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Morphology transformation of primary strip α phase in hot working of two-phase titanium alloy

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Abstract: Microstructural development in hot working of TA15 titanium alloy with primary strip α structure was investigated with the aim to globularize α strips. Results show that the mechanisms of morphology transformation are the same to the spheroidization mechanisms of lamellar structure. Boundary splitting and termination migration are more important than coarsening due to the large size of strip α. The α strips are stable in annealing due to the unfavorable geometrical orientation of intra-α boundaries, the large thickness of strip and the geometrical stability of α particles. Predeformation and low speed deformation accelerate globularization of α strips in the following ways: direct changing of particle shape, promotion of boundary splitting and termination migration by increasing high angle grain boundaries and interfacial area, promotion of coarsening by forming dislocation structures. Large predeformation combined with high temperature annealing is a feasible way to globularize strip α.

Key words: titanium alloy; primary α strips; globularization; morphology transformation; hot working; coarsening

1 Introduction

Titanium alloys have gained increasing applications due to the high specific strength and good corrosion resistance. Hot working is often employed to transform the lamellar structure to equiaxed structure, so the ductility and fatigue resistance can be improved. This is commonly referred to globularization or spheroidization. Globularization of lamellar structure occurs during primary working, in which ingots are transformed to semi-products by rotary forging or rolling [1]. The large unidirectional elongation of work-piece will affect the morphology of α phase. Some α phases may appear in strip form with high aspect ratio (they are referred to as strip α herein and after) under improper processing route. To enhance the isotropy and fatigue resistance of material, the strip α should be transformed to globular ones.

By now, most work on the morphology transformation of α phase was about the globularization of lamellar α. It begins with the loss of coherency of α/β interfaces [2] and formation of boundaries across α platelets by deformation [3]. The intra-α boundaries can be subgrain boundaries produced by dynamic recovery or high angle boundaries caused by dynamic recrystallization [4,5]. The intra-α boundary creates unstable dihedral angle with neighboring α/β interface. To lessen surface tension, β phase wedges into α platelets along the boundary so that the dihedral angle is reduced and stabilized [6]. The so called thermal grooving splits α platelets into particles with lower aspect ratio. α lamellae can be further globularized by termination migration and Ostwald ripening [6]. The first stage of globularization is deformation induced. Meanwhile, the second and third stages are diffusion controlled and time dependent. So globularization occurs dynamically during deformation and statically in the subsequent heat treatment.

Globularization kinetics is sensitive to processing parameters. Dynamically globularized fraction increases with strain in a sigmoidal way [7]. A critical strain is required for the initiation. The globularization rate increases with increasing temperature and decreasing strain rate. On the other hand, the statically globularized fraction increases with the increase of time in an

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asymptotic way [8,9]. It increases with applied strain and holding temperature but is less sensitive to strain rate.

Break-down of strip *α* may be similar to globularization of lamellar *α*. However, a previous work [10] suggested that break-down of *α* strips was so sluggish that globularized structure was not observed at 80% reduction. This might be caused by the lack of second and third stages, i.e., *α* strips may have already broken into several grains but were not separated by *β* phase. As the width of *α* strips is much larger than that of *α* lamellae, the required time for static globularization is much longer.

The morphology transformation can be speeded up if the diffusion of solutes is accelerated, as both the second and third stages are diffusion controlled. This can be achieved by imposing low speed deformation at high temperature. SEMIATIN et al [11] reported that dynamic coarsening rates were enhanced by 5 times relative to those for static coarsening. Also, it has been reported in many alloys that fiber structure becomes globular after superplastic deformation, which also occurs at a low strain rate. The titanium alloy exhibits excellent superplasticity. MOTYKA et al [12] have reported spheroidization of predeformed lamellar *α* of Ti−6Al−4V alloy during superplastic deformation. The *α* strips may be broken down in the same way.

In this work, different hot working schemes were used to globularize strip *α* phase produced in rolling. The morphology transformation was quantitatively measured. Feasible processing route for globularization of strip *α* was proposed. The results can be used to improve the microstructure of titanium alloy products.

