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A step deformation method for superplasticity improvement of coarse-grained Ti–15–3

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KEYWORDS

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Abstract Ti–15 V–3Cr–3Sn–3Al (Ti–15–3), a kind of metastable beta titanium which has high specific strength and good cold-formability, is highlighted for applications in the aerospace manufacture industry. However, the technique for improving its formability at elevated temperatures is still a challenge at present. In this work, a step deformation method is proposed for superplasticity improvement of coarse grained Ti-15-3 plates at temperatures around its beta transus. The effects of the strain rate and the strain at the first stage on the superplasticity are investigated. The results show an increase of the strain rate sensitivity and a decrease of the flow stress under the step deformation mode compared to those obtained under constant strain rates at 780 °C. The maximum strain to failure obtained in the step mode is 93% higher than that deformed in the constant strain rate mode. Strain rates, strains at the first stage, and temperatures have influences on the superplasticity improvement. The deformation mechanism is concluded as subgrain formation accommodated by grain boundary sliding rate-controlled by dislocation climb. The improved *m* value in the step deformation is accounted to the extra dislocation density produced during the strain rate reduction.

1. Introduction

Ti–15 V–3Cr–3Sn–3Al (Ti–15–3), a kind of metastable beta titanium alloy, was invented in the 1980s which has high specific strength and good cold-formability.[1] Theoretically more slipping systems of bcc structures than those of hcp structures lead to better plasticity. The cold-formability of Ti–15–3 is superior to α + β and α titanium alloys.[1] Through solid solution treatment and aging, the strength of the alloy can be elevated to the range of 1000–1300 MPa.[2] The application of the alloy to aerospace manufacture industry is highlighted.[2]

Although better cold-formability of Ti-15-3 alloy, the plastic forming of the alloy is usually performed at elevated temperatures for reducing flow stress. The hot deformation behaviors of Ti–15–3 alloy and other near-beta titanium alloys have been investigated by several authors.[2–11] The investigation on the superplasticity of Ti–15–3 plates with an average grain size of 80 μm was reported by Hamilton.[3] A strain to

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failure of 229% and a strain rate sensitivity (m) of 0.5 at 815 °C and $2 \times 10^{-4}\,s^{-1}$ were obtained. Srinivasan and Weiss[4] performed hot deformation study on casted and recrystallized Ti–15–3 in the temperature range of 927–1260 °C at the strain rate range of 0.1–0.001 s^{-1}. A sharp peak stress was exhibited initially in stress-strain curves followed by a constant stress state. An inhomogeneous substructure was found when deformed to large strains. Hot-deformation of a near-β titanium alloy Ti–10V–2Fe–3Al[5,6] at the temperatures of α + β phase and β phase areas was studied. The deformation mechanisms were summarized as dislocation glide at high strain rates and diffusion creep at low strain rates. Griffiths and Hammond[7] investigated the superplasticity of coarse grained beta Ti alloys Ti-8Mn, Ti-15Mo and Ti-13Cr-11V-3Al above the temperatures of beta transus. As a result, the m values of these titanium alloys approach 1 as the strain rate is lower ($1 \times 10^{-5}\,s^{-1}$), whereas the m value is 0.3 at the strain rate of $1 \times 10^{-3}\,s^{-1}$. Using Herring-Nabarro diffusion creep, an m value of 1 at lower strain rates was predicted, while using Weertman's model involving the glide and climb of dislocations, an m value of 0.3 at higher strain rates was predicted.

Even with these investigations, it is still necessary to improve the superplasticity of Ti-15-3 for meeting the requirement of the manufacture industry. Some detailed studies are still required for full understanding of the deformation mechanism of Ti-15-3. In this work, a continuous step deformation technique was induced to attempt to improve the superplasticity of coarse grained Ti-15-3. Relatively fast strain rate at the first stage was set and followed by lower strain rate deformation. The temperature was chosen around its beta transus, which was considered to be beneficial to optimize the mechanical properties after deformation. The effects of the strain rate and the strain at the first stage on the following deformation were investigated.

