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A synchrotron radiation study of high-pressure ice rheology

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Introduction

It is indispensable to construct flow laws of high-pressure ices in the grain size-sensitive (GSS) creep regime especially for low-stress conditions expected in the convecting interiors of icy moons. However observations and controls of the grain size of high-pressure ices are generally difficult. Rheology of high-pressure ices has been studied by using a gas-medium deformation apparatus. With the use of cryogenic scanning electron microscope, a change in deformation mechanism from the grain size-insensitive (GSI) to GSS creep has been observed [1]. We present here preliminary results on synchrotron radiation studies on high-pressure ice rheology.

Experimental method

Plastic deformation experiments of ice VII were carried out by using a deformation-DIA apparatus (D-DIA) installed at NE7A of Photon Factory, Japan [2]. We used monochromatic X-ray (50 keV, collimated to 100-500 microns) and obtained two-dimensional X-ray diffraction (2D-XRD) patterns every 3-5 minutes using imaging plate (IP). The number of diffraction spots on IP that fulfill the Bragg condition is proportional to the grain density. We expect to observe changes of the grain size from the evolution of numbers of diffraction spots as a function of time [3]. Differential stress of the sample in uniaxial compression can be measured from distortions of Debye ring on IP (azimuth angle-dependence of *d*-values). X-ray radiography image is used to determine the sample strain during plastic deformation.

Results and discussion

We first compressed water enclosed in teflon capsule using D-DIA at 300 K, and synthesized relatively coarse-grained ice VII showing spotty diffraction patterns. Then, the polycrystalline ice VII was uniaxially deformed at 3-7 GPa, 300 K, and constant strain rates of around 4×10^{-5}/s. The total strain reached up to 27% (Fig. 1). We observed that *d*-values in the compression axis (σ_1) become slightly smaller than those in the σ_3 direction during deformation, which allows quantitative analysis on the differential stress. We preliminarily estimated flow stresses of 40 and 70 MPa at pressures of 4 and 7 GPa, respectively. The number of diffraction spots increased with plastic strain, which may indicate dynamic recrystallization of ice VII. Based on the relationship between the number of spots and the grain sizes in standard samples, we estimated the grain size of polycrystalline ice VII decreased from 30-40 micron to 10-20 micron during the plastic deformation.

The grain size of the starting ice VII polycrystal can be controlled by changing the pressure-increasing rate during the solid state VI-VII transformation. Spotty patterns are good for the grain size measurements, but not good for the stress measurements. We are now trying to use NaCl polycrystal for the stress measurements. Although some improvements are needed to conduct the quantitative rheological study, we expect that these experimental methods based on synchrotron radiation are useful to explore both GSI and GSS creep of high-pressure ices.

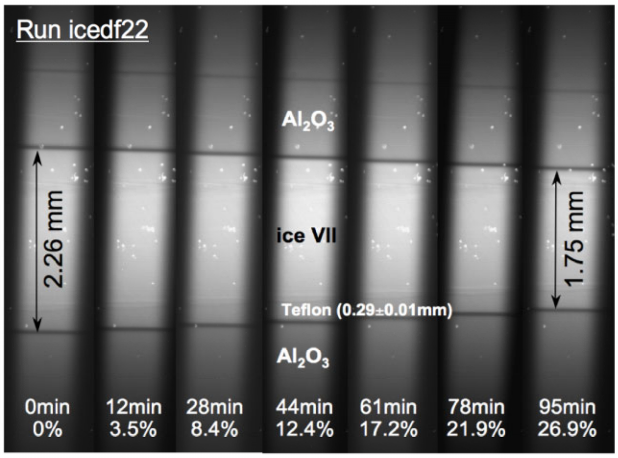

Fig. 1 X-ray radiography images showing plastic deformation of polycrystalline ice VII with the constant starin rate of 4.7×10^{-5} s^{-1} at 2.4-3.9 GPa and 300K. The sample was enclosed in teflon capsule and sandwiched by two alumina pistons. The sample strain measured by using the gold strain marker was also shown with time.

References

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