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Microstructure refinement of a dual phase titanium alloy by severe room temperature compression

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Abstract: Microstructure refinement of a dual phase titanium alloy, Ti−3Al−4.5V−5Mo, by severe room temperature compression was investigated. Nanocrystalline grains were observed in the sample with 75% reduction, in which the grain sizes of *α* phase and *β* phase were approximately 50 and 100 nm. Conversely, the average thicknesses of *α* phase and *β* phase in as-received microstructure were measured to be 0.7 and 0.5 μm, respectively. TEM and XRD methods were used to analyze the microstructure and texture changes after severe deformation. Microstructure refinement was deduced to the complex interaction among slip dislocations in the *α* phase, the complex interaction among slip dislocations and martensites in the *β* phases. In addition, the interaction between the *α* phase and the *β* phase also contributed to the microstructure refinement.

Key words: dual phase titanium alloy; Ti−3Al−4.5V−5Mo alloy; severe plastic deformation; microstructure refinement; nanocrystalline grains; texture

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1 Introduction

It has already been established that the material strength increases with the reducing of grain size according to the famous Hall-Petch equation. This trend of thought has led to an invariable interest in producing materials with extremely fine grains. Recently, severe plastic deformation (SPD) techniques, which have attracted increasing attentions in material fields, have been widely used to produce ultrafine grains and nanocrystalline grains materials. Numerous available literatures have described the application of SPD technologies in a serial of pure metals and simple alloys [1,2].

Titanium alloys have been extensively utilized in aerospace and automobile industries due to their low density, high strength, high toughness, good corrosion resistance and fatigue resistance. Grain refinement has continuously been a very important scientific and research topic in titanium alloy fields. However, only micron grain-sized titanium alloys can be got by traditional hot working technologies. Therefore, it should be a very meaningful work to refine titanium alloy materials by new technologies. Some researchers have tried to refine commercially pure titanium (CP-Ti) and Ti−6Al−4V alloy by SPD technologies in order to improve their strength or enhance the feasibility of superplastic processing [3−8]. However, due to the low ductility and difficulty to deform at ambient temperature, the deformation of Ti−6Al−4V alloy is generally conducted at higher temperature and needs more processing turns.

Recently, some heavily stabilized *β* titanium alloys have been investigated to decrease the grain size by severe cold deformation due to their higher room temperature ductilities. The grain size of Ti−24Nb−4Zr−7.9Sn titanium alloy can be decreased to less than 50 nm after 90% reduction in thickness by rolling, during which highly localized deformation plays an important role in grain refinement [9]. The Ti−25.4Nb−7.1 Ta−1.2In titanium alloy, a less stabilized *β* titanium alloy with low stacking fault energy, can be severely plastic deformed to nanocrystalline grains in conventional uniaxial compression due to the formation of stress-induced fine α'' martensite [10].

However, few reports could be found to describe the *α*+*β* typed dual phase titanium alloys by severe cold deformation at ambient temperature due to their limited room temperature ductilities. In this work, we used an *α*+*β* typed dual phase titanium alloy, Ti−3Al−4.5V−5Mo, which has higher room temperature ductility, to

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investigate the feasibility of producing ultrafine and nanocrystalline grains by conventional room temperature uniaxial compression.

2 Experimental

Ti−3Al−4.5V−5Mo alloy samples with 6.2 mm in diameter used in this investigation were machined from hot rolled and annealed rods. The measured composition of this alloy (in mass fraction, %) was 3.48 Al, 5.23 Mo and 4.68 V. The beta-transus temperature was measured to be 865 °C by metallographic method. Figure 1 shows the typical as-received microstructure of the annealed Ti−3Al−4.5V−5Mo alloy, which is homogeneously composed of lamellar α phase and β phase. The average thicknesses of α phase and β phase in the lamellar structure were measured to be 0.7 and 0.5 μm, respectively. The cylindrical samples for the present compression tests had a length-to-diameter ratio of 2:1. Uniaxial compression deformation was carried out at a constant ram speed of 7.44 mm/min on a Shimadzu testing machine. The reduction ratios in height of 50% and 75% were selected. Microstructure observations were performed using an Axiovert200 MAT optical microscope and Tecnai G^2 20 transmission electron microscope operating at 200 kV. The phase constitutions were detected on a Rigaku D/max−2400PC X-ray diffractometer using Cu K_α radiation, at a voltage of 56 kV and a current of 182 mA. The TEM foils were first mechanically thinned to about 50 μm in thickness and further thinned using a Tenupol-5 twin-jet electrolytic polisher.

