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Work-hardening and plastic deformation behavior of Ti-based bulk metallic glass composites with bimodal sized B2 particles

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In this work, the role of individual B2 particles with bimodal length scale on work-hardening and plastic deformation behaviors of Ti-based bulk metallic glass composites has been studied by systemic microstructural and mechanical investigations. At the early stage of plastic deformation, work-hardening characteristic was clearly observed. This work-hardening behavior can be supported by the martensitic transformation and the deformation induced twinning in both small- and large-sized B2 particles during deformation. On progress of plastic deformation after work-hardening, small-sized B2 particles (1–10 μm) were penetrated by propagation of main shear bands while large-sized B2 particles (100–200 μm) were severely interacted with shear bands leading to formation of multiple shear bands and impeding the propagation of principal shear bands. This reveals that each B2 particle with different length scale plays a distinct role on the stage of plastic deformation depending on the particle size.

1. Introduction

Bulk metallic glasses (BMGs) have been highlighted as an highly accessible engineering material for advanced structural application due to their high strength, high hardness and large elastic limit [1–4]. However, BMGs commonly undergo inhomogeneous plastic deformation at room temperature caused by local shear deformation and lead to catastrophic failure [5–7]. In order to overcome such a critical drawback of BMGs, the several attempts for improving the macroscopic ductility have been performed. For example, second phase reinforced bulk metallic glass matrix composites (BMGCs) were developed [8–13]. Plastic deformation of BMGCs was governed by formation of multiple shear bands and suppression of the rapid propagation of shear bands via severe interaction between shear bands and reinforcements [14–18]. Along the same line, introducing the structural and chemical heterogeneities in the metallic glass matrix was suggested as another way to promote the macroscopic plasticity [19–22]. In particular, ductile dendrite reinforced BMGCs are well-known due to their pronounced plasticity [13,23,24]. Although these BMGCs show large plastic strain, they exhibit macroscopic work-softening with an occurrence of necking immediately after yielding. Therefore, lack of work-hardening can be considered as a serious problem for practical engineering applications of BMGCs.

Recently, it was reported that the CuZr-/Ti-based BMGCs containing intermetallic B2 phase phase represent obvious plastic deformation and exceptionally pronounced work-hardening behavior under compression as well as tension [25–28]. These outstanding mechanical properties are mainly related with the martensitic transformation from austenite B2 phase to monoclinic B19′ phase during deformation. The stress-induced martensitic

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transformation in CuZr-/Ti-based BMGCs can improve effectively the rate of work-hardening and suppress the early necking [29,30]. Normally, work-hardening rate and large plasticity of B2 particles reinforced BMGCs are dependent on the volume fraction of B2 particles. The maximum plasticity was achieved when volume fraction of the B2 particle is optimized with 20 ~ 40 vol.% [26,33]. More recently, Ti-based BMGCs with bimodal size of B2 particles have been developed [32]. They found that the compositional tuning from the $Ti_{45}Cu_{40}Ni_{7.5}Zr_5Sn_{2.5}$ heterogeneous BMG having nano-scale chemical fluctuation and the minor addition of additional elements are very effective to introduce the B2 particles with bimodal size distribution on the metallic glass matrix [16,31,32]. Interestingly, $Ti_{45}Cu_{40}Ni_7Zr_5Sn_{2.5}Si_{0.5}$ and $Ti_{45.3}Cu_{39.5}Ni_{7.8}Zr_{4.9}Sn_{2.5}$ BMGCs containing bimodal size of B2 particles show large difference (~7%) in fracture strain despite having similar volume fraction of B2 particle [32], which deviates from general correlation between plasticity and volume fraction of B2 particle [26,33]. Based on these results, one can believe that the characteristics of B2 particle i.e., volume ratio between small- and large-sized particles is another crucial factor to control the plasticity of BMGCs with bimodal sized particle distribution apart from total volume fraction of particles. However, there is no systematic study about the influence of volume ratio of particles with bimodal length scale on the plastic deformation. Therefore, it is noteworthy to explore the role of individual B2 particles with different length scale but similar volume fraction in Ti-based BMGCs with bimodal distribution of B2 particles.

