Materials Science & Engineering A 668 (2016) 50–54

Contents lists available at ScienceDirect

Materials Science & Engineering A

journal homepage: www.elsevier.com/locate/msea

Tuning the performance of bulk metallic glasses by milling artificial holes

Feng Gong [a], Shun Hua Chen [b], Jia Qi Ran [a], Zhi Yang [a], Jiang Ma [a,*]

[a] Key Laboratory of Advanced Manufacturing Technology for Mold and Die, College of Mechatronics and Control Engineering, Shenzhen University, Shenzhen 518060, PR China
[b] Advanced Manufacturing Technology Research Centre, Department of Industrial and Systems Engineering, The Hong Kong Polytechnic University, Hung Hom, Hong Kong

ARTICLE INFO

Article history:
Received 7 January 2016
Received in revised form
15 April 2016
Accepted 13 May 2016
Available online 14 May 2016

Keywords:
Bulk metallic glasses
Artificial holes
Shear bands

ABSTRACT

The mechanical performance of materials is greatly affected and could be tuned by artificial defects, especially for amorphous alloys. In present work, specially designed holes are created for bulk metallic glass and apparent mechanical performance improvement is obtained when compared with the intact ones. The fracture characterization discovers that the inner wall of the artificial hole has a blocking effect to shear bands (SBs), leading to an apparent enhancement of mechanical property. Our results demonstrate that the blocking effect of SBs induced by the designing artificial hole may provide some new sights on the plastic deformation mechanism of metallic glasses rather than the improved plasticity itself.

1. Introduction

Excellent mechanical performance such as high strength combined with good plasticity is earnestly pursued by people during the seeking of superior materials for engineering applications [1]. As for crystalline alloys, this goal could often be achieved through the reduction of grain size, unfortunately, the incompatibility between plasticity and strength constraints the mechanical performance of materials [2]. What is more, such incompatibility persists in nanocrystalline metals and alloys, which display highly improved strength but very little plastic deformation [3], and also in bulk metallic glasses (BMGs) with completely disordered atomic structures. The unique properties of BMGs, such as high strength, high specific strength, large elastic strain limit, and excellent wear and corrosion resistances along with other remarkable engineering properties, have made these materials of significant interest for science and industry [4–18]. However, the lack of plasticity makes them prone to catastrophic failure in load-bearing conditions and greatly restricts their wide-spread applications. In order to improve the mechanical performance of BMGs, it is widely accepted that efforts should be made from the following aspects [19]: designing BMGs by modulating their elastic modulus [20,21]; introducing nano-scale structural heterogeneity [22]; minor alloying some elements with low μ/B (or, equivalently, high υ) as constituents to induce randomly distributed free volume [23]; tuning the casting conditions [24]; composition design from the structural perspective [25]; designing BMG composites with nanocrystals or quasicrystals [8], ductile dendrites [26–28], fibers [29], particles [30,31], phase separation [32], and crystalline layers [33]; forming porous BMGs [34,35]; and surface treatment [36,37] or pre-deformation treatment [38]. Previous work also found that plasticity could be achieved by designing artificial defects, such as notches or micro structures [39–41].

For crystalline materials, the dislocations and slip systems are the key factors controlling the plastic deformation behavior [39], however, for metallic glasses without lattice dislocations and slip systems, shear banding becomes the significant plastic deformation mechanism [17]. Once yielding starts, the shear bands (SBs) propagate rapidly, resulting in a catastrophic fracture. It is generally accepted that there is a strong connection between the density of shear bands and the plasticity of BMGs [17,39], therefore, efforts have been made to create enough shear bands in order to improve the property of BMGs. On the other hand, the primary SB which brings the final catastrophic fracture always propagates through the interior of the specimen, if the propagation routine was cut off by artificial defects, shear bands in metallic glasses expand with difficulty when stimulated by designed structures, the entire plasticity should be greatly enhanced. Following such strategies, in the present work, we created a series of through holes in the BMG specimen body, hoping to promote the generation of SBs and make difficulties for them to expand. Compared with the intact specimens, the plasticity of the metallic glass with

* Corresponding author.
E-mail address: majiang@szu.edu.cn (J. Ma).

http://dx.doi.org/10.1016/j.msea.2016.05.048
0921-5093/© 2016 Published by Elsevier B.V.

artificial holes can be clearly increased, however, the yield strength has no apparent decay. Furthermore, the fracture morphologies of different specimens are also characterized and compared to find out how the artificial holes affect the mechanical performance of BMGs. The current results demonstrate that the blocking effect of SBs induced by designing artificial through hole may provide some new understanding on the plastic deformation mechanism of metallic glasses rather than the improved plasticity itself.

2. Experimental details

Zr-based metallic glass rods with a nominal chemical composition of $Zr_{35}Ti_{30}Cu_{8.25}Be_{26.75}$, which are prepared by the arc melting and copper mold suck-casting method, were chosen for present research. The final rods have a diameter of 3 mm and a height of 6 mm. A series of holes with different diameters of 0.9, 1.2, 1.5, 1.8, 2.1 and 2.4 mm were drilled by the milling machine on the right center of the metallic glass rod, resulting different diameter ratio of hole to rod (DR), which were 3:10, 2:5, 1:2, 3:5, 7:10 and 4:5, respectively. The illustration of the mechanical performance test for the intact and machined specimens are presented in Fig. 1(a). To examine if the unexpected crystallization was introduced during the milling, the chips were collected and identified by X-ray diffraction (XRD; Bruker D8 advance) with Cu K_α radiation, and the result is presented in the inset of Fig. 1(b), it is found that the chips were amorphous, which implies that the inner wall of the hole remains the amorphous nature. The residual stress of the samples after drilling was removed by vacuum annealing at 200 °C for 1 h, after that, the final surfaces were polished by the electrochemical method (Struers, LectroPol-5) in order to fully eliminate the influence of the drilling [42].