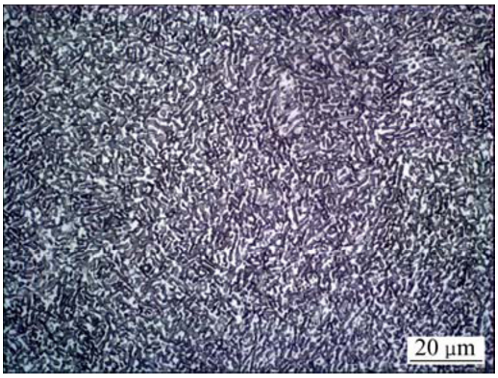

Fig. 1 Optical microstructure micrograph of as-received Ti−3Al−4.5V−5Mo titanium alloy

3 Results and discussion

XRD patterns before and after deformation are presented in Fig. 2. There exists some orthorhombic α'' martensite in patterns of 50% reduction and 75% reduction besides α phase and β phase. This indicates that stress-induced α'' martensite transformation had occurred in β phase during compression deformation. Deformation-induced texture evolution of α phase is measured using the peak intensity ratio $I_{0002}/I_{10\bar{1}0}$. The ratios for the as-received, 50% reduced and 75% reduced samples are 0.23, 4.13 and 7.80, respectively, which indicates a transformation from $(10\bar{1}0)$ plane texture to the (0001) plane texture with increasing in strain level. The ratios of I_{110}/I_{200} in β phase for as-received, 50% reduced and 75% reduced samples are 36.84, 1.58 and 2.36, respectively, demonstrating that (110) plane texture decreases while (200) plane texture increases with increasing the strain level. The observed stress-induced α'' martensite presents a (022) texture. The lattice correspondence between β and α'' phases can be expressed as follows [11]: $[100]_\beta//[100]_{\alpha''}$, $[010]_\beta//[01\bar{1}]_{\alpha''}$ and $[001]_\beta//[011]_{\alpha''}$. Therefore, it could be deduced that the $\{022\}_{\alpha''}$ plane is the principal transform plane when the $\{200\}_\beta$ plane is perpendicular to the compression direction. As shown in the XRD patterns in Fig. 2, the diffraction intensities of α'' martensite decrease when the deformation increases from 50% up to 75% reduction. This may be caused by the α'' martensite reversible transformation backward to the β phase, due to the localization temperature rising. The broadening of the XRD peaks after compression deformation in Fig. 2 indicates that grain refinement occurred.

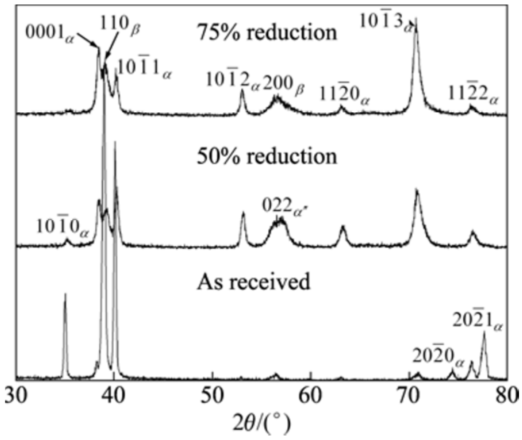

Fig. 2 XRD patterns of as-received, 50% reduced and 75% reduced samples after compression deformation

A homogeneous microstructure of 50% reduced sample is shown in Fig. 3. A great number of grain boundaries in 50% reduced sample are wavy and not well delineated. There are many dislocation tangles and dislocation cells which subdivide α phase and β phase. Especially, the dislocation tangles in β phase are less than those in α phase. The selected area electron diffraction (SAED) patterns of α phase and β phase with 50% reduction deformation are presented in Figs. 3(b) and 3(c). The diffraction spots have elongated into