

Microstructure and tensile properties of high-strength high-ductility Ti-based amorphous matrix composites containing ductile dendrites

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Abstract

In the present study, two Ti-based amorphous matrix composites containing ductile dendrites dispersed in an amorphous matrix were fabricated by a vacuum arc melting method, and deformation mechanisms related to the improvement of strength and ductility were investigated by focusing on how ductile dendrites affected the initiation and propagation of deformation bands, shear bands or twins. Ti-based amorphous matrix composites contained 70–73 vol.% coarse dendrites of size 90–180 μm , and had excellent tensile properties of the yield strength (1.2–1.3 GPa) and elongation (8–9%). The Ta-containing composite showed strain hardening after yielding, and reached fracture without showing necking, whereas necking occurred straight after yielding without strain hardening in the Nb-containing composite. The improved tensile elongation and strain hardening behavior was explained by the homogeneous distribution of dendrites large enough to form deformation bands or twins, the role of β phases surrounding α phases to prevent the formation of twins, and deformation mechanisms such as strain-induced β to α transformation.

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1. Introduction

Bulk amorphous alloys are currently well recognized as leading-edge new materials worldwide, because they have excellent properties such as strength, hardness, stiffness and corrosion resistance [1–3]. Their potentialities in structural applications have been made possible by continued advancements in manufacturing technologies. For wider applications of amorphous alloys, however, problems remain to be solved, a typical one being brittle fracture [4]. This brittle fracture not only seriously limits applications to high-functional components, but also works as an obstacle to good reliability of high-performance structural materials.

Since plastic deformation at room temperature in amorphous alloys is concentrated on highly localized shear

bands, plastic zones are hardly observed under tensile or compressive loading [4–9]. The plastic deformation at one shear band is highly localized, and only a few shear bands work until reaching a final brittle fracture. This is why stress–strain curves are observed in brittle materials such as ceramics, and their plastic strain ranges from 0% to 2% under compressive loading, while it is almost nil under tensile loading [10–16].

To improve the ductility, intensive studies have been conducted to fabricate composites by dispersing ductile crystalline particles in the amorphous matrix. Ways of fabricating amorphous alloy matrix composites include one in which amorphous alloys are partially crystallized to disperse nanocrystallines [17,18], and one in which crystalline particles are added to the amorphous melt [19]. Also included are ways of casting reinforcing fibers and amorphous alloys at the same time [20], and a way of generating dendritic phases from the amorphous melt [21,22]. In

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amorphous matrix composites, where ductile dendrites are formed in situ in the amorphous matrix, the formation of multiple shear bands at dendrites can favorably affect ductility, since it works as an important deformation mechanism in amorphous alloys in which dislocations do not exist [23,24]. Hays et al. [21,22] reported that the elongation of Zr-based amorphous matrix composites containing ductile dendrites was improved by the formation of more shear bands than those formed in a monolithic amorphous alloy. However, explanations of this phenomenon vary with investigators, and the improved ductility in these composites is not sufficient. In particular, amorphous matrix composites containing ductile dendrites show limited ductility under tensile loading, although they show good ductility under compressive loading [23,25].

In the present study, two Ti-based amorphous matrix composites containing ductile dendrites dispersed in an amorphous matrix were fabricated by a vacuum arc melting method. Microstructures of the fabricated composites were analyzed, and their mechanical properties were evaluated by conducting tensile tests. Deformation mechanisms related to improvement of strength and ductility were investigated by focusing on how ductile dendrites affected the initiation and propagation of deformation bands, shear bands or twins.

2. Experimental

The Ti-based amorphous composites used in the present study were $\text{Ti}_{48}\text{Zr}_{27}\text{Ni}_6\text{Nb}_5\text{Be}_{14}$ and $\text{Ti}_{48}\text{Zr}_{27}\text{Ni}_6\text{Ta}_5\text{Be}_{14}$ (at.%). They have excellent amorphous forming ability, hardness, strength and corrosion resistance [1,2]. Nb and Ta work as stabilizers of a β phase in titanium alloys [26], and the composites containing Nb and Ta are referred to as 'A' and 'B', respectively. The composites were fabricated by a vacuum arc melting method, held at 800–900 °C, in which liquid and solid phases exist together for 1–2 h to eliminate inhomogeneous cast structures, and were quenched to obtain the amorphous matrix. The final microstructures of the two composites consist of dendrites and amorphous matrix.

The composites were polished in diamond paste (size 0.25 μm), etched by a solution of 40 ml HF, 20 ml HNO_3 , 40 ml HCl and 200 ml H_2O , and observed by scanning electron microscopy (SEM; model JSM-6330F, Jeol, Japan).

Crystalline phases were identified by X-ray diffraction (XRD) and transmission electron microscopy (TEM), and their average size and volume fraction were measured by an image analyzer. For TEM observation, specimens were mechanically polished to a thickness of 50 μm , punched to prepare disc specimens (diameter 3 mm) by a disc cutter, and then ion-milled to prepare thin foil specimens. The thin foils were observed by a TEM (model 2100, Jeol, Japan) operating at an acceleration voltage of 200 kV. Electron back-scatter diffraction (EBSD) analysis (resolution 0.2 μm) was conducted by field emission scanning electron microscopy (FE-SEM; model Helios Nanolab™, FEI, USA). The data were then interpreted by orientation imaging microscopy analysis software provided by TexSEM Laboratories, Inc. The hardness and elastic modulus of the dendrites and amorphous matrix were measured by an ultra-micro Vickers hardness tester (model DUH-W201S, Shimadzu, Japan). A triangle-cone-type indenter and a load of 5 g were used for measuring the hardness of individual phases, and then the hardness values were converted to those of the square-cone-type indenter.

The composites were machined into plate-type tensile specimens (Fig. 1), and room-temperature tensile tests were conducted on these specimens at a cross-head speed of 1.59×10^{-4} by a universal testing machine (model 4202 Load Frame, Instron, USA) with a capacity of 10,000 kg. In order to closely investigate the tensile deformation behavior, the deformed area of the tested specimen was photographed by SEM.

3. Results

3.1. Microstructure

Fig. 2a and b shows SEM micrographs of the Nb- and Ta-containing composites (A and B composites), respectively. A dendritic structure is well developed in both composites. Dendrites are evenly distributed in the amorphous matrix, and their size and volume fraction are $\sim 10 \mu\text{m}$ and 70%, respectively.

A TEM bright image of the A composite and selected area diffraction (SAD) patterns of dendrites and amorphous matrix are shown in Fig. 3a–e. The A composite contains dendrites in the amorphous matrix (Fig. 3a), and the amorphous matrix can be confirmed by ring

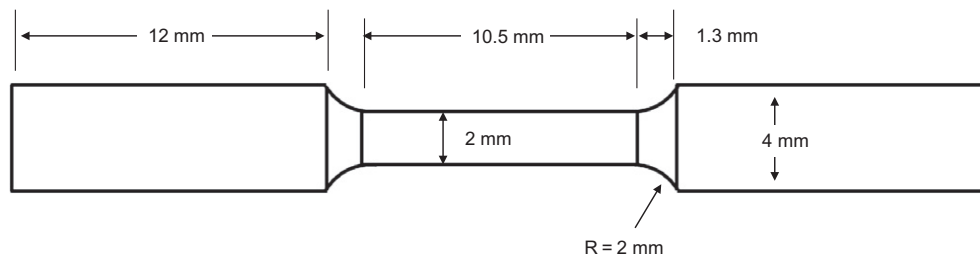


Fig. 1. Shape and dimensions of a tensile specimen (units mm).

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