

Experimental study on cratering processes of porous icy satellites experienced densification

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Recent advances in planetary exploration have confirmed the existence of impact craters on the icy satellites of Saturn and Jupiter. The porosity estimated from the bulk density of these icy satellites ranges from less than 5% to more than 50%. On the other hand, the surface composition of such icy satellites has not been clarified. The surface composition of bodies can be estimated by their crater morphology. In order to estimate the surface composition of ice satellites from crater morphology, it is necessary to understand the crater formation processes on the icy crust and the applicable scaling law for crater size. Last year, the DART project was carried out to artificially collide with a small body that is potential to collide with Earth in the future and to change its orbit. The relationship between spacecraft impact conditions and momentum transfer efficiency between the body and the spacecraft is being studied. Previous studies have shown that the momentum transfer efficiency depends on the physical properties of the target body, especially the strength and porosity. In this study, we investigate the momentum transfer efficiency of icy matter, one of the most ubiquitous materials in the solar system. It is also to simulate a comet nucleus, one of the small bodies that could collide with the Earth.

In this study, in order to investigate porosity dependence of crater size and momentum transfer efficiency of icy bodies, high-velocity impact experiments were carried out using snow targets with various porosities. Then, we constructed the crater scaling law and an empirical formula for momentum transfer efficiency applicable to icy bodies.

The snow target was prepared by putting ice particles with a size less than 710 μm in a cylindrical container, and compressing it with a piston using a hydraulic pump. Five types of snow targets with porosities ranging from 10% to 50% (changed by 10%) were prepared by changing the mass of snow particles put in the container. For the ice target, a commercially ice plate cut into rectangular parallelepipeds with a flattened surface was used. Impact experiments were carried out using a horizontal two-stage light gas gun at Kobe University. An aluminum sphere with a diameter of 1 mm was used as the projectile, and the impact velocity was changed in the range of 1.2-5.0 km/s. We used sequential images from a high-speed camera to track the post-impact motion of the target and analyzed the change in momentum before and after impact.

The crater observed in this study was a typical crater in the strength-dominated regime: a bowl-shaped pit in the center surrounded by spalling area. We measured the radii of pits and spalling area, respectively, and investigated the porosity and impact velocity dependence. First, it was found that the larger the porosity, the smaller the radius of spalling area. Therefore, the radius of spalling area was applied to the π -scaling law in the strength-dominated regime proposed by Housen & Holsapple (2011), and the normalized tensile strength was used to organize the results. However, the porosity dependence of the radius of spalling area could not be explained only by the porosity dependence of the tensile strength. Therefore, the effects of the initial impact pressure and the decay constant of the shock wave on the porosity were investigated. As a result, the relationship, $m=(2.13\pm0.38)(1-\phi)^{-0.95\pm0.05}$, between the decay constant m of the impact pressure and the porosity ϕ was obtained. From this result, the porosity dependence of the radius of spalling area could be explained by considering not only the tensile strength but also the porosity dependence of the decay constant of the impact pressure.

On the other hand, the pit diameter decreased when the porosity increased from 0% to 20%, and conversely increased when the porosity increased from 20% to 50%. When this result was arranged using

the π -scaling law using the normalized compressive strength π_{Y_c} , the pit diameter with a porosity of 20% or more was arranged by considering the porosity dependence of the strength. The relationship between the normalized pit radius $\pi_{R_{pit}}$ and the π_{Y_c} is $\pi_{R_{pit}} = (0.05 \pm 0.02) \pi_{Y_c}^{-0.44 \pm 0.04}$.

It was found that the momentum transfer efficiency $\beta - 1$ increases with decreasing porosity. With an impact velocity of 1 km/s and a target with a porosity of 40% or more, the amount of ejecta is small. Therefore, $\beta - 1$ was about 1/10 smaller than that of snow target with porosity less than 30%. In addition, when compared with the results for rocks, it was found that the smaller the porosity, the higher the momentum transfer efficiency for both rocks and snow targets.

Keywords: cratering experiments, snow, porosity, crater size scaling law, momentum transfer efficiency, strength-dominated regime