

Microstructure and Mechanical Properties of TC18 Titanium Alloy



Sun Shuyu¹, Lv Weijie²

¹ Taizhou University, Taizhou 318000, China; ² State Key Laboratory of Metal Matrix Composites, Shanghai Jiaotong University, Shanghai 200240, China

Abstract: Ti-5Al-5Mo-5V-1Fe-1Cr Ti alloy (TC18) was fabricated via a consumable vacuum arc-remelting furnace, and then subjected to thermo-mechanical processing and heat treatment. The microstructural characteristics and mechanical properties of the heat-treated alloy were investigated. Results show that primary α phase exhibits spherical, near equiaxed, plate- and rod-shaped morphologies after heat treatment. This is associated with boundary segregation of α grain. The alloy presents a good combination of strength and plasticity during tensile test. However, the value of σ_y/σ_b of the alloy reaches 0.95. It is suggested that the grain boundaries absorb dislocations during tensile test; therefore, the dislocation strengthening increases very slowly. This is the primary reason for the high value of σ_y/σ_b .

Key words: TC18 Ti alloy; microstructure characteristics; mechanical properties; value of σ_y/σ_b

High-strength titanium alloys are widely used in aviation, aerospace and other economic sectors owing to their excellent combination of strength and toughness. The constant drive for higher specific properties has led to continuous improvement of Ti alloy design [1-4].

Ti-5Al-5Mo-5V-1Fe-1Cr (TC18) Ti alloy is one of important aviation material, which can be used as aeroplane parts and large force-bearing components. The mechanical properties of the alloy have been investigated in recent years [5-10]. However, little information is available to date on the value of σ_y/σ_b (yield strength/ultimate strength) of the alloy during tensile test at room temperature. The aim of the present paper is to study the reasons why TC18 alloy possesses very high value of σ_y/σ_b and what is the role of the load-bearing effect of α grain in TC18 Ti alloy microstructure, so as to provide valuable technical information for further R&D of TC18 Ti alloy.

1 Experiment

The raw materials were sponge Ti (grade I) and other alloying elements including Al, Al-Mo, Al-V, Fe and Cr.

According to the stoichiometric composition of TC18 Ti alloy the above raw materials were blended together thoroughly and then compacted into pellets. The pellets were melted in a consumable vacuum at least twice to promote microstructure homogeneity.

The as-cast ingot was forged at 1150 °C and rolled at 840 °C, and then is subjected to heat treatment. In order to control the overgrowth of grains and obtain good comprehensive mechanical properties, we employed triplex heat treatment procedures as follows: 830 °C/1.5 h+furnace cooling, 750 °C/1.5 h+air cooling, 600 °C/4 h+air cooling.

The heat-treated rods were machined into the samples for tensile test at room temperature. Microstructure observations were conducted by optical microscope (OM) and scanning electron microscope (SEM) after the polishing and etching. Moreover, transmission electron microscope (TEM) was also used.

2 Results and Discussion

2.1 Microstructure of the alloy

Fig.1a shows the microstructure of the as-cast alloy. The α

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Corresponding author: Sun Shuyu, Ph. D., Lecturer, School of Mechanical Engineering, Taizhou University, Taizhou 318000, P. R. China, Tel: 0086-576-88661930, E-mail: sun_shuyu@126.com

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grain shows needle-shaped morphology due to high contents of β stabilizing elements. The microstructure of the alloy after thermo-mechanical processing is inhomogeneous (Fig.1b). Fig.1c shows the microstructure of the alloy undergoing the heat treatment. Since the segregation increases the anisotropy of the boundary migration of α grain, the primary α dispersing in β phase shows spherical, near equiaxed, plate-shaped and rod-shaped morphologies. Fig.1d shows the characteristics of Widmannstatten structure. The high-stage temperature of the triplex heat treatment (870 °C) is higher than the β transus one (865 °C). The boundary α decorating β exerts Zener pinning force on the boundary migration of β grain. The boundary α has a wide range of size distribution, which gives rise to a large Zener dragging force^[11]. Moreover, the morphology diversity of the β is also associated with grain boundary segregation.

