University of Groningen

Shear band morphology of indented region in Cu-based metallic glass

Csach, Kornel; Huráková, Mária; Juríková, Alena; Miškuf, Jozef; Ocelík, Václav; De Hosson, Jeff Th M.

Published in:
Metallography XVI

DOI:
10.4028/www.scientific.net/MSF.891.500

IMPORTANT NOTE: You are advised to consult the publisher's version (publisher's PDF) if you wish to cite from it. Please check the document version below.

Document Version
Publisher's PDF, also known as Version of record

Publication date:
2017

Link to publication in University of Groningen/UMCG research database

Citation for published version (APA):
Csach, K., Huráková, M., Juríková, A., Miškuf, J., Ocelík, V., & De Hosson, J. T. M. (2017). Shear band morphology of indented region in Cu-based metallic glass. In *Metallography XVI* (pp. 500-503). (Materials Science Forum; Vol. 891 MSF). TRANS TECH PUBLICATIONS LTD. https://doi.org/10.4028/www.scientific.net/MSF.891.500

Copyright
Other than for strictly personal use, it is not permitted to download or to forward/distribute the text or part of it without the consent of the author(s) and/or copyright holder(s), unless the work is under an open content license (like Creative Commons).

The publication may also be distributed here under the terms of Article 25fa of the Dutch Copyright Act, indicated by the “Taverne” license. More information can be found on the University of Groningen website: https://www.rug.nl/library/open-access/self-archiving-pure/taverne-amendment.

Take-down policy
If you believe that this document breaches copyright please contact us providing details, and we will remove access to the work immediately and investigate your claim.

Downloaded from the University of Groningen/UMCG research database (Pure): http://www.rug.nl/research/portal. For technical reasons the number of authors shown on this cover page is limited to 10 maximum.

Download date: 05-06-2022

Materials Science Forum
ISSN: 1662-9752, Vol. 891, pp 500-503
doi:10.4028/www.scientific.net/MSF.891.500

Submitted: 2016-05-31
Accepted: 2016-09-16
Online: 2017-04-03

Shear Band Morphology of Indented Region in Cu-Based Metallic Glass

Kornel Csach[1, a *], Mária Huráková[1, b], Alena Juríková[1, c], Jozef Miškuf[1, d], Václav Ocelík[2, e] and Jeff Th.M. De Hosson[2, f]

[1]Institute of Experimental Physics, Slovak Academy of Science,
Watsonova 47, 040 01 Košice, Slovakia

[2]Department of Applied Physics, Faculty of Mathematics and Natural Sciences, University of Groningen, Nijenborgh 4, 9747 AG Groningen, The Netherlands

[a,*]csach@saske.sk, [b]hurakova@saske.sk, [c]akasard@saske.sk, [d]miskuf@saske.sk,
[e]v.ocelik@rug.nl, [f]j.t.m.de.hosson@rug.nl

Keywords: amorphous alloys, plastic deformation, nanoindentation.

Abstract. Plastic deformation after indentation of the metallic glass $Cu_{47}Ti_{35}Zr_{11}Ni_6Si_1$ at different loading conditions was examined. Discontinuities on the loading curves were observed, the magnitude of which depends on the loading rate. The presence of these discontinuities is influenced by the precise shape of the indentation tip. At lower loading rates and using a cube corner indenter tip the discontinuities on the loading curves are more pronounced. An increase of the loading rate tends to diminish instantaneous plastic deformation as appear by pop-ins. Using a Berkovich type indenter tip the plastic deformation is more steady. It is concluded that the final morphology of the pile-up area strongly depends on the geometry of the indenter tip, whereas no correlation between discontinuities in the loading part of the indentation curve and the formation of shear band patterns was observed.

Introduction

Metallic glasses are amorphous alloys without a long-range order in atomic structure, dislocations or other precise crystalline defects. They exhibit several unique properties such as an extremely high strength in compression. At ambient temperature the plastic deformation of metallic glasses is highly localized into shear bands, near the planes of maximum shear stress and appears to be correlated to a local change in the viscosity [1-3].

Nanoindentation is a versatile technique for measuring the mechanical properties of a small volume of material and it may aid to unravel the mechanisms of the deformation of metallic glasses [4, 5]. Serrated flow was observed on the load-displacement (*P-h*) curves during load rate-controlled nanoindentation and correlated with the discrete shear banding events [3]. Systematic research by Schuh and Nieh [3-6] indicated that the discontinuities (pop-ins) on *P-h* curves are associated with shear band nucleation, its propagation and that they are strongly depending on the chemical composition of the alloy and the indentation loading rate. The pop-ins are observed mainly at lower loading rates and gradually disappear with increasing loading rate. Nevertheless, this can be caused also by the indenter geometry [7]. Using two indenter tips with different angles (a commonly used Berkovich and sharper cube corner indenter tip) it was found that pop-in events depend significantly on the indenter angle [8]. As a consequence the use of different indenter tips can be helpful in investigating the deformation process in metallic glasses.

