多孔質氷の流動則に対する空隙率の効果
Experimental study on the flow law of water ice with porosity higher than 50%

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Small to middle-sized icy satellites in the solar system (diameter < several hundreds of km) are mainly composed of water ice and rocky debris and they have porosity over a wide range. On these satellites, various landforms caused by tectonic activities are found; for example, impact craters on icy satellites has a shallow depth, compared with those on rocky bodies such as the Moon. The shallow depth is expected to be caused by the difference of viscosity and deformation strength, that is the strength of water ice is smaller than that of rock. Thus, to understand the tectonic activities on small to middle-sized ice satellites, it is necessary to understand the deformation strength of ice-rock mixtures over a wide range of porosity. Flow law is one of the most important rheological properties to understand the formation processes of flow features found on icy bodies. Furthermore. a deformation strength is characterized by a flow law. Yasui and Arakawa (2010) examined the flow law of ice-silica mixtures with silica mass content of 0-50 wt.% and porosity of 0-20% and they reconstructed the flow law by introducing the factors of silica mass content and porosity. In this study, we focused on the effect of porosity over a range of porosity higher than that explored by Yasui and Arakawa (2010). We carried out creep tests of water ice with a porosity higher than 50% and examined the effect of porosity on the flow law of water ice.
The samples were made of ice grains with an average diameter of 20 μm: they were put in a stainless mold of inside diameter 25 mm and then compressed by a piston to control the porosity of 50, 60, and 65%. We performed creep tests under constant stress from 6.6 to 59 kPa in a temperature-controlled box or a cold room at Kobe University. The temperature was set to be -20 or -10° C.
In the case of water ice without porosity, the constant strain rate showing beyond a strain of 2% on the creep curve (a relationship between strain and time) was applied to the flow law. However, in the case of our porous water ice, the strain rate continued to decrease with increasing the time even beyond a strain of 2%. This was caused by the compaction during creep test: for example, the porosity of our porous water ice measured before and after the test was changed from ~50 to ~45% at the temperature of -10° C. Therefore, we examined the strain rate in increments of a strain of 0.02 over a range of strain from 0.02 to 0.16 on the creep curve to examine the flow law. As a result, the slope of the fitting line on the relationship between strain rate and stress increased with the increase of strain. In this study, we applied the strain rate at a strain of 0.14 on the creep curve to the flow law to examine the effects of porosity and temperature.
The flow law could be expressed as $d\varepsilon/dt = B\sigma^n$, where $d\varepsilon/dt$ is strain rate, σ is stress and B and n are constants. At same temperature, the strain rate increased with the increase of porosity, that is, the constant B exponentially increased with an increase in porosity: for example, the B of the porosity of 50%, 5.3×10^{-11} $s^{-1}(Pa)^{-n}$, was two orders of magnitude smaller than that of 65%, 1.4×10^{-9} $s^{-1}(Pa)^{-n}$. However, the slope of the fitting line became almost constant, irrespective of porosity. This means that the stress exponent n became almost constant, ~0.9, and it was about 1/3 as small as that of water ice without porosity (n~3). In the case of same porosity, the strain rate increased as the temperature became higher while the stress exponent n became almost constant, irrespective of temperature. The B could be

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expressed by using the activation energy Q as $B=B_0\exp(-Q/RT)$, where T is temperature, R is gas constant and B_0 is constant. The activation energy Q of our porous water ice was about 60 kJ/mol, irrespective of porosity, and it was a little smaller than that of water ice without porosity, 80 kJ/mol (Barnes *et al.*, 1971).

キーワード：流動則、水氷、空隙率、クリープ試験、活性化エネルギー、小・中氷衛星
Keywords: flow law, water ice, porosity, creep tests, activation energy, small to middle-sized icy satellites

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