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Experimental study on the impact strength of planetary bodies damaged by multiple collision

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High velocity collisional disruption of small icy bodies is one of the most important physical process related to the formation of the debris disk and the collisional growth of planetesimals in the outer solar nebula. Therefore, there are a lot of studies on the collisional disruption of icy bodies such as polycrystalline ice and snow systematically. As a result, the impact strength of polycrystalline ice was obtained to be 90 J/kg, and the snow was found to change the impact strength with the porosity. While in the case of the collisions among the real small bodies, the bodies could be sometimes collided at many times before they were disrupted. We definitely observe so many craters on the surfaces of icy bodies and the large crater that is more than a half of the size is also observed in many icy bodies. Thus, we should consider the effect of these pre-impact damages in the icy bodies when we apply our laboratory results to the real collisions in the solar system. Because these pre-impacted bodies could be weaker than the intact bodies. Therefore, we studied the effect of pre-impact damage on the impact strength of polycrystalline ice systematically, and the effects of the pre-impact time and the each impact energy on the impact strength was determined quantitatively.

Impact experiments were made by using a vertical gas gun set in a large cold room which room temperature was -15 degree or -10 degree. The ice target was a cube with the size from 3 to 10 cm (Mt=100 - 3000 g) and the projectile was a icy cylinder with the size of 1.5cm or 1cm (m_p=1.5g or 0.2g). The impact velocity was from 100 to 480 m/s, and the projectile was collided on the different surface of the cube target or the same surface for the multiple impact experiment. We also change the energy density given to the target for each impact. After the impact, the target was recovered to measure the weight of each fragment. When the target was not disrupted severely, the elastic velocity through the recovered target was measured at 3 different positions. We also measured the static indentation strength of the recovered target, so the target was sliced into 3 plates and there plates were slowly pushed by an indenter. The elastic wave velocity of each plate was measured before the indentation test. Then, we tried to obtain the relationship between the elastic wave velocity and the indentation strength.

In the case of the impact at the different surface of the cube target, we found that the sum of the energy density for each impact (Q_{sum}) was a good parameter to describe the impact strength because the relationship between Q_{sum} and the largest fragment mass consists each other irrespective of the impact time and they are consistent with the result of the intact ice disrupted at once. In the case of the impact at the same surface, the Q_{sum} was apparently larger than that was necessary for the impact at the different surface. This difference of the impact strength depending on the impact surface could be caused by the difference of the internal crack density and the distribution. Then, we studied the relationship between the elastic wave velocity and the indentation strength, and we obtained the following empirical equation, $Y/Y_0=1-1.34\ dV/V^{0.78}$. We applied this equation to the scaling parameter P_I proposed by Mizutani et al. (1990) and studied the relationship between P_I and the largest fragment mass. Thus, we found that all the data merged on one line and the empirical relationship was obtained to be $m_l/M_t=0.0413P_I{}^{-4.82}$. So, the effect of the pre-impact damage by multiple impacts is found to be quantified by the elastic velocity. This enable us to estimate the impact strength of the real small icy bodies by the measurement of the elastic wave velocity of these interiors.

Keywords: icy planetesimals, impact disruption, crack, sound velocity, mechanical strength, scaling law