A detailed and accurate record of the applied load and the tip displacement during nanoindentation experiments allows to examine the characteristics of the process. For example the work-of-indentation can be calculated from a complete *P-h* curve. The area under the loading curve gives the total work done by the loading device during indentation. From the area under the unloading curve the reversible elastic contribution to the total work can be derived and the energy absorbed by solely the plastic deformation is the difference between the total work and elastic contribution of the total work [9, 10]. In our work we focus on inhomogeneous plastic deformation process during nanoindentation of CuTiZrNiSi amorphous alloy with two different tip shapes of the indenter.

Experimental

The samples of the amorphous metallic ribbon with a nominal composition of $Cu_{47}Ti_{35}Zr_{11}Ni_6Si_1$ (at. %) were used for the nanoindentation test. The ribbon with the cross-sections of 1.72 × 0.02 mm^2 was prepared by rapid melt quenching on a spinning metallic disc.

Before nanoindentation tests the specimens were mechanically polished to mirror finish and tested using the nanoindentation equipment of MTS NanoIndenter® XP with a Berkovich and a cube corner diamond tips. The fused silica was used for the tip calibration procedure. The nanoindentation measurements were performed at room temperature in the load rate-control mode up to the maximal load of 250 mN using the loading rates 0.1 and 10 $mN.s^{-1}$. For each measurement up to twenty-five indents were made. After nanoindentation, the morphology of the indents and the shear bands were observed by XL30S SEM-FEG scanning electron microscope.

Results and Discussion

Indentation curves of the alloy during indentation with Berkovich indenter tip and for loading rates 0.1 $mN.s^{-1}$ and 10 $mN.s^{-1}$ are shown in Fig. 1 (left). The details of the loading final part of the indentation curves are depicted in Fig. 1 (right). It is visible that the indentation curves for the examined alloy change with loading rate only in the details. The very small pop-ins on the final part of loading curve visible at low loading rate disappeared at higher loading rate.

For indentation with a cube corner indenter tip, the indentation curves are shown in Fig. 2 (left) and details of the final parts of the loading segment can be seen in Fig. 2 (right). The pop-ins are more developed at lower loading rate in comparison with higher loading rate. It is evident that at nanoindentation using the cube corner indenter tip, the pop-ins are more pronounced than using Berkovich indenter tip.

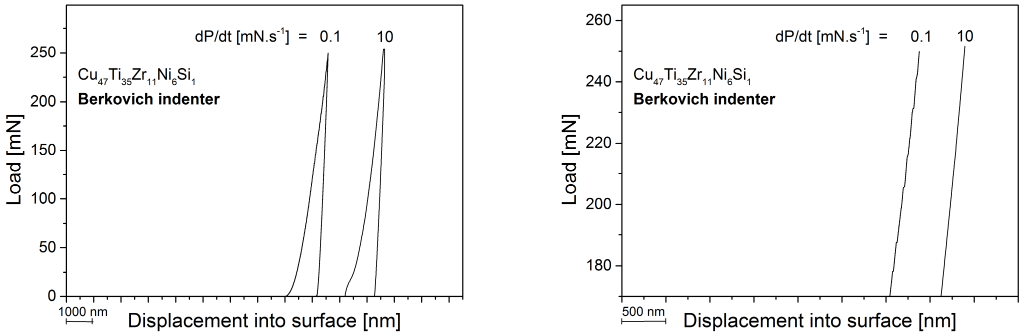

Fig. 1 *P-h* curves during indentation with Berkovich indenter for loading rates of 0.1 and 10 $mN.s^{-1}$ (left) and a detail of the loading part of the indentation curves (right)

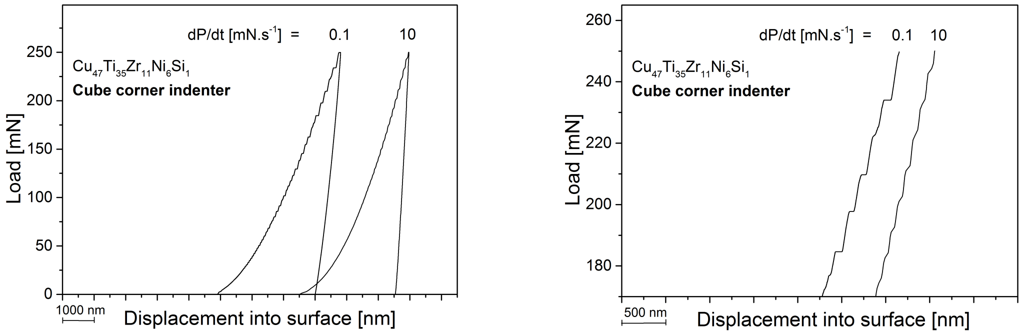

Fig. 2 *P-h* curves during indentation with cube corner indenter for used loading rates (left) and a detail of the loading final part of the indentation curves (right)

