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The effect of microstructure on the mechanical properties of TC4-DT titanium alloys

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A B S T R A C T

This paper presents the results on the microstructure and mechanical properties of damage tolerance TC4-DT titanium alloy after different heat treatments. The influence of volume fraction of primary α-phase and the morphology of lamellar microstructure on the tensile properties and fracture toughness of the alloy was studied. Static tensile, fracture toughness tests and microstructure investigations were performed. The result shows that heat-treatment can adjust the microstructure feature, and cooling rate and aging conditions have remarkable effect on the microstructure parameters, such as the content of equiaxed α, dimension of β grains and thickness of lamellar α, which has a significant effect on the properties of the alloys tested.

1. Introduction

Titanium alloys are widely used in the aerospace industry due to low density, high strength, toughness and good high-temperature properties. Mechanical properties of titanium alloys are important criteria of material service capabilities both in aerospace and industrial applications. It is well known that the microstructure of the alloy is one of the important factors controlling its tensile properties, fatigue strength and fracture toughness. The microstructure of the alloy can be changed from equiaxial through bi-modal to fully lamellar. A bi-modal microstructure is reported to have advantages in terms of yield stress, tensile stress and ductility and fatigue stress. A fully lamellar structure is characterized by high fatigue crack propagation resistance and high fracture toughness. The different cooling rates lead to a diffusion controlled nucleation and growth process of α-lamellae into the β-grains. A high cooling rate results in a martensitic transformation of the β-phase [1–8]. In recent years, the moderate strength or high strength titanium alloys with higher fracture toughness and slower crack propagating rate have been developed to adjust the damage tolerance design requirements [9]. TC4–DT and TC21 titanium alloys are two developed alloys. TC21 is a high strength, ultimate tensile stress UTS $\geq$ 1100 MPa, high toughness($K_{IC} \geq 70$ MPa.$\sqrt{m}$), high damage tolerance titanium alloy, and TC4-DT is a moderate strength (UTS $\geq$ 820 MPa), high toughness ($K_{IC} \geq 90$ MPa$\sqrt{m}$), high damage tolerance alloy. TC4-DT alloy can acquire a large variety of microstructures with different α morphologies depending on thermomechanical treatment. Its mechanical properties are strongly influenced by oxygen content and preformed microstructure. This alloy contains a maximum oxygen content of 0.12 wt% as against 0.20 wt% in commercial grade, and is preferred in applications, where fracture toughness is to be maximized. To enlarge the use level of titanium alloys in the aviation department and improve the stability and safety of aircraft, it is very necessary to research the TC4-DT titanium alloy in-depth. The mechanical properties of high damage tolerance titanium alloys depend on the lamellar microstructure dimension including original β grains size, size of the colonies of α phase lamellae and thickness of α lamellar, while the lamellar microstructure dimension depends on heat-treatment procedure [10–13]. Hence, it is equally important to confirm the heat-treatment technology in manufacturing high damage tolerance titanium alloy components. The aim of the present study was to determine the relationship between heat treatment and alloy microstructure, and the effect of the morphology of the microstructure, the volume fraction of primary α-phase and the thickness of lamellar α on the mechanical properties including fracture toughness of TC4-DT titanium alloy, and the crack propagating path and fractographs were observed to research fracture mechanism.

2. Experimental procedure

TC4-DT alloy used in the present work was a bar of 80 mm × 80 mm × *L*. The beta transus temperature of the alloy was (980 ± 5) °C and its chemical composition shown in Table 1.

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The initial microstructure of the alloy is a typical equiaxed structure consisting of a large volume fraction of fine equiaxed alpha with a grain size of 3–5 μm and a small amount of transformed beta, as shown in Fig. 1. This microstructure suggested that the final processing had been done at a relatively low temperature in the alpha–beta region.

Table 1
Chemical composition of TC4-DT alloy (mass fraction, %).

Al	V	O	N	C	Fe	H	Ti
6.08	4.19	0.11	0.005	0.009	0.06	0.002	Bal.

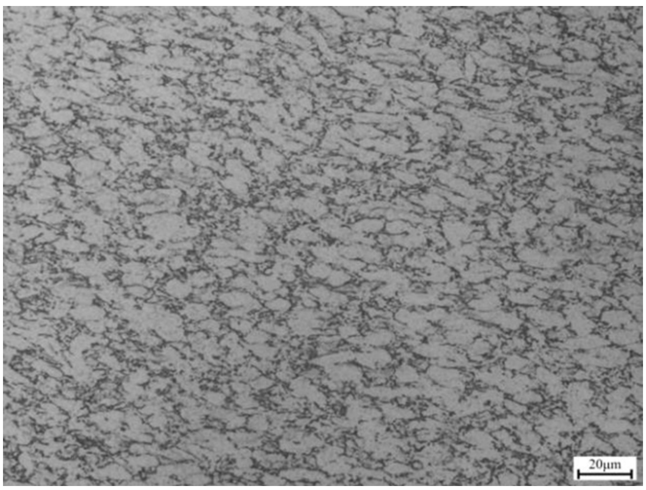

Fig. 1. Initial microstructure used in the experiment.

