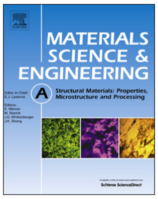
Materials Science & Engineering A 731 (2018) 85–92

Contents lists available at ScienceDirect

Materials Science & Engineering A

journal homepage: www.elsevier.com/locate/msea



Influence of alpha/beta processing on fracture toughness for a two-phase titanium alloy

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ARTICLE INFO

Keywords:
Fracture toughness
Ti-17
Microstructure
Model

ABSTRACT

Effect of alpha/beta processing on fracture toughness of Ti-17 alloy is investigated. For this purpose, Ti-17 alloy is deformed to 0, 30% and 50% height reductions at 820 °C, subsequently heat treated for 820 °C/4 h/WQ (water quenching) + 630 °C/8 h/AC (air cooling). The interrelationship of fracture toughness and microstructure is evaluated, and the fracture mechanism is analyzed. The results show that beta particles are stretched along the metal flow direction as alpha/beta deformation, and the aspect ratios for microstructures with 0, 30% and 50% deformations are 1, 2 and 4, respectively. Alpha phase presents an almost perfect basket-weave structure for undeformed material, whereas the globularized structure can reach 25% and 60% for material of 30% and 50% deformation. Fracture toughness exhibits a decreasing trend as the increasing deformation degree, which is opposite with change law of the globularization fraction. The lamellar alpha can increase the tortuosity of the crack propagation path. For undeformed material, the fracture surface is characterized by large amplitude of ravines with steep ups and downs, and a long crack propagation path is created. In this case, the highest fracture toughness is obtained. As alpha/beta processing, the fracture surface is smoother, the steep ups and downs disappear, and a shorter crack path is created. This results in decreased fracture toughness of material. The tortuosity ratios $L(\varepsilon)/L_0(\varepsilon)$ are about 1.45, 1.23 and 1.15 for 0, 30% and 50% deformations, respectively. In addition, the prediction model of fracture toughness considering tensile properties is established based on the Griffith-Orowan-Irwin relation, and it can provide a relatively reliable prediction for fracture toughness of Ti-17 alloy during alpha/beta processing.

1. Introduction

Damage tolerant is an important criteria to evaluate aero-engine and has been widely used in aviation industry [1,2]. Fracture toughness, representing one of most important properties in damage tolerance design concept, is a basic standard to measure the performance of compression disk of aero-engine. It simulates a state of containing a precrack and describes the ability of resisting fracture. Nowadays, fracture toughness of aeronautical materials, especially aero-engine materials, has caused great attentions from sciences and engineering fields [3–6].

Titanium alloy has attracted the increasing attentions from the area of aviation due to their excellent properties, such as low density, high strength, good corrosion resistance [7,8]. It has found its way in larger quantities into aero-engine like 1–3 grade compressor disk. However, the fracture failure of material will directly affect performance and service life of aero-engine. In order to manufacture advanced aerospace engines and extend their service life, it is of great importance to optimize the fracture toughness of titanium alloys. As well all know, microstructure decides mechanical properties. It is the most direct and effective way to improve fracture toughness by controlling microstructure morphology of titanium alloy. For this purpose, many investigations have been conducted for the effect of microstructure on fracture toughness and its inner mechanisms for titanium alloy [9–15]. For example, Richards [10] investigated the relationships between microstructure and fracture toughness for Ti-6Al-5Zr-4Mo-1Cu-0.2Si and Ti-6Al-4V alloys. They found that the decreasing platelet spacing and increasing platelet thickness can result in improvement of fracture toughness. Bhattacharjee et al. [11] indicated that the ductile fracture toughness of Ti-10V-2Fe-3Al alloy increases with decrease in grain size, and it exhibits a Hall-Petch kind of relationship. In addition, they successfully separated out grain boundary and stress-induced martensitic contribution to fracture toughness. Benhaddad et al. [12] studied the influence of microstructure and texture on fracture toughness in titanium alloy corona-5 and pointed out that the lamellar structure and texture near the orientation {1010} ⟨1120⟩ are beneficial to high

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https://doi.org/10.1016/j.msea.2018.06.035
Received 18 May 2018; Received in revised form 8 June 2018; Accepted 9 June 2018
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values of fracture toughness. Greenfield et al. [14] revealed that the increasing of grain boundary alpha thickness can to some extent improve fracture toughness of titanium alloys. But above all, microstructure changes have significant effect on fracture toughness for titanium alloys. The optimal match between microstructure and fracture toughness is the guarantee of realizing applied and economic values for titanium alloys.

Ti-17 (namely Ti-5Al-4Mo-4Cr-2Sn-2Zr) is a beta-rich two-phase titanium alloy and has been used widely in jet engine fan and compressor disk components due to excellent thermal stability, high strength and fatigue resistance performance [16–18]. Shi et al. [19] researched the effect of three cooling models (water quenching, air cooling, slow air cooling) followed by beta processing on fracture toughness of Ti-17 alloy. The results showed that the longest and thickest alpha platelet is obtained under condition of slow are cooling, which leads to the highest fracture toughness. This work provides a good guidance for beta processing of Ti-17 alloy. However, Ti-17 alloy has become a potential candidate for manufacturing the dual-property blisk of compressor in China [20,21]. Alpha/beta processing is a key technology and necessary procedure to manufacture the dual-property blisk. Thus, the requirement of developing the interrelationship of microstructure and fracture toughness during alpha/beta processing is urgent for Ti-17 alloy. The objective of this work is to establish the connection between microstructure evolution in alpha/beta phase field and fracture toughness of Ti-17 alloy, and further interpret the influence of alpha/beta processing on fracture toughness of Ti-17 alloy.

