Japan Geoscience Union Meeting 2013
(May 19-24 2013 at Makuhari, Chiba, Japan)

PPS21-P20 会場:コンベンションホール 時間:5 月 20 日 18:15-19:30

Inelastic Collisions between Icy Bodies: Dependence on Impact Velocity and Its Fluctuations

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In a ring system, energy loss during collisions of particles may play a crucial role in determining not only the mean free path between collisions but also the physical characteristics of the ring (e.g., kinematic viscosity, spreading rate, thickness, shape) and the rate of cooling in the system. The coefficient of restitution is a key parameter for evaluating such energy loss during collisions (Dilley and Crawford, 1996). Icy particles are commonly found in the rings of Saturn, and due to their closeness to our living environment, their coefficient of restitution has been intensively studied. Earlier works on collisions of icy bodies normally suggest that the restitution coefficient strongly depends on the impact velocity. More recent approach to the problems of energy loss and cooling in a ring system includes the concepts developed in the theory of granular flow, but due to the lack of precise information about the velocity dependence of the restitution coefficient, it is often assumed that the coefficient is constant (velocity-independent) in granular flow-based analyses of inelastic collisions. Here, in order to better understand the physical characteristics of ice as a granular material and gain more quantitative information about the effect of impact velocity on the collisions of icy bodies, first, we experimentally monitor the mechanical behavior of an ice sphere impinging upon a plate of ice (235 mm x 320 mm x 60 mm) with a digital high-speed video camera system introduced in our laboratory. The diameter of an ice sphere is either 25 mm or 50 mm, and each sphere is kept in a freezer at a temperature of -10 degrees Celsius for more than 30 hours before every experiment starts. We intend to obtain the variation of the normal restitution coefficient for the free fall of spheres with 17 different falling distances between 40 and 450 mm. For that purpose, we take full-color digital photographs at a frame rate of 7,000 frames per second and record the collision process: From the photographs, we can calculate the velocities of an ice sphere just before and after the collision and with these velocities we may evaluate the normal restitution coefficient. We perform our preliminary series of experiments on collisions of ice spheres at least 10 times for each sphere size and falling distance at room temperature of 21 degrees Celsius. The range of falling distance mentioned above gives an impact velocity of 60-370 cm/s for 25 mm diameter spheres and 90-380 cm/s for 50 mm diameter ones. Care is taken not to induce any rotation and fracture of the ice spheres during the collision process. We also observe the roughness of the sphere surfaces as well as the fluctuations of the obtained coefficient for each sphere size and impact velocity. Then, based on the ED (Event-Driven) method, we perform numerical simulations of the cooling process during collisions of 3,000 ice spheres that are initially located randomly in a two-dimensional square. In the simulations, the experimentally obtained velocity-dependent restitution coefficient and its fluctuations are taken into account for the inelastic collisions between ice spheres. The results show the final temperature is about 4 % lower than that obtained without considering the fluctuations of the velocity dependence of the coefficient.

キーワード: ring system, icy bodies, inelastic collision, coefficient of restitution, cooling process, granular flow
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