

The Evolution of Microstructure of Ti-6Al-4V Alloy during Water Cooling

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Abstract. In this paper, Ti-6Al-4V alloy was water cooled from three different temperatures after solution treating. The microstructure of the specimens after thermomechanical treatment testing was observed by light optical microscopy (LOM) and scanning electron microscopy (SEM), respectively. The hardness of specimens was measured for each heat-treated condition. The evolution of microstructure of Ti-6Al-4V alloy during water cooling was investigated. The results showed that the hardness of the specimen increases with increasing water cooling temperature. Grain boundary provides nucleation sites when Ti-6Al-4 alloy was water cooled from 800°C after solution anneal followed by cooling at a cooling rate of 5°C/min. Higher water cooling temperature tends to promote the more homogeneous structures, whereas lower water cooling temperature result in less homogeneous alpha plates. Therefore, alpha phase refines with increasing water cooling temperature. The coarsest platelet alpha formed at water cooling temperature of 600°C, this is because enough time is allowed for grain growth of alpha plates. Water cooling temperature after solution treatment affects the variety of the hardnesses and the evolution of microstructure for Ti-6Al-4V alloy. The highest hardness value (HV5=243) were obtained when the specimens were water cooled at 800°C, this is attributed to finer platelet alpha and homogeneous structures.

Introduction

Titanium alloys are extensively used in aerospace applications such as turbine engines, airframe applications and space shuttles, mainly because of their superior strength to weight ratio [1-4]. The microstructure of conventional titanium alloys is primarily described by the size and arrangement of the two phases α and β [5, 6]. The most common $\alpha + \beta$ alloy is Ti-6Al-4V. The Ti-6Al-4V alloy was developed in the early 1950s. Ti-6Al-4V, in fact, accounts for more than half of the current U.S. titanium market [7]. The most research attention is paid to Ti-6Al-4V which is a representative in titanium alloys[8-10].

The properties of $\alpha + \beta$ alloys can be controlled through heat treatment, which is used to adjust the amounts and types of β phase present. Solution treatment followed by aging at 480 to 650°C precipitates α , resulting in a fine mixture of α and β in a matrix of retained or transformed β phase. Many previous investigators have shown that substantial benefits in yield, tensile and fatigue strengths can be achieved when Ti-6Al-4V alloy is solution treated and aged [11].

Generally, the different microstructures of titanium alloys are generated by thermomechanical treatments. In the present work, Ti-6Al-4V alloy was water cooled from three different temperatures after solution treating. The evolution of microstructure of Ti-6Al-4V alloy during water cooling was investigated. Further, the relationship between microstructure and hardness was discussed.

Experimental

The material used in thermomechanical treatment tests is from the same batch of Ti-6Al-4V alloy. Nine test pieces (10mm×10mm×10mm) were cut from a piece of 100×100×30 mm thick slab. they were water cooled from three different temperatures after solution treating. The experimental procedures used in this work are presented in Fig. 1. In Fig. 1, solution-annealing temperature of 1000°C is used. The specimens were water cooled from 600°C, 700°C and 800°C, respectively, after slow cooling (5°C/min).

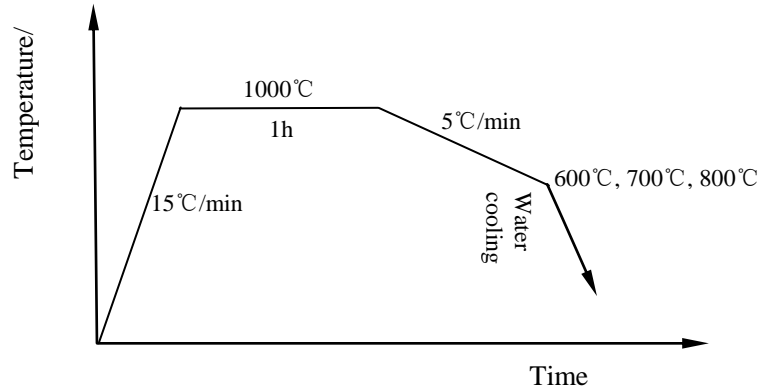


Fig.1 The processing schedule of Ti-6Al-4V alloy

The microstructure of the specimens after thermomechanical treatment testing was observed by light optical microscopy (LOM) and scanning electron microscopy (SEM), respectively. Mean value of Vickers (HV5) hardness of three test pieces for each heat-treated condition was collected.

Experimental Results

The variety of the hardnesses

TC4 titanium alloy was water cooled from different temperatures after slow cooling (Fig. 1). Three specimens after water cooling at each temperature exhibit almost similar hardness values. Average hardnesses of three specimens which were water cooled from three different temperatures are shown in Fig. 2. In Fig. 2, the hardness of the specimen increases with increasing water cooling temperature. The processing conditions of water cooling at 600°C produced the lowest hardness value. The highest hardness value (HV5=243) of the specimen after water cooling at 800°C were obtained.

