

Flow behavior and deformation mechanism in the isothermal compression of the TC8 titanium alloy

K. Wang, M.Q. Li*

School of Materials Science and Engineering, Northwestern Polytechnical University, Xi'an 710072, China

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ABSTRACT

The TC8 titanium alloy was isothermally compressed at the deformation temperatures ranging from 820 °C to 980 °C, strain rates of 10 s^{-1} , 30 s^{-1} and 50 s^{-1} , and a height reduction of 60%. An optical microscope (OM) and a transmission electron microscope (TEM) were used to examine the microstructure. The flow stress decreases with the increasing of deformation temperature and decreasing of strain rate. The strain rate sensitivity exponent m increases gradually to a maximum value as the deformation temperature increases from 820 °C to 940 °C, and then decreases at the deformation temperature of 980 °C. The strain hardening exponent n decreases with the decreasing of deformation temperature, and gets a maximum value at the strain rate of 30 s^{-1} and a given deformation temperature. According to the microstructure examination, the variation of flow stress, m and n values are found to depend on the phase transformation, grain morphology, dislocation content, dynamic recovery (DRV) and dynamic recrystallization (DRX) of primary α and β phases. The apparent activation energy for deformation is $429.766 \pm 80.394\text{--}383.478 \pm 78.734\text{ kJ mol}^{-1}$, and indicates that the dislocation climbing is not the main deformation mechanism. This deduction agrees well with the microstructure examination which shows that the DRX of primary α phase and β phase play an important role in the isothermal compression of TC8 titanium alloy.

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1. Introduction

Hot deformation of titanium alloys in the two phase region is associated with two major requirements: (1) the production of usable shapes through primary working (ingot breakdown); (2) the optimization of mechanical properties through microstructure control. However, titanium alloy is not easy to be deformed at high temperature because the resistance of deformation is sensitive to temperature, which results in the narrow temperature range of hot deformation. It is therefore important to gain a good insight into the flow behavior and deformation mechanism during hot deformation so as to optimize the processing parameters and control the microstructure of titanium alloys.

Many investigators studied the flow behavior of different kinds of titanium alloy, and found that the flow stress is very sensitive to the processing parameters [1–6]. It is well known that the strain rate sensitivity exponent m is an important parameter in determining the tensile ductility of superplastic material and related to the deformation mechanism [7,8], and the strain hardening exponent n is an important parameter in controlling the amount

of uniform plastic strain which the material can undergo before strain localization, necking and failure [9]. In order to study the flow ability and the dependence of flow stress on the processing parameters, many investigations focused on the variation of m and n values in the hot deformation of titanium alloy. Some investigators pointed out that the m and n values were sensitive to the processing parameters [10,11]. Luo et al. [12,13] studied the variation of m and n values in the isothermal compression of Ti60 alloy and Ti–6Al–4V alloy, and found that the dependence of m and n values on the processing parameters was related to the β phase content and primary α grain size. Huang et al. [14] studied the flow behavior in the hot deformation of Ti–24Al–14Nb–3V–0.5Mo alloy, and suggested that the grain boundary slipped as the m values exceed 0.3. Meanwhile, the apparent activation energy for deformation is an important parameter for the kinetic analysis in the high temperature deformation of titanium alloy. Wanjara et al. [15] and Jia et al. [16] pointed out that the dislocation climbing was the main deformation mechanism if the apparent activation energy for deformation is close to that for self-diffusion. However, it is necessary to further analyze the relationship between flow behavior and microstructure evolution, such as dynamic recovery (DRV) and dynamic recrystallization (DRX).

The TC8 titanium alloy (corresponding to Russia titanium alloy BT8) is a kind of α/β titanium alloy which has been widely used in

* Corresponding author. Tel.: +86 29 88460328; fax: +86 29 88492642.

E-mail address: honeyqli@nwpu.edu.cn (M.Q. Li).

the aeronautical industries due to its highly attractive properties, such as high strength, low density, high toughness and good high-temperature properties. In the recent investigations, the authors [17] studied the precipitation mechanism of the secondary α phase in the TC8 titanium alloy compressed in the $\alpha+\beta$ phase field. However, there are few reports focusing on the deformation behavior in the hot deformation of TC8 titanium alloy.

In practice, the minimum value of strain rate in the forging of titanium alloy is 10 s^{-1} , so this work selected the strain rate as $10\text{--}50\text{ s}^{-1}$ for the isothermal compression of TC8 titanium alloy in the two phase region. An optical microscope (OM) and a transmission electron microscope (TEM) were used to observe the microstructure. The flow behavior, including flow stress–strain curve, strain rate sensitivity exponent, strain hardening exponent and

kinetic analysis, was investigated with the help of the microstructure examination of TC8 titanium alloy.

