates that the intragranular dislocation movement is very active and is accompanied by the occurrence of dynamic recrystallization, which is beneficial to promote the grainboundary sliding and to relieve the stress concentration. The superplastic deformation mechanism of Ti600 alloy is grainsgroup sliding accommodated by dislocation movement and dynamic recrystallization. The model of this mechanism is a corrected Ball–Hutchinson Model.

1. Introduction

Titanium alloys are widely used in aviation, aerospace, marine and chemical industries due to their high ratio of strength to weight, good mechanical properties, and excellent corrosion resistance and so on. However, their application is hampered by low machinability and poor deformation characteristics [1]. In the past years, superplastic forming (SPF) of titanium alloys has emerged as a promising technology since significant saving in manufacturing cost and weight of airframe structures can be achieved. Considerable efforts have been devoted to investigate superplastic deformation behavior of various titanium alloys, especially on the Ti–6Al–4V alloy [2]. As a result, the role of processing parameters such as deformation temperature, strain rate, grain size and volume fraction of component phase have been well established in relation to the actual forming process of Ti–6Al–4V alloy [3]. Some other (α+β) alloys such as Ti–6Al–2Sn–4Zn–2Mo, Ti–6Al–4V–2Fe, Ti–3Al–2.5V have also been investigated. Their superplastic deformation mechanism has been accepted as grain boundary sliding (GBS) and its accommodation process [4].

However, no work so far has been systematically reported on superplastic behavior of a new near-alpha titanium alloy Ti–6Al–2.8Sn–4Zr–0.5Mo–0.4Si–0.1Y called Ti600 alloy, especially on its SPF mechanism. Therefore, in addition to investigate the superplastic deformation behavior of Ti600 alloy in a range of temperatures, our study attempts to analyze the superplastic deformation mechanism of Ti600 alloy based on the microstructure analysis using TEM: one is to investigate the grainboundary sliding (GBS) characteristics and the other is to verify the accommodation mechanisms and deformation mechanism model.

2. Experimental

The material used in this study was hot rolled and annealed Ti600 alloy in sheet form with a thickness of 2 mm supplied by Northwest Institute for Nonferrous Metal Research in China. Its normal chemical compositions in weight percent were Ti–6Al–2.5Sn–4Zr–0.5Mo–0.4Si–0.1Y. The β transformation temperature of Ti600 alloy is 1010 °C. As a recently developed high temperature titanium alloy, Ti600 alloy has good tensile strength, excellent creep performance and superior fatigue resistance at the servicing temperature of at least 600 °C. However, it is rather difficult to form into complex shape by using conventional processing method because of its poor workability. Therefore, study of its superplasticity is necessary.

The experimental specimens, 10 mm in gauge length and 6 mm in width, were electro-discharge machined from the sheets in the longitudinal orientation for superplastic tensile tests, as shown in Fig. 1. The microstructure of the as-received specimens of Ti600 alloy is consist of equiaxed α phase and a small quality of β phase, as shown in Fig. 2.

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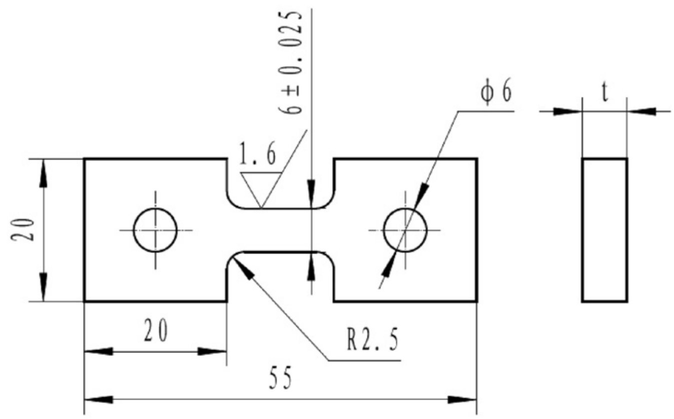

Fig. 1. Schematic diagram of specimens for superplastic tensile test.

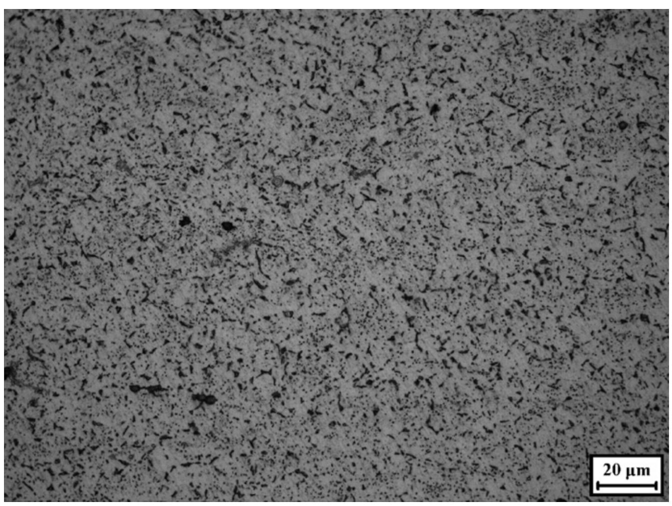

Fig. 2. Microstructure of as-received specimen of Ti600 alloy.

