Japan Geoscience Union Meeting 2010
(May 23-28 2010 at Makuhari, Chiba, Japan)

SIT037-P07 Room: Convention Hall Time: May 26 17:15-18:45

Deformation experiment and grain growth experiment using a rock analogue

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1. Introduction

For better understanding of the physical and chemical properties of rocks, it is necessary to investigate the properties of polycrystalline materials. We use an aggregate of organic crystalline, borneol ($C_{10}H_{18}O$) as a rock analogue. Because the melting temperature of this material is much lower than those of rock forming minerals, thermally-activated processes occur at much lower temperatures (30-70°C). This enables us to investigate the high-temperature mechanical properties for a broad range of frequencies, from 10^{6}Hz (elastic) to 10^{-4}Hz (anelastic), and steady-state conditions (viscous). By adding another end-member component to borneol, we can obtain a binary eutectic system with a eutectic temperature of 43°C. This also enables us to investigate the effects of partial melt on the mechanical properties. In applying this analogue material to such experiments, it is important to know the deformation mechanisms acting under various stress and temperature conditions, and also to control the grain size of the aggregates. We therefore performed a series of grain growth experiments and uniaxial deformation experiments. We report the results of these experiments.

2. Experimental details

Finely ground powder of borneol (grain size was about 4micron) was pressed at room temperature to form a cylinder with 15mm diameter and about 12mm height.

Grain growth experiments were performed in a thermostat bath filled with uniformly heated water (40 and 45°C). A polished surface of each specimen was observed with laser microscopy and grain size was measured.

Uniaxial deformation experiments were performed using an INSTRON 5567 apparatus at ERI, Tokyo University. Temperature was controlled by using a thermostat cell filled with heated water (40 and 45°C). In initial experiments, the samples were deformed under constant piston speed 0.00 1-0.008mm/min (in strain rate, 10^{-6}-10^{-5}1/s), where stresses were 2.5-4MPa.In further experiments, we will apply the deformation experiments under much lower stresses (0.5-1MPa), by using constant load (10-20kg).

3. Results

The increase of mean grain size at 40 and 45°C was measured by a series of grain growth experiments. The empirical relationship between time and grain size of polycrystalline aggregates is given by d^{n}? d_{0}^{n} = kt (d is grain size, d_0 is initial grain size, t is time and k is constant). For borneol aggregates at 40 and 45°C, the exponent n was 6-8, which was larger than that for Forsterite (n was about 3; Hiraga et al., 2010).

From the uniaxial deformation experiments, we obtained a power-law flow law with a stress exponent of about 5. This indicates that deformation at 40-45°C and 2.5-4MPa is rate-controlled by dislocation creep.

4. Discussion and future direction

Borneol belongs to a group called organic plastic crystals, which were predicted to undergo ductile deformation by the same kinds of dislocation and diffusion processes as minerals, metals and ceramics (Sherwood, 1979). Takei (2005) reported the occurrence of diffusion creep in borneol in the presence of melt. This study demonstrats the occurrence of dislocation creep. We will perform deformation experiments for wide ranges of stress and temperature to obtain a deformation mechanism map for borneol aggregates.

Deformation mechanism maps are influenced by grain size. Also, the grain size dependence of anelasticity is poorly understood and is a matter of intensive study. Therefore, it is important to clarify the grain growth law to accurately control the grain size of borneol samples. Because melt can significantly affect grain growth, we are planning to perform grain growth experiments for partially molten samples. The similarities and differences between our results for borneol and the results for rock samples will contribute to the understanding of kinetics of grain growth.

Keywords: polycrystal, grain growth, creep, analogue experiment, rheology