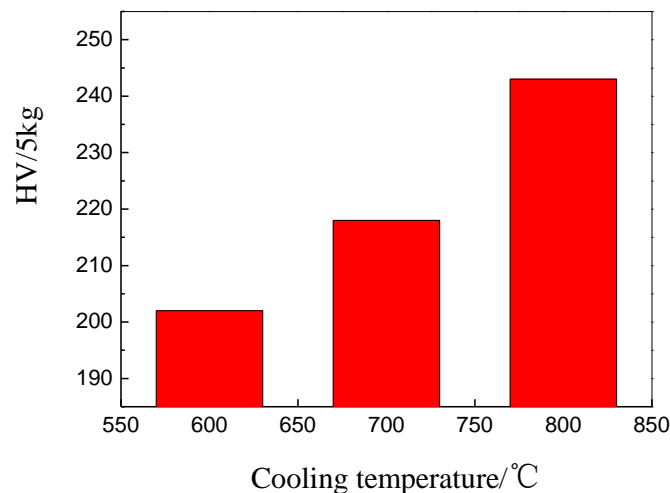


Fig.2 The variety of the hardnesses depending on water cooling temperatures

Microstructures

Fig. 3 shows LOM micrographs of three specimens after water cooling at three different temperatures. In Fig. 3, the microstructure all consists of two phases (α - β). It can be found with a bimodal microstructure, i.e., primary α grains surrounded by α + β lamellar matrix. Blocky alpha plates of the specimen after water cooling at 600°C were obtained (Fig. 3 (a)). The microstructure of the specimen refined with increasing water cooling temperature (Fig. 3 (b)). Relatively fine platelet alpha was observed in the specimen after water cooling at 800°C (Fig. 3 (c)).

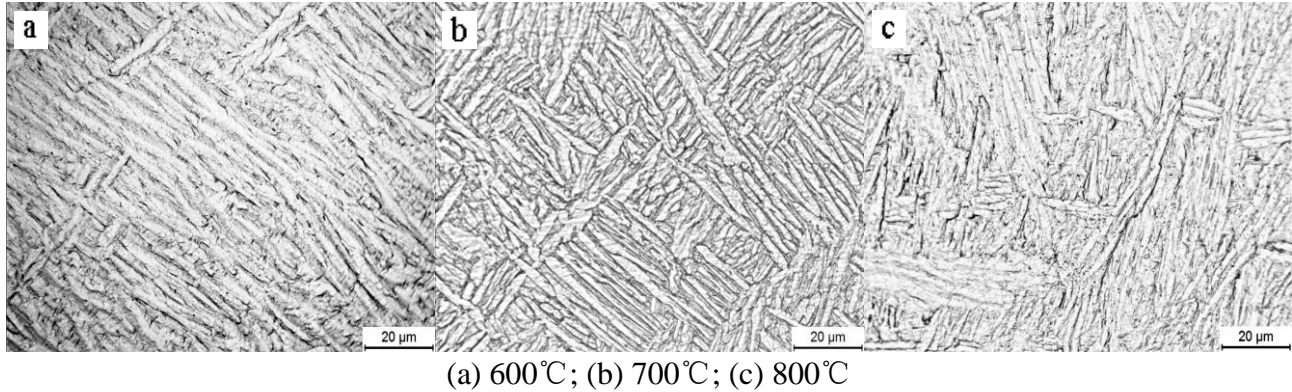


Fig.3 Optical micrographs of specimens (etched by 4% nital)

All constituents of Ti-6Al-4V alloy microstructure can clearly be seen by SEM. In Fig. 4, very obviously laminated alpha-beta structures are consistent with the light optical microscopy observation. The trend is that α phase coarsens with decreasing water cooling temperature.

