SHEAR FAILURE OF AMORPHOUS ALLOY AT NANOINDENTATION

M. Huráková, K. Csach, J. Miškuf, A. Juríková, Š. Demčák, V. Ocelík, J. Th. M. De Hosson

Abstract

The amorphous alloy with nominal composition $Fe_{40}Ni_{40}B_{20}$ (at. %) was studied by nanoindentation method with cube corner indenter at different loading rates from 0.05 to 100 mN.s^{-1}. At certain loading rates discontinuities (pop-ins) were observed on the nanoindentation curves. The shear band density was compared with the pop-in presence on the loading parts of nanoindentation curve. After the initial stage of the indentation the distance of observed shear bands increases until reaches its maximal value and subsequently decreases. During nanoindentation the stepwise plastic deformation occurs and the catastrophic failure is suppressed. Using scanning electron microscopy the shear band pattern on the indent region was observed.

Keywords: nanoindentation, shear bands, pop-ins, metallic glass

INTRODUCTION

Metallic glasses are potential structural materials due to their high strength, high hardness, good wear and corrosion resistance, good soft magnetic properties, excellent elasticity and readily forming in viscous state, but their applications are limited by the lack of plastic deformation at room temperature. The precise nature of deformation mechanisms in these amorphous materials remains unclear [1-3]. Amorphous alloys exhibit inhomogeneous plastic deformation that is highly localized into very narrow zones, so-called shear bands, near planes of maximum shear and appears to be related to a local change in viscosity within these shear bands. It is recognized that shear band formation is very weakly dependent on the strain rate or temperature [4], but some reports suggest that the strain rate affects the shear band formation. Mukai et al. [5] reported that the density of shear bands in a Pd-based bulk metallic glasses increased with the strain rate.

Nanoindentation is a useful technique for measuring the mechanical properties of small volume of materials and nanoindentation experiments have provided insights into mechanisms of metallic glass deformation [6, 7]. The displacement bursts in the load-displacement (*P-h)* curves are produced during load rate-controlled nanoindentation and correlated with the discrete shear banding events [8]. Golovin et al. [9] and Greer [10, 11] reported continuous serrations (serial pop-ins) in P-h curve as another interesting feature of inhomogeneous deformation during nanoindentation of metallic glasses. Serrated flow is also characterized by repeating cycles of a sudden stress drop during displacement rate-controlled experiments followed by the elastic reloading [12]. It is assumed that the

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Mária Huráková, Kornel Csach, Jozef Miškuf, Alena Juríková, Institute of Experimental Physics, Slovak Academy of Sciences, Watsonova 47, 040 01 Košice, Slovakia
Štefan Demčák, Department of Environmental Engineering, Faculty of Civil Engineering, Technical University of Košice, Vysokoškolská 4, 040 01 Košice, Slovakia
Václav Ocelík, Jeff Th.M. De Hosson, Department of Applied Physics, Faculty of Mathematics and Natural Sciences, University of Groningen, Nijenborgh 4, 9747 AG Groningen, The Netherlands

serrations are associated with shear band nucleation and their propagation. The number of pop-ins correlates directly with the number of shear bands observed on the surface of the sample around the indent. The displacement discontinuities increase in the size with increasing load or displacement. This may be caused by the nature of the geometrically self-similar sharp indenter where the amount of strain accommodation by each pop-in is substantially independent on the load level or the high indentation loading rate at early stages of the indentation under constant loading rate [13]. In contrast, Golovin et al. [9] noted a good correlation between the number of pop-ins in the loading curve and the number of shear bands seen microscopically around the indents.

In this work we concentrated on the plastic deformation and shear failure during nanoindentation experiments of FeNiB type of metallic glass over a wide range of loading rates.

EXPERIMENTAL MATERIAL AND METHODS

The samples of amorphous metallic ribbons with the nominal composition of $Fe_{40}Ni_{40}B_{20}$ (at. %) were used for the nanoindentation experiments. The ribbons with the cross-section of 10 mm × 0.018 mm were prepared by the technique of rapid melt quenching on a spinning metallic disc.

The samples were mechanically polished to mirror finish and tested using nanoindentation equipment MTS NanoIndenter® XP with a cube corner diamond tip. 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 five loading rates from 0.05 to 100 $mN.s^{-1}$. For each measurement up to twenty-five indents were carried out. After nanoindentation, the morphology of pile-up area around indents and shear bands of the ribbon was observed by XL30 ESEM-FEG scanning electron microscope (SEM).