2. Experimental procedure

In this study, hot-rolled Ti–15–3 plates with the thickness 13 mm were commercially obtained from Nippon Steel Co. Ltd. The composition is listed in Table 1. As-received Ti–15–3 occupies a microstructure of equiaxial grains (see Fig. 1) with an average grain size of 112 μm. The beta transus of the alloy was known as 760 °C.[2] Dog-bone shaped tensile specimens with the thickness of 2 mm, gauge length of 10 mm, and gauge width of 3 mm were prepared by wire-cutting with the tensile axis parallel to the rolling direction. Tensile tests were carried out by using a standard constant cross-head speed machine in argon gas atmosphere at temperatures of 700, 780 and 850 °C, respectively. Before the tensile tests, specimens loaded to the testing machine were kept at the temperature for 15 min to achieve temperature homogenization. The strain rate step model was set with the strain rate $\dot{\varepsilon}_1 = 0.1$ and 0.01 s^{-1} and the strain $\varepsilon_1 = 0.2$, 0.3, 0.5 and 0.6 at the first stage. At the second stage, the strain rates were in the range of $\dot{\varepsilon}_2 = 3 \times 10^{-4}$–$7 \times 10^{-3}\,s^{-1}$ for superplastic deformation. Constant strain rate tests were also carried out for comparison. Deformed specimens were quenched into water at the end of the first stage for freezing the deformed microstructure. Microstructural observations were performed on frozen specimens by an optical microscope and a scanning electronic microscope (SEM) equipped with electron back scattering diffraction (EBSD) system.

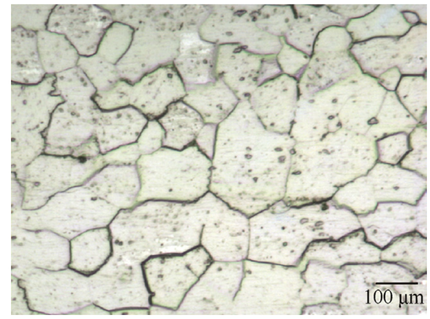

Fig. 1 Optical microstructure of as-received Ti–15–3 with average grain size of 112 μm.

3. Results and discussion

3.1. Stress-strain curves

Fig. 2 shows the true stress-true strain curves of the step deformation at the temperature 780 °C. The curves shown in Fig. 2(a) and (b) were obtained under the conditions of $\dot{\varepsilon}_1 = 0.1\,s^{-1}$, $\varepsilon_1 = 0.3$, and $\dot{\varepsilon}_1 = 0.01\,s^{-1}$, $\varepsilon_1 = 0.2$, respectively. A sharp peak stress is exhibited at the initial stages of the curves. In the following deformation the flow stress decreases moderately with the strain. When the strain rate drops suddenly at a strain, the flow stress is decreased sharply. The flow stress in the follow undergoes short increase and then slow decrease with the strain increased.

The peak stress occurs under every strain rate in this work. However, it is not exhibited at the second stage. The magnitude of the peak stress depends on the strain rate and temperature. With the decrease of the strain rate and the increase of the temperature, the peak stress is decreased which indicates thermal activated mechanism.

The phenomenon of the peak stress was observed in the hot deformations of near-beta and beta titanium alloys such as Ti–29Ta–13Nb–5Zr,[12] Beta–CEZ[13] and Ti–10V–2Fe–3Al[14]; however, it was not exhibited in the beta phase deformations of commercially pure titanium[15] and Ti–6Al–4V.[16] The microstructural understanding of this phenomenon is related to rapid hardening caused by solute-dragged dislocation slip and high solute concentration on dislocations. Rapid hardening happening in bcc structure rather than hexagonal closed-packed structure is due to the loose atomic package and facile

Table 1 Compositions of Ti–15–3.

Element	Al	Sn	V	Cr	Fe	C	O	N	H	Ti
Content (wt%)	3.19	3.10	15.05	3.27	0.01	0.0049	0.081	0.011	0.0189	Bal.