Effect of porosity on restitution coefficients of snowball simulating Saturn’s ring: implication for inelastic collision

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Saturn's rings have a width of tens of thousands of kilometers and a thickness of hundreds 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 less than several cm/s. Numerical simulations indicate that the restitution coefficient of ring particles should be less than 0.6 to maintain thin annular rings. Higa et al. (Icarus, 1998) showed that the restitution coefficient of ice ball covered with a thin ice frost was <0.6 . However, Cassini's observations expected that ring particles might be aggregates of ice particles with high porosity while the porosity of their ice ball were almost zero so it is inappropriate for the candidate of ring particles. Therefore, it is necessary to examine whether the porous ice can maintain the thin annular Saturn’s rings or not.

The purpose of this study is to clarify the mechanism of energy dissipation for the inelastic collision of porous ice and to estimate the internal structure of ring particles for maintaining thin annular Saturn’s rings. Therefore, we conducted low-velocity impact experiments for porous ice balls in order to examine the effect of porosity on the relationship between the impact velocity and the restitution coefficient.

We did free-fall impact experiments for a porous ice ball on a plate. Porous ice sphere (radius of 1.5 cm, porosity Φ of 47%, 53%, 60%) was made by compacting ice particles (average size of 20 μm) into spheres by using a spherical jig. The target plates were a granite plate, an ice plate, and a porous ice plate with a radius of 1.5 cm, a height of 2 cm, and a porosity of 43% to 62% which was made in the same way as the spheres. The restitution coefficient was determined by measuring the time interval between the collision using an AE sensor, a laser displacement meter, and a small high-speed camera. The impact velocity ranged from 0.78 to 265.8 cm/s.

The restitution coefficient of the porous ice ball, *e*, continued to decrease with increasing the impact velocity for all plates. At high impact velocity, the *e* decreased as the porosity increased, while it was almost consistent, irrespective of porosity at small impact velocity. This relationship can be expressed by the empirical equation, $e=e_0 \cdot v_i^{-b}$, and the *b* increased with increasing the porosity.

We calculated the collisional energy dissipation by using the obtained *e* and the compression volume by using the width of depression of sphere. The relationship could be expressed by the empirical equation, $V = V_0 \cdot E_{dis}^{n}$ and the *n* was determined as 0.75–1.53, that is, the compression volume was proportional to the energy dissipation. Therefore, we assumed the energy conservation in collision and obtained the equation, $E_{dis}=Y_{d\_i} \cdot V$. From this equation, the compressive strength, Y_{d_i}, was estimated to be 5.25–7.97 MPa for Φ=47%, 3.46–5.19 MPa for 53%, and 0.27–0.50 MPa for 60%.

We also conducted compression deformation tests for a porous ice ball by using a small deformation tester. We calculated the compression volume by using the width of depression of ice ball and the compression energy by using the load to estimate the compressive strength by using the formula $E_{comp}=Y_{d\_d} \cdot V$. As a result, the compressive strength, Y_{d_d}, was estimated to be 2.72 MPa for Φ=47%, 1.35 MPa for 53%, and 0.45 MPa for 60%. We found that the Y_{d_i} for Φ=60% was almost same with the Y_{d_d}, but the Y_{d_i}

was about 2–4 times largerthan the Y_{d_d} for 47 and 53%. Therefore, the reduction mechanism of the restitution coefficient of a porous ice with Φ=60% might be explained by the compression volume and the compressive strength. However, for Φ=47 and 53%, other energy dissipation mechanisms might affect.

We estimated the restitution coefficient, *e*, of Saturn’ s ring particles by extrapolating our results to the range of their impact velocities and found that the *e* for a collision between porous ices was <0.6.