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Thermomechanical characterization of P/M Ti–Fe–Mo–Y alloy with a fine lamellar microstructure

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ABSTRACT

Thermomechanical response of a newly designed $\alpha+\beta$ type Ti–1.5Fe–2.25Mo–0.6Y (wt.%) alloy produced by elemental powder metallurgy (P/M) route was studied using hot compression process. Detailed analyses of the deformation behavior combined with a microstructure observation were carried out to characterize the deformation mechanisms under various conditions. The results indicate that the flow softening of the present alloy is a continuous dynamic-recrystallization (DRX) process. At a given strain, the proportion of low angle grain boundaries (LAGBs) shows a close affinity to the Zener–Hollomon parameter (Z) and the relation can be expressed as LAGBs% = $(-10.2 \pm 5) + 4 \log Z$, which well describes the relation between the deformed microstructure and deformation parameters. The P/M Ti–1.5Fe–2.25Mo–0.6Y alloy is found to possess good workability, based on the compression experiments and the processing map. The good deformation ability is believed to be attributed to the initial fine microstructure derived from the P/M route.

1. Introduction

Although the performance advantages of titanium alloy in automotive applications have been established and widely reported over many years, thus far, the widespread use of titanium alloys in automotive applications has still been limited because of the high costs involved [1]. Therefore, the design of low-cost titanium alloy in which the expensive elements (particularly the β stabilizing elements) are replaced with some relatively cheap elements is especially attractive. Fe and Mo are potential promising alloying elements to fabricate low-cost titanium alloy, and have been widely used for reducing the costs in the TIMLET LCB titanium alloy [2] and the commercial steel [3]. The low cost is expected to be further reduced by using the P/M technology. At the same time, Fe and Mo have positive effects on fabrication and mechanical properties of P/M titanium alloy. For example, Fe has high diffusion rate in titanium [4] and can form a transient eutectic-liquid phase during sintering [5]; Mo can strengthen the titanium matrix by solution strengthening. These advantages make the Fe and Mo the good candidate alloying elements for fabricating P/M titanium alloys. Based on this alloy design strategy, we designed a new P/M titanium alloy with composition of Ti–1.5Fe–2.25Mo–0.6Y [6]. This alloy possess a fine microstructure (with a typical colony size of d = 20–40 μm) and good mechanical properties at as-sintered state [6]. Hot deformation is not only necessary for fabricating components but also effective in further improving the properties of titanium alloys, especially P/M titanium alloys. Therefore, research on deformation behavior of the present alloy, especially the precise control of deformation, temperature, and strain rate during processing, is required.

In this study, the workability of the P/M Ti–1.5Fe–2.25Mo–0.6Y alloy was evaluated by using the hot compression experiments, and a processing map was constructed to characterize the flow behavior accurately and to obtain the appropriate deformation parameters since the processing map is an effective tool in characterizing flow behavior and evaluating material workability and has been widely used in researches of hot deformation of the Cu, Al, Ni alloys, etc. [2,7]. Deformation mechanisms are also discussed in detail on the basis of the electron-backscatter-diffraction (EBSD) technology.

2. Experimental

The physical characteristics of elemental powders used in the fabrication of the Ti–1.5Fe–2.25Mo–0.6Y alloy are listed in Table 1. The raw powders were blended in a high-efficiency v-type blender (SPEX 8000M, SPEX SamplePrep INC, USA) for 1 h under an Ar atmosphere, followed by cold isostatic pressing at room temperature at a pressure of 200 MPa. The powder compacts were sintered at 1300 °C for 3 h in a vacuum of 5×10^{-3} Pa and then furnace cooled.

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Table 1
Characterizations of raw elemental powders.

Element/master alloy	Average particle size (μm)	Oxygen content (wt.%)	Preparation[a]
Ti	8.0	0.34	HDDH
Fe	4.15	0.54	CD
Mo	4.96	0.20	RO
Y	8.65	0.26	

[a] HDDH, hydride–dehydride; CD, carbonyl decomposition; RO, reduction of oxides.

Cylindrical specimens, 8 mm in diameter and 12 mm in height, were machined from the sintered compact. Compressive tests were carried out in a vacuum of 1×10^{-2} Pa using a computer-aided compression equipment (Thermecmastor-Z, Fuji Electronic Industrial Co., Ltd., Saitama, Japan). The test temperatures are from 650 °C to 1000 °C and the strain rates are from 0.001 s^{-1} to 10 s^{-1}. After deformation, all specimens were quenched by a mixture of N_2 (6 MPa) and He (4 MPa) gas at a cooling rate of approximately 50 °C/s in order to preserve the as-deformed microstructure. During the hot compression test, barreling occurred because of the friction at the contact surfaces between the specimen and the anvil. In addition, there was a possibility of work heating because of the adiabatic deformation at a relatively high strain rate. Therefore, the effects of friction and work heating on the stress–strain relation were compensated using the procedures given in Ref. [8].

