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The role of dynamic and post dynamic recrystallization on microstructure refinement in primary working of a coarse grained two-phase titanium alloy

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ABSTRACT

Dynamic and post dynamic recrystallization in primary working of a coarse grained two-phase TA15 titanium alloy were investigated. It is found that in β deformation, dynamic recrystallization (DRX) can be triggered at a low strain. The low nucleation rate retards DRX. It is prone to producing a duplex grain structure. During post-deformation holding, both meta-dynamic recrystallization (MDRX) and static recrystallization (SRX) occur. The average recrystallized grain size increases sharply in the early stage of holding due to MDRX but varies slightly after SRX occurs. Post dynamic recrystallization can be finished in a short time and additional β annealing after deformation is unnecessary. Refining the initial structure can accelerate recrystallization and decrease the recrystallized grain size.

1. Introduction

The two phase titanium alloy is widely used in aviation industry due to its high specific strength and good corrosion resistance. It is often made into large scale integral component for the purpose of light weight and high performance. To ensure the service performance, hot working is employed to manufacture forging from ingot. Commonly, it includes a primary working which transforms the ingot to semi-product with specific microstructure, and a secondary working which shapes the semi-product to forging. The primary working is very important to the microstructure and performance of the final product. In a typical primary working, the ingot is deformed firstly above the β transus temperature (β working) to refine the coarse β grains. A fully transformed structure consisting of colonies of α lamellae within original β grains is obtained, which is known as lamellar structure. Then, the workpiece is deformed below the β transus temperature (α + β working) to spheroidize α lamellae. This would produce an equiaxed structure with good comprehensive mechanical properties. It is easier to obtain qualified equiaxed structure if the original β grains are small and uniform, as the β grain size determines the size of α colonies.

Grain refinement is commonly achieved by recrystallization in hot deformation. However, the two phase titanium alloy exhibits strong dynamic recovery and high diffusivity in β working due to the bcc crystal structure and high deformation temperature. Dynamic recrystallization is suppressed while grain coarsening is very fast, which would hinder grain refinement. Lütjering and Williams (2007) summarized that the high-low-high scheme is the mostly used processing route for primary working with aim to refine the β grains, i.e., β working followed by α + β working then β working. The β grain refinement is achieved by the static recrystallization in β annealing after α + β working. The deformation amount in α + β working is limited due to the low ductility and narrow processing window below the β transus temperature. Meanwhile, the deformation and thermal history can be inhomogeneous in large scale billet. So, multiple β deformation and subsequent annealing are often employed to avoid non-uniform microstructure. Quantitative measurement and prediction of the dynamic and post dynamic microstructure developments are important to the process control in β working.

To date, much work has been carried out on the microstructure evolution in β working of titanium alloys. Dikovits et al. (2014) determined the deformation mechanisms at different temperatures and strain rates for a near-β Ti55531 titanium alloy. They found geometric dynamic recrystallization (GDRX), continuous dynamic recrystallization (CDRX) and deformation banding (DB) occurred besides dynamic recovery while discontinuous dynamic recrystallization (DDRX) was not observed. However, the kinetics of microstructure evolution is not quantified. Similarly, Montheillet et al. (2012) concluded three stages of microstructure development in β working of a Ti17 titanium alloy: deformation of initial grains, generation of some new grains by GDRX and complete fragmenta-

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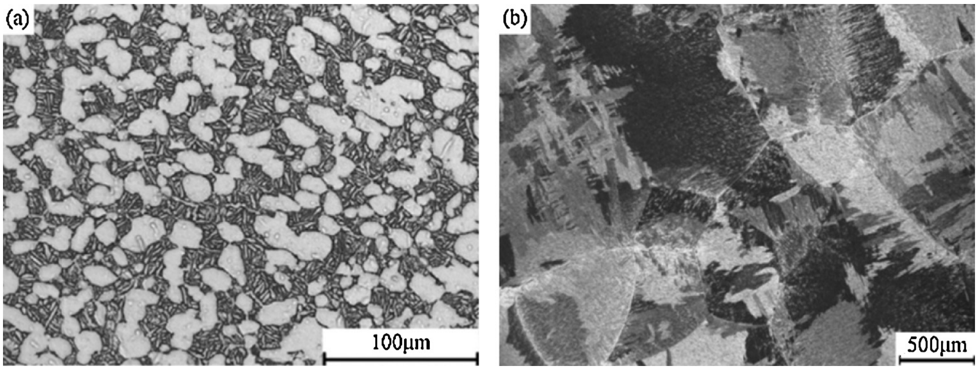

Fig. 1. Microstructures of the as received (a) and β annealed (b) TA15 alloy.

