

PHASE FORMATION in Mg-BASED BULK METALLIC GLASS COMPOSITE DURING CASTING



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Overview

Bulk metallic glasses (BMGs) have attracted significant technological interest due to their ease of processing, high strength and hardness and excellent corrosion resistance etc. [1,2]. However, they have poor ductility. The presence of crystalline phases in a BMG is known to improve its ductility by combining the high strength of the BMG with the high ductility and fracture toughness of the crystalline phases [3,4]. In-situ BMG composites are produced when crystalline phases are precipitated during cooling from the melt. In this project, the nucleation and growth of crystalline phases, together with composition redistribution, were examined to reveal the phase formation during cooling from the melt of an Mg-based BMG composite.

Experimental Procedure

An Mg₇₇Cu₁₂Y₆Zn₅ alloy was cast into 50 x 12 x 1 mm plates [4,5]. Its 2D as-cast structure was examined by optical microscopy and scanning electron microscopy (SEM), and its 3D structure by 3D-FIB tomography using a Nova NanoLab 200 DualBeam platform. Crystallographic features of various phases were studied by convergent-beam electron diffraction (CBED) and atomic resolution imaging using a JEOL 3000F TEM. Compositional analysis was carried out using energy dispersive x-ray spectroscopy within a Philips CM200 TEM.

As-cast Microstructure

α -Mg flakes were found to precipitate out in the melt during cooling. After casting, the microstructure consisted of 88% amorphous matrix (grey), 10% α -Mg flakes (black), <0.5% Y-rich phases (white), and a small amount Mg₁₂YZn and Mg₂₄Y₅ (Fig. 1a) [5]. Y-rich particles, particularly of sizes larger than 2 μ m, have a faceted cubic shape (Figs 1a & b). The Mg flakes were found to radiate out from both the large faceted and smaller Y-rich particles into the amorphous matrix and, as shown in Figs 1b & c.

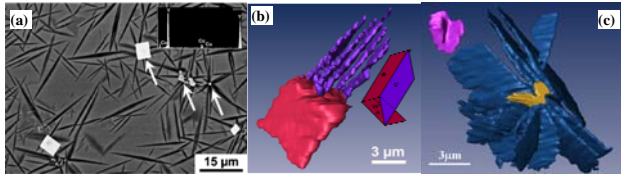


Figure 1. (a) SEM micrograph (BEI) of as-cast Mg₇₇Cu₁₂Y₆Zn₅ alloy consisting of an amorphous matrix, Mg flakes, and Y-rich particles, as shown in the inset by EDAX spectrum. The potential nucleation sites of the flakes are arrowed. (b) 3D structure of flakes (purple) growing from a large faceted Y-rich particle (red), and (c) two clusters of flakes (blue and pink) forming around a smaller Y-rich particle (yellow).

Crystallographic Analysis of Growing Flakes

Figure 2a shows a group of flakes growing from a Y-rich particle (black) into the surrounding amorphous matrix. It was found that flakes 1-3 have the same orientation relationship with the particle, i.e.: (004)_Y//(0002)_{Mg} and [100]_Y//[10-10]_{Mg}, with a habit plane of (040)_Y//(1-210)_{Mg}. Figure 2b shows how the (004)_Y of the particle matches closely with (0002)_{Mg} of flake 2 together with a similar d-spacing (0.261 nm for (0002)_{Mg} and 0.265 nm for (004)_Y). Figure 2c gives the proposed interface atomic structure between the particle and flake 2. Another orientation relationship was found for flake 4, i.e.: (004)_Y//(0002)_{Mg} and (2-1-10)_Y//[100]_{Mg}, with a habit plane (0002)_{Mg}//(004)_Y.

