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Fracture instability in brittle Mg-based bulk metallic glasses

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Abstract

A densely packed striation structure is observed in the apparently featureless mirror area of the fracture surface of brittle Mg-based bulk metallic glass. Taylor instability analysis based on grease model combined with a competitive microvoid formation mechanism ahead of a blunted crack tip suggests that the fracture of metallic glass is controlled by both viscous flow and ductile fracture mechanism. Spacing size of the striation is correlated with macroscopic fracture toughness.

Keywords: Metallic glass; Fracture; Toughness; Fractograph

1. Introduction

Despite extensive investigations, the exact deformation and fracture mechanism of metallic glass remains unclear compared with that of crystalline materials. Generally, plastic deformation in metallic glass is highly localized and followed by rapid propagation of the crack and catastrophic fracture [1–3]. To understand the mechanism of strain localization, two important models have been proposed from the viewpoint of local structural change and local temperature rise [4–6]. In both cases, the local viscosity is decreased for several orders of magnitude, leading to a typical vein pattern and even liquid-like pattern on the fracture surface [1–3]. The characteristic vein pattern in metallic glass has been successfully simulated using a grease model [7].

However, for brittle bulk metallic glass (BMG), e.g. Mg-based and Fe-based BMG whose brittleness is comparable with that of silicate glass (which behaves in a perfectly brittle manner [8]), the dominant character in fracture surface is featureless mirror area instead of vein patterns [9,10]. The reasonable extend to which current models (e.g. strain softening mechanism and grease model) can be applied is open for discussing. Commonly, the lustrous mirror area is believed containing no furthermore valuable information about the fracture process and can be sorted as an ideal brittle fracture. However, recent research has shown such is not necessarily the case. In the apparently featureless mirror area in the fracture surface of brittle BMG, the existence of dimple structures of nanoscale due to the highly localized strain was reported and a correlation between fracture toughness and plastic zone size for various metallic glasses was established based on this observation [11].

Keeping in mind with a thought that the apparently featureless mirror area might provide some profitable evidence in helping understanding the fracture mechanism of brittle BMG in more detail, we carried out observations of high-resolution scanning electric microscopy (HRSEM) on the fracture surface of Mg-based BMGs. In this paper, a striking striation structure of 50 nm in spacing in the featureless mirror area of fracture surface is presented. The characteristic morphology is a direct evidence of viscous flow behavior in nanoscale during fracture of metallic glass. A fracture mechanism based on grease model combined with a competitively periodic microvoid nucleation and growth process ahead of a blunted crack tip is proposed. The correlations among the striation spacing, the crack opening distance (COD) and the fracture toughness are discussed.

2. Experimental

The fracture specimen of BMG were prepared by three-point bending of single-edge notched round samples of 4 mm in diameter in material test system (MTS810) at displacement speed ranging from 0.1 μm/s to 1 mm/s. Observations of fracture surface were performed using high-resolution scanning electron microscopy (HRSEM, Supra350). Investigated materials were $Mg_{65}Cu_{20}Ni_5Gd_{10}$ and $Mg_{65}Cu_{20}Ag_5Gd_{10}$. The amorphousity was

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confirmed by X-ray diffraction (XRD) and high-resolution transmission electron microscopy (HRTEM) and no crystallization and phase separation were observed.

3. Results and discussion

A typical vein pattern of $Mg_{65}Cu_{20}Ag_5Gd_{10}$ is illustrated in Fig. 1(a). However, for $Mg_{65}Cu_{20}Ni_5Gd_{10}$ whose fracture surface is dominated by mirror area, Fig. 1(b) and (c) shows a striking circular striation pattern being convex in the overall direction and pointing back to the pre-notched crack origin. Spacing or wavelength of the densely packed striation pattern is about 50 nm and roughness of the striated surface is estimated to be about decades of nanometers. The striation pattern could expand across the whole fracture section, but striation structures with different orientations may co-exist as shown in Fig. 1(d) in which two striations encounter. The dashed line shows the border of the two structures. The width of the border is about decades to hundreds of nanometers which means structures with different orientations can hardly be superposed together. In higher magnification (Fig. 1(e)), some craze-like matter exists in the corrugation of the striation, which may be due to the viscous flow in finer scale. In the opposite side of the pre-notched end in the section, the stress state might be complex due to the existence of some compressive stress component. Fig. 1(f) shows the striation pattern seems to be broken and typical dimple structure is observed. Such is also the case in the border of two encountering structures as shown in Fig. 1(d). At different