2. Experimental procedures

The TC8 titanium alloy used in this study was received in the form of a rod with a diameter of 25 mm and with the chemical composition (wt%) of 6.5 Al, 3.3 Mo, 0.3 Si, 0.06 Fe, 0.01 C, 0.002 H, 0.075 O, 0.005 N, and a balance of Ti. The microstructure of the as-received TC8 titanium alloy is shown in Fig. 1. The β transus temperature is measured to be $1000\text{ }^{\circ}\text{C}$ [17]. Cylindrical specimens that were 8.0 mm in diameter and 12.0 mm in height were machined from the TC8 titanium alloy rod. The alloy was isothermally compressed on a Gleeble 3500 thermal simulator at the deformation temperatures ranging from $820\text{ }^{\circ}\text{C}$ to $980\text{ }^{\circ}\text{C}$ with an interval of $40\text{ }^{\circ}\text{C}$, the strain rates of 10 s^{-1} , 30 s^{-1} and 50 s^{-1} , and a height reduction of 60%. Before compression, the specimens were heated to the deformation temperature and held for 3 min to establish a uniform temperature. After compression, the specimens were cooled in wind to room temperature.

To observe the microstructure evolution, the compressed specimens were sectioned along the compression axis and prepared for microstructure examination by standard metallographic techniques. For the OM examinations, the sectioned specimen was prepared following standard grinding/polishing procedures and etched in a solution of 5% HF, 15% HNO_3 , and 80% H_2O . For the TEM examination, the sectioned specimen was ground to $60\text{--}80\text{ }\mu\text{m}$ followed by twin-jet electropolishing. An OLYMPUS GX71 OM and a Tecnai F30 G² TEM were used to examine the microstructure.

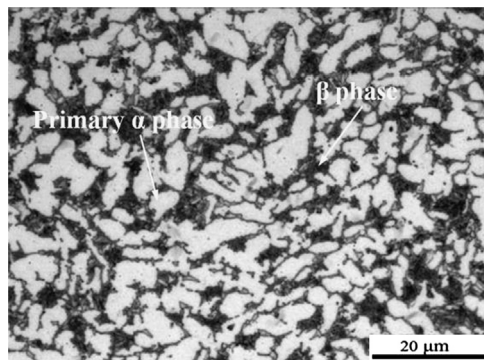


Fig. 1. Microstructure of the as-received TC8 titanium alloy.

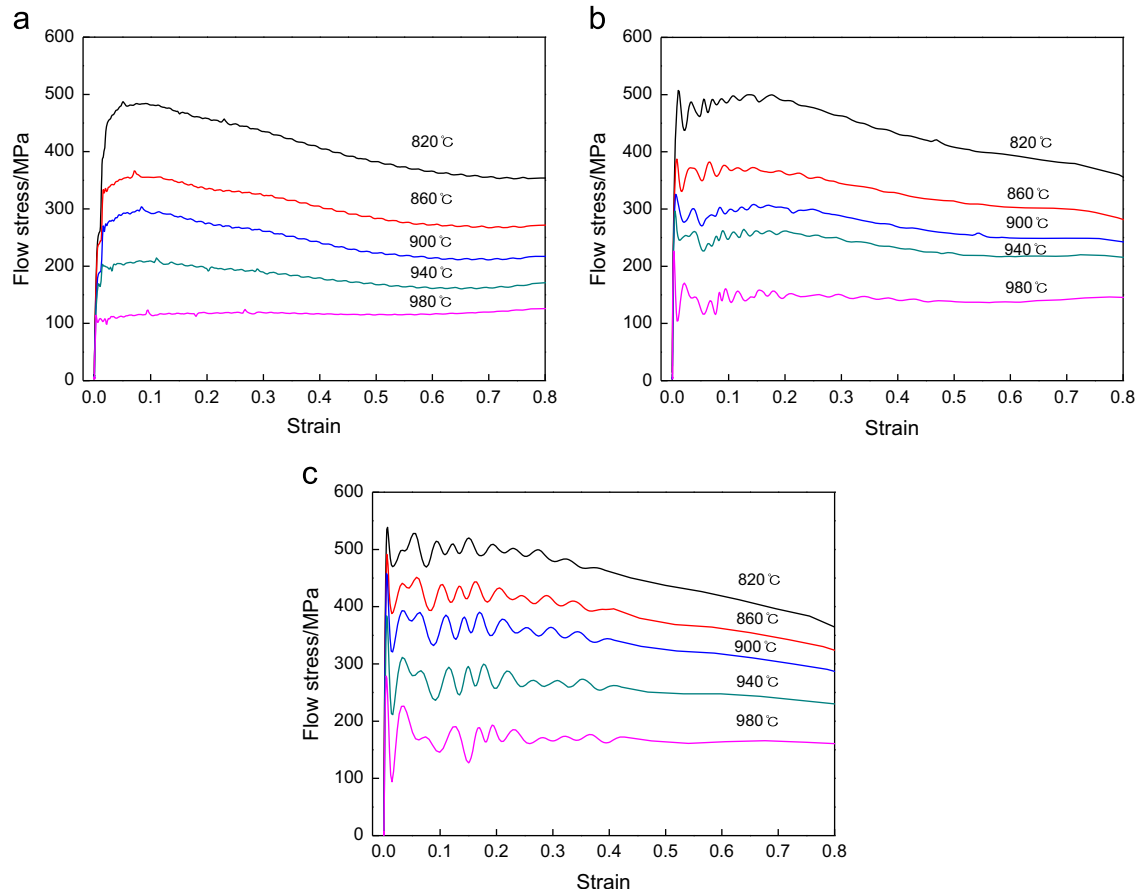


Fig. 2. Flow stress–strain curves in the isothermal compression of TC8 titanium alloy at the strain rates of: (a) 10 s^{-1} , (b) 30 s^{-1} , and (c) 50 s^{-1} .

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