Journal of Alloys and Compounds 740 (2018) 660–668

Contents lists available at ScienceDirect

Journal of Alloys and Compounds

journal homepage: http://www.elsevier.com/locate/jalcom

In-situ observations of the tensile deformation and fracture behavior of a fine-grained titanium alloy sheet

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ARTICLE INFO

Article history:
Received 8 October 2017
Received in revised form
12 December 2017
Accepted 2 January 2018
Available online 3 January 2018

Keywords:
Ti-6Al-4V titanium alloy
In-situ SEM
Slip band
Fracture surface

ABSTRACT

Deformation and crack initiation of industrial Ti-6Al-4V titanium alloy sheet were investigated using in-situ scanning electron microscopy (SEM) at room temperature. The results showed that slip band originated from α/α and α/β interfaces when the tension reaches the yield stage, and the slip mode develops from single slip to multi slip and finally the cross-slip occurs. Microcracks initiate primarily at the phase boundary or along the slip band within α phase, cracks are mainly connected along the 45° line. The fracture surface is full of dimples. Intergranular cracking is the main fracture mechanism.

1. Introduction

Titanium alloys are widely used in the aerospace, energy, chemical, military, marine and biomedical industries [1–3]. The most used of them is the Ti-6Al-4V alloy which is a two-phase alloy with an hcp α phase and a bcc β phase, due to its high specific strength, superior corrosion and oxidation resistance, and good biocompatibility [4–8], Ti-6Al-4V alloy is a two-phase alloy with an hcp α phase and a bcc β phase. Mechanical properties of titanium alloys are important criteria of material service capabilities both in aerospace and industrial applications [9]. Over the last few years, most researchers pay much attention to the thermos-mechanical processing, phase transformation and microstructure-mechanical properties relationships of the Ti-6Al-4V alloys [9–15]. However, direct reports on observations of the microprocess of plastic deformation and fracture are rarely reported. Depending on thermo-mechanical treatment, Ti-6Al-4V alloy can appears a large variety of microstructures with different morphologies, such as, lamellar, equiaxed, bi-modal and widmanstatten microstructures. A fine-grained equiaxed microstructure is reported to have advantages in terms of tensile stress and plasticity at room temperature, as well as superplasticity at high temperature. Thus, the large-scale industrial Ti-6Al-4V alloy sheet with fine-grained microstructure has an important application in the aerospace. As well known, the crack initiation or propagation is fundamental in controlling the deformation behavior, it is significant to study the intrinsic factors for the crack initiation of the Ti-6Al-4V alloy.

In-situ scanning electron microscopy (SEM) is a very effective and direct method to study the deformation and fracture of materials. It can be used to observe the crack initiation, propagation and fracture in the process of tensile deformation. It has been used to research the fracture behavior of titanium alloys in recent years [16–21]. Such as, H. Shao et al. [16] using in-situ scanning electron microscopy investigated the deformation and crack initiation of TC21 titanium alloy with equiaxed microstructure, W. J. Zhang et al. [18] have reported in-situ scanning electron microscope observations of fracture behavior of BT25y alloy during tensile process, B. G. Yuan et al. [19] researched the effect of hydrogen on fracture

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https://doi.org/10.1016/j.jallcom.2018.01.009

behavior of Ti-6Al-4V alloy by in-situ tensile test. However, most of the researchers were limited to the laboratory, in-situ investigation on the deformation and fracture mechanism under mechanical loading of large-scale industrial Ti-6Al-4V sheet is few.

In the present work, uniaxial tension tests on Ti-6Al-4Vsamples from industrial sheet were conducted in-situ with scanning electron microscopy observations at room temperature. The study aims to reveal the uniaxial tension behavior and the microstructure evolution for Ti-6Al-4V at different direction, and the microcrack nucleation and propagation process were observed to research fracture mechanism. The results would be of importance for better understanding of the structure-property relationship, as well as for practical application of the rolled Ti-6Al-4V alloy sheet.

2. Materials and methods

The material in this study is an industrial rolled Ti-6Al-4V sheet with an original size 2000 × 1000 × 1.2 mm, which was provided by the WESTERN TITANIUM TECHNOLOGLES CO., LTD. The α/β transition temperature of the alloy was about 980 ± 5 °C and its chemical components were listed in Table 1.

In–situ tensile specimens were machined from the industrial products via wire-electrode cutting along the transverse and longitudinal directions, respectively. Dimension of the specimen was presented in Fig. 1. The sample thickness is 1.0 mm.

In order to reveal the prevailing microstructure of the samples under scanning electron microscopy, the specimens were first polished until a near-mirror finish was obtained. They were later etched in mixed solution of HF: HNO_3: H_2O = 1:1:5 to reveal their microstructures. Microstructure of the specimens is shown in Fig. 2.

Table 1
Chemical composition of industrial Ti-6Al-4V alloy sheet (wt%).

Al	V	Fe	C	N	H	O	Ti
6.16	4.17	0.062	0.009	0.003	0.002	0.15	Bal.