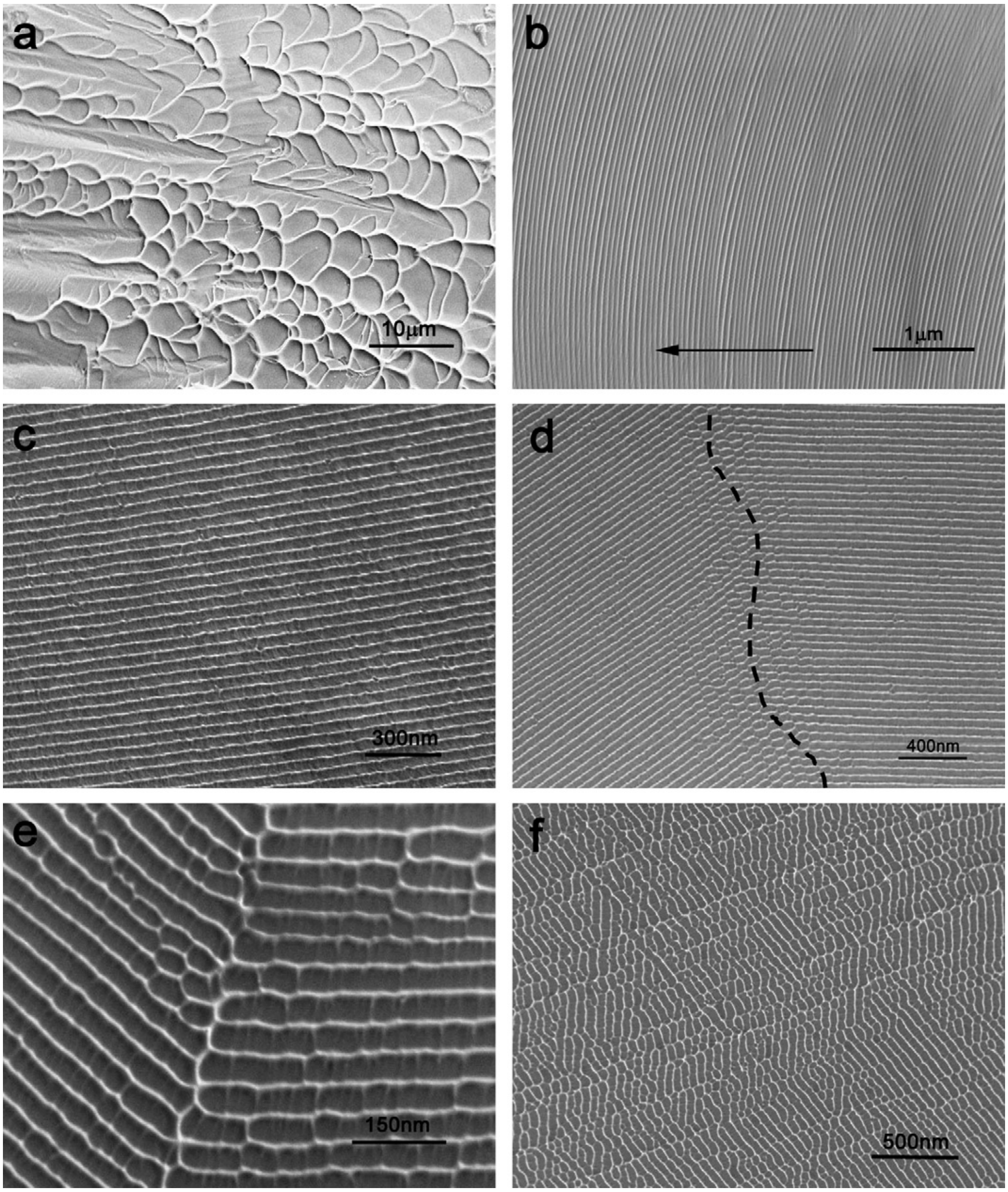

Fig. 1. HRSEM fracture surface images: (a) typical vein pattern of $Mg_{65}Cu_{15}Ag_5Gd_{10}$, (b) circular striation structure of $Mg_{65}Cu_{15}Ni_5Gd_{10}$, the arrow designates the crack propagation direction, (c) higher magnification of striation structure, (d) two encountering striation structures, (e) higher magnification of the encountering border, and (f) broken striation structure in the opposite end of the pre-set notch.