

Experimental study on collisional disruption of differentiated icy planetesimals

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In the protosolar nebula, planetesimals are thought to have grown into planets through repeated collisional disruption and re-accumulation. Icy planetesimals play an important role in the planetary evolution processes in the outer solar system beyond Jupiter, and various icy bodies are thought to have been generated by the disruption and re-accumulation of icy planetesimals due to high-velocity collisions between them. In addition, when icy satellites in the solar system exceed 500 km in diameter, it is said that the interior either have a layered structure depending on the density, or is completely differentiated into a core and mantle structure. Therefore, it is necessary to take into account the internal structure of the bodies in order to clarify the collisional evolution of icy planetesimals. However, most of the previous laboratory impact experiments of icy planetesimal simulants have used targets with a homogeneous structure such as ice and snow, and there have been few experiments using ice targets with a layered structure.

Therefore, in this study, we conducted high-velocity impact experiments using a layered structure target with a snow mantle around an ice core to determine the cumulative number distribution of impact fragments and impact strength, and investigated the degree of disruption. In the conventional method using a high-speed camera, only fragments ejected from the target surface can be observed, so a hemispherical target was prepared to observe the disruption inside the target.

Impact experiments were conducted using a two-stage light gas gun installed at Kobe University. The projectile was a polycarbonate sphere with a diameter of 4.7 mm, and the impact velocities were 1 km/s and 2 km/s. The target was a sphere with a diameter of 60 mm, and was made by putting ice particles in a hemispherical metal mold and compressing it with a piston hollowed out in a hemispherical shape from the top. The snow porosity was set to 50%. The layered target was compressed by placing a 30 mm diameter ice ball in the center. For the hemispherical sample, an acrylic plate was attached to the cross section, and a projectile was impacted near the adhesive surface. The collision phenomena were observed by a high-speed camera from two directions, horizontal and vertical to the target.

We found that the layered target was disrupted more than the homogeneous targets at the same impact velocity. As a result of the cumulative number distribution, the largest fragment of the layered target is a mantle fraction, and the degree of core fragmentation is smaller than that of mantle fragmentation, indicating that the mantle fragmentation dominates the size distribution of impact fragments throughout the target.

The impact strength of the homogeneous target was determined to be 166 J/kg. The normalized maximum fragment mass (normalized by the target mass) of the layered target would be three times to one order of magnitude smaller than that of the homogeneous target at the same specific energy, so the impact strength would be much smaller than 166 J/kg. Comparing the impact strength of the homogeneous target in this study and that of the snowball (porosity of 50%) of Nakamura (master's thesis, 2020), the impact strength in this study was smaller than that obtained by Nakamura. This difference was expected to be due to different impact velocities, so we reanalyzed the normalized

maximum fragment mass using parameters that take into account the impact velocity dependence, and obtained an empirical equation that can explain both data with new parameters that combine impact velocity and specific energy.

Next, we observed the disruption of the internal structure. For the homogeneous target, cracks grew radially from the impact point, and fragments were ejected symmetrically with respect to the impact axis (ballistic trajectory). On the other hand, in the layered target, finer cracks were observed in the mantle, and the mantle was pushed out faster from the core-mantle boundary in the direction perpendicular to the impact axis. This phenomenon is caused by the pressure gradient at the boundary between the ice core and the snow mantle at the impact, which pushes the mantle out of the ejecta released from the ice core.

Keywords: impact strength, differentiated icy planetesimals, layered ice targets, impact experiments