Impact experiments for crater scaling laws and impact-induced seismic shaking on rubble-pile asteroids

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Impact cratering is one of the most important physical processes, then we study crater impact scaling laws in order to elucidate the impact processes on asteroids. It is suggested that the size ratio of the impactor to the surface boulders and the fracture strength of the boulders could affect the crater formation process. In addition, it is suggested that the impact-induced seismic shaking could propagate through an asteroid interior and change the surface topography. Therefore, it is important to understand the impact-induced seismic shaking and to construct crater scaling laws considering the surface boulder strength. Then, in this study, we performed impact cratering experiments by using the target composed of low-strength coarse particles, and studied the effect of the size ratio of the projectile to the target grains, and the fracture strength on the crater scale law, and also investigated the impact-induced seismic shaking.

Cratering experiments were conducted by using a gas gun set at Kobe University and ISAS. Granular targets were prepared by using weathered tuff granules with the size of 1 to 4mm (small particle) and the size of 1 to 4cm (large particle). The crush strength of these tuff particles was measured to be about 60 kPa and 30 kPa. A spherical projectile with the size of 3mm (SUS, zirconia, alumina, glass, and nylon) was lunched at the impact velocity from 40 to 200m/s, and a spherical projectile with the size of 2mm (WC, copper, SUS, zirconia, titan, Al, and nylon) was lunched at the impact velocity from 1.2 to 4.5 km/s, and these two types of the projectile were impacted on the target surface at the normal direction. Impact cratering process was observed by a high-speed camera at 10^3-10^5fps. After the shot, the crater morphology was observed and the diameter and the depth were measured. Impact-induced seismic waves were measured by using 3 accelerometers (specific frequency is 30kHz) set at different positions from the impact point, and a data logger was used to record the seismic data through charge amplifiers (data acquisition rate is 100kHz) connecting to the accelerometer.

The crater size was found to increase with the projectile kinetic energy (E_k) at lower than 0.14J and at higher than 0.63J, so that the crater size was almost constant among them, and more the crater size obtained at very high $E_k$was almost on the extrapolated line from the relationship given by the low $E_k$data. In addition, the crater formation efficiency of the large grain was lower than that of the small grain. The pi-scaling law was used to construct the relationship between normalized radius and the normalized gravity, and all the data was found to be separated into two regions with a large offset according to the impact velocity and the projectile material. This offset might be caused by the disruption energy of several tuff grains. From the above results, it was recognized that the crater formation process of the low-strength coarse grain was different from that of the sand grain target, that is, the crater formation efficiency of the target composed of low-strength grains was lower than that of sand targets composed of high-strength quartz grains.

The propagation velocity of the impact-induced seismic wave was obtained from the accelerometer data. The propagation velocity was 47.0 ±7.6 m/s for the small grain regardless of the impact velocity, and was 42.7 ±4.7 m/s for the large grain regardless of the impact velocity and projectile material. Compared to previous studies, it was found that the propagation velocity was similar to that of quartz sand. Furthermore, we obtained the relationship between the maximum acceleration and the distance from the impact point. Then, we scaled this relationship with the distance normalized by the crater radius and obtained the following empirical formulas for the attenuation. For small grain target, $g_{max=}10^{1.81}(x/R)^{-1.98}$. For large grain target, $g_{max}=10^{1.77}(x/R)^{-2.21}$.

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