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Free Volume in a cold-worked $Zr_{55}Cu_{30}Ni_5Al_{10}$ Bulk Metallic Glass

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1 Introduction

It was reported that the volume fluctuation called the free volume is introduced into a plastically deformed amorphous alloy and metallic glass [1, 2]. However, the change in the glass structure of a deformed metallic glass has been insufficiently studied for recent years. The discovery of bulk metallic glasses (BMGs) gives us much opportunity to elucidate the structural properties in a deformed metallic glass. The high intensity x-ray of PF enables us to obtain new information of the details of plastically deformed BMGs.

2 Experiment

The $Zr_{55}Cu_{30}Ni_5Al_{10}$ BMG was prepared by the tilted cupper mold-casting technique [3] with a size of 14 mm in diameter and 30 mm in length. Two disks with a thickness of about 2 mm were cut from the rod shape BMG. One piece was thinned down into a fraction of about 90% by cold working at room temperature and another was regarded as the standard sample. The structure of both samples was investigated by a normal scattering technique with x-ray energy of selected 15.000 keV at BL7C station. The scattering experiment was performed with a vertical type two-axis goniometer and a SSD (Ge) detector. Then the scattering angle (2θ) was changed from 4 to 140 degrees. The coherent intensity of scattered photons was estimated from the diffracted beam and the structure factor, $S(Q)$, was derived, where Q is the magnitude of the scattering vector.

3 Results and Discussion

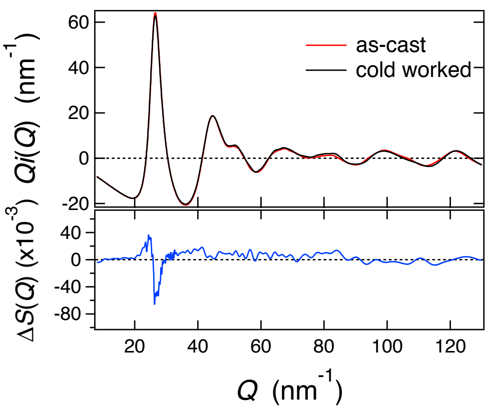

Fig. 1: $Qi(Q)$'s of as-cast, deformed BMGs and the difference of $S(Q)$.

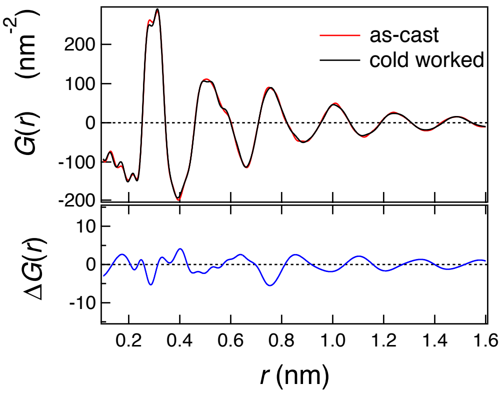

Fig. 2: $G(r)$'s of as-cast, deformed BMGs and the difference of $G(r)$.

The reduced radial distribution function, $G(r)$, was calculated by Fourier transformation of $S(Q)$. Figure 1 exhibits, $Qi(Q)=Q(S(Q)-1)$, of standard as-cast and 10% cold-worked BMGs and the difference of $S(Q)$, $\Delta S(Q) =S_{cw}(Q)-S_{as}(Q)$. The change in $S(Q)$ representatively appears around its first peak, i.e. a peak shift to lower side and a small broadening of peak. The corresponding $G(r)$'s are shown in Fig. 2 together with the difference, $\Delta G(r)=G_{cw}(r)-G_{as}(r)$. The overall behavior in $\Delta G(r)$ is definitely in anti-phase to both $G_{as}(r)$ and $G_{cw}(r)$, meaning that the amplitude of $G_{cw}(r)$ became smaller than the $G_{as}(r)$. The result suggests that the topological disorder of the as-cast BMG increased by cold working. The change in the glass structure by the structural relaxation was quantitatively investigated by the atomic level stress model [4]. Following this model, the $\Delta G(r)$ for structural relaxation was expressed as,

$$\Delta G(r) \approx -\tfrac{1}{2}\gamma^2\, \partial^2 G_0 \big/ \partial r^2 \left(\left\langle p^2 \right\rangle_{as} - \left\langle p^2 \right\rangle_{relax} \right),$$

where $<p^2>$ is the fluctuation of the atomic level hydrostatic pressure, and γ^2 is the r-dependent parameter approximately equivalent to a constant over first peak of $G(r)$. The G0(r) is the reduced radial distribution function from the region with almost 0 pressure, and it is actually approximated by the $G(r)$ in as-cast state. In case of structural relaxation, the $\Delta G(r)$ changed in phase to a minus second derivative of $G_{as}(r)$, $-\partial^2 G_0/\partial r^2$, and consequently a positive change in $<p^2>_{as}-<p^2>_{relax}$ was obtained. The result was interpreted as the decrease of topological disorder, i.e. the fluctuation of atomic level stress. Figure 3 plots $-\partial^2 G_0/\partial r^2$ against the distance, r,

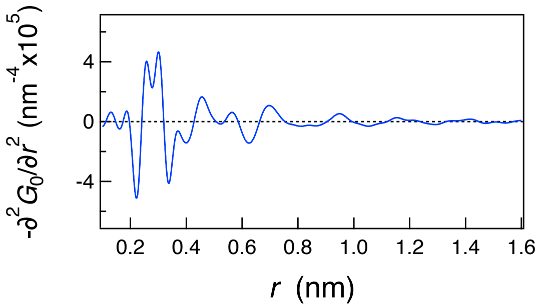

Fig. 3: $-\partial^2 G_0/\partial r^2$ of as-cast $G(r)$

where the curve was smoothed by cubic spline functions after the subtractive calculation. We can easily see an anti-phase behavior of $-\partial^2 G_0/\partial r^2$ against $\Delta G(r)$, meaning that $\langle p^2\rangle_{as}$-$\langle p^2\rangle_{cw}$ becomes a negative value, and it is an opposite sign to the structural relaxation. Thus we conclude that the volume fluctuation, which is characterized by the atomic-level stress, increases after plastically deforming BMG. The result consists with the volume and enthalpy change of cold-worked $Zr_{55}Cu_{30}Ni_5Al_{10}$ BMG [5].

References

[1] Y. Waseda and T. Egami, J. Mater. Sci., **14** (1979) 1249.

[2] D. Deng and B. Lu, Scr. Met., **17** (1983) 515.

[3] Y. Yokoyama, K. Yamano, K. Fukaura, H. Sunada and A. Inoue, Mater. Trans., **42** (2001) 623.

[4] D. Srolovitz, T. Egami and V. Vitek, Phys. Rev. B, **24** (1981) 6936.

[5] O. Haruyama *et al*., Acta mater. to be submitted.

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