3. Results and discussion

The mechanical performance of the BMG specimens was measured on the electromechanical MTS 810 equipment and the stress and strain curves are presented in Fig. 1(b). The aspect ratio of height to diameter was 2:1. To obtain the reliable results, all of the compression tests for the samples under one condition were repeated for five times. It can be seen that the fracture behavior of the as-cast specimen is a typically brittle one, with average fracture strength of 1870 MPa and almost no plasticity. However, the specimens with artificial holes reveal different mechanical performance. In contrast with the intact specimen, the specimens with artificial holes show improvements in plasticity. One can see that the specimens with DRs of 3:10, 2:5 and 1:2 have only little plasticity improvement, which is not obvious. However, as for the specimens with DRs of 3:5, 7:10, the conditions were different, significant improvements on plasticity were achieved, which is not at the cost of the decrease of fracture strength. As it is shown in Fig. 1(b), the strength of the specimens with DRs of 3:5 and 7:10 were 1810 and 1900 MPa, respectively. What is more, the plasticity of them was increased from nearly zero of the intact one to 2% and 4.5%. The artificial holes were not always favorable for the mechanical performance enhancement, when the DR of BMG specimen was increased to 4:5, the mechanical performance became bad. The strength was 1732 MPa and nearly no plasticity was observed. Maybe the reason is when the DR value is large, the wall thickness becomes very small and unexpected mechanical failure occurred under compression. The results show that it is an effective approach to tune the mechanical performance of BMGs by drilling artificial holes, and this method may provide a new idea to improve the property of those BMG systems without any intrinsic

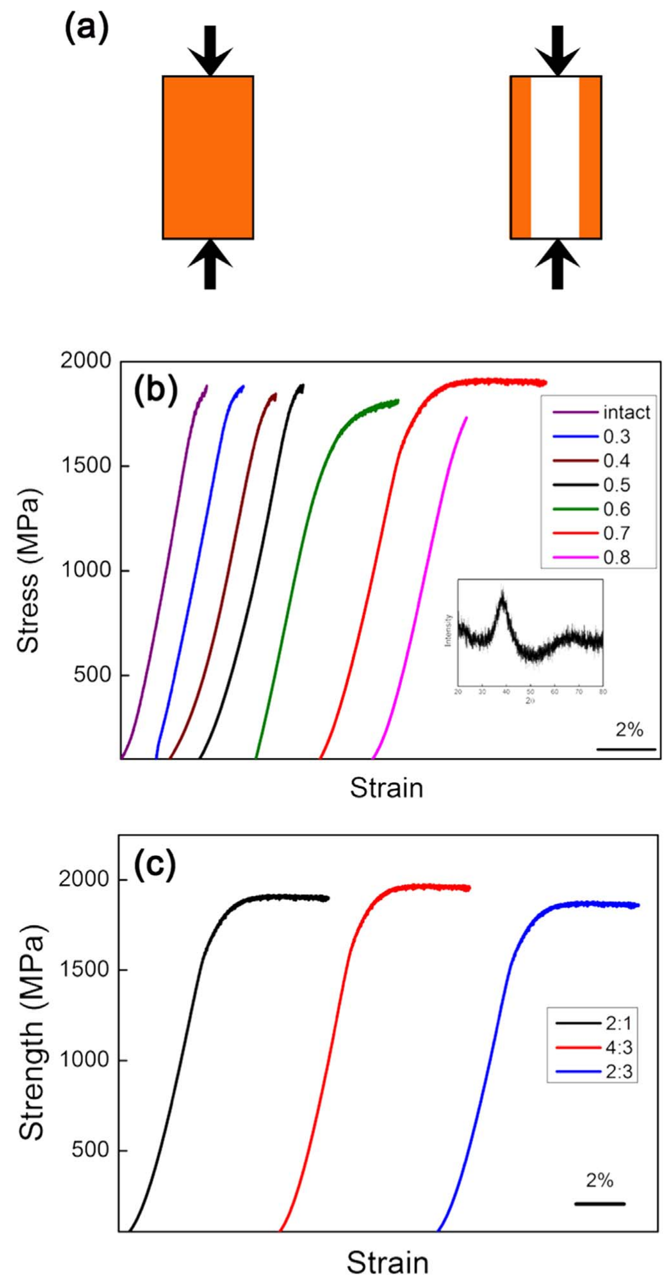

Fig. 1. (a) Illustration of the intact and through hole BMG samples under compression. (b) Stress-strain curves of the intact and machined BMG specimens with different DR values. The inset presents the XRD pattern of the chips during the milling of holes. (c) Stress-strain curves of the specimens with different aspect ratio values of height to diameter.

plasticity.

Moreover, the effect of the aspect ratio of height to diameter was also considered. Fig. 1(c) presents the stress-strain curves of the specimens with different aspect ratio values of height to diameter, which were 2:1, 4:3 and 2:3, respectively. These specimens had with a fixed DR=0.7. When the height is small compared with the diameter (e.g. aspect ratio of height to diameter is 2:3), it seems the specimen has a slightly larger plasticity of about 4.6%, only 2% higher than the specimen with aspect ratio of height to diameter 2:1. That is to say, the aspect ratio of height to diameter has limited effect on the mechanical performance of BMG specimens with artificial holes.

To investigate the reason of the improved mechanical performance more clearly, the fracture morphologies of the BMG