High-energy X-ray measurements of structural anisotropy and excess free volume in homogenously deformed metallic glass

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Introduction

For low applied stresses and high temperatures, metallic glasses deform homogeneously. Previous research has shown that homogeneously deformed metallic glasses experience strain-induced structural disordering, which can be described phenomenologicaly using the free volume model [1,2]. Recently, Yavari and coworkers have shown that X-ray scattering can be utilized to measure excess free volume in metallic glasses [3].

In addition to excess free volume creation, homogeneous deformation can also result in an anisotropic atomic structure after unloading. By comparing the diffraction spectra from a sample where the scattering vector was both parallel and perpendicular to the tensile loading axis, Egami and coworkers found the total scattering function to be anisotropic [4].

Here we report on using high-energy X-ray scattering to examine the dependence of excess free volume creation and structural anisotropy on the amount of plastic strain for a homogeneously deformed Zr-based metallic glass. The effects of increasing strain localization near the fracture tip on the two quantities are discussed.

Methods and Materials

Standard "dogbone" samples of metallic glass of composition $Zr_{41.2}Ti_{13.8}Cu_{12.5}Ni_{10}Be_{22.5}$ were used for the creep experiments, which were performed in uniaxial tension at 25 K below the glass transition temperature of the alloy. For the experiments, the applied load was held constant, thus the true stress changed during deformation due to necking of the samples. The variation of cross-sectional area along the gauge length provided a gradient of plastic strains in the creep sample. To account for the accompanying structural relaxation that occurs at the elevated test temperature, a stress-free companion sample from the same alloy was placed in the creep rig with the creep sample.

The Synchrotron X-ray experiments were performed at the MUCAT (6-IDD) beamline of the Advanced Photon Source at Argonne National Laboratory. Monochromatic 130 keV X-rays were used for the transmission mode experiments. A MAR 345 digital image plate with a 100 µm x 100 µm pixel size was used to record the scattered intensity from the sample following creep deformation. Patterns were collected from different regions along the gauge length to examine material that had undergone varying amounts of plastic strain.

Results

The excess free volume and degree of structural anisotropy for a creep sample loaded at an initial stress of 400 MPa is shown in Fig. 1. The excess free volume was calculated by comparing the fitted positions of the first diffuse scattering peaks (in reciprocal space) of the creep and companion samples. The amount of structural anisotropy was calculated by subtracting the fitted peak position in the transverse direction (scattering vector normal to loading axis) from the peak position in the longitudinal direction (scattering vector parallel to loading axis).

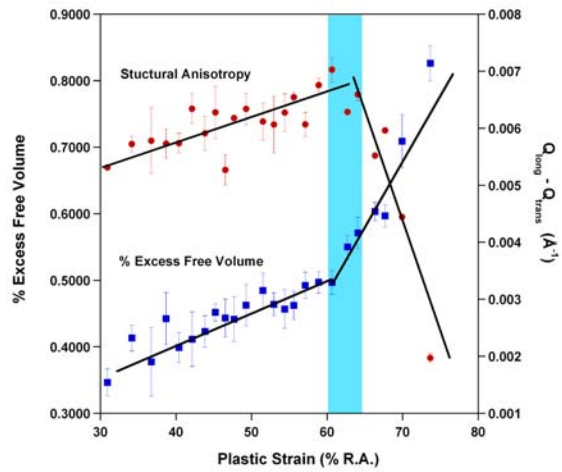

Fig. 1. Excess free volume and structural anisotropy as a function of plastic strain (% reduction in area). The shaded region corresponds to the localization of the plastic strain in the creep sample.

Discussion

For plastic strains below 60%, both the excess free volume and structural anisotropy increase with increasing plastic strain. For plastic strains above 60%, the excess free volume shows a large increase, while the degree of structural anisotropy exhibits a marked decrease. Examination of the test piece shows that this region corresponds to an increase in the localization of the plastic strain near the fracture tip. Therefore, it appears that the increasing localization of the plastic strain has an opposite effect on the excess free volume creation and structural anisotropy. The results show that high-energy X-ray scattering is an effective technique for examining the effects of homogenous deformation on the excess free volume and structural anisotropy in metallic glasses.

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