Effect of porosity and multiple impacts on restitution coefficient and sticking properties of snowball simulating Saturn’ s rings

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Saturn's rings have a width of tens of thousands of kilometers and a thickness of tens of meters, and they are composed of water ice particles with a diameter of mm to meters. The average relative impact velocity among ring particles is estimated to be < several cm/s. Numerical simulations indicate that ring particles should impact each other inelastically. Although previous laboratory experiments were conducted by using non-porous or frosted ice particles, ring particles are predicted by Cassini's observations to be highly porous ice particles such as ice aggregates. Therefore, it is necessary to examine whether the ice aggregates can maintain the thin annular rings of Saturn.
The purpose of this study is to clarify the velocity dependence of restitution coefficient (ε) and the threshold velocity for sticking of porous ice, we then try to estimate the internal structure of ring particles suitable for maintaining Saturn rings. Therefore, low-velocity impact experiments were performed between a porous ice ball and a porous ice plate or a granite plate, and we investigated the porosity dependence of the relationship between the impact velocity and the ε and the threshold velocity for sticking.

The ε was measured by letting a ball fall freely on a plate. Porous ice balls (the radius of 1.5 cm, the porosity of 47%, 53% and 60%) were made by compacting ice particles (the average size of 10 μm) in a spherical mold. A porous ice plate which was made in the same way as porous ice spheres (the radius of 1.5 cm, the thickness of 2 cm, the porosity of 43% to 62%) and a granite plate were used for the target plate. The ε was determined by measuring the time interval among collisions using a laser displacement meter. The impact velocity was changed from 0.78 to 101.3 cm/s.

The ε of the porous ice ball decreased with the increase of the impact velocity. Also, the decreased as the porosity increased for first collision, but the porosity dependence was not recognized for multiple collision. This velocity dependence of the ε can be expressed by the Andrews’ model, $\varepsilon^2 = 1/\{3(v_i/v_c)^2\}$ * $[-2+\{30(v_i/v_c)^2-5\}^{1/2}]$, where v_i is the impact velocity and v_c was critical velocity, and decreased with the increase of the porosity. On the other hand, v_c was 0.28 cm/s for all porosities in multiple collision. The reason for the decrease in ε for multiple collision is thought to be the decrease in the strength caused by the partial disruption of the sintered bond due to the previous impact.
For collisions between porous the ice ball and the granite plate, we observed quasi-elastic region where ε was about 0.6 regardless of the v_i and we found that the critical velocity v'_c was 6 cm/s at the porosity of 47%, 4.5 cm/s at 53%, and 3.5 cm/s at 60%, respectively. Using the obtained v'_c, we calculated the impact pressures based on Hertzian elasticity theory and were 2.24 MPa at the porosity of 47%, 1.16 MPa at 53%, and 0.43 MPa at 60%. This is in good agreement with the compressive strength of porous ice balls measured in static compression tests. Therefore, it is speculated that the plastic deformation would begin at the impact velocity beyond the critical velocity; it might cause the energy dissipation and the decrease of ε.
We found both rebound and sticking in this study. However, at the circumstance temperature around Saturn of about 100 K, the threshold velocity for sticking was speculated to be lower because the threshold velocity was obtained at 258 K in this study. Then, by extrapolating the empirical equation obtained in this study, we assume that the equation could be independent on the temperature: it is

applicable at the Saturn’s region that ε is 0.4 to 0.7 at the impact velocity from 0.5 to 3 cm/s. This velocity range was almost consistent with those of ring particles obtained from the numerical simulation (0.3 to 2 cm/s). Therefore, it could be possible that the Saturn’s ring particles are porous ice balls with porosity of 47 to 60%.

Keywords: Saturn's ring, restitution coefficient, sticking

