Available online at www.sciencedirect.com
SciVerse ScienceDirect
Acta Materialia 60 (2012) 4136–4143
Acta MATERIALIA
www.elsevier.com/locate/actamat

Stress-state-dependent deformation behavior in Ni–Nb metallic glassy film

Y. Ma [a], Q.P. Cao [a,*], S.X. Qu [a,b], D.X. Zhang [c], X.D. Wang [a], J.Z. Jiang [a,*]

[a] International Center for New-Structured Materials (ICNSM), Laboratory of New-Structured Materials, Department of Materials Science and Engineering, Zhejiang University, Hangzhou 310027, People's Republic of China
[b] Institute of Applied Mechanics, Zhejiang University, Hangzhou 310027, People's Republic of China
[c] State Key Laboratory of Modern Optical Instrumentation, Zhejiang University, Hangzhou 310027, People's Republic of China

Received 8 March 2012; received in revised form 18 April 2012; accepted 19 April 2012
Available online 18 May 2012

Abstract

The transition in deformation mode from highly localized to non-localized deformation was investigated in $Ni_{60}Nb_{40}$ glassy film by monitoring the reduction in thickness during film/substrate co-bending. It is revealed that in addition to the film thickness, the mode of plastic deformation depends on the stress state. With the reduction in thickness of thin film, tensile stress can efficiently suppress the change in deformation mode from highly localized to non-localized deformation in comparison with compressive stress. A mechanism for the stress-state-dependent deformation mode change in glassy alloys is discussed on the basis of the pressure/stress effect of plastic deformation and Griffith's crack-propagation criterion. This study provides distinct evidence of the deformation mode change in metallic glassy film via the variation in stress state, and also sheds light on the deformation mechanism of glassy alloys.
© 2012 Acta Materialia Inc. Published by Elsevier Ltd. All rights reserved.

Keywords: Metallic glasses; Mechanical property; Stress state; Shear band; Non-localized deformation

1. Introduction

Metallic glasses (MGs) combine impressive room-temperature mechanical properties, such as high strength approaching the theoretical limit and a large elastic limit (~2%), with unique forming capabilities in the supercooled liquid region, making them attractive for numerous applications [1–3]. At low temperatures well below the glass transition temperature, however, plastic deformation is highly localized in shear bands, resulting in macroscopically catastrophic failure and limiting the structural reliability of these materials [4,5]. The deformation behavior of MGs can be modulated by temperature and strain rate [6–8], and the change in deformation mode from highly localized to non-localized was also achievable by decreasing the specimen size under compression/tension [9–17]. It was proposed that such a specimen size effect was possibly due to the existence of a critical strained volume that is required for the shear band formation [9,13], although the mechanism for deformation mode change and critical specimen size are still under debate [18–21].

MGs experience distinct volumetric dilatation during plastic deformation [22,23]. Consequently, the applied pressure/stress clearly influence yield behavior, while pressure/stress effects are often negligible in crystalline materials due to insignificant volume changes associated with plastic flow [5,24]. The Mohr–Coulomb criterion, which takes into account the effect of normal stress on shear plane, rather than the von Mises and Tresca criteria, which consider only shear stress, is more suitable for describing the deformation behavior of MGs [25], further confirming the existence of a pressure/stress effect. Such a pressure/stress dependence of plastic flow in MGs is manifested in

* Corresponding authors. Tel.: +86 571 8795 2107; fax: +86 571 8795 1528.
E-mail addresses: caoqp@zju.edu.cn (Q.P. Cao), jiangjz@zju.edu.cn (J.Z. Jiang).

1359-6454/$36.00 © 2012 Acta Materialia Inc. Published by Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.actamat.2012.04.028

tension–compression asymmetry in the yield strength and fracture angle [5,26]. The reported fracture angles in tension, which range from 48° to 60°, are usually larger than those in compression, which range from 40° to 44°, while the yield strength in compression typically exceeds those in tension by less than 20%. Mechanical loading on large-scale specimens always produces shear bands irrespective of whether the stress state is tension or compression or some combination of these [26–29]. An interesting question has been raised: does the variation of stress state have any impact on deformation mode in MGs? Here, we report the results of the effect of stress state on deformation mode for glassy $Ni_{60}Nb_{40}$ (at.%) thin films with different thicknesses on Ti substrate prepared by direct-current magnetron sputtering. Compressive and tensile stresses at different parts of the same specimen were simultaneously introduced by bending [30,31]. With the reduction in film thickness, it is revealed that tensile stress can efficiently suppress the change in deformation mode from highly localized to non-localized deformation in comparison with compressive stress, i.e. the critical thickness for non-localized deformation in tension is much less than that in compression. A mechanism for the stress-state-dependent deformation behavior (focusing on the critical thickness for non-localized deformation vs. stress state) is discussed on the basis of the pressure/stress effect of plastic deformation and Griffith's crack-propagation criterion.

