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Experimental study on equal-sized collision of sintered porous ice spheres: Porosity dependence of collisional sticking

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The formation process of planetesimals in protoplanetary disk thought to be involved in collisional process of dust aggregates, but has not been fully understood yet. The relative collision velocity of dust aggregates in plotoplanetary reaches several 10s m/s. Recent numerical and experimental studies suggest that the collisional sticking growth of silicate dust aggregates in protoplanetary disk cease at centimeter size because of bouncing barrier [1]. Another numerical simulations about collision of highly porous dust aggregates indicate that icy dust aggregates could grew in size up to ~50 m/s [2], but for icy material it is necessary to consider sintering of ice particles [3]. In this study we performed the low-velocity collisions of isometric porous ice spheres with the porosity from 40% to 80% and examined the effect of sample porosity on the restitution coefficient and the deformed volume by impact.

All experiments were conducted in a large cold room at temperature of -10 ?C at Institute of Low Temperature Science, Hokkaido University. The samples were sintered porous ice spheres with a diameter of 30 mm and a porosity of 40% to 80% (mass of 7.52-2.54 g). The ice particles used to construct the samples had an average diameter of ~28 um and prepared by freezing small water droplets in liquid nitrogen. The ice particles were put into a spherical mold and compressed gradually. To distinguish the projectile from the target, the target was made up by colored ice particles prepared by adding red ink. By using two-stage release system, samples with same porosity were collided during free fall with relative velocity of 0.43-4.12 m/s at nearly head-on. The samples were landed on an airbag. The collisional behavior was recorded by two high-speed video cameras perpendicularly and the impact and rebound velocity (V_i, V_r) and the impact parameter were measured, then the restitution coefficient ($e=V_r/V_i$) was calculated. After the impact experiment, the mass and contact area during impact were measured.

All of the collisional outcomes were classified into bounce, no-bounce and sticking according to the recorded video images. The restitution coefficient of porous ice was found to be independent on the impact parameter and the impact velocity, but strongly dependent on the porosity (P) and become zero at 70% porosity. By comparing our data to result of polycrystalline ice [4], we obtained empirical equation as follows;

$$e=11.3(1-P)^{-0.9log(1-P)}.$$

The contact area during impact was found to increase with the increase of the impact velocity and the porosity. The relationship between the estimated deformation volume and the impact energy was fitted by power law equation and found that its slope is 0.81 to 1.31, indicating that they are almost proportional. If we assume that the impact kinetic energy was divided into the rebound kinetic energy and volume deformation, the dynamic compressive strength to achieve required deformation was found to be 2-4 times larger than the static compressive strength.

[1] Blum 2010, Res. Astron. Astrophys. 10 1199. [2] Wada et al. 2009, Apj 702 1490. [3] Sirono 1999, A&A 347 720. [4] Higa et al. 1996, Icarus 44 917.

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