Experimental study on impact ejecta velocity scaling law for regolith layer composed of weak boulders

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Impact cratering on solid bodies is one of the most important geological processes in our solar system. The excavation and ejection processes of sub-surface materials during the crater formation process are keys to understand the regolith formation and the escape of meteorite precursors from asteroids. Thus, it is essential to understand the ejecta velocity distribution regarding the crater formation process. Previous studies showed that both the size ratio of an impactor to surface boulders and the fracture strength of boulders would affect the final crater size, and they would also affect the ejecta velocity distribution. Then, in this study, we conducted impact experiments on granular targets composed of coarse-grains with low strength in order to study the effects of size and strength of target grains on the ejecta velocity distribution.

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 for small particles and 30 kPa for large particles. A spherical projectile with the size of 3mm (stainless steel, 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 (tungsten carbide, copper, stainless steel, zirconia, titan, aluminum, and nylon) was lunched at the impact velocity (U) 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 10^3-10^5 fps. We tracked positions of individual particles in the recorded high-speed images and tracked back initial positions of these tracked particles. Then, the ejection velocity and the ejection angle of these particles were calculated according to the ballistic trajectories.

As a result of the analysis for the high-speed images, we found that the large particles near the impact point were disrupted and the fractured particles were then ejected as a dust cloud immediately after the collision. After that, the intact large particles were ejected out of the crater slowly. The ejection velocity of the particles (v_e) decreased with the increase of the initial position (x), and we obtained the relationship between the normalized ejection velocity (v_e/U) and the normalized initial position (x/a), where a is a projectile radius. The slopes of these distributions were found to be dependent on the projectile density, so the conventional ejecta velocity scaling law was applied to these results. Then, we examined how the size and the strength of these particles affected the ejecta velocity distribution. All the data were clearly separated into two regions: One had large ejection velocities ($v_e/U > 10^{-3}$) and the other had small ejection velocities ($v_e/U < 10^{-3}$). The large normalized ejection velocities would represent those of disrupted particles around the impact point, thus we speculate that the ejection velocity could be scaled by the crushed strength scaled velocity of a particle. On the other hand, the small ejection velocities would show those of the intact particles, so the ejection velocities would be scaled by the gravity scaled velocity. Furthermore, the ejecta velocities at the crater wall were two to three times larger than those in the previous study, and the slope of the velocity distribution was gentler than those in previous studies. We obtained the relationship between the ejection angle and the normalized initial position (x/R), where

R is a crater radius, and the ejection angle was found to scatter from 20°to 80°depending on x/R, irrespective of the projectile density.

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