The superplastic tensile tests at a constant strain rate were conducted on CMT-4104 microcomputer controlled electronic universal testing machine at temperatures ranging from 840 to 960 °C with 40 °C intervals and at strain rate of $5\times10^{-4}\,s^{-1}$. Glass-protective lubricants were used to resist the oxidation. Specimens were held at the deformation temperatures for 30 min and quenched immediately in the water after fracture.

The metallographic specimens after deformation were ethed with a solution of $1HF+3HNO_3+5H_2O$ (volume fraction) and then examined by an optical microscope (OM) Leica DFC320. Thin foils for TEM were prepared by mechanical thinning to 120 μm, and then, by an electrolytic thinning using a twin jet polisher with an electrolytic solution of 6% perchloric acid, 34% *N*-butanol and 60% methanol (volume fraction) at −30 °C. The foils were examined by transmission electron microscope (JEM-2000X) operating at an accelerating voltage of 200 kV.

3. Experimental results

3.1. Tensile behavior

The true stress–strain curves of Ti600 alloy for deformation at four different temperatures are shown in Fig. 3. At all the tested temperatures, the peak stress decreases markedly due to the easier dislocation movement [5]. With increasing temperature, the stress–strain curve changes from strain softening to quasi-

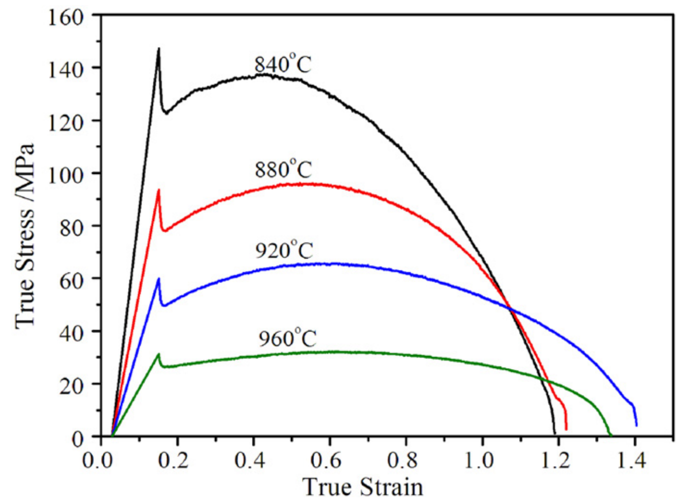

Fig. 3. True stress-true strain curves of Ti600 alloy during tensile tests.

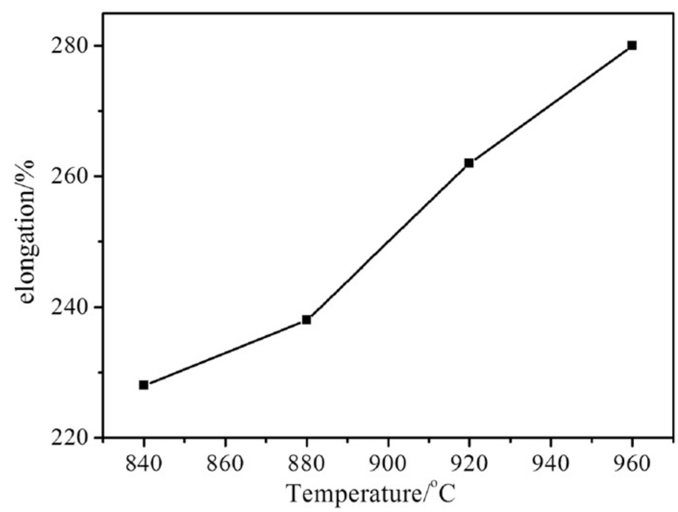

Fig. 4. Effect of temperature on elongation of Ti600 alloy.

steady state which is a typical characterization of the superplastic deformation.

The dependence of elongation on temperature for Ti600 alloy is shown in Fig. 4. It can be seen that Ti600 alloy exhibits good superplasticity at various temperatures. Moreover, the elongation increases with increasing of the temperature from 840 °C to 960 °C and a maximum elongation of 280% is obtained at 960 °C.

With the temperature increases, the flow stress decreases and the elongation increases, as shown in Fig. 3 and Fig. 4. It can be concluded that, with increasing temperature, more slip systems may become active since the critical resolved shear stress of the other slip system is reduced.

3.2. Microstructures after superplastic deformation

Fig. 5 shows the OM microstructures of Ti600 alloy deformed at different temperatures. As the temperature increases, the primary α-grains grow together and still keep equiaxed (Fig. 5). At 920 °C, the equiaxed area with black and white alternation occurs in the microstructure (Fig. 5c). The white area is equiaxed α phase and the black area is (α+β) phase. This is because most transformed β phase is stabilized after quenched from hot deformation. At 960 °C, lots of small dot-like α-grains are observed due to dynamic recrystallization during superplastic