Materials and Design 93 (2016) 81–90

Contents lists available at ScienceDirect

Materials and Design

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

Comparative study on superplastic tensile behaviors of the as-extruded Ti6Al4V alloys and TiBw/Ti6Al4V composites with tailored architecture

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ARTICLE INFO

Article history:
Received 25 November 2015
Received in revised form 24 December 2015
Accepted 29 December 2015
Available online 29 December 2015

Keywords:
Titanium matrix composites
Titanium alloy
Superplasticity
Microstructure evolution
Elongation

ABSTRACT

The superplastic tensile behaviors and mechanisms of Ti6Al4V alloys and TiBw/Ti6Al4V composites with tailored architecture were comparatively studied in order to reveal the superplasticity mechanisms. The superplastic tensile tests were carried out at the temperatures of 900 °C, 925 °C, 950 °C and 975 °C with the strain rate of 0.000316/s, 0.001/s and 0.00316/s, respectively. The composites exhibited higher superplasticity, higher strain rate sensitivity index *m* and lower activation energy *Q* than the alloys. This might be attributed to the small lamellar aspect ratio and TiBw reinforcement addition. Microstructural observation showed that the aspect ratio of α phase in the Ti6Al4V alloys decreased with increasing strains, and transferred to equiaxed grains only in the tip area. Therefore, necking could not be constrained and transferred to other positions with unfavorable microstructure, led to the needle-like fracture macro morphology. On the contrary, the TiBw/Ti6Al4V composites had weak necking tendency due to the globalization process completed at small strain, which contributed to the large elongations. Recrystallization should be responsible for the decrease in lamellar aspect ratio and increase in volume fraction of β phase, which are considered to be the major coordination mechanism of superplasticity for the as-extruded TiBw/Ti6Al4V composites.

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1. Introduction

Titanium matrix composites (TMCs) possess high specific strength, specific stiffness, wear resistance and high temperature durability, which promoted them extensive applications in the field of aerospace, shipping and chemical engineering [1–3]. In the past decades, lots of researches have been concentrated on achieving a homogeneous distribution of reinforcement in the matrix [4,5]. However, the experimental results revealed that the composites with a homogeneous microstructure could only exhibit a limited improvement in strength but at the cost of ductility [6,7]. Recently, Huang et al. [8] has proposed a kind of TMCs with tailored network microstructure. It is surprising to find that the TiBw/Ti6Al4V composites with network microstructure exhibited superior strength and ductility over those with a homogeneous one [9]. Zhang et al. [10] further verified the superiority by designing and fabricating similar inhomogeneous microstructure of TiBw/Ti6Al4V composites.

However, the high cost and poor machinability of the TMCs have restricted their wide applications. In addition, the TMCs components prepared via casting route cannot avoid casting defects like porosity and blowholes. Superplastic deformation (SPD), an economical and near net shape technique and the key solution to solve the above two problems, has become one of the essential processing techniques for the TMCs due to the specific advantages such as reducing material waste, component weight reduction, ability to manufacture special materials and cutting processing cost [11–13].

Many efforts have been made from academic and industries to research the superplastic behaviors, optimize deformation parameters and superplastic properties of the TMCs for establishing the theoretical basis to guide the superplastic deformation process [14,15]. Sinha et al. [16] studied the superplastic deformation behaviors of the 0.1 wt.% B reinforced Ti6Al4V alloys with equiaxed and fine grain microstructure. The results suggested that the optimal deformation temperature of the Ti6Al4V–0.1B composites was 900 °C, which was similar to the conventional Ti6Al4V alloys. In addition, based on the calculation of activation energy and microstructure observation results, grain boundary sliding accompanied by dislocation motion along grain boundaries was the operating deformation mechanism for the composites. Lu et al. [17] carried out superplastic tensile test on the (TiB + TiC)/Ti6Al4V composites with coarse grain size. The maximum elongation of 462% was obtained at 920 °C and 0.001/s for the composites, but much smaller than that of Ti6Al4V alloys with similar microstructure. The decrease in elongation could be attributed to the cavities formed

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http://dx.doi.org/10.1016/j.matdes.2015.12.162
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around the reinforcements in the composites. Finally, the dislocation movement inside α phase was found to be the main accommodation mechanism in superplastic deformation of coarse-grained composite. Huang et al. [18] conducted preliminary research on the superplastic behaviors of the as-sintered TiBw/Ti6Al4V composites with novel network microstructure. It can be observed from the morphology of tensile specimen that the equiaxed network microstructure was drawn into lamina microstructure after superplastic tensile test. What's more, the dynamic recrystallization of Ti6Al4V alloy matrix was found to be an essential coordination mechanism for the composites. However, contrary to the other reports, the novel network distribution of the TiBw reinforcements was considered to be helpful for superplastic deformation process by inhibiting local deformation, decreasing crack propagation rate and refining grain size.

It can be concluded from the above analysis that mechanisms behind the superplastic behavior of the TMCs were still ambiguous. In addition, the composites with inhomogeneous microstructure exhibited a superior combination of strength and ductility compared with the homogeneous composites. Therefore, it is significant to carry out superplastic tensile tests on the TMCs with inhomogeneous microstructure and reveal the deformation mechanisms thereby promoting further applications of TMCs with superior mechanical properties.

