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RHEOLOGY OF WATER AND AMMONIA-WATER ICES; D.L. Goldsby[1], D.L.Kohlstedt[1], and W.B.Durham[2], [1]Dept. of Geology and Geophysics, Univ. of Minnesota, Minneapolis, MN 55455, and [2]Lawrence Livermore National Lab, Livermore, CA 94550

Creep experiments on fine-grained water and ammonia-water ices have been performed at one atmosphere and high confining pressure P_c in order to develop constitutive relationships necessary to model tectonic processes and interpret surface features of icy moons of the outer solar system. The present series of experiments explores the effects of temperature T, strain rate $\dot{\varepsilon}$, grain size and melt fraction on creep strength. In general creep strength decreases with increasing temperature, decreasing strain rate, and increasing melt fraction. A transition from dislocation creep to diffusion creep occurs at finer grain sizes, higher temperatures and lower strain rates.

A method was developed for producing fine-grained (20-30 μm) samples to insure textural equilibrium in partially molten ammonia-water ice samples and to minimize microcracking caused by thermal and elastic anisotropies in water-ice samples. After Ice I powders were prepared by misting triply distilled water into a liquid N_2 reservoir, they were separated into the desired powder size by wet sieving in LN_2. Single-phase water-ice samples were then prepared by uniaxially hot-pressing these fine-grained Ice I powders at 12 MPa and 253 K for 24 h. Scanning electron microscopy (SEM) micrographs show that these samples have a grain size of 20-30 μm. Ammonia-water ice samples were prepared with 1, 5 and 8% NH_3 by flooding Ice I powders with an appropriate mixture of NH_3OH and water, followed by slowly cooling to and cycling through the peritectic temperature (T_p=176 K at 1 atm), using the procedure described by Durham et al. (1993).

Constant-load creep experiments at 1-atm confining pressure were performed on the single-phase water-ice samples, over the temperature range 250 to 273 K, at a differential stress of 0-2 MPa. High-pressure experiments were conducted on both pure water and ammonia-water ice samples in a gas-medium apparatus designed for cryogenic use at Lawrence Livermore National Lab under the following conditions: $3.5 \times 10^{-7} < \dot{\varepsilon} < 3.5 \times 10^{-4}$ s^{-1}, $160 < T < 220$ K, P_c=50 MPa.

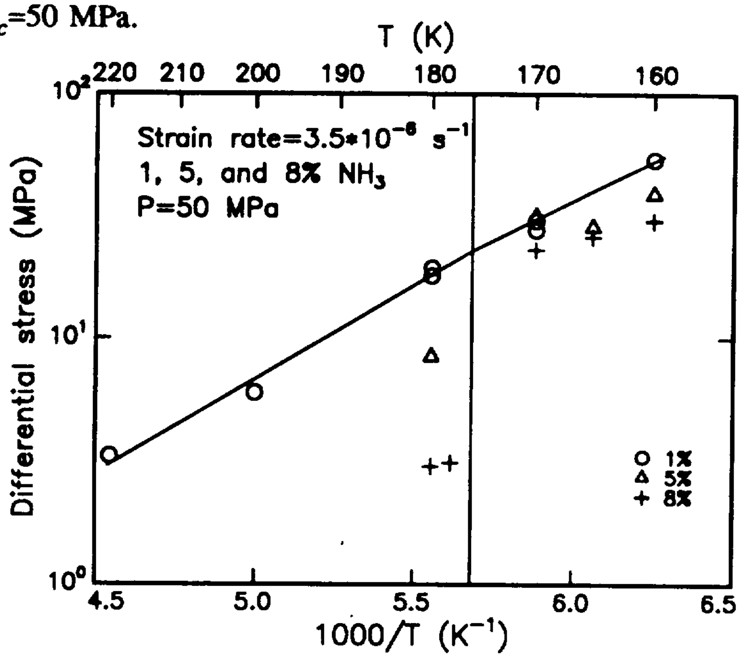

Figure 1: Differential stress versus inverse temperature for ammonia-water ice samples. Creep data for samples with 1, 5 and 8% NH_3 are plotted. Experiments were carried out at a strain rate of $3.5\times10^{-6}s^{-1}$ and a confining pressure of 50 MPa. The vertical line marks the peritectic temperature.