2. Materials and methods

Thin films with nominal composition $Ni_{60}Nb_{40}$ with different thicknesses were deposited on cleaned Si wafers and polished Ti plate separately in a direct-current magnetron sputtering system (DCMS, JZCK-400). The thicknesses of deposited films were determined by field-emission scanning electron microscopy (FE-SEM, Hitachi S-4800); the amorphous structure was confirmed by diffraction (SR-XRD) at beamline BL14B1 of the Shanghai Synchrotron Radiation Facility (SSRF) at a wavelength of 0.12398 nm and field-emission transmission electron microscopy (FE-TEM, JEOL 2100F); and the elastic modulus was measured by nanoindentation (Agilent Nano Indenter G200) [32]. Bars 2 mm wide × 1 mm thick × 15 mm long were cut from the deposited strips with Ti substrate and bent using mandrels with radii of 4 and 15 mm along the width of the bar by a home-made apparatus [33]. SEM (Hitachi TM-1000, Hitachi S-4800) and atomic force microscope (AFM, AFM-II) were used to monitor the evolution of the morphology of the film after bending under different conditions.

3. Results and discussion

3.1. Tension–compression asymmetry in critical film thickness for non-localized deformation

The $Ni_{60}Nb_{40}$ films and Ti substrate were co-bent using a mandrel with a radius of 4 mm along the width of the bar; this enables both compressive and tensile stresses in different parts of one specimen to be obtained as shown in Fig. 1a. The evolution of the surface morphology of the film during bending was monitored by SEM. We focused our SEM observation at a location 0.2 mm away from the edge (black circles marked in Fig. 1a), where the specimen experienced total compressive or tensile strain of about 16%. Since the bent bars are composed of Ti substrate and sputtered amorphous thin film, the evolution of the morphology of the Ti substrate alone in the tensile and compressive region were examined during bending at 298 K with a strain rate of $2 \times 10^{-3}\ s^{-1}$ as shown in Fig. 2a and b, respectively. A number of slip bands randomly orientate on the surface, not perpendicular to the direction of applied stress. Fig. 3a–d shows the evolution of the morphology of bent thin films with different thicknesses on the compressive side at 298 K and $2 \times 10^{-3}\ s^{-1}$. When the thickness is larger than 500 nm, shear bands perpendicular to the direction of applied stress are observed, as shown in Fig. 3a and b. With a decrease in thickness, shear bands become absent in bent films 250 and 50 nm thick as shown in Fig. 3c and d, respectively, indicating non-localized compressive deformation. When the stress state changes from compression to tension in the same specimen, many cracks perpendicular to the direction of applied stress can be clearly observed for films 500 and 250 nm thick, as shown in Fig. 3e and f, respectively. For the 100 nm thick film, some slight cracks are still visible

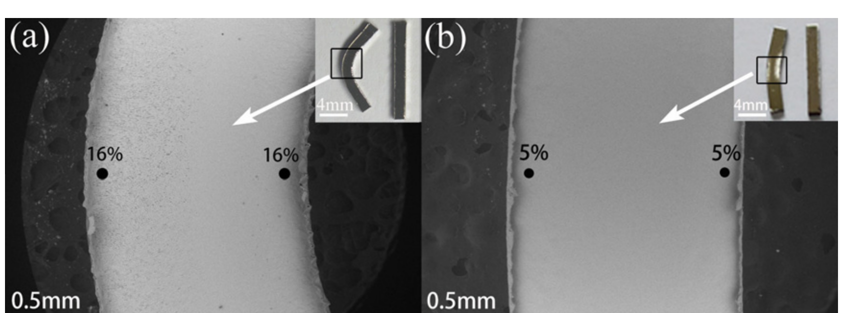

Fig. 1. Typical SEM images of a bar bent by a mandrel with a radius of (a) 4 mm and (b) 15 mm. The surface morphology of the film experiencing a strain of about 16% and 5% (marked by black circles) was monitored. The inset shows the overall image of the specimen before and after bending.

Download English Version:

https://daneshyari.com/en/article/1446661

Download Persian Version:

https://daneshyari.com/article/1446661

Daneshyari.com