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Microstructural characteristics and mechanical properties of in situ synthesized (TiB + TiC)/TC18 composites

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ABSTRACT

Trace reinforcements can significantly refine microstructure and improve mechanical performance of composite. In this work, the in situ synthesized Ti–5Al–5Mo–5V–1Fe–1Cr titanium matrix composite containing trace TiB and TiC is fabricated. The microstructural characteristics and tensile properties of the heat-treated materials are investigated, with particular emphasis on researching the spheroidization of α phase and the effects of trace reinforcements. It is revealed that it presents the division of α grain during spheroidization process. The separated α phase, near equiaxed α phase and short-rod α phase tend to be spheroidized during the processing of diffusion. The trace reinforcements can accelerate the spheroidization of α by accelerating the extent of diffusion and then the microstructural homogeneity is promoted. The composite manifests excellent comprehensive mechanical properties due to the microstructural improvement and the effect of the trace reinforcements.

1. Introduction

Ti–5Al–5Mo–5V–1Fe–1Cr (TC18) titanium alloy is an important aviation structural material [1]. The alloy has some unique microstructural features such as high dispersivity and large concentration gradient between α and β phase. Discontinuous fiber and particle can efficiently refine microstructure and promote mechanical properties of Ti alloy [2–4]. However, little information is available so far on TC18 Ti matrix composite (TMC).

In this work (TiB + TiC)/TC18 composite is prepared by the consumable vacuum arc-remelting furnace. The matrix is also prepared for the comparative research. The as-cast materials are then subjected to thermo-mechanical processing and heat treatment. The microstructural characteristics and mechanical properties of the composite are investigated, with particular emphasis on the spheroidization of α during heat treatment. Moreover, the effects of trace reinforcements on microstructural evolution and mechanical properties of the composite are examined. Though the spheroidization of α in Ti alloy during deformation and anneal has been reported [5,6]. The spheroidization phenomenon in this work is different as marked on two points: 1. The microstructures of the deformed materials are heterogeneous. 2. The spheroidization process is mainly completed during heat treatment.

2. Experimental

The studied materials are fabricated into the ingots with the diameter of φ120 mm by the consumable vacuum arc-remelting furnace. Small addition of B_4C (0.4 wt.%) to Ti produces TiB and TiC during solidification by in situ chemical reactions [2,7]:

$$5Ti + B_4C = 4TiB + TiC \quad (1)$$

$$Ti + C = TiC \quad (2)$$

Phase identifications indicate that there are three kinds of phases in the composites, Ti, trace TiB and TiC.

The materials are then forged at 1150 °C and rolled at 840 °C into the rods with the diameter of 15 mm. For subsequent intensive investigation, the rods are subjected to heat treatment. In order to control the overgrowth of grains, while obtaining good comprehensive mechanical properties, we employ triplex heat treatments. The processes are: (a) heat treatment A (HTA), 830 °C (1.5 h) + Furnace Cooling, 750 °C (1.5 h) + Air Cooling, 600 °C (4 h) + Air Cooling. (b) Heat treatment B (HTB), 870 °C (1.5 h) + Furnace Cooling, 770 °C (1.5 h) + Air Cooling, 600 °C (4 h) + Air Cooling.

After the heat treatment, the tensile properties of the composite and matrix are examined at room temperature. Microstructure observations are conducted by optical microscope (OM), scanning electron microscope (SEM) and transmission electron microscope (TEM).