RESULTS

Load-displacement (*P-h*) curves of the studied alloy during indentation with loading rates *dP/dt* ranging from 0.05 to 100 $mN.s^{-1}$ are presented in Fig.1 (left). The details of the final loading parts of loading sequence on the *P-h* nanoindentation curves for all loading rates are shown in Fig.2 (right). It is visible that the pop-in events are more pronounced at lower loading rates (0.05, 0.1 and 1 $mN.s^{-1}$) and gradually disappear with the higher loading rates [14].

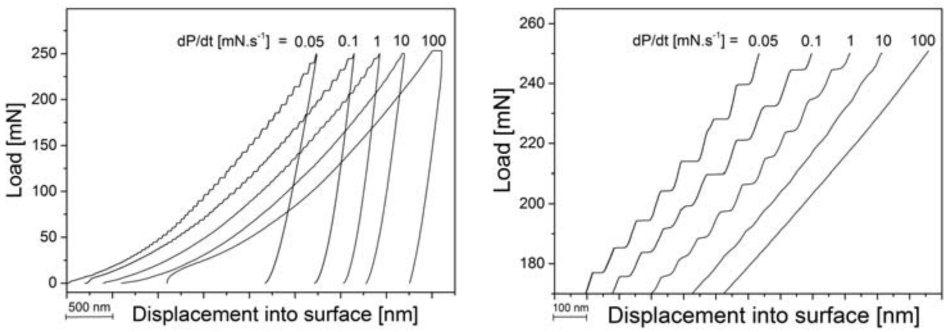

Fig.1. *P-h* nanoindentation curves for different loading rates (left) and details of the final loading parts of these curves (right).

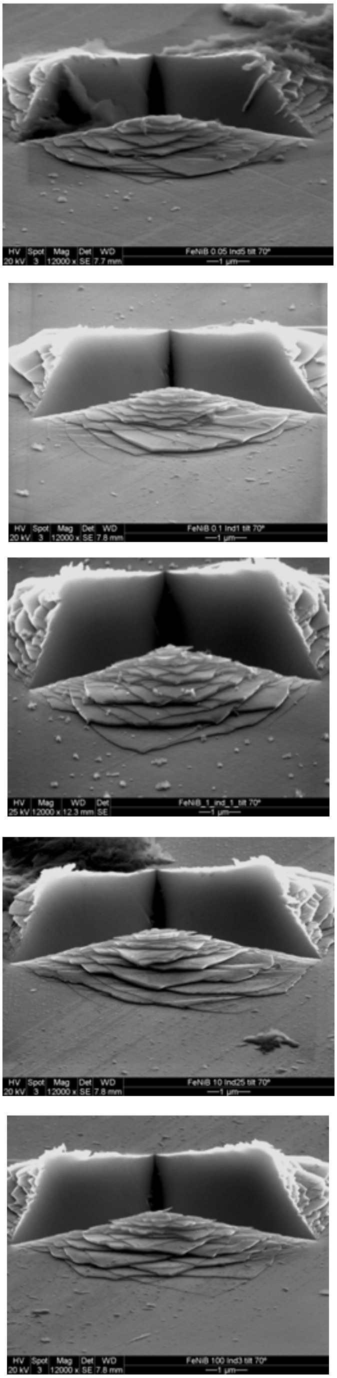

Fig.2. Morphology of indents after nanoindentation for all used loading rates.

