Experimental study on collisional processes of highly porous ice balls simulating Saturn’s ring particles

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Introduction: Saturn's rings consist of mm- to meter-sized particles of water ice, and they collide with each other at the relative speed slower than a few cm/s. After the collisions, the ring particles coagulate or rebound or fracture, and it could affect the evolution and the structure of Saturn's rings. Saturn’s rings were a very thin disk (the thickness thinner than 100-200 m) and this is because the particles collide with each other inelastically so the kinetic energy might dissipate effectively. Therefore, in order to clarify the formation processes and the evolution of Saturn’s rings, it is necessary to investigate the collisional properties of the ring particles. In particular, it is very important to examine the effects of material properties of the ring particles and the impact velocity on the coefficient of restitution (*e*).

It is estimated from ground observations and planetary explorations that the ring particles are speculated to be a non-porous ice, porous ice (snow), non-porous ice covered with frost etc. Previous studies have investigated the e of non-porous ice and that covered by the frost, but the e of porous ice (snow) has not been investigated yet in detail. In this study, we focused on the porosity of Saturn ‘s ring particles and examined the dependence of the porosity on the relationship between the *e* and the impact velocity.

Experimental methods: We used ice balls with a smooth surface and snowballs with the porosity of 45, 50, 60% having the diameter of 3 cm to simulate the Saturn’s ring particles. We conducted free fall experiments of the balls on an ice plate with a smooth surface and a granite plate. The impact velocity changed from 0.8 to 280 cm/s. We measured the e by two methods. One is an acoustic emission (AE) method. The AE sensor was attached on the plate and it could detect the elastic wave by each collision of the ball. So the impact and the rebound velocities of the ball could be calculated by measuring the time interval between the collisions. Another is a laser displacement meter method. A laser displacement meter was used to measure the position of the free falling ball with time. The e was calculated from the time interval between the collisions of the ball, as same as AE method.

Experimental Results: In the case of ice ball- ice plate collision, the e was almost constant (~0.9) at low impact velocity (quasi-elastic region), while as the impact velocity exceeded a critical velocity, the e decreased drastically (inelastic region). This critical velocity, v_c, was obtained to be 24.5 cm/s. In the inelastic region, the relationship between the e and the impact velocity could be fitted by using the empirical equation, $e=e_{qe}(v_i/v_c)^{-\log(v\_i/v\_c)}$, where v_i is the impact velocity and e_{qe} is the average value of the e in the quasi-elastic region. In the case of ice ball-granite plate collision, the relationship between the e and the impact velocity was similar to that of ice ball-ice plate collision, but the v_c was obtained to be 11.2 cm/s, which is almost a half of the ice ball-ice plate collision result.

The e of the snowball continued to decrease as the impact velocity increased and the critical velocity, v_c, could not be appeared for both collisions on the granite plate and the ice plate. Furthermore, the e of the snowball decreased as the porosity increased monotonically, but they merged with each other at the impact velocity lower than 10 cm/s. This is because the kinetic energy of the snowball was consumed by crushing the pores near the impact point on the snowball surface at higher impact velocities. We found that the relationship between the impact velocity and the e could be shown by $e=a \cdot v_i^{-b}$ where *a* and *b* are constant. The *a* was obtained as 0.9 - 0.97, irrespective of the porosity, while the *b* increased with the increase of the porosity.