Plastic deformation plays a significant role in improving the mechanical properties of TMCs [19]. Among all the plastic deformation techniques, hot extrusion is the most popular one. In addition, the previous studies [8,20,21] have revealed that the tensile strength could be further increased by 13% and the elongation remarkably improved from 3.6% to 6.5% after extrusion, which suggested an excellent combination of strength and ductility of the as-extruded TiBw/Ti6Al4V composites with tailored architecture. Therefore, the present work focuses on the difference of superplastic tensile behaviors and mechanisms between the as-extruded Ti6Al4V alloys and TiBw/Ti6Al4V composites.

2. Experimental procedures

In this study, the TiBw/Ti6Al4V composites with tailored architecture were fabricated according to the quasi-continuous network principle [8]. In addition, to study the effect of TiBw reinforcements during superplastic deformation process, the Ti6Al4V alloys were also prepared by the same methods. Spherical Ti6Al4V powders with a diameter of 150 μm on average and hexagonal-prismatic TiB_2 powders with a size range from 1 to 8 μm were adopted in this study. The morphology of the two raw materials was shown in Fig. 1(a) and (b). Afterwards, in order to make the fine TiB_2 powders adhere onto the surface of large spherical Ti6Al4V powders, low energy ball milling with a speed of 150 r/min for 5 h was carried out. The morphology of Ti6Al4V and mixed Ti–6Al4V–TiB_2 powders after ball milling was shown in Fig. 2(a) and (b), respectively. It can be seen from the SEM images that the morphology of spherical Ti6Al4V remained unchanged and the TiB_2 powders coated onto the surface uniformly after the low energy ball milling. Subsequently, the Ti6Al4V alloys and 3 vol.% TiBw/Ti6Al4V composites were fabricated by reactive hot pressing (RHP) in vacuum at 1200 °C for 1 h with a pressure of 25 MPa. During this process, the TiBw reinforcements were in situ synthesized around the spherical Ti6Al4V powders and formed the network microstructure [22], according to:

$$Ti + TiB_2 \rightarrow 2TiB. \quad (1)$$

Fig. 3 shows the morphology of the as-sintered Ti6Al4V alloys and TiBw/Ti6Al4V composites after RHP. It can be seen from Fig. 3(a) and (b) that the Ti6Al4V alloys had coarse grains with a typical widmanstätten microstructure. The grain size was measured to be 2 mm on average, much larger than that of Ti6Al4V powders, which suggested that no physical interface left after RHP. However, the widmanstätten microstructure formed due to the high temperature combined with a slow cooling speed in furnace was considered to be unfavorable for the strength, ductility and creep resistance of the titanium alloys. The microstructure could be eliminated by followed deformation and heat treatment. Fig. 3(c) and (d) shows the morphologies of TiBw/Ti6Al4V composites fabricated at the same parameters. It is clear that the lamella (similar but not equal to the basketweave) instead of widmanstätten microstructure formed in TiBw/Ti6Al4V composites, which was suggested to be caused by the space restraint from TiBw reinforcements with network microstructure.

The as-sintered Ti6Al4V alloys and TiBw/Ti6Al4V composites were hot extruded at 1100 °C with a ratio of 9 in this study according to the optimized parameters in previous work [8,10]. The superplastic tensile tests were carried out on the as-extruded alloys and composites. The superplastic tensile tests were carried out at the temperature range from 900 °C to 975 °C. The strain rates were decided to be 0.000316/s, 0.001/s and 0.00316/s, respectively. In order to prevent serious oxidation of the tensile specimens at the evaluate temperatures, a layer of glass-ceramic protective coating was covered uniformly on the surface with a melting point of 800 °C and then adhered onto the surface of specimen. After the tensile test, the microstructure and morphology of tensile sample and fracture was characterized using a scanning electron microscopy (SEM, Quanta 200FEG).

3. Results and discussion

3.1. Microstructure observation

The superplastic deformation behavior was found to be sensitive to microstructure, grain size and morphology in particular. Therefore, the microstructure of the as-extruded Ti6Al4V alloys and TiBw/Ti6Al4V

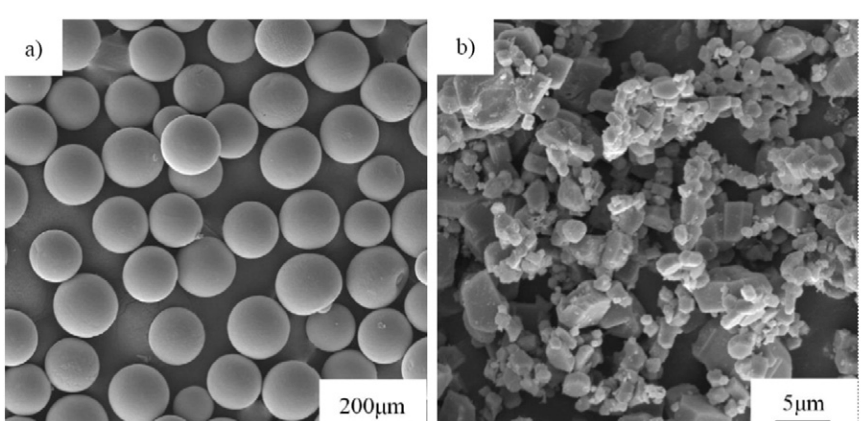

Fig. 1. Morphologies of (a) spherical Ti6Al4V powders and (b) hexagonal-prismatic TiB_2 powders.

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