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Microstructural evolution and deformation mode under high-temperature-tensile-deformation of the Ti-6Al-4V alloy with the metastable α′ martensite starting microstructure

Hiroaki Matsumoto [a,*], Takuro Nishihara [b], Yohei Iwagaki [c], Tohru Shiraishi [c], Yoshiki Ono [c], Akihiko Chiba [d]

[a] Department of Advanced Materials Science, Faculty of Engineering, Kagawa University, 2217-20 Hayashi-cho, Takamatsu, Kagawa 761-0396, Japan
[b] Graduate student, Faculty of Engineering, Kagawa University, 2217-20 Hayashi-cho, Takamatsu, Kagawa 761-0396, Japan
[c] NHK Spring Co., Ltd, Research & Development Division, 3 – 10 Fukuura, Kanazawa-ku, Yokohama 236-0004, Japan
[d] Institute for Materials Research, Tohoku University, 2 – 1-1 Katahira, Aoba-ku, Sendai, Miyagi 980-8577, Japan

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ABSTRACT

Ti-6Al-4V alloy having the metastable α′ martensite starting microstructure was investigated for microstructural changes during high-temperature-tensile-deformation at temperatures from 700 °C to 900 °C. As compared to the deformation of Ti-6Al-4V alloy with similar lamellar morphology consisting of an equilibrium (α+β) phase, the quite larger elongation to fracture and the higher strain-rate-sensitivity (*m*) are exhibited in the case of the α′ martensite starting microstructure. The dynamic globularization associated with an occurrence of the discontinuous dynamic recrystallization is enhanced during tensile deformation of the α′ martensite starting microstructure, resulting in the activation of grain boundary sliding at latter stage of deformation (which contributes to an increase in tensile elongation). Furthermore, dynamic β precipitation from the α′ martensite during deformation also results in contribution to an additional stress-accommodation mechanism. As compared to the case in the equilibrium (α+β) lamellar microstructure, the present work indicates that the metastable microstructure of the α′ martensite starting microstructure is more beneficial for an enhancement of high temperature ductility associated with enhancement of dynamic globularization and an occurrence of boundary sliding.

1. Introduction

Titanium alloys have a high specific strength and a good corrosion resistance. The most widely used Ti alloy is Ti-6Al-4V alloy (in wt%)(hereafter designated as Ti-64 alloy) because of its good strength-ductility balance and excellent superplastic property. For enhancement of superplastic property, the microstructure with a grain size less than 10 μm, an equiaxed grain shape, and a relatively homogeneous structure is more preferable [1]. The refinement of microstructure in the Ti-64 alloy produced by severe plastic deformation technique has contributed to the decrease in superplastic temperature to below 750 °C [2–4]. In addition, stress induced phase transformation has been reported to act as an additional stress accommodation mechanism at grain boundary, leading to an enhancement of superplasticity [5,6]. Herein, the dynamic β precipitation, which is attributed to stress-induced type or formation from the metastable α single phase, contributed to stress accommodation. So, it implies that the metastable microstructure is also beneficial for an enhancement of superplasticity.

For refinement of microstructure in Ti alloy, hot working of the α′ martensite microstructure is also reported to result in ultrafine-grained (UFG) microstructure in Ti alloy [7–11]. This is mainly due to the enhancement of dynamic globularization. And the present authors have mentioned that this enhancement of dynamic globularization is attributed to the frequent occurrence of discontinuous dynamic recrystallization [11]. Herein, these works focus on the production of UFG microstructure by hot working. However, the effect of the microstructural conversion related to an enhancement of this dynamic globularization on the dynamic change in deformation mode is still unclear. In addition, this dynamic change in deformation mode in the α′ martensite starting microstructure under tensile deformation mode is also unclear. Quite recently, the present authors have presented the influence of the α′ starting microstructure on tensile deformation behavior at high temperature [12], however, there is no detailed results on the microstructural conversion process and associated deformation

* Corresponding author.
E-mail address: matsu_h@eng.kagawa-u.ac.jp (H. Matsumoto).

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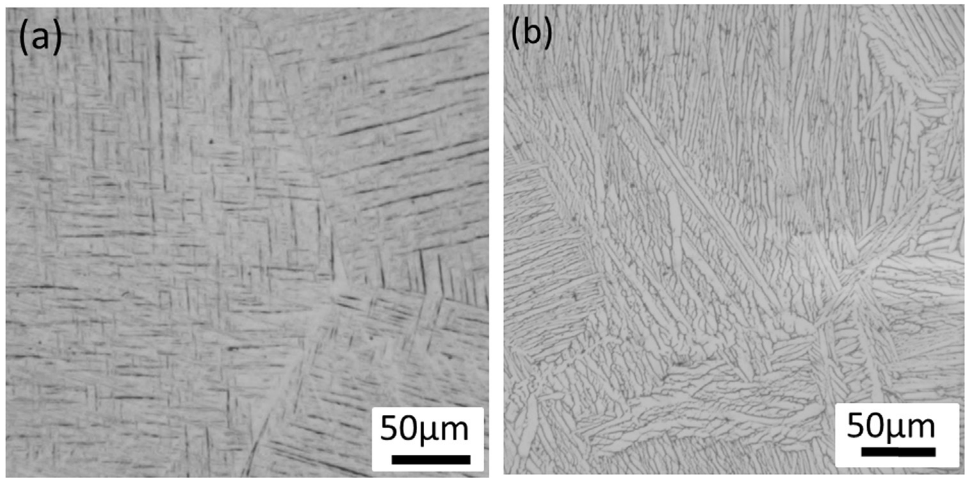

Fig. 2. Optical micrographs of the starting microstructures of (a) the STQ specimen and (b) the ST-FC specimen.

characteristic. Therefore, this work aims at examining the microstructural conversion and the deformation characteristic during high-temperature-tensile-deformation of the Ti-64 alloy having the α′ martensite starting microstructure, and discussing the role of dynamic microstructural change (e.g. globularization, phase transformation) from the α′ martensite on the dynamic change in deformation mode in detail.

