AR-NE7A/2014G680

Low-temperature plasticity of ringwoodite at high pressure

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1 Introduction

It has been observed that on the basis of seismic tomography images, some subducting oceanic plates (slabs) horizontally stagnate near 660 km discontinuity [e.g., 1]. However, it has been difficult to explain the large deformation of deep slabs in mantle transition zone because the flow law of constituent minerals such as ringwoodite has not been determined yet. Although the grain-size reduction due to the olivine-spinel transformation possibly weakens the slab, which can be responsible for the large deformation of deep slabs [e.g., 2], the fine-grained weak region may be relatively limited just below the narrow metastable wedge [e.g., 3, 4]. Low temperature plasticity (Peierls mechanism) could be a dominant deformation mechanism outside the fine-grained slab core. In order to construct the flow law of ringwoodite in this deformation mechanism, we conducted deformation experiments of $(Mg_{0.9},Fe_{0.1})SiO_4$ ringwoodite at low temperature conditions. Here, we report its preliminary results.

2 Experiment

High-pressure deformation experiments were conducted at 9-14 GPa and 300-600°C in constant-strain rate mode ($1.0\text{-}9.1\times10^{-5}$ s^{-1}) by using Deformation-DIA (D-DIA) apparatus installed at NE-7 beamlines in synchrotron facilities of PF-AR [5]. We synthesized a polycrystalline ringwoodite with height of 1.2 mm and diameter of 0.9 mm at 22 GPa and 1400°C for 180 min from a single crystalline San Carlos olivine using a Kawai-type multi-anvil apparatus in Kyushu University. This was recovered and used as a starting material for the deformation experiment. The starting sample was first compressed at room temperature by the 6-6 type multi-anvil assembly, heated to desired temperature by cylindrical graphite furnace, and then uniaxially deformed by the D-DIA system. We used monochromatic X-ray (50 keV, collimated to 200 microns) to obtain two-dimensional X-ray diffraction (2D-XRD) patterns every ~5 minutes using imaging plate (IP). Differential stress of the sample in uniaxial compression can be measured from distortions of Debye ring on IP. X-ray radiography image is used to determine the sample strain during plastic deformation. Thus, we measured stress-strain curves at various pressure, temperature, and strain rate conditions to construct flow law of ringwoodite.

3 Results and Discussion

Although deformation experiments were performed outside the ringwoodite stability field, we did not observe the back transformation up to at least 600°C. Fig.1 shows an example of the stress-strain curve obtained at 13 GPa and 600°C. The sample stress almost reached steady state at the strain of about 5%, and then slightly increased under strain up to ~25%, suggesting the strain hardening. The effect of pressure was negligible in our experimental condition. The flow stresses of ringwoodite ranged 3.3 to 4.1 GPa under the present experimental conditions, which is smaller than those obtained at room temperature in the previous study [5].

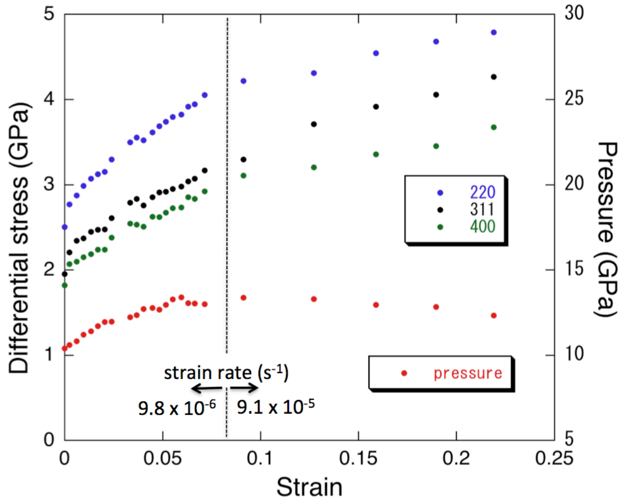

Fig. 1: Stress-strain curve obtained from ringwoodite deformed at 13.0 GPa and 600°C (Run rwdefp33). The deformation was conducted in two steps by changing the strain rate. The stress value calculated from three different diffraction peaks of ringwoodite (220, 311, and 400) are shown.

Preliminary analysis of the creep data obtained at 500°C based on the power law creep indicates that the apparent stress exponent is about 6.5 (Fig. 2). Fig. 2 also indicates that the strength of ringwoodite obtained in the present study is much lower than that of the dislocation creep predicted by the Si diffusivity [7], and comparable to that of the peiers mechanism creep estimated from relaxation test [2, 8]. These facts suggest that ringwoodite was deformed in low-temperature plasticity regime under the present experimental conditions. Although further experiments are needed to construct the quantitative flow law in low-temperature plasticity regime, the obtained strength of ringwoodite may be still too high to explain the large deformation of the deep slab.

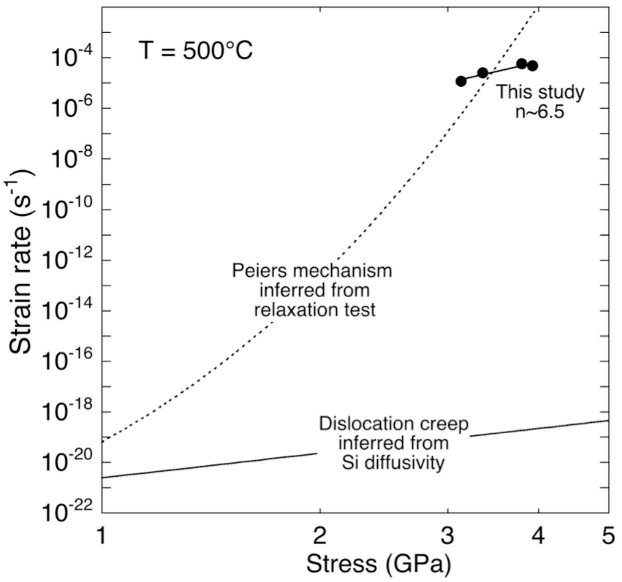

Fig. 2: Plots of strain rate as a function of stress in ringwoodite at 500°C (solid circle). Data from the dislocation creep estimated from the Si diffusivity [7], and from the peiers mechanism estimated from relaxation test [2, 8] are also shown.

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