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High temperature deformation behavior of near alpha Ti–5.6Al–4.8Sn–2.0Zr alloy

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Abstract

Isothermal compression of Ti–5.6Al–4.8Sn–2.0Zr alloy was carried out on a Thermecmaster-Z simulator at deformation temperatures between 960 and 1060 °C, constant strain rate between 0.001 and 10.0 s^{-1}, and a maximum height reduction of 70%. The high temperature deformation behavior of Ti–5.6Al–4.8Sn–2.0Zr was characterized based on an analysis of the stress–strain behavior, kinetics and processing map. The activation energy for deformation obtained during high temperature compression of Ti–5.6Al–4.8Sn–2.0Zr alloy are 221.7 kJ/mol in the β phase region and 1082.4 kJ/mol in the α + β phase region. The constitutive equation proposed to describe the flow stress as a function of strain rate, strain and deformation temperature during high temperature compression of Ti–5.6Al–4.8Sn–2.0Zr alloy enables a close agreement between the predicted and experimental stress–strain curves.

Keywords: Titanium alloy; High temperature deformation; Processing map; Constitutive equation

1. Introduction

The latest high temperature titanium alloys, such as Ti-1100 and IMI834 have good creep resistance against high temperature, excellent thermo-stability and mechanical properties at the servicing temperatures of 600 °C [1]. Ti–5.6Al–4.8Sn–2.0Zr alloy is another titanium alloy considered for high temperature applications, such as for the manufacture of the aerofoil blades and discs in the aviation and aerospace industries [2].

In order to develop plastic forming methods, such as forging, it is necessary to characterize, at the deformation conditions, the material behavior, which includes the flow stress behavior, deformation mechanisms and microstructure evolution. Numerous investigations have been performed to characterize the hot working behavior of some high temperature titanium compositions, such as IMI834, IMI685 alloys [3–8]. For instance, Wanjara et al. [3] have investigated the effect of process parameters on the flow stress behavior [3] and microstructural evolution [9,10] during isothermal compression of near alpha IMI834 titanium alloy at different strain rates and deformation temperatures in the alpha and α + β phase regions. Also, the deformation behavior of the IMI685 alloy during the isothermal forging has been investigated for deformation temperatures between 1025 and 1075 °C and strain rates of 0.09–0.005 s^{-1} by Liu and Baker [4].

In this paper, isothermal compression of Ti–5.6Al–4.8Sn–2.0Zr alloy has been conducted at different hot working temperatures, strain rates and strains to characterize the flow behavior and understand the deformation mechanisms during processing in the α + β and β phase regions.

2. Experimental conditions

Ti–5.6Al–4.8Sn–2.0Zr alloy was received in bar form with a diameter of 18 mm. Heat treatment prior to isothermal compression was applied as follows: (1) heating to 990 °C and holding for 2 h, (2) air-cooling to room temperature, (3) heating to 700 °C and holding for 2 h and (4) air-cooling to room temperature. Cylindrical compression specimens were machined from the heat-treated bar to have dimensions of 8 mm in diameter by 12 mm in height. The as-received microstructure of the Ti–5.6Al–4.8Sn–2.0Zr alloy consisted of the α grains having a grain size 5.0 μm, as illustrated in Fig. 1.

To investigate the effects of process parameters on deformation behavior and microstructural evolution of the Ti–5.6Al–4.8Sn–2.0Zr alloy, isothermal compression at a constant strain rate was conducted on a Thermecmastor-Z simulator with an optical dilatometer. Specifically, the specimens were held for 3 min prior to isothermal compression at the nominal hot working temperatures, which were studied between 960 and 1060 °C, in intervals of 10 °C. At each deformation temperature, constant strain rates from 0.001 to 10.0 s^{-1} were examined to an isothermal compression reaching 70.0% of maximum height reduction. After deformation, the specimens were air-cooled to room temperature. During

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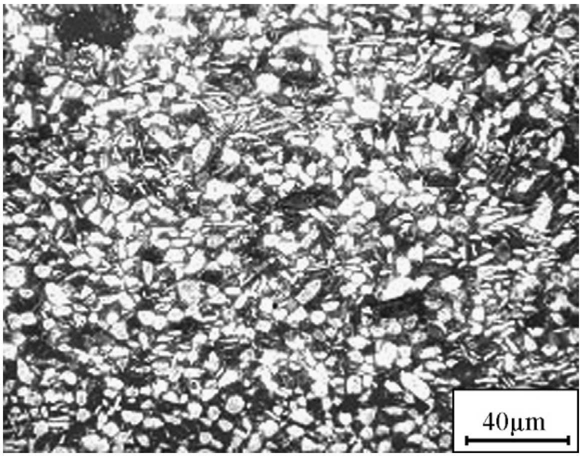

Fig. 1. Micrograph of the received Ti–5.6Al–4.8Sn–2.0Zr alloy.

isothermal compression, the flow stress was recorded as a function of strain for each deformation temperature and strain rate. This experimental data was used for the calculation of the activation energy and for constructing the processing map. For microstructural examination, the isothermally deformed specimens were sectioned parallel to the compression axis, and microscopic examination was conducted at an OLYMPUS PMG3 optical microscope.