2. Material and experimental procedures

2.1. Material

Ti-17 alloy used in this work is provided in a bar form with a diameter of 75 mm and its beta transus temperature is measured as 895 °C. The measured composition is listed in Table 1. Fig. 1 shows microstructure of as-received material, which presents the morphology of fully lamellar alpha structure. It is a typical beta-processed material. Ti-17 is a near-beta biphasic titanium alloy, and its thermomechanical processing often involves a series of hot-working and heat treatment steps. The initial step is usually conducted in single beta phase field to produce a basket-weave structure, just like microstructure of the program material in this work (Fig. 1). The subsequent hot-working and heat treatment steps are carried out in the two-phase field, which will generate a more homogeneous microstructure. Such operations are known as alpha/beta processing, that is the keystone of the present work.

2.2. Experimental procedures

Alpha/beta processing of as-received Ti-17 alloy is divided into two parts: isothermal forging and solution plus aging treatment. The bars are first forged on a 2000T hydropress at 820 °C. The three height reductions are chosen to simulate the forging process of dual-property blisk. They are 0, 30% and 50% deformations corresponding to different parts of dual-property blisk, respectively. Air cooling is followed after the isothermal forging. Then heat treatment is conducted using the regime of 820 °C/4 h/WQ (water quenching) + 630 °C/8 h/AC (air cooling). The specimens were prepared for metallographic observation and mechanical properties testing at 1/2 radius of deformed bars. The effective strains of sampling points were calculated to be 0.36 and 0.71 for height reductions of 30% and 50%. Microstructure observations were carried out with Olympus PM-T3 optical microscope and JSM-6390 scanning electron microscope (SEM). Mechanical property testing was divided into two parts: tensile property and fracture toughness. The cylinders with 13.5 mm in diameter and 70 mm in length were prepared for room temperature tensile. Tensile tests were conducted according to Chinese National Standard: GB/T228–2010 [22]. The standard compact tension (CT) specimens with the dimensions of 63 × 68 × 27 mm were manufactured for fracture toughness tests. Precrack is first prepared using MTS-810 fatigue testing machine, and then the CT specimens were stretched to fracture. Fracture toughness tests were done according to Chinese National Standard: GB/T4161-2007 [6]. Fracture toughness specimen after test was shown in Fig. 2. The macro and micro appearances of fracture were analyzed using the SEM.

Table 1
The chemical composition of Ti-17 alloy (wt%).

Al	Cr	Mo	Sn	Zr	Fe	C	N	H	O	Ti
5.02	3.93	3.88	2.37	1.95	0.05	0.01	0.01	0.003	0.12	Bal

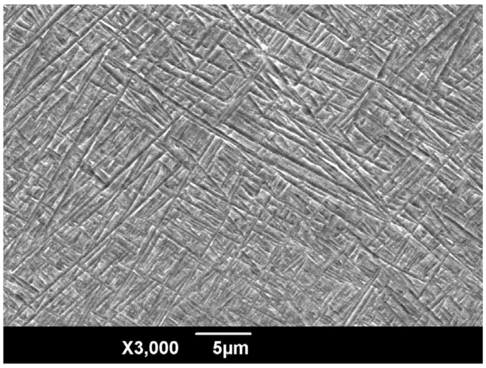

Fig. 1. Microstructure of as-received Ti-17 alloy.

3. Results and discussion

3.1. Microstructure observations

Microstructure characteristics of Ti-17 alloy under different conditions are observed by optical microscope (OM), as shown in Fig. 3. It can be found that beta particles present different morphologies due to various deformation degrees. For undeformed material (Fig. 3a), the equiaxed beta particles can be observed and the aspect ratio (long axis/short axis) is about 1. The sizes of beta particle are about 300–500 μm. Microstructure has traces of deformation for the compressed materials (Fig. 3b and c). Beta particles are stretched along the metal flow direction, and the aspect ratios of microstructures with height reductions of 30% and 50% are 2 and 4, respectively. The average areas of beta particle under three deformation conditions are similar, and they merely have different geometrical shapes. In addition, recrystallized beta particles induced by deformation are found when height reduction reaches 50%. In this work, the compression deformation is carried out in the two-phase field. Changes of alpha phase may be more important

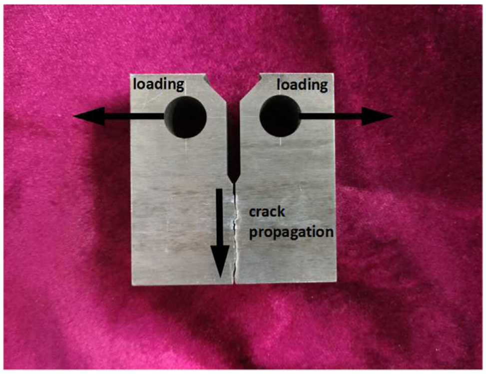

Fig. 2. Fracture toughness specimen after test.

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