The localized plastic flow of the deformation in the pile-up area around the indent with both types of indenters was scrutinized using scanning electron microscopy. Fig. 3 (upper row) shows the plastic flow around Berkovich indents on the surface for the loading rates of 0.1 $mN.s^{-1}$ and 10 $mN.s^{-1}$. The plastic flow around cube corner indents at the same loading rates is shown in Fig. 3

(lower row). Around all indents the deformed region with shear bands is present, but it is clear that the shear band pattern on the deformed indent region depends on the precise shape of the indenter tip. The pile-up areas are more pronounced at cube corner indentation. At nanoindentation with a Berkovich indenter tip, the shear bands create concentric circles around the indent axis whereas at indentation with a cube corner tip the deformed region consists of parallel polygonal edged plates. Although the loading rate influences the presence of the pop-in events on the loading part of the *P-h* curve for both indenter tips, the morphology of indent area is independent on loading rates applied.

The energies involved during nanoindentation were determined through the integral of the loading and unloading part of the indentation curves. The energy of plastic deformation at nanoindentation with the Berkovich indenter tip was determined as 0.103 ± 0.032 μJ and with cube corner indenter as 0.262 ± 0.031 μJ. Due to the difference in the shape of the tip, the specific energy related to the creation of the volume unit (1 μm^3) of the indent depression was calculated using *P-h* data respecting the indent tip geometry. The calculated values of indent volume at the Berkovich and cube corner tip indent were 19.7 and 36.0 μm^3, respectively. As a result for the creation of 1 μm^3 indent region an internal energy of 5.2 mJ/m^3 for the Berkovich tip is added to the system and 7.3 mJ/m^3 in case of using the cube corner tip.

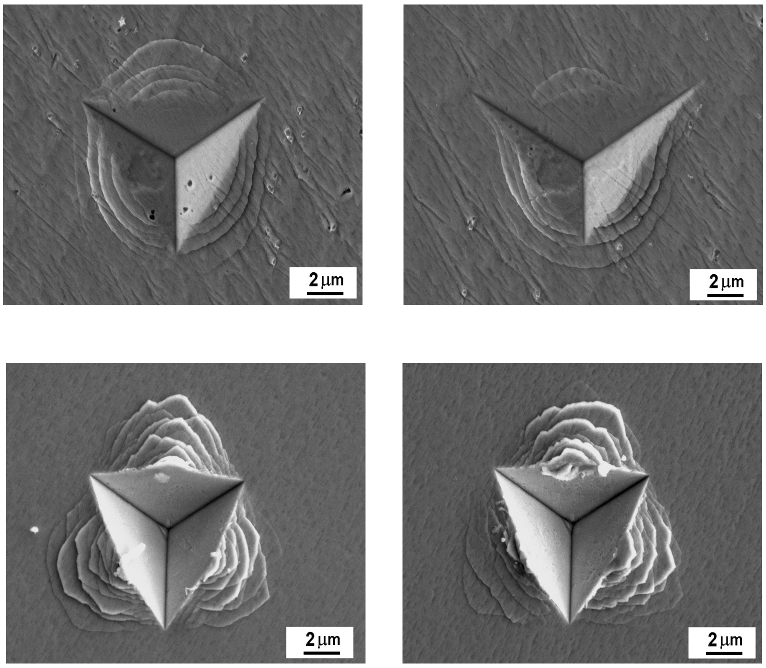

Fig. 3 Shear band morphology under identical loading conditions with Berkovich indenter tip (upper row) and cube corner indenter tip (lower row) for the loading rate of 0.1 $mN.s^{-1}$ (left column) and 10 $mN.s^{-1}$ (right column)