3. Experimental results and discussion

3.1. Flow stress

To represent the flow behavior in two phase (α + β) and the single phase (β) regions, the typical stress–strain curves at a deformation temperature 970 and 1060 °C are given in Fig. 2 for different strain rates. The flow behavior, both above and below the nominal β transus temperature of 1030 °C for the Ti–5.6Al–4.8Sn–2.0Zr alloy, exhibits an initial increase in the stress with increasing strain until a peak stress value beyond which there is a decrease in the stress with the increasing strain. Under some conditions, a steady state region is achieved in which the flow stress was observed to remain nearly constant with increasing strain. With increasing strain rate, the flow stress value of both the peak stress and steady state stress were observed to increase.

The peak stress values occurring during isothermal compression of Ti–5.6Al–4.8Sn–2.0Zr alloy, shown in Fig. 3a, were observed to generally increase with increasing deformation temperature. However, the overall increase was relatively small for low strain rate values (0.001 s^{-1}) and increased with increasing strain rate. Also, the peak stress of Ti–5.6Al–4.8Sn–2.0Zr alloy has a slope drop and then becomes steady above a deformation temperature of 1000 °C resulting from dynamic recrystallisation. The steady state flow stress in the high temperature deformation of Ti–5.6Al–4.8Sn–2.0Zr alloy, shown in Fig. 3b, exhibits a similar behavior as the peak stress to increases in the deformation temperature and strain rate. These experimental flow stress results indicate that Ti–5.6Al–4.8Sn–2.0Zr alloy has a poor workability, which is characterized a narrow range of deformation temperatures and a significant effect of temperature, strain and/or strain rate.

Most of plastic power converts to heat and results in temperature rise in the high temperature deformation process of materials. Assume that the strain increment is $\Delta\varepsilon$ and the homogeneous temperature rise ΔT can be calculated in the following equation [11].

$$\Delta T = \frac{\eta}{\rho c}\int_0^{\varepsilon} \sigma \, d\varepsilon \tag{1}$$

where c is the specific heat (J/g K^{-1}), ρ the material density (g/cm^3), σ the flow stress (MPa), ε the strain and η is thermal efficiency being calculated as follows.

$$\eta = \begin{cases} 1 & \dot{\varepsilon} \geq 1.0\,s^{-1} \\ (3 + \lg\dot{\varepsilon})/3 & 0.001\,s^{-1} \prec \dot{\varepsilon} \prec 1.0\,s^{-1} \\ 0 & \dot{\varepsilon} \leq 0.001\,s^{-1} \end{cases} \tag{2}$$

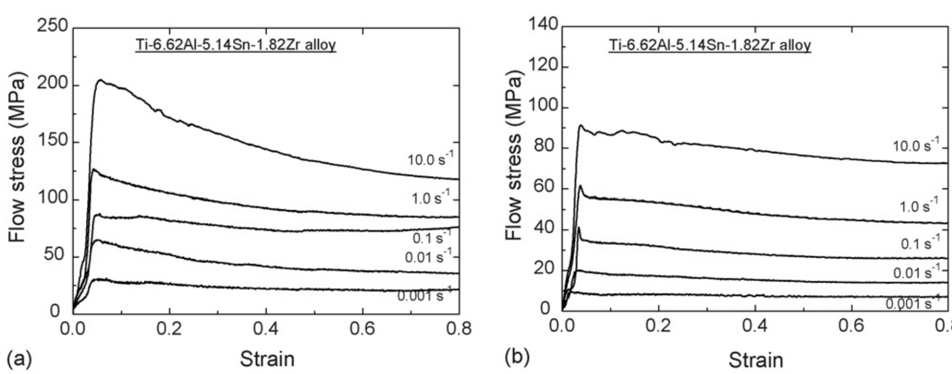

Fig. 2. Stress–strain curves in the isothermal compression of Ti–5.6Al–4.8Sn–2.0Zr alloy: (a) 970 °C and (b) 1060 °C.

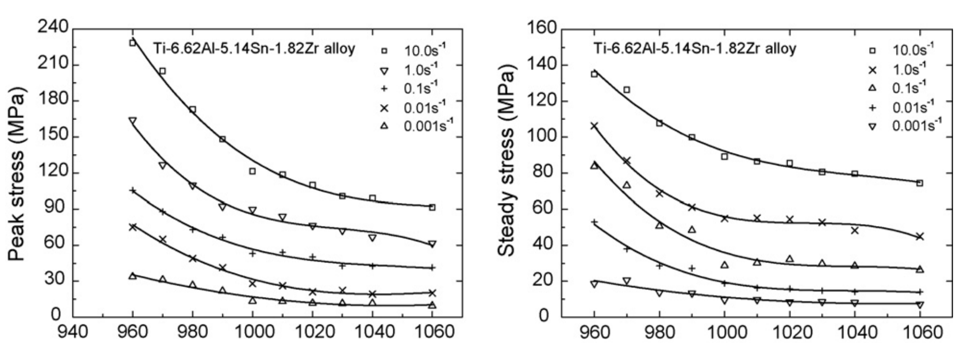

Fig. 3. (a) Peak and (b) steady stress in the isothermal compression of Ti–5.6Al–4.8Sn–2.0Zr alloy.