2. Experimental procedure

The material used in this work was Ti-64 alloy with a chemical composition (in wt%) of 6.50 Al, 4.24 V, 0.17 O, 0.004 N, and balance Ti. The hot rolled Ti-64 alloy plate having an equiaxed (α+β) microstructure with a thickness of ranging from 2 mm to 2.5 mm was solution treated at 1100 °C-600 s followed by quenching in ice water or cooling (in argon atmosphere) at a rate of 0.45 °C/s to room temperature. Hereafter, the quenched specimen and the slow cooled (at a rate of 0.45 °C/s) specimen would be called as the STQ specimen and the ST-FC specimen, respectively.

Microstructures were identified by an optical microscopy (OM), a field emission scanning electron microscopy (FE-SEM) and an electron backscatter diffraction (EBSD) analysis. In EBSD analysis, the data were post-processed by means of TSL orientation microscopy (OIM) data analysis software. Samples for observation by SEM-EBSD were prepared by mechanical polishing followed by final polishing with colloidal silica suspension for 3.6 ks. For observation by optical microscopy, Kroll's reagent (5 pct HNO_3, 10 pct HF and 85 pct H_2O) was used for etching samples.

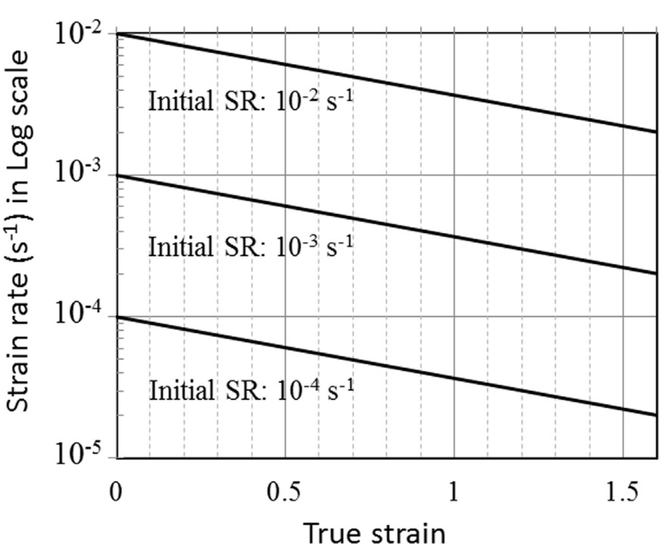

Fig. 1. Dynamic change in strain rate during deformation at condition of constant crosshead speed.

High temperature tensile behaviors were evaluated by tensile test at temperatures at 700 °C, 800 °C, 900 °C and at constant crosshead speeds to be initial strain rates ranging from 1.0×10^{-4} s^{-1} to 1.0×10^{-2} s^{-1} in air atmosphere. Herein, the heating before deformation was carried out at a rate of 60 °C/min and the rate of cooling after deformation was approximately 20 °C/min. Tensile testing was conducted at constant crosshead speed, therefore, true strain rate was dynamically changed during deformation. So, Fig. 1 summarizes the change in true strain rate as a function of true strain for each condition of initial strain rate. Hereafter, what has to be noticed is that microstructural evolution (as stated below) is occurred under the dynamic change in true strain rate.

In addition, in order to analyze the change in strain rate sensitivity (m) during deformation, the tensile strain rate jump test was also carried out. Then, deformation was underwent under the condition of constant crosshead-speeds up to true strain of approximately 0.4, followed by consecutive change in steps under the condition of constant true-strain-rates of 10^{-2} s^{-1}, 5×10^{-3} s^{-1}, 10^{-3} s^{-1}, 5×10^{-4} s^{-1} and 10^{-4} s^{-1}. Detailed testing condition was given in Section 3.3.2. In tensile specimen, the initial gauge length was 5 mm. Oxidation protection glass paint was coated on the surface of tensile test specimens before testing in order to reduce the influence of oxidation as much as possible.

3. Results and discussion

3.1. Initial microstructure before tensile test

The starting microstructures observed by optical microscopy for tensile test were shown in Fig. 2. The STQ specimen as shown in Fig. 2(a) reveals the acicular microstructure. According to the TEM observation, the $\{10\bar{1}1\}$ twin is observed to be formed inside of the acicular variant, indicating that martensitic transformation indeed occurs in the STQ specimen. So, the STQ specimen consists of a single α′ martensite microstructure. In the ST-FC specimen as shown in Fig. 2(b), the lamellar (α+β) microstructure (white phase: α phase, black phase: β phase) is observed. The average size of inter lamellar spacing is 0.88 μm in the STQ specimen and 4.1 μm in the ST-FC specimen, respectively.