別紙４（課程博士）

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Abstract

論文内容の要旨 （博士）

Title of Thesis 博士学位論文名	Tailoring mechanical properties of bulk metallic glass through controlling microstructure by plastic deformation (塑性変形による組織制御に基づくバルク金属ガラスの力学的高機能化)

(Approx. 800 words)
(要旨 1,200 字程度)

Bulk metallic glasses (BMGs) have excellent mechanical properties as structural materials, such as high strength, fatigue limits, and corrosion resistance. However, BMGs fracture with zero ductility, especially under tensile stress. Such catastrophic failure is caused by a formation of single shear band across a sample, and the strain localization owing to the significant softening within the shear band. It is widely believed that the plastic deformation of BMGs is governed by the activation of shear transformation zone (STZ) model, which considers stress relaxation through the local atomic rearrangement at the clusters consisted of a few to hundreds of atoms. The preferential STZ activation sites are expected to have larger free volume (FV) fraction because such site can rearrange the structure without affecting surrounding. The cause of poor plasticity in conventional BMG is small number of STZs activated during loading. In order to improve plasticity of BMGs, increasing the number of STZ activation during loading and controlling the easiness of STZ activation are quite important.

As the STZ activation seems to occur at the site with higher FV, FV is thought to be the key factor to control the mechanical properties of BMGs. The FV fraction is easy to reduce from the as-produced state through structural relaxation by sub-T_g annealing. The only way to introduce FV is plastic deformation. However, there is no valid and feasible deformation process to introduce the FV fraction in a BMG, since cracks are easy to form during deformation process using conventional process such as cold rolling.

Alternatively, the β-relaxation, which is the single atomic diffusion-like structural relaxation process in BMGs is closely related to the STZ activation. The energy barrier for the STZ activation, W_{STZ}, and the activation energy for β-relaxation, E_β, which. That is $W_{STZ} \approx E_\beta$. The relation between E_β and glass transition temperature, T_g, have been also reported: $E_\beta = 26RT_g$. Since the T_g is the material's constant, these two relations imply that the ease with which STZs can be activated is strictly limited by the composition.

In this study, it is shown that the number of STZ activation sites and the W_{STZ} can be controlled using high-pressure torsion (HPT) process, which can deform brittle material under high pseudo-hydrostatic pressure, and the mechanical properties of BMGs are consequently improved. The physical origin of the mechanical property evolution induced by HPT process has been also investigated in this study.

FV increment after HPT process was confirmed by both density measurement and thermal analysis. The density decrease caused by the HPT process indicates that the FV fraction higher than that achieved by conventional deformation process can be obtained using HPT process. The tensile strength was not decreased even after HPT process, indicating that the cracks were not formed in the sample during HPT process.

The relaxation enthalpy, ΔH, owing to the structural relaxation of FV became larger with increasing applied strain in HPT process in accordance with the density measurement. The parameters derived from the Arrhenius temperature dependence of relaxation time in enthalpy relaxation were in good agreement with the characteristics of β-relaxation in general BMGs reported previously. However, the activation energy distribution of β-relaxation significantly became broader after HPT process, indicating that the site with lower activation energy for β-relaxation was generated by HPT process. Considering the E_β is equivalent to W_{STZ}, the decrease in yield stress can be well explained. Furthermore, since the E_β has broad distribution comparing with general BMGs, STZs can be activated continuously throughout wide stress range, and strain hardening therefore occurred in the HPT-processed sample.

Nanoscale microstructure introduced by the HPT process was investigated by the unique technique combining small-angle X-ray and neutron scattering technique, to evaluate the structural origin of pronounced β-relaxation appeared after the HPT process. It is found that Cu should be segregated near the FV to explain the measured scattering intensity. The segregation of the smallest Cu atoms in the FV seems effectively works to reduce the E_β and to improve the mechanical property.

After the HPT-process, the tensile plastic elongation of 0.34 % was obtained in $Zr_{50}Cu_{40}Al_{10}$ BMG. The yield stress showed significant decrease from 1800 MPa to 1477 MPa after HPT process, while tensile strength increased over 100 MPa after HPT process. During plastic deformation, HPT-processed sample exhibited strain hardening, which cannot be observed in conventional BMGs deform via shear band formation. The shear bands observed in samples after tensile test could not explain the plastic elongation achieved in the tensile test. When the stress above yield stress is applied to HPT-processed sample, the stress was relaxed with the same time dependence as β-relaxation without forming shear band, whereas nondeformed sample showed no stress relaxation. This result indicates that the plastic deformation in HPT processed sample is governed by the pronounced β-relaxation.

The one of the biggest advantage of crystalline materials is easily controllable mechanical property after the production by heat treatment and/or deformation processes. In the field of BMGs, in contrast, it has long been recognized that mechanical properties are decided by the composition. However, this study revealed that such compositional limitation could be overcome using the plastic deformation process, and the key factor governing the plastic deformation in BMGs is β-relaxation process. These findings open up new avenues for designing plastic bulk metallic glasses focusing on the β-relaxation.