The tensile specimens were electro-discharged machined from the bar with a gauge length of 25 mm and a diameter of 5 mm. The normative *T–L* specimens are used for fracture toughness test, and the thickness of the specimens was 25 mm. The microstructures were observed using a light microscope of OlympusMP3, the fracture surfaces of the specimens after the fracture toughness tests were observed using a scanning electron microscopy.

Heat treatments were carried out at the temperature of 930 °C, 955 °C, 965 °C, 975 °C separately for 1 h followed by air cooling (AC), the specimens were then subjected to aging treatments at the temperature of 550 °C for 4 h. In order to obtain the lamellar microstructure, the specimens were heated to 1000 °C, a temperature above the beta transus for this alloy. The specimens were cooled by furnace cooling (FC), air cooling and water quench (WQ) respectively after holding at 1000 °C for 1 h, and then aged at 550 °C for 4 h.

3. Results and discussion

3.1. Effect of solution temperature on microstructure and properties

Fig. 2 shows the microstructure of TC4-DT alloy under different heat treatment conditions. As seen in Fig. 2(a), the microstructure of the material consisted of primary α, secondary α and intercrystalline β, it is noticed that the content of the primary α decreases with increasing of solution treatment temperature. The differences of microstructure display changes of the relative

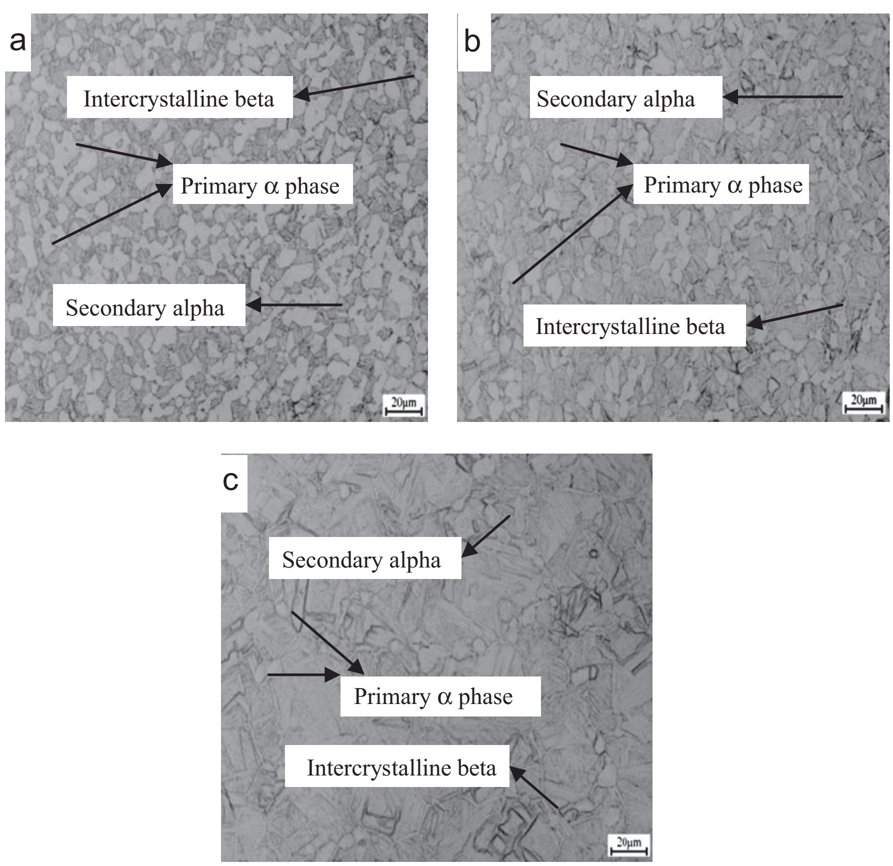

Fig. 2. Microstructure under the different solution treatments followed by aging (a) 930 °C/1 hAC+550 °C/4 hAC, (b) 955 °C/1 hAC+550 °C/4 hAC and (c) 975 °C/1 hAC+550 °C/4 hAC.