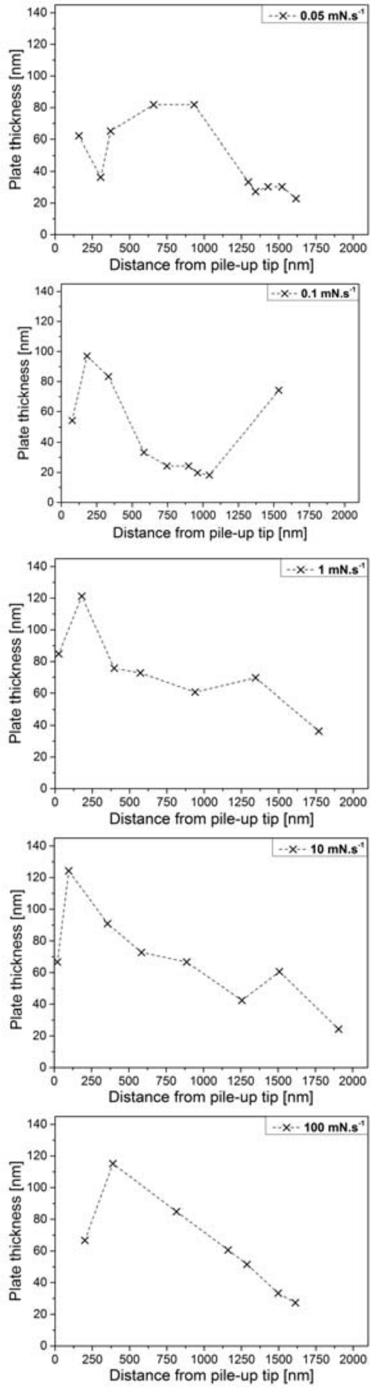

Fig.3. Dependences of thickness of individual plates on the distance from pile-up tip.

Bei et al. [15] also observed serrated flow on the load-displacement curves which were a result of the transition from perfectly elastic behaviour to plastic deformation. The first pop-in corresponds to a transition from perfectly elastic to plastic deformation that is considered the onset of plastic flow (incipient plasticity) in the metallic glasses. In other words, the material is deformed plastically at loads higher than the first pop-in load. A manifestation of the plastic deformation in metallic glasses during nanoindentation is the formation of shear bands around the indents. These shear bands indicate that the plastic deformation is highly localized irrespective of whether there is serrated flow during indentation or not [1].

Typical surface morphology of indents after nanoindentation at the loading rates from 0.05 to 100 mN.s^{-1} is shown in Fig.2. The shear bands were observed at 70° tilt of sample in the pile-up area surrounding the indents of studied alloy. The plate-like morphology of pile-up areas is similar for all indents. The plate thickness (inverse proportional to the shear band density) was measured across the pile up zone from its tip toward to the undeformed area. Dependences of thickness of individual plates on the distance from pile-up tip for all indentation loading rates are shown in Fig.3.

It seems that the plate thickness depends on the loading rate. At loading rate of 0.05 mN.s^{-1} the plate thickness varies from 20 to 85 nm. With increased loading rates the plate thickness increases to the value of 120 nm. This plate thickness range corresponds with the shear band densities on the range of 8-50 μm^{-1}. These semi-quantitative results indicate that with increasing of loading rate the plate thickness increases too. The plates created around the pile-up tip are thin. With increasing the distance from pile-up tip the thickness of plates increases up to a maximal value and at final stage of indentation the plate thickness gradually decreases.

Subsequently, we designed the scheme of the formation and propagation of shear bands at nanoindentation (Fig.4). The colour scale points on the degrees of deformation, the darker colour represents the greater deformation γ. In amorphous alloys the deformation occurs via the formation and propagation of the shear bands. The proposed scheme respects the generation of the shear bands in the plane of maximal shear stresses. As the loading increases, the new shear bands are stepwise generated. Beside the stepwise deformation the continual deformation occurs by the growth of previous created shear bands.

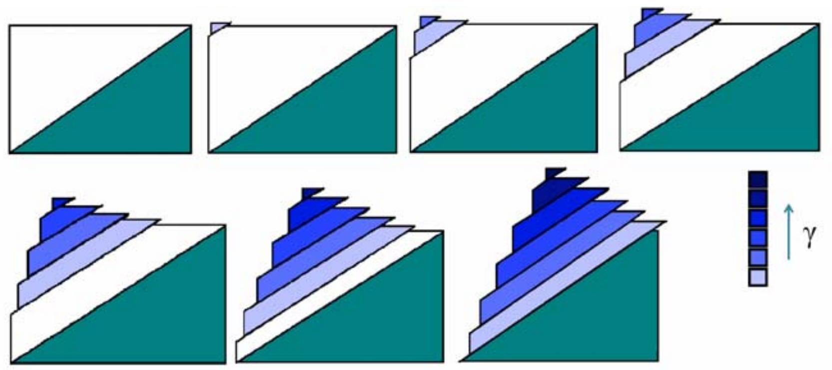

Fig.4. The scheme of the formation of shear bands at nanoindentation.

CONCLUSION

During load-control instrumented nanoindentation experiments on the amorphous alloy FeNiB in the wide range of deformation rates the presence of deformation discontinuities were observed. As the loading rate increases above 10 $mN.s^{-1}$ the pop-ins vanished. The observation of the deformed zone of indent area shows similar morphology for all used loading rates. The measured effective shear band density varies from 8-50 μm^{-1}.

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