High-velocity impact experiments on porous ice with a porosity less than 30%: Momentum transport and crater formation processes

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Many small to middle-sized icy satellites could have various porosities in their interiors. Their bulk porosities depend on the mass fraction of ice, silicates, and organic matters, so their bulk porosities are expected to change in the range from 10% to >50%. Proto-planets and asteroid parent bodies are believed to have formed via mutual collisions among planetesimals and re-accumulation. Therefore, the crater formation process and the momentum transfer resulting from their mutual collisions give us important clues to understand the evolution of solar system bodies. AIDA mission is planned to study the orbital deflection of a small asteroid by an artificial impact. In order to estimate the orbital change, many researchers began to examine the momentum transfer by numerical simulations and laboratory experiments. They use the momentum enhancement factor β, which is the ratio of the impactor's momentum to the difference of momentum of target's body before and after the impact. Thus, the effects of impact conditions such as impactor's material properties and the impact velocity on the momentum transport efficiency, β-1, have been studied.

Many experiments were conducted to study the crater formation processes and the momentum transfer in the strength dominated regime but they used rocky materials or water ice. Porous ice targets were studied in previous studies with the porosity larger than 40% and those with a porosity smaller than 30% have not been used until now. In this study, we conducted high-velocity impact experiments on porous ice targets with the porosity smaller than 30% to investigate the porosity dependence of the crater morphology and the strength dependence of the momentum transfer efficiency, β-1.

The targets had a cylindrical shape with the height and the diameter of 7 cm. They were made by compaction of ice particles with the grain size less than ~710 mm. The target porosities were 10, 20, and 30%. Impact experiments were conducted using a horizontal two-stage light gas gun at Kobe University. The target was set in a chamber equipped in a cold room at -15C. The impact velocity ranged from 1 to 5 km/s. An aluminum sphere with the diameter of 1 or 2 mm were used as a projectile.

Firstly, we examined the specific energy corresponding to the boundary between the crater formation mode and the collisional disruption mode. As a result, the specific energy necessary for the collisional disruption decreased with the decrease of porosity: The specific energy for the boundary was 30 J/kg for 10% porosity target, 130 J/kg for 20%, and 260 J/kg for 30%.

The crater had a pit at the center surrounded by the spall region. This is a typical crater morphology in the strength-dominated regime. In order to obtain the spall and pit diameters (Dp and Ds) and the crater depth (H), we measured the crater profile which traced the cross section of the target cut at the center after the shot. The Ds increased with the decrease of the porosity at the same kinetic energy of projectile: e.g., it was ~34 mm for 10% porosity target while it was ~14 mm for 30% at the impact velocity of ~1 km/s. However, the Ds of 10% target was about 1.4 times larger than that of non-porous water ice (Shrine et al., 2001). The Dp and H did not depend on the porosity: at ~1 km/s, they were 2.2 and 4.3 mm for 10%, 1.6 and 3.9 mm for 20%, and 3.0 and 5.3 mm for 30%, respectively. Furthermore, the Dp could be scaled by the crater size scaling law in the strength-dominated regime, which include the effect of the compressive

strength of snow changing with the porosity.
The momentum transport efficiency β-1 was larger in all energy density range as the porosity was smaller. The β-1 decreased with the increase of the specific energy . We observed that the ejecta curtain open angle at the crater formation time decreased linearly with the increase of the β-1 so we suggested that the momentum transport efficiency had negative correlation to the ejecta curtain open angle.

Keywords: crater, momentum transfer, collision experiment

