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Relationships among reinforcement volume fraction, microstructure and tensile properties of ($TiB_w + TiC_p$)/Ti composites after ($\alpha + \beta$) forging

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ABSTRACT

In this study, ($TiB_w + TiC_p$)/Ti composites reinforced with various volume fraction were prepared by in situ casting route and subsequent ($\alpha + \beta$) forging. The relationships among reinforcement volume fraction, microstructure and tensile properties of the composites are investigated and discussed. The results indicate that the aspect ratios of the reinforcements are reduced and relatively uniform distribution of the reinforcements is obtained after ($\alpha + \beta$) forging. Meanwhile, with the increase in volume fraction of reinforcement, the α phase is significantly refined due to dynamic recrystallization (DRX). The tensile testing results indicate that the yield strength and ultimate tensile strength of the composites exhibit a rising trend with the volume fraction of reinforcements while the elongations gradually reduce both at RT and elevated temperature. With the increasing of tensile temperature, the ultimate tensile strength of the composites obviously decreases while the elongation increases. The strengthening mechanism as well as the softening phenomena is discussed.

1. Introduction

With rapid advance in aerospace and industry, particles reinforced titanium matrix composites (PRTMCs), owing to such outstanding properties as high strength, elastic modulus, superior creep resistance and high temperature durability, have been emerged as attractive candidate materials for modern applications [1–3]. Recently, in-situ synthesis methods have been extensively adopted to prepare the PRTMCs, such as power metallurgy (PM) [4], rapid solidification [5], combustion assisted cast (CAC) [6] and mechanical alloying [7]. As one of the paramount processing techniques, CAC route, of which the core features including simplicity, large scale production, net-shape and flexibility have attracted wide concern [8].

The large-scale engineering applications for PRTMCs prepared by CAC route, as known to all, are severely stymied by the prevalence of low ductility at RT and limited high temperature performance. In order to circumvent this defect, one feasible and effective approach can be applied by thermo-mechanical processing (TMP), getting a favorable balance of strength and ductility, which was reported by several research groups. Tang et al. [9] reported the elongation of 10 vol% as-cast TiB_w/Ti composites after hot-forging is up to 5.6%. Imayev et al. [10] investigated the Ti-TiB based composite hot-deformed in β phase field, and found that 2-D forging resulted in alignment of the borides predominantly perpendicular to the forging directions. The study performed by Ma et al. [11] revealed that a remarkable increase in the high temperature tensile strength and the ductility of ($TiB_w + TiC_p$)/Ti-1100 composites can be obtained by conventional forging. Nevertheless, to date, the efforts in previous research was primarily focused on hot-forging in β phase field and conventional forging, and little study has been systematically conducted on ($\alpha + \beta$) forging. In effect, substantial studies [12,13] regarding of as-deformed titanium alloys in ($\alpha + \beta$) phase field have declared that equiaxed and bimodal microstructures can be acquired. It has been widely recognized that the equiaxed microstructure owns good plasticity and low cycle fatigue properties while the bimodal microstructure possesses good fatigue and creep resistant properties [13]. Additionally, for TMCs, the reinforcements present in which play a crucial part in the matrix microstructure. The previous work by Bermingham has confirmed that the presence of TiB_w can enhance the kinetics of phase transformation by providing nucleation sites [14]. Meanwhile, Ma et al. [15] investigated 5 vol% in situ TiC_p reinforced Ti-1100 composite, and also found that the particle TiC can assist the nucleation of α phase. However, with regard to hybrid (TiB_w

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+ TiC_p) reinforced TMCs, the effect of reinforcements on matrix microstructure (especially the recrystallization of α phase) during deformation is unclear. Therefore, it is imperative to conduct a systematic research on the effect of different volume fraction of reinforcements on the microstructure and subsequent tensile properties of (TiB_w + TiC_p)/Ti composites after (α + β) forging.

In this experiment, (TiB_w + TiC_p)/Ti-6Al-2.5Sn-4Zr-0.7Mo-0.3Si composites were fabricated via reacting Ti and B_4C followed by 1-D forging. The central issue of present research consists in probing into the relationships among reinforcement volume fraction, microstructure characteristic and mechanical properties of (TiB_w + TiC_p)/Ti composites after (α + β) forging.

2. Material and experimental procedures

In this experiment, an induced skull melting furnace (ISM) was used to fabricate Ti-6Al-2.5Sn-4Zr-0.7Mo-0.3Si matrix composites reinforced with 0, 2.5, 5 and 7.5 vol% (TiB_w + TiC_p). The composites melts were cast into a machined metal mould to form cylindrical ingots with diameter and height of 140 mm and120mm, respectively. The other specific details were described in our previous study [16]. Measured by metallographic techniques, the β transus temperature (β_t) for 5 vol% (TiB_w + TiC_p)/Ti composite was identified as approximate 1378 K, which is about 100 K higher than that of monolithic Ti alloy (βt temperature is about 1280 K). Then, the as-cast ingots were subjected to hot-forged at 1323 K with a total reduction of 75% followed by air cooling. In order to eliminate the stress during forging deformation, the as-forged composites pancakes were annealed at 923 K for 6 h and furnace-cooled.

