

Effect of porosity on restitution coefficient of porous ice ball simulating Saturn's ring particles

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Introduction: Saturn's ring system is very thin disk. The main rings are composed of water ice particles with a diameter of cm to meters. Cassini's observations suggested that main rings were flattened and dynamically steady state. The velocity dispersion of ring particles should be controlled by the normal restitution coefficient of ring particles, so it is crucial to study the normal restitution coefficient of ring particles in order to understand the dynamics of the Saturn's rings. Although the internal structure of ring particles is unknown, ring particles are predicted to be highly porous ice particles such as ice aggregates by recent observations. However, the restitution coefficients of water ice have been studied only for water ice without porosity and ice covered with a frost layer, but that of porous water ice balls have not been studied yet. Therefore, we conducted the low velocity impact experiments using porous ice balls simulating Saturn's ring particles and the restitution coefficients were measured to study the effects of porosity.

Experimental method: The restitution coefficient was measured by letting a porous ice ball fall freely on a porous ice plate. The Porous ice ball (the radius $R_p = 1.5$ cm, the porosity $\Phi = 49.6, 53.8$ and 60.8%) was made by compacting ice particles in a spherical mold. The Porous ice plate (the radius of 1.5 cm, the thickness of 2 cm, $\Phi = 40.9$ to 60.8%) was made in the same way as the porous ice ball. The restitution coefficient was determined by measuring the time interval among collisions using a laser displacement meter. The impact velocity was changed from 0.93 to 96.9 cm/s.

Experimental results and discussions: It was found that the relationship between the impact velocity (v_i) and the restitution coefficient (ε) could be divided into two regions by the critical velocity v_c . In the quasi-elastic region ($v_i < v_c$), the ε was constant value (ε_{qe}) regardless of the v_i . In the inelastic region ($v_i > v_c$), the ε decreased with increasing of the v_i , and this relationship could be explained using Andrews' model which included the effects of plastic deformation. In this study, we improved this model introducing ε_{qe} as following equations to explain our experimental results.

$$\varepsilon = \varepsilon_{qe} \quad (v_i < v_c)$$

$$\varepsilon = \varepsilon_{qe} [-(2/3)(v_c/v_i)^2 + \{(10/3)(v_c/v_i)^2 - (5/9)(v_c/v_i)^4\}^{1/2}]^{1/2} \quad (v_i > v_c)$$

From our experimental results, it was found that the ε decreased with the increasing of Φ of the porous ice. This was considered to be because the volume of plastic deformation in the inelastic region and the efficiency of energy dissipation in the quasi-elastic region were increased with the increasing of Φ . Then we considered the Φ dependence of ε . The Φ dependence of v_c could be determined by fitting our experimental results with $v_{c,0}$ which corresponded to v_c of the non-porous ice derived by previous study ($v_c = v_{c,0} f^{q_1}$, q_1 : constant). The ε_{qe} could be explained by using the viscous dissipation model developed by Dillley with the parameter ξ ($\varepsilon_{qe} = \exp[-\pi \xi / (1 - \xi^2)^{1/2}]$). The Φ dependence of ξ could be determined by fitting our experimental results with ξ_0 which corresponded to ξ of the non-porous ice derived by previous study ($\xi = \xi_0 f^{q_2}$, q_2 : constant). Finally, we extrapolated the Φ dependence of ε for the collisions between the porous ice ball with $R_p = 1.5$ cm and that with sufficiently larger radius. And we compared these extrapolated results with the minimum value of the condition for the steady state of main rings. As a result, it was found that the ring particles with $\Phi = 50-70\%$ could establish the steady state with all v_i , but that with $\Phi < 40\%$ could establish the steady state with only $v_i > 20-100$ cm/s.

Keywords: Saturn's ring, Restitution coefficient, Porous ice