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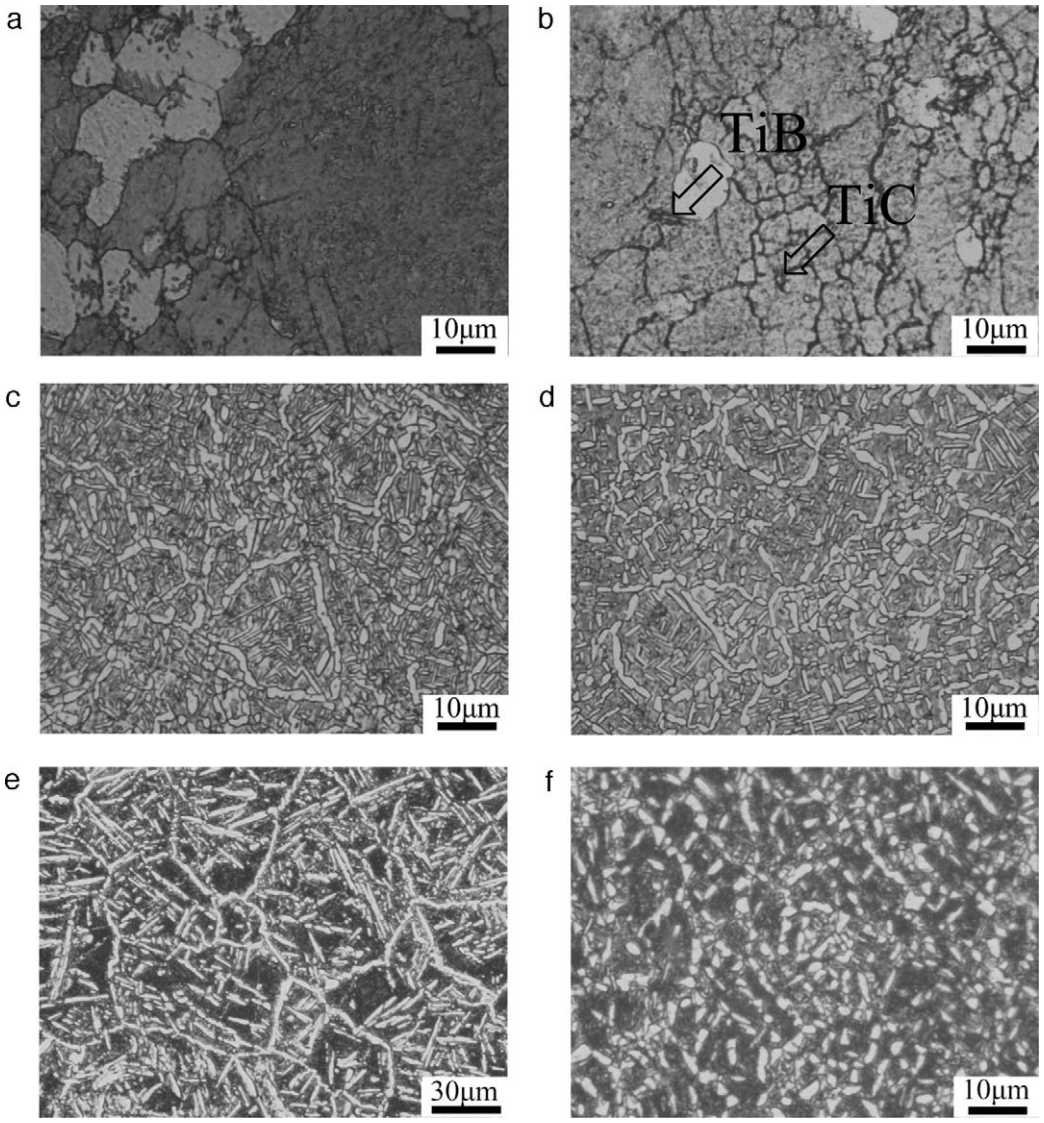

Fig. 1. Optical micrographs of (a) the alloy after the forging and rolling. (b) The composite after the forging and rolling. (c) Alloy undergoing HTA treatment. (d) Composite undergoing HTA treatment. (e) Alloy undergoing HTB treatment. (f) Composite undergoing HTB treatment.

3. Result and discussions

The in situ synthesized TiB and TiC have small length scale due to their small volume fraction. Moreover, the trace reinforcements have a tendency to segregate at grain boundaries [8]. The solid solubility of boron (B) and carbon (C) is low in Ti alloy, e.g., the solubility of B is less than 0.02 wt.%. Solute enrichment results in constitutional supercooling which in turn provides the driving force for nucleation and increases the nucleation rate. Furthermore, excess B and C in the solide-liquid interface also lower the growth rate of the grains [9]. The refinement of prior β grains and intersection of different orientated acicular α colonies within β grains retard the further growth of α [10].

Fig. 1 shows optical micrographs of the specimens under the treatment of thermo-mechanical processing and heat treatment. Comparing with Fig. 1a and b, it is observed that the microstructure of the composite is refined. The pinning effect of trace TiB and TiC on grain boundary migration known as Zener drag markedly reduces grain size and promotes microstructural homogeneity [11].

The microstructures of the composite and matrix undergoing HTA treatment both exhibit as α–β structure (Fig. 1c and d). Primary α dispersing in β phase shows as near equiaxed, plate-shaped and rod-shaped, respectively. However, the composite and matrix undergoing HTB treatment present totally different microstructures. This is primarily due to the enhancement of β transus of the composite induced by boron and carbon. The matrix shows Widmanstatten structure (Fig. 1e). Whereas the composite still exhibits as α–β structure (Fig. 1f). Some spherical and elliptical primary α grains with an average length of 1.46 μm are observed (Fig. 1f). Comparing with the composite undergoing HTA treatment, plate-shape α phase has been reduced significantly.

Fig. 2 shows TEM images of the composite undergoing HTA treatment. Fig. 2a–c describe the dislocation motion and substructural formation. Two main processes such as the annihilation and rearrangement of dislocations appear. The excess dislocations gradually transform into the cell structure and low angle grain boundaries (LAGB). Sub-boundary migration and sub-grain coalescence ultimately may form high angle grain boundary (HAGB) [12,13]. However, it only presents in situ recrystallization in α due to the high stacking fault energy of hcp structure and high dispersivity of α. There often presents annealing twins (Fig. 1d) in α phase along with the recrystallization process. Interfacial energy of twins is lower than that of HAGB which contributes to the decrease of system free energy.