Samples for microstructural observation and tensile test were cut by electric discharging from the pancakes. Quantitative measurement of the microstructural parameters and reinforcements was carried out by Image-Pro-Plus analysis software. The microstructures were examined by FEI-Quanta-200F scanning electron microscope (SEM) and FEI Tecnai G2F30 transmission electron microscopy (TEM). Concerning tension test, the gage sections of the RT and elevated temperature tensile specimens are 20 mm × 6 mm × 2 mm and 20 mm × 5 mm × 2 mm, respectively. The tensile samples were performed on Instron 5500 R testing machine at the strain rate of 0.5 mm/min at ambient temperature, 873 K, 923 K and 973 K. Three samples for repeated tensile test were conducted at each condition. The longitudinal sections near the fracture surfaces were conducted utilizing a scanning electron microscope (SEM, Hitachi S-570) after tensile tests.

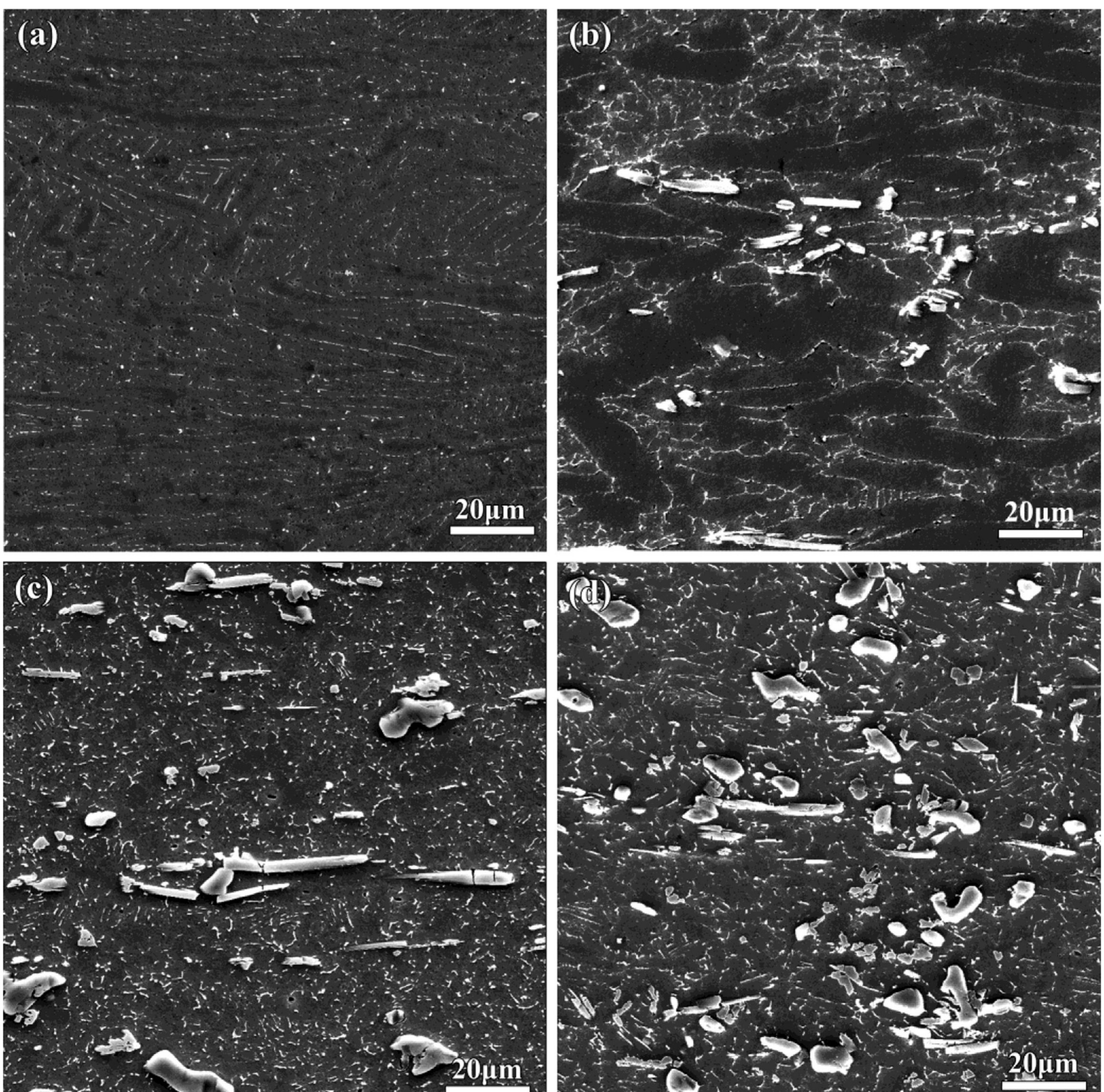

Fig. 1. Microstructure of as-forged (TiB_w + TiC_p)/Ti composites with different volume fraction of reinforcement: (a) 0 vol%, (b) 2.5 vol%, (c) 5 vol%, (d) 7.5 vol%.