Fig.2a shows TEM image of the alloy undergoing by heat treatment. The secondary α phase precipitates during aging. Fig.2b shows the secondary α with the annealing twins. The interfacial energy of the annealing twins is a stacking fault energy, which is significantly lower than that of LAGB (low angle grain boundaries) or HAGB (high angle grain boundaries). Since the precipitation temperature of the secondary α phase is relatively low, the secondary α is difficult to be spheroidized. Nevertheless, the lentoid shape of the secondary α is favorable for decreasing elastic strain energy caused by the difference of specific volume between α and β phase. Fig.2c shows the dislocations in the primary α . Dislocations may enter grain boundary of α . Fig.2d shows the sub-grain of primary α . When the high-stage temperature approaches to the β transus temperature of the alloy, the

defects such as sub-grain boundary and dislocations may form high diffusivity path. The segregation induces chemical potential gradient, which accelerates surface diffusion. β stabilizing elements penetrate along the path into α which may lead to the division of α finally^[12].

2.2 Mechanical properties of the alloy

Table 1 is the mechanical properties of TC18 alloy.

Fig.3 shows the features of dimple fracture. The equiaxed dimples distribute uniformly. The average size of the dimples is 4.3 μm . The tearing-mode cracks are observed. It is suggested that some dimples result from the fracture or interface debonding of secondary α . The relatively large depths of the dimples indicate that the work-hardening parameter of the alloy is relatively low. Namely, the dislocation strengthening increases slowly during the process of the deformation. This is consistent with the result of the tensile test.

The dislocation strengthening is determined by the multiplication and pilling-up of dislocations. The slow increase in the stress indicates that the dislocation pilling-up increases slowly.

The segregation concentration of grain boundary increases under the effects of tensile stress^[13]. The dislocations can enter grain boundaries under the effect of stress gradient, which can be also pinned by the segregated alloying elements in the grain boundaries. This will decrease the dislocation pilling-up in grains during tensile test significantly.

Table 1 Mechanical properties of TC18 alloy

σ_s/MPa	σ_b/MPa	ε_f/MPa	$\varepsilon/\%$	$\psi/\%$	σ_s/σ_b
1106	1160	15.1	13.5	19.7	0.95

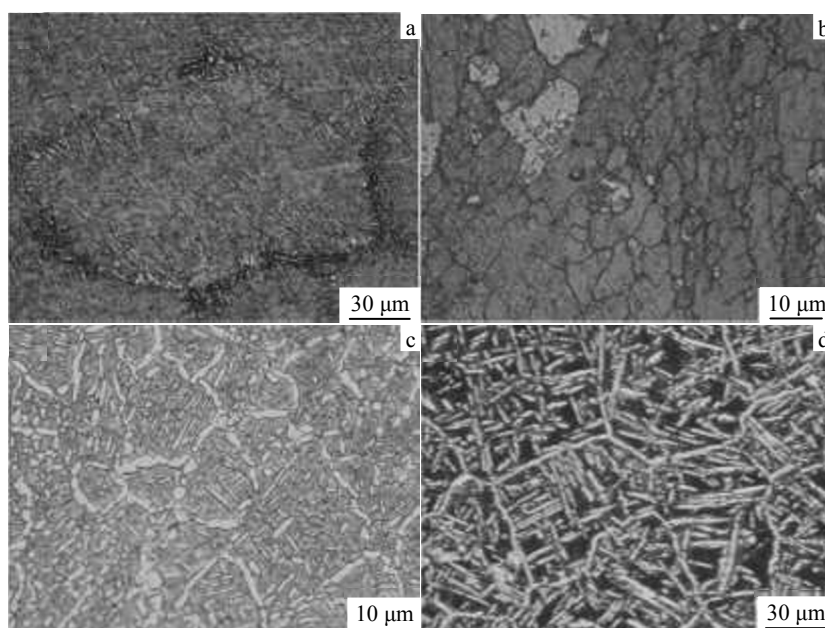


Fig.1 Optical micrographs of TC18 alloy: (a) the as-cast alloy; (b) the alloy after forging and rolling; (c) the alloy undergoing heat treatment; (d) Widmannstatten structure

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