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For ammonia-water ice samples, the creep strength decreases with increasing NH_3 content over the entire experimental temperature range, as illustrated in Figure 1. A sharp decrease in strength occurred near the peritectic temperature for the 5 and 8% NH_3 samples, while a more gradual decrease in strength with increasing temperature occurred for the 1% NH_3 sample. The marked decrease in strength of the 5 and 8% NH_3 samples may be due to the relatively large amount of melt (>15%) that forms just above the peritectic temperature. For the 1% sample, <4% melt forms even at 220 K. Our fine-grained samples both with and without melt are weaker than coarse-grained samples (~250 μm) of the same bulk composition (Durham et al., 1993).

For the water-ice samples, the creep results for our fine-grained samples are in good agreement with those of Durham et al. (1992) for coarser-grained aggregates for $\dot{\varepsilon}=10^{-6}\ s^{-1}$, as shown in Figure 2. At $\dot{\varepsilon}=10^{-7}\ s^{-1}$, our fine-grained samples have slightly higher strengths than their coarse-grained samples at low temperatures. However, they are weaker than the coarse-grained samples at higher temperatures (220 K), probably reflecting a change in deformation mechanism at higher temperatures. The creep data for the fine-grained water-ice samples deformed at high confining pressure and the extrapolation of the data for the samples deformed at 1 atm at nearly identical strain rates are in good agreement with one another, suggesting that microcracking did not significantly affect the creep strength in the experiments carried out at 1 atm. The stress exponent, *n*, decreases systematically from ~7 at 160 K to ~2 at 260 K. This behavior is consistent with a transition from dislocation creep to diffusion creep or to grain boundary sliding accommodated creep.

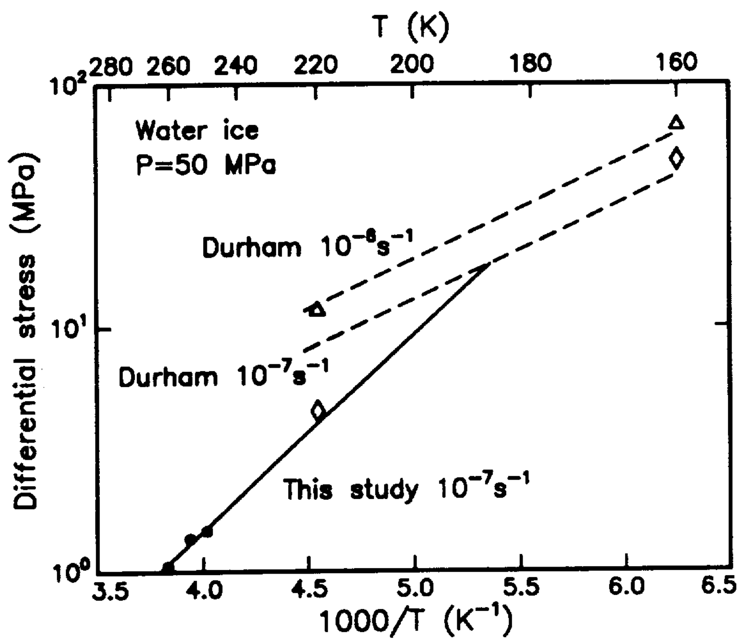

Figure 2: Differential stress versus inverse temperature for water-ice samples. The dashed lines are from Durham et al. (1992). The triangles are from this study for a strain rate of $10^{-6}s^{-1}$, while the circles and diamonds are for a strain rate of $10^{-7}s^{-1}$. The open symbols represent data obtained at P_c=50 MPa and the closed symbols represent data obtained at P_c=1 atm.

Durham, W.B., Kirby, S.H. and Stern, L.A., (1992). Effect of dispersed particles on the rheology of water ice at planetary conditions, *J. Geophys. Res.*, in press.

Durham, W.B., Kirby, S.H. and Stern, L.A., (1993). Flow of ices in the ammonia-water system, *J. Geophys. Res.*, in press.