Experimental estimate of mass loss rate by cratering for rubble-pile asteroids

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Both Ground-based and spacecraft observations suggest that many small asteroids (< 10 km) have rubble-pile structures based on spin-rate, density, and geological features [1]. Recently theoretical study indicated that cratering might play a decisive role for size-frequency distribution of the main-belt asteroids besides catastrophic disruption [2]. Cratering on rubble-pile targets, which are