Deformed specimens were sectioned vertically, and metallographic samples were ground, polished, and etched with a solution of 10% HF, 5% HNO_3, and 85% H_2O (in volume). The microstructure was examined using optical microscope (OP) and scanning electron microscope (SEM) (Hitachi 6460, Hitachi Co. Ltd., Japan). The crystallographic analysis was carried out by EBSD using an orientation imaging microscope (TexSEM Laboratories, Inc., Provo, UT) attached to a field-emission scanning electron microscope (FESEM) (XL30S-FEG, Philips). The step size used in the measurements was 0.2 μm, the acceleration voltage was 30 kV, and the beam current was approximately 100 μA. Because the severe deformation could cause orientation uncertainty and orientation noise, misorientation below 2° were usually not considered. Boundaries with misorientation between 2° and 15° were defined as low-angle grain boundaries and those of misorientation >15° as high-angle grain boundaries (HAGBs).

3. Results

3.1. Initial microstructure

The microstructures prior to the deformation are shown in Fig. 1. Fig. 1a is an SEM micrograph (this image and all subsequent SEM microstructures were captured via backscattered electron imaging), and Fig. 1b and c are the EBSD phase map and the inverse pole figure (IPF) map, respectively. In Fig. 1a and b, the as-sintered alloy exhibits a lamellar microstructure with the β phase volume fraction of approximately 15%. The initial grain size is approximately 35 μm, which is considerably smaller than that of the as-cast Ti–6Al–4V alloy with lamellar microstructure (average lamella colony size ≈ 1000 μm), and close to the Ti–6Al–4V alloy with an equiaxed α + β microstructure (average grain size ≈ 8 μm) [2,9]. The relative density of the as-sintered compact is nearly 97%, therefore, in the following study of hot deformation, we ignored the volume compression effect which is often mentioned in the case of powder forging [10]. In Fig. 1c, the black lines and blue lines indicate the HAGBs, where the blue lines are the grain boundaries with Burgers orientation relationship (OR)

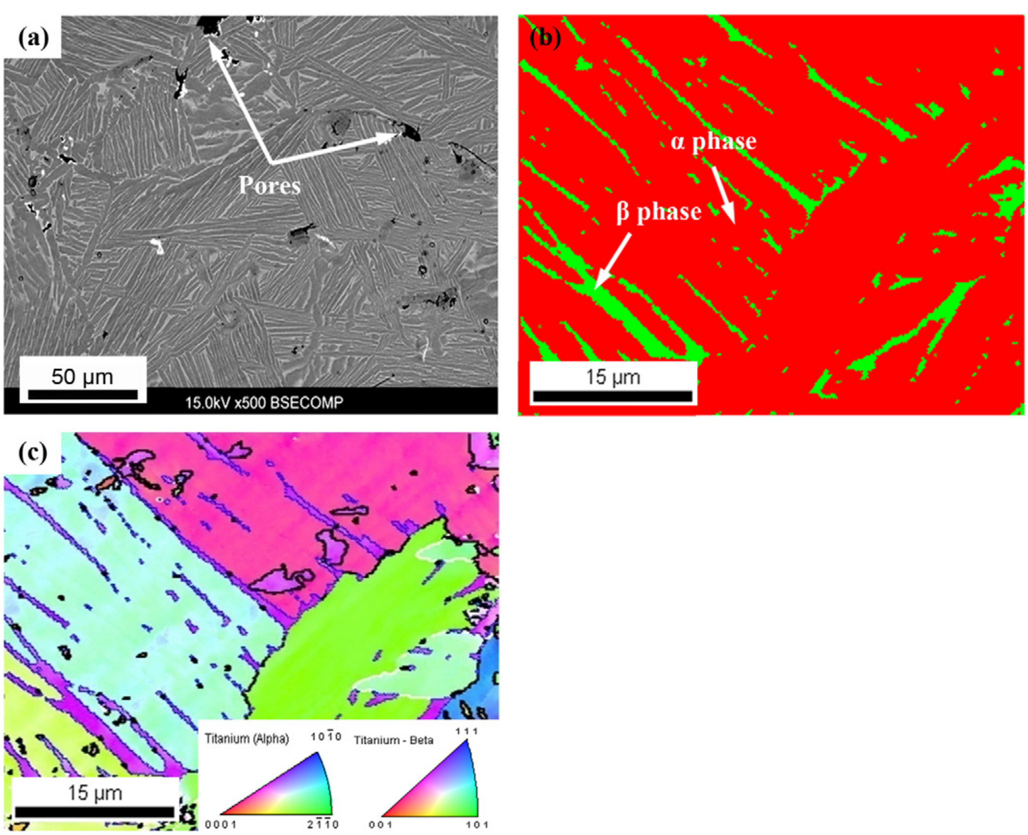

Fig. 1. Initial microstructure of the Ti–1.5Fe–2.25Mo–0.6Y alloy: (a) SEM image, (b) phase map, and (c) IPF map.