Rheology of bcc-iron at high-pressure and -temperature

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Although many hypotheses have been proposed for origin of the seismic anisotropy in the Earth’s inner core, there is no general consensus for its origin. Lasbleis and Deguen (2015) discussed that dominant mechanism of the inner core dynamics depends on the inner core age and viscosity, and there are several candidate mechanisms which includes anisotropic growth model (Yoshida et al., 1996) and thermal convection model (Jeanloz and Wenk, 1988). It had been widely accepted that the inner core consists of iron-rich alloy with hexagonal close-packed (hcp) structure. However, some recent computational mineral physics studies (e.g. Belonoshko et al., 2017) claimed that the iron-rich alloy in the inner core possibly has body-centered cubic (bcc) structure rather than hcp. Therefore, information of viscosity of bcc-iron is important for the accurate understanding of the inner core dynamics. In this study, we have studied rheology of bcc-iron based on high-pressure and high-temperature deformation experiments.

Uniaxial deformation experiments were carried out using a deformation-DIA apparatus SPEED-MkII-D installed on a beamline BL04B1 at SPring-8. Using polycrystalline iron aggregate as a starting material, deformation experiments were carried out at pressure of 2.0-6.0 GPa, temperature of 523-823 K, and strain rate of $0.8–5.7\times10^{-5}$ s^{-1}. Stress and strain during deformation were determined based on two-dimensional X-ray diffraction and X-ray radiography, respectively, using monochromatized synchrotron X-ray with energy of 60 keV.

A preliminary analysis of the derived data suggests that power-law dislocation creep with stress exponent of ~5 and activation volume of 2-3 cm^3/mol is dominant. Extrapolation of the data to ambient pressure is generally consistent with the well-established ambient pressure rheology of this material (Frost and Ashby, 1982). When compared with rheology of hcp-iron at same deformation condition, stress value of bcc-iron is lower by ~1 order of magnitude. This means that viscosity of bcc-iron is lower by ~5 orders of magnitude than that of hcp-iron because stress exponent for the both iron polymorphs is considered to be ~5. If the inner core mostly consists of bcc-iron, the viscosity in the inner core is estimated to be significantly lower than the previous estimates where hcp-iron was assumed to be the dominant inner constituent.

Keywords: inner core, bcc-iron, rheology