Compaction experiments of ice-silica particles mixtures: Implications for compaction of icy satellites

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Recent explorations have revealed that icy bodies have different densities. For example, we can see icy bodies with the almost same size have different densities: Dione and Tethys have the radius of about 550 km, but the mean densities are 1470 and 960 kg/m^3. Also, the densities of small icy bodies are found to be lower than that of H_2O ice. They are mainly composed of H_2O ice and silicates, so they are expected to be porous. There are two main factors to determine the mean density of icy bodies, porosity and silica content. That is, the mean density increases with the silica content, and furthermore, the silica content varies with the porosity of icy bodies. The compaction tests have been conducted for H_2O ice. On the other hands, the effect of silica content on the compaction of ice-silica mixtures has not been clarified yet. Therefore, we carried out compaction experiments of ice-silica mixtures to determine the origin of icy bodies with different mean densities.

We made the samples by mixing ice grains (smaller than 710 micron) with silica beads (1 micron) evenly, and set the silica volume fraction f from 0 to 0.29. We carried out compaction experiments by using piston-cylinder compression method. The mixture was compacted at the constant compression speed of 2.0mm/min. and at the temperature of -10 and -71 ^oC by using a mechanical testing machine in a cold room. The load was applied until 30 MPa at -10 ^oC, and 80 MPa at -71 ^oC. The temperature of -71 ^oC was achieved as follows: the device was set in the container filled with dry ice for a night before the test; during the test, it was also kept in the dry ice and the temperature was monitored by thermo-couple. We recovered the compacted samples from the cylinder after the test, and then we measured the mass, the length and the diameter to calculate the porosity. Furthermore, we observed their thin sections by optical microscope and examined the internal structure.

According to the compaction curves of the mixtures with different silica fractions at -10 ^oC, we found the final porosity increased with the f. And, the porosity of the curves at -71 ^oC was larger than that of the curves at -10 ^oC in the whole range of pressure, but the slope of the curve with the same f at -10 and -71 ^oC is almost same at the porosity less than 0.2-0.3. From previous works of compaction for water ice, we know the compaction mechanisms change with porosity. By comparing these previous results with our results, we can expect the dominant compaction mechanism at each porosity as follows.

1) Larger than 0.3: Rearrangement of ice grains and silica beads. The compaction curves do not depend on the f.

2) Smaller than 0.2: Ductile deformation, brittle failure, and recrystallization of ice grains, and rearrangement of silica beads. The curves change with the f.

We analyzed compaction curves by using equations suitable for fitting them in each region: the 1) is fitted by an exponential equation, and the 2) is by a power law equation. As a result, the exponent in the 1) is almost same, about -0.3 to -0.4, at -10 ^oC, and about -0.1, at -71 ^oC. On the other hand, if we write the power of the fitting equation in the 2) as b, it does not change with the temperature, and they can be fitted by the linear equation and written as b=-1.0+2.7f.

We calculated the porosity distribution in icy bodies by using the empirical equations for compaction curves. We assumed the radius of 550km and examined the mean density of the body with different silica fractions by using the calculated porosity distributions. As a result, as the f changed from 0 to 0.29, the mean density changed from about 800 to 1200 kg/m^3 at -10 ^oC, and about 700 to 1100 kg/m^3 at -71 ^oC. And we could estimate the f of Dione and Tethys to be 0.5 and 0.1 at -10 ^oC, respectively, while those are 0.6 and 0.2 at -71 ^oC.