Cratering experiments on snow at very low temperature: Scaling law of crater size in gravity regime

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In order to estimate the surface age of solid bodies in the solar system except for the Moon, the crater size scaling law should be applied to the crater chronology. Icy satellites are expected to be covered with ice particles formed by the excavation of impact craters (We call this as regolith layer). Furthermore, the surface temperature of icy satellites is very low, so the ice particles constituting the regolith layer are expected not to be sintered like sand. In this case, it is necessary for the crater size scaling law in the gravity regime to apply the crater chronology of icy satellites. However, the crater size scaling law of ice in the gravity regime is not clarified because ice particles are sintered very quickly in the freezer so they have physical strength. Therefore, in this study, we established the method of impact experiments at very low temperature (<210 K). Then, we conducted impact cratering experiments on unsintered ice particles (snow) and study the crater size scaling law of ice in the gravity regime.

Ice particles with the diameter less than 710 μm were used as target. When ice particles were put into the target container, liquid nitrogen was also put in several times simultaneously, so the very low temperature could be kept. The porosity of snow target was 50%. The thermocouples were set on the bottom and the surface of the target, and the temperature during the evacuation and just before the shot was measured. The target bottom temperature just before the shot was 110–210 K. We used five kinds of spherical projectiles with the diameter of 2 mm, nylon, aluminum, titanium, stainless-steel, and brass. The impact velocity ranged from 77 to 168 m/s. The target container was set in the vacuum chamber at <100 Pa. The ejecta curtain growth was observed by using the high speed camera. The target was recovered after the shot to measure the crater diameter and depth. We determined the sintering degree of snow target at the crater formation by using the images of ejecta curtain growth and the crater morphology.

First, we examined the relationship between the target temperature and the crater diameter and found that the crater diameter was about 1.5 times larger at the temperature lower than 160 K when the kinetic energy of projectile was same. At the temperature higher than 160 K, the discontinuous ejecta curtain, typical one in the strength regime, was observed in the images of high speed camera, and the crater rim was unclear. Therefore, we expected that the temperature boundary between the gravity regime and the strength regime, T_b, was 160 K. Next, we examined the relationship between the crater diameter, D, and the kinetic energy of projectile, E_k, at low T_b. As a result, the relationship can be fitted by $D=aE_k^b$, and the parameters, a and b, were obtained to be 51.5 and 0.17. Furthermore, we compared our results with the previous results of 15-min sintered snow at 258K obtained by Arakawa & Yasui [1] and found that the data at low T_b was about 1.5 times larger than them at same kinetic energy of projectile.

We examined the crater size scaling law of ice by using the results at low T_b. The crater size scaling law is expressed as $\pi_R=K_1\pi_2^p\pi_4^q$, where π_R, π_2, and π_4 are the non-dimensional parameters: $\pi_R=R(\rho_t/m_p)^{1/3}$ (R is the crater radius and m_p is the projectile mass), $\pi_2=r_pg/v_i^2$ (r_p is the projectile radius, g is the gravitational acceleration, and v_i is the impact velocity), and $\pi_4=\rho_t/\rho_p$ (ρ_t and ρ_p are the density of target and projectile, respectively. As a result, the parameters, K_1, p, and q were obtained to be 0.55, -0.17, and 0.20. Our data was almost consistent with that of quartz sand obtained by Tsujido et al. [2].

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Furthermore, the scaling parameter, m, was obtained to be 0.41 from the parameter, q, and it was same as that of sand (Housen & Holsapple [3]).

[1] Arakawa & Yasui (2011), Icarus 216, 1–9. [2] Tsujido et al. (2015), Icarus 262, 79–92. [3] Housen & Holsapple (2011), Icarus 211, 856-875.

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