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Effect of globularization behavior of the lamellar alpha on tensile properties of Ti-17 alloy

Jianwei Xu, Weidong Zeng*, Yawei Zhao, Zhiqiang Jia, Xin Sun

State Key Laboratory of Solidification Processing, Northwestern Polytechnical University, Xi'an, 710072, PR China

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ABSTRACT

In this work, the effects of processing parameters on microstructure evolution and tensile properties of Ti-17 alloy with a colony lamellar structure were investigated. For this purpose, a series of deformation and heat treatment experiments were conducted in the two-phase field. Microstructure observations indicated that the main feature of microstructure evolution during deformation and heat treatment is the globularization behavior of alpha phase. Furthermore, the globularization process was found to be prestrain dependent. The globularization fraction increased with the increasing of prestrain. In turn, tensile properties changed with the globularization fraction of alpha phase. The globularization behavior could refine the grain, decrease slip length and lead to a smoother alpha/beta interface. Such changes would improve tensile properties. Both strength and plasticity exhibited the increasing tendency with the globularization fraction. The quantitative investigations found that there are linear relationships between tensile properties and the globularization fraction. At both room temperature and 400 °C, tensile properties could be adjusted in the range of 1145–1258 MPa (RT)/945–990 MPa (400 °C) and 1068–1190 MPa (RT)/775–835 MPa (400 °C) for ultimate tensile strength and yield strength and 12–16% (RT)/13–17.5% (400 °C) and 19–31% (RT)/34–42% (400 °C) for elongation and reduction of area via varying the globularization fraction of alpha phase. These linear equations were determined by fitting the experimental data, respectively. The high correlation coefficients indicated that these equations could be used to represent the relationships between tensile properties and the globularization behavior for Ti-17 alloy.

1. Introduction

Titanium alloys, particularly the two-phase (alpha/beta) titanium alloys, have received the increasing attentions from aerospace, energy and bio-medical applications due to their unique combination of high specific strength, good fatigue performance and excellent corrosion resistance [1–3]. The typical processing route for the two-phase titanium alloys often involves a series of hot working and heat treatment steps. The initial processing is usually carried out in the single beta phase field to break down the ingot microstructure and form a transformed microstructure. Following beta processing, a hot working step and final heat treatment are conducted in the two-phase field to break down the transformed microstructure [4,5]. The size, volume fraction and morphology of alpha phase formed during hot working and heat treatment in the two-phase field can influence the mechanical properties [6,7]. Such characterizations of alpha phase are determined by processing parameters, such as strain, temperature and holding time. Thus, the mechanical properties of titanium alloys can be improved by processing parameters [8].

Tensile property is one of the most important mechanical properties to evaluate the performance of titanium alloys, so extensive studies have been conducted on the relationships among the processing parameters, microstructure and tensile properties [9–16]. Wang et al. [9] studied the effect of hot working and heat treatment on microstructure and tensile properties of TG6 (Ti-5.8Al-4.0Sn-4.0Zr-0.7Nb-1.5Ta- 0.4Si-0.06C) alloy. It was found that the tensile strength was more sensitive to heat treatment, while the tensile plasticity was mainly determined by the forging temperature. Li et al. [10] investigated the microstructure and tensile properties of a new high strength Ti–6Cr–5Mo–5V–4Al alloy, and found that this alloy was heat treatable to obtain an excellent

* Corresponding author.
E-mail addresses: xjw@mail.nwpu.edu.cn (J. Xu), zengwd@nwpu.edu.cn (W. Zeng).

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balance of strength and plasticity, the ultimate strength and elongation could reach 900–1600 MPa and 6–20%, respectively. Chen et al. [11] indicated that the strength decreased with increasing of aging temperature and ductility changed in opposite way for Ti–3.5Al–5Mo–6V–3Cr–2Sn–0.5Fe alloy. Jia et al. [12,13] discussed the effect of thermal exposure and aging on the tensile properties and microstructure of Ti60 alloy. The results showed that the variation of tensile properties after thermal exposure or aging treatment depended on the change of microstructure morphology strongly. In addition, Chavam et al. [14] established the flow behavior modeling of IMI834 titanium alloy during hot tensile deformation. Liu et al. [15] studied the tensile characteristics of friction stir welded joint of Ti–6Al–4V alloy. As a whole, the specific tensile properties that are obtained are a function of the characteristics of microstructure. In turn, these microstructure characterizations are a function of the processing parameters, such as strain, temperature and holding time. Thus, in order to obtain the excellent mechanical properties, the appropriate processing parameters are very beneficial to both scientific and engineering perspectives [4].