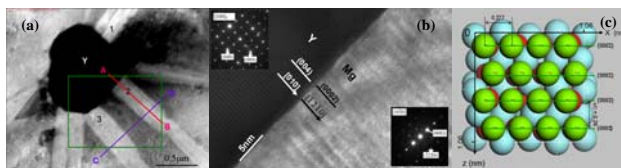


Figure 2. (a) Bright field TEM micrograph showing a group of flakes radiated out from a Y-rich particle. The orientation relationships between the Y-rich particle and flakes 1-3 and elemental distribution were characterized within the green box along the lines A-B and C-D. (b) Crystallographic relationships and (c) proposed atomic configuration at the interface between the particle and flake 2.

Growth Behaviour of Flakes

Figure 3a shows the 3D schematic diagram of flake nucleation and growth, clearly showing that flakes maintain an OR1 and OR2 with the Y-rich cube during nucleation on its faceted surface; they grow normal to the cube surface along (0001)_{Mg} and (1100)_{Mg}, respectively.

Figure 3b is an atomic resolution micrograph showing the growth behaviour of a flake along <-12-10>_{Mg} in the {0001} plane. The growing front, as indicated by the two boxes, meet with a large amount of short range atom clustering (existing in the low temperature liquid metal) aligning to the orientation {0001}<-12-10>_{Mg}, as indicated by the high intensity diffraction spots from (0002)_{Mg} and (1-210)_{Mg} planes. The TEM micrograph indicates that the flake has grown into the liquid, not by the addition of single atoms to the flake surface, but by the addition of aligned clusters of atoms.

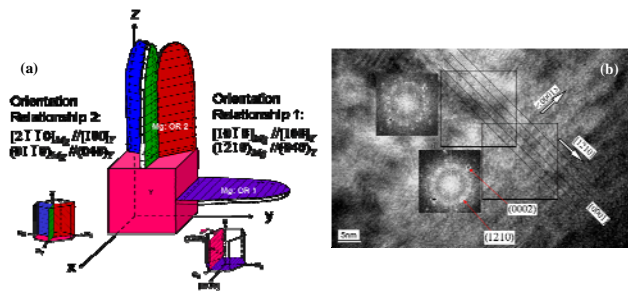


Figure 3. (a) Schematic diagram of flake nucleation and growth where the pink cube represents the Y-rich particle and its orientation (the hcp unit cells represent the orientations of the flakes on the top and right of the Y-rich cube, respectively). (b) HREM micrograph showing short range ordering (atom clusters) within the two boxes located in the growing front of a flake with the diffraction pattern next to each of box showing the high intensity of the <-1-210>(0002)_{Mg} oriented clusters.

Distribution of Elements in As-cast Microstructure

Figure 4 shows the elemental distribution within the green box of Fig. 2a showing a high Mg concentration and lower Y, Cu and Zn content in the flakes compared with the matrix. Figure 4e shows that the Mg concentration also decreases along A-B whereas there is a slight decrease for Y, Cu and Zn. Figure 4f shows a composition profile along C-D. The earlier nucleated flakes contain higher Mg and lower Y, Cu and Zn compared with those flakes that nucleate later. These concentration profiles indicate extensive segregation among the crystalline flakes and amorphous matrix, as well as differences within adjacent flakes and along a given flake.

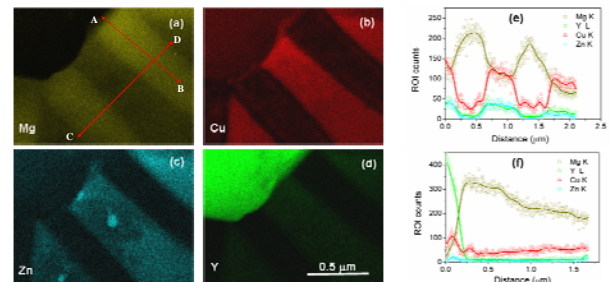


Figure 4. Elemental distribution of: (a) Mg, (b) Cu, (c) Zn and (d) Y taken from within the green box in Fig. 2a. Concentration profiles along (e) A-B and (f) C-D.

References

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