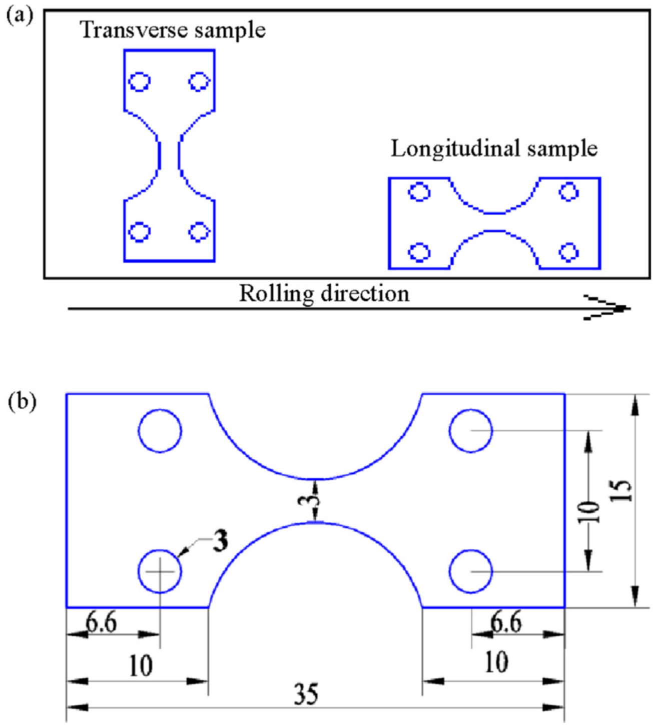

Fig. 1. Schematic image of in-situ tensile test specimen.

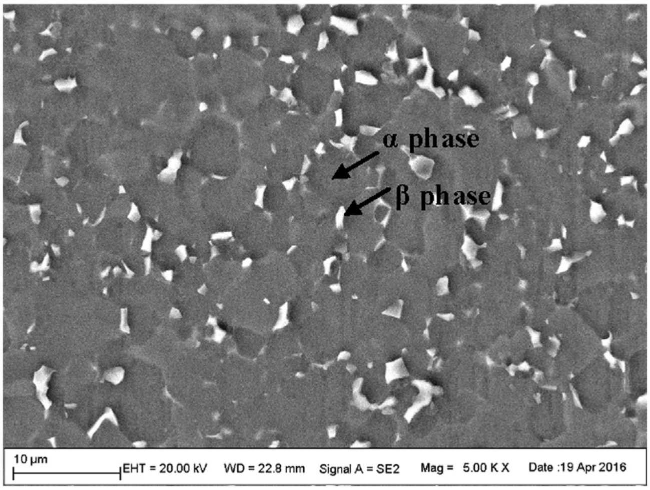

Fig. 2. Microstructure of Ti-6Al-4V alloy sheet.

The specimen has an equiaxed α phase and β phase. The dark regions represent α phase and the white regions represent β phase. The mean grain size of α was approximately 3 μm.

In-situ observations during tensile process were performed at room temperature in a ZEISS SUPRA 55 scanning electron microscopy. Tensile tests were performed using a loading stage placed inside the scanning electron microscopy chamber. The specimen was strained at a strain rate of 0.01 mm/min. During tensile process, at certain load levels, as shown in Fig. 3, the tensile process was paused and the load was held, and then scanning electron microscopy images were taken. It should be pointed out that a slight stress relaxation occurred during the pauses. After imaging, the load or displacement was continued at the same level.

3. Results and discussion

3.1. In-situ tensile curves

A typical tensile stress-displacement curve at room temperature is shown in Fig. 3. Various stress levels at which the test is paused

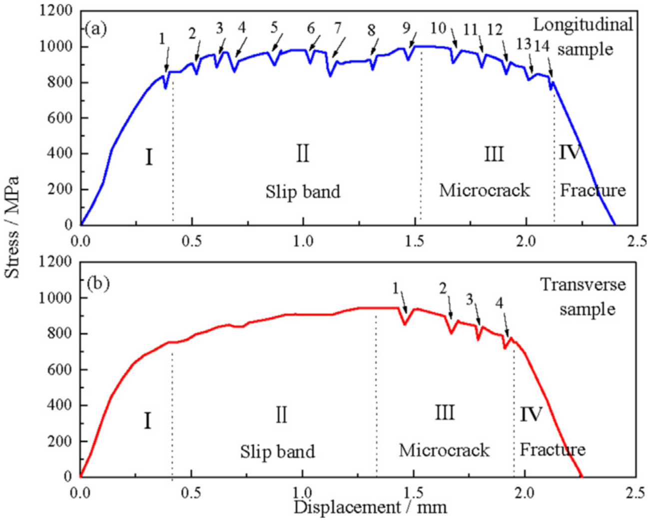

Fig. 3. Stress vs. displacement curves during the in-situ experiment in which specimen surfaces were observed at different displacements.