In order to investigate the effect of individual B2 particles with distinct length scale (small and large) on the deformation behavior of Ti-based BMGCs with bimodal length scale of B2 particles, we selected two alloys ($Ti_{45}Cu_{40}Ni_7Zr_5Sn_{2.5}Si_{0.5}$ and $Ti_{45.3}Cu_{39.5}Ni_{7.8}Zr_{4.9}Sn_{2.5}$) with similar total volume fraction of B2 particles but with different volume ratio of small- and large-sized B2 particles. Here we report the influence of volume ratio of B2 particles between small and large one on plastic deformation behavior of Ti-based BMGCs via systemic mechanical and topological investigations for deformed samples with different degree of plastic deformation i.e., early stage of plastic deformation (work-hardening state) and late stage of pronounced plastic deformation (after work-hardening). In addition, deformation mechanism of work-

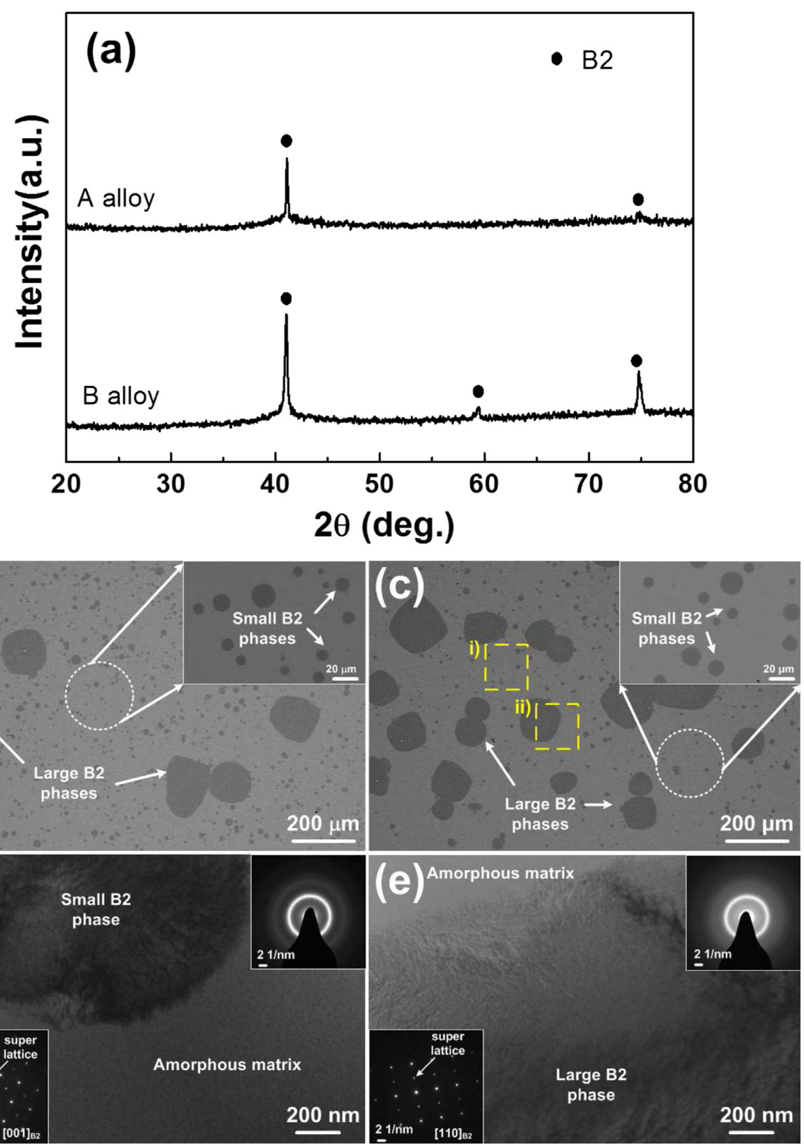

Fig. 1. XRD patterns (a), SEM BSE images [(b) and (c)] and TEM BF images [(d) and (e)] of as-cast A and B alloys, together with SAED patterns of amorphous matrix and small/large B2 particle of as-cast B alloy.