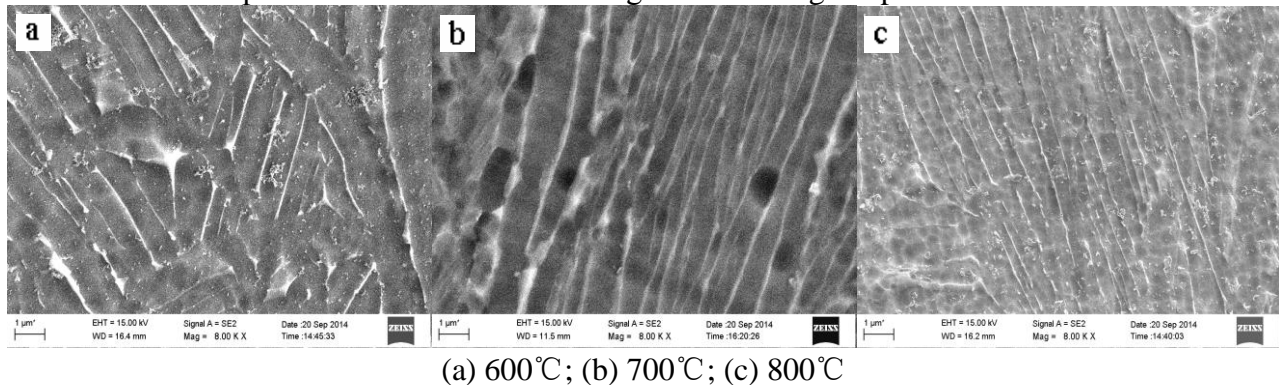


Fig. 4 SEM micrographs of the specimens

Discussion

The investigated Titanium alloy contains Al and V. Al is a α -stabilizer, it is by far the most important alloying element of titanium. V is a β -stabilizer (the β -isomorphous element). The addition of alloying elements divides the single temperature for equilibrium transformation into two temperatures-the alpha transus, above which the alpha phase begins transformation to beta, and the beta transus, above which the alloy is all-beta. Between these temperatures, both alpha and beta are present.

Ti-6Al-4V alloys were solution-treated at 1000°C, for 1h, and then water cooled from three different temperatures. The transformation kinetics and the morphology of the newly formed α -phase can be determined by different cooling conditions [12]. The lamellar microstructure is generated upon cooling from the β phase field. Lamellar microstructures are a result of simple cooling from temperatures above the β -transus temperature. Once the temperature falls below the transus temperature α nucleates at grain boundaries and then grows as lamellae into the (prior) β grain [13].

Ali, who discovered that thermo-mechanical processing can increase the phase transformation kinetics by increasing the number of nucleation sites and also by enhancing the growth of the already formed α -phase [12]. Relatively very fine platelet alpha in a alpha-beta structure was found because grain boundary provides nucleation sites when Ti-6Al-4 alloy was water cooled from 800°C after solution anneal followed by cooling at a cooling rate of 5°C/min (Fig. 3 (c), 4 (c)). Depending on the temperature before water cooling, the lamellae are either fine or coarse. The lamellae becomes coarser with reduced water cooling temperature due to a relatively long time to grow (Fig. 3 (b), 4 (b)). The coarsest platelet alpha formed at water cooling temperature of 600°C, this is because enough time is allowed for grain growth of alpha plates (Fig. 3 (a), 4 (a)).

The properties of titanium alloys are primarily determined by the arrangement, volume fraction, and individual properties of the two phases α and β [14]. The morphology of α - β phase and $\alpha \rightarrow \beta \rightarrow \alpha$ transformation affect not only the metallurgical textures, but also the properties for Ti-6Al-4V alloy [14]. Higher water cooling temperature tends to promote the more homogeneous structures, whereas lower water cooling temperature result in less homogeneous alpha plates. As a result, the hardness value was greatly reduced due to the coarse platelet alpha within the microstructure when the specimens were water cooled at 600°C. The highest hardness value (HV5=243) were obtained when the specimens were water cooled at 800°C, this is attributed to finer platelet alpha and homogeneous structures. The various microstructures have a strong influence on the mechanical behavior of the titanium alloys. Fine-scale microstructures increase the strength as well as the ductility. Furthermore, they retard crack nucleation and are a prerequisite for superplastic deformation [13]. Moreover, as mentioned previously, the lamellar microstructure was obtained under the processing conditions. Lamellar structures have high fracture toughness and show superior resistance to creep except for the hardness value in Barkia's work [15]. Therefore, the experimental study of the evolution of microstructure for Ti-6Al-4V alloy during water cooling would be of important practical value.

Conclusions

(1) Water cooling temperature after solution treatment affects **the** variety of the hardnesses and the evolution of microstructure for Ti-6Al-4V alloy.

(2) The hardness of the specimen increases with increasing water cooling temperature. The processing conditions of water cooling at 600°C produced the lowest hardness value.

(3) Grain boundary provides nucleation sites when Ti-6Al-4 alloy was water cooled from 800°C after solution anneal followed by cooling at a cooling rate of 5°C/min. Higher water cooling temperature tends to promote the more homogeneous structures, whereas lower water cooling temperature result in less homogeneous alpha plates. Therefore, alpha phase refines with increasing water cooling temperature. The coarsest platelet alpha formed at water cooling temperature of 600°C, this is because enough time is allowed for grain growth of alpha plates.

(4) The highest hardness value (HV5=243) were obtained when the specimens were water cooled at 800°C, this is attributed to finer platelet alpha and homogeneous structures.

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