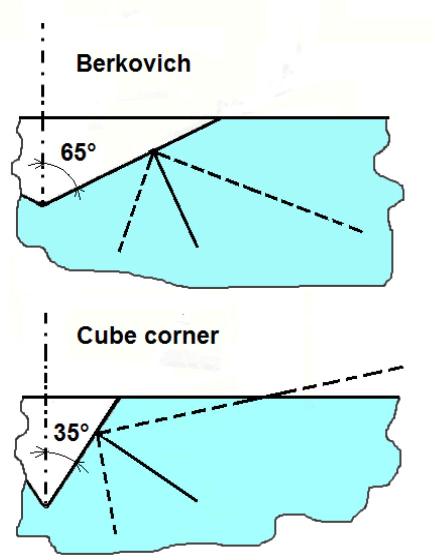

Fig. 4 Geometric conditions for shearing at different indenter tips

We propose that the specific work of plastic deformation is related to the pile-up area. Higher energy is stored in larger volume of the pile-up. The shear band pattern for cube corner indent is larger and less complex in comparison with the Berkovich indentation. In the pile-up area of the cube corner indent the parallel plates are created due to the small number of the shear bands. Therefore the plate morphology with sharp edges is present. In the case of the pile-up area around the Berkovich indent, the shear bands pattern is more complex. The plastic deformation is carried out via shearing in many active and intersecting shear bands.

The geometrical conditions for the indenter tip shapes applied are sketched in Fig. 4. The plastic deformation in metallic glasses occurs via the creation of the narrow shear bands in the plane of maximal shear stress. Using sharper cube corner tip the plane of maximal shear stresses intersect the free surface. This can be the reason for shearing in only a low number of selected shear bands.

Conclusion

The morphology of the indented regions reflects the plastic deformation mechanisms in metallic glasses at the macroscopic level. The shear band pattern on the indented region depends on the shape of the indenter tip. Using a Berkovich indenter the shear bands create concentric circles around the indent axis. Using a cube corner indenter tip the deformed area consists of parallel polygonal edged plates. No influence of the loading rate on the morphology of the indents was observed. At a higher loading rate the pop-in events are inhibited. More complex shearing is observed when using a Berkovich indenter. It consumes a lower energy per unit of volume.

Acknowledgement

This work was supported by Slovak Academy of Sciences – VEGA 2/0045/14 and by the project No. 26210120012 provided in the frame of Structural fund of the European Union.

References

[1] A.S. Argon, J. Megusar, N.J. Grant, Shear band induced dilations in metallic glasses, Scripta metall. 19 (1985) 591-596. DOI: 10.1016/0036-9748(85)90343-6.

[2] W.J. Wright, R. Saha, W.D. Nix, Deformation mechanisms of $Zr_{40}Ti_{14}Ni_{10}Cu_{12}Be_{24}$ bulk metallic glass, Mater. Trans. 42 (2001) 642-649. DOI: 10.2320/matertrans.42.642.

[3] C.A. Schuh, A.L. Lund, T.G. Nieh, New regime of homogeneous flow in the deformation map of metallig glasses: elevated temperature nanoindentation experiments and mechanistic modeling, Acta Mater. 52 (2004) 5879-5891. DOI: 10.1016/j.actamat.2004.09.005.

[4] C.A. Schuh, T.G. Nieh, A nanoindentation study of serrated flow in bulk metallic glasses, Acta Mater. 51 (2003) 87-99. DOI: 10.1016/S1359-6454(02)00303-8.

[5] C.A. Schuh, T.G. Nieh, A survey of instrumented indentation studies on metallic glasses, J. Mater. Res. 19 (2004) 46-57. DOI: 10.1557/jmr.2004.19.1.46.

[6] C.A. Schuh, T.G. Nieh, Y. Kawamura, Rate depencence of serrated flow during nanoindentation of a bulk metallic glass, J. Mater. Res 17 (2002) 1651-1654. DOI: 10.1557/JMR.2002.0243.

[7] B.N. Lucas, W.C. Oliver, Indentation power-law creep of high-purity indium, Metall. Mater. Trans. A 30 (1999) 601-610. DOI: 10.1007/s11661-999-0051-7.

[8] B.G. Yoo, J.Y. Kim, J.I. Jang, Influence of indenter geometry on the deformation behavior of $Zr_{60}Cu_{30}Al_{10}$ bulk metallic glass during nanoindentation, Mater. Trans. 48 (2007) 1765-1769. DOI: 10.2320/matertrans.MJ200752.

[9] J.R. Tuck, A.M. Korsunsky, S.J. Bull, R.I. Davidson, On the application of the work-of-indentation approach to depth-sensing indentation experiments in coated systems, Surface and Coatings Technology 137 (2001) 217-224. DOI: 10.1016/S0257-8972(00)01063-X.

[10] D. Beegan, S. Chowdhury, M. T. Laugier, Work of indentation methods for determining copper film hardness, Surface and Coatings Technology 192 (2005) 57-63. DOI: 10.1016/j.surfcoat.2004.02.003.