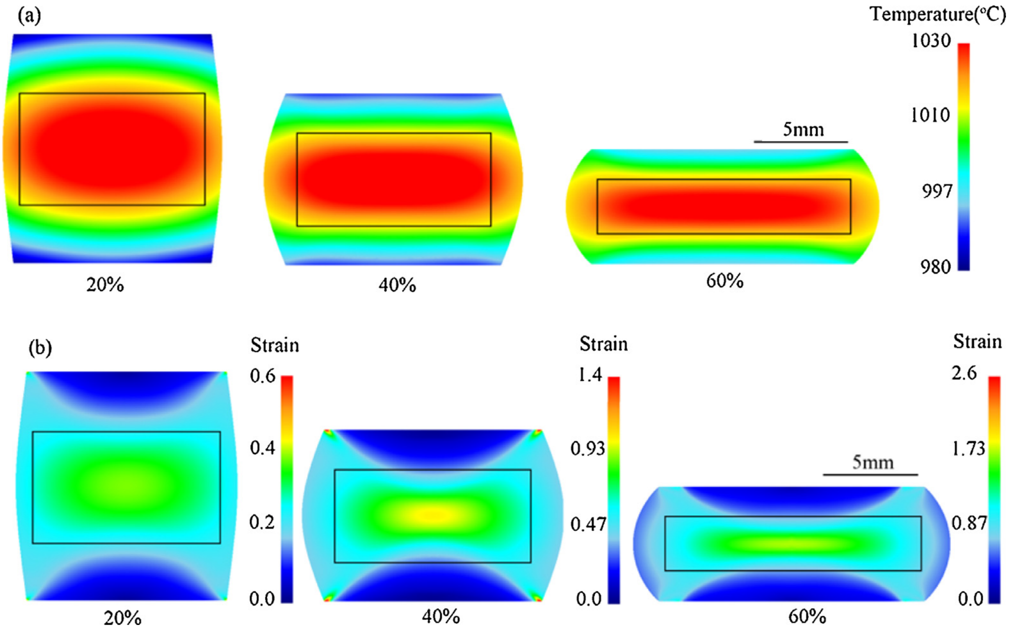

Fig. 2. Temperature (a) and strain (b) distributions in the image locations (Image locations are indicated by black wireframes).

tion by CDRX. However, fully recrystallized structure can only be obtained at very large strain, which is not available for β working of large scale billet. On the other hand, Ding et al. (2004) reported DDRX in two-phase Ti-6Al-4V alloy and presented numerical simulation on DDRX. As DDRX kinetics is sluggish, the post dynamic recrystallization should be concerned. Vo et al. (2008) also reported that complete grain refinement was achieved through static recrystallization for a near-α IMI834 alloy. The initial structure used in their work was much finer than that in actual β working, which could affect the recrystallization behavior.

In the present work, the microstructure evolution in multiple β working of a coarse grained TA15 titanium alloy was investigated by hot compression tests. The microstructure evolution during deformation, holding and annealing was quantified. Mathematical models were established for recrystallization. The results can be used to optimize the β working of titanium alloy.

2. Material and procedures

The material employed is a near-α TA15 titanium alloy with measured chemical composition of 6.69 Al, 2.25Zr, 1.77Mo, 2.25V, 0.14Fe, 0.12O, 0.002H and balanced Ti (wt.%), and β transus temperature of 985 °C. The as-received material was a hot forged bar with equiaxed structure (Fig. 1(a)). Three heat treatment routes were used prior to deformation to obtain initial structures with different β grain sizes: 1200 °C/150 min (average β grain size was about 1 mm, as shown in Fig. 1(b)); 1300 °C/15 min (700 μm); deformation temperature/15 min(250–500 μm).

Three hot working schemes were used in this work: 1-deformation, 2-deformation and holding, 3-deformation and annealing. For all schemes, the β deformation was conducted on a Gleeble3500 thermal simulator. Cylindrical specimens of 15 mm in height and 10 mm in diameter were machined from the annealed material. Thin tantalum layers were placed between the specimen and anvils to minimize friction. The specimen was heated at a rate of 10 °C s^{-1} to 100 °C below the deformation temperature, then heated to the deformation temperature at 2 °C s^{-1}, and deformed at constant temperature and strain rate. The compression tests were performed at temperatures of 1020–1180 °C, strain rates of 0.01–1 s^{-1}, and reduction rates of 20–60%. For Scheme 1, the specimens were cooled immediately after deformation. In Scheme 2, the specimens were held at the deformation temperature for 25–600 s before cooling down. In Scheme 3, the specimens were cooled to room temperature immediately after deformation, reheated to the single β region and held for different times. It was impossible to preserve the high temperature β phase by water quenching due to the martensitic transformation. Instead, air cooling was used so