Ti-17 (Ti–5Al–2Sn–2Zr–4Mo–4Cr) alloy is a near-beta two-phase titanium alloy with high specific strength, good corrosion resistance and excellent high-temperature properties [17]. It is designed for application in aviation parts for temperature range up to 400 °C [18]. In China, it has received the increasing attentions from the aviation industry as a potential candidate of materials to manufacture the dual-property blisk. For example, Ma et al. [19] modeled constitutive relationship of Ti-17 alloy with starting lamellar microstructure using artificial neural network method. Li et al. [20] studied the mechanism in beta phase evolution of Ti-17 alloy during hot deformation. Furthermore, the dynamic globularization [21] and static globularization [22] for Ti-17 alloy had also been quantitatively analyzed, respectively. It can be found that most of the researches were focused on microstructure evolution. The investigations about the relationships among the processing parameters, microstructure and tensile properties are limited. In the present work, the effects of thermomechanical processing parameters on microstructure evolution and tensile properties are investigated. Moreover, the quantitative relationships between microstructural features and tensile properties will be established. The aim of the present work is to optimize processing parameters of Ti-17 alloy and to obtain satisfactory properties.

2. Materials and experimental procedures

2.1. Materials

The program alloy used in the present work was Ti-17 alloy, which was provided by Baoshan Iron & Steel Co., Ltd. in a bar form with a diameter of 75 mm. It had a measured composition (in weight percent) of 5.02Al, 3.93Cr, 3.88Mo, 2.37Sn, 1.95Zr, 0.05Fe, 0.01C, 0.01N, 0.003H, 0.12O, and balance Ti. The beta transus temperature, as determined by metallographic observations, was about 895 °C. The as-received material was a typical beta-processed microstructure, as shown in Fig. 1. It comprised of the fully lamellar alpha in the transformed beta matrix. The measured thickness of alpha lamellae was about 0.35 μm. The grain boundary could be clearly observed, and the thickness of grain boundary was about 0.45 μm. In addition, the lamellar alpha in the adjacent beta grains showed an entirely different orientation.

2.2. Experimental procedures

In order to investigate the effect of processing parameters on the tensile properties, hot working and heat treatment experiments were conducted in the two-phase field. Firstly, the beta-processed bars were isothermally forged at 820 °C to the height reductions of 20%, 40%, 60% and 80%, respectively, followed by air cooling. Then, cylindrical samples with 13.5 mm in diameter and 70 mm in length were prepared from the bars. The sampling point was selected as 1/2 radius of the bars to ensure uniform strain distribution. The effective strains at 1/2 radius were calculated to be 0.25, 0.52, 1.03 and 1.27 for 20%, 40%, 60% and 80% reductions, respectively [22]. Heat treatment was carried out in the two-phase field using the combination of solid solution plus aging treatment (820 °C/4 h/WQ + 630 °C/8 h/AC). After heat treatment, the standard tensile test samples were machined from the cylindrical samples, as shown in Fig. 2. The tensile properties were evaluated at room temperature and 400 °C. Finally, optical microscopy (OM) was employed to characterize the microstructural morphology under different conditions. The relationships between tensile properties and microstructure evolution were quantitatively analyzed.

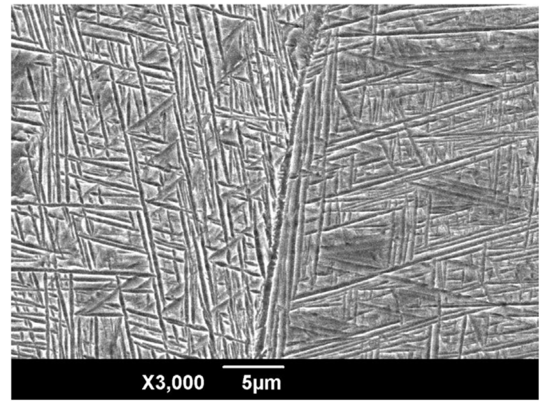

Fig. 1. Micrograph of as-received Ti-17 program alloy.

3. Results and discussion

3.1. Microstructure evolution

Microstructure evolution for the material deformed to different height reductions at 820 °C and subsequently heat treated by 820 °C/4 h/WQ + 630 °C/8 h/AC was examined and shown in Fig. 3. The main feature of microstructure evolution during deformation and heat treatment was the globularization behavior of alpha phase (globularization was affirmed for an alpha grain with the aspect ratio less than 2.5). The globularization fraction increased with the increasing strain. For the undeformed samples, a fully lamellar-alpha structure could be observed. Such lamellar structure would be broken down step by step with strain. When Ti-17 alloy was deformed to a strain of 0.25, the globularization fraction of alpha phase was at comparatively low level. A small percentage of alpha lamellae were globularized, but most of primary alpha phase

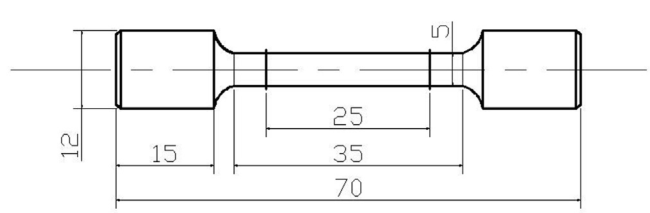

Fig. 2. The standard tensile test sample.