2 Experimental

A near-*α* TA15 titanium alloy was employed in this work. The as-received material was an 18 mm-diameter hot rolled bar with measured chemical composition of Ti−6.06Al−1.86Zr−2.08Mo−1.32V (mass fraction, %) and *β*-transus temperature was 985 °C. The initial structure consisted of about 50% primary *α* within transformed *β* matrix, as shown in Fig. 1. The primary *α* particles were elongated in the rolling direction. Meanwhile, they had irregular cross sections. So, the *α* particles were rod-like with the axis parallel to the rolling direction. Herein and after, the *α* particle denotes the *α* phase isolated by *β* matrix. A *α* particle may contain several *α* grains which cannot be differentiated by the optical micrograph or SEM [13]. This was confirmed by electron backscatter diffraction (EBSD) analysis (Fig. 2). The crystal orientation varied in the *α* particle. There existed boundaries inside *α* strips (black lines in Fig. 2).

Three working schemes were used to globularize strip *α*. The material was annealed at 930 and 970 °C for 0.5−16 h. The material was deformed at 930 °C to 40% reduction at strain rate of 0.1 s^{-1} and then annealed at 970 °C for 0.5−16 h. The material was deformed at temperatures of 930 and 970 °C, strain rates of 1×10^{-3} and 1×10^{-4} s^{-1} to true strains of 0.6, 1.2 and 1.8.

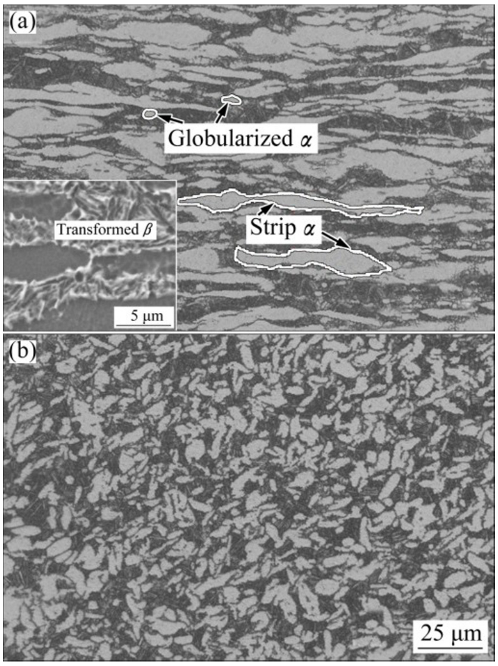

Fig. 1 Optical micrograph of as received hot rolled bar: (a) Axial section; (b) Cross section (The axial direction (rolling direction) is horizontal in Fig. 1(a))

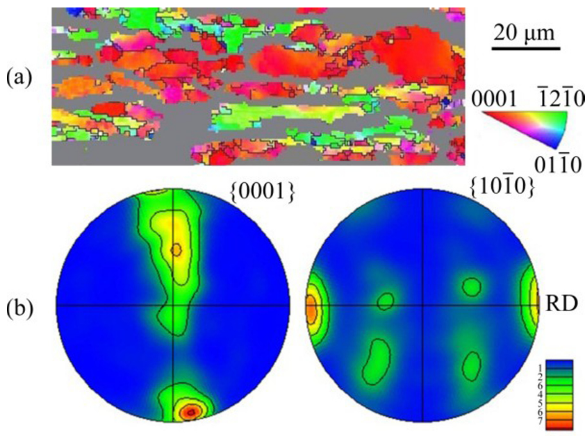

Fig. 2 Inverse pole figure map (a) and pole figures (b) of strip *α*

High temperature deformation was conducted on a SANS CMT5205 electric universal testing machine. The specimens were cylinders of 15 mm in diameter and 24 mm in height with the axis parallel to rolling direction. They were heated to the deformation temperature at 12 °C/min, held for 15 min and compressed. The constant anvil speed was used throughout deformation. Here, the die speed was set to be 1.5×10^{-2} and 1.5×10^{-3} mm/s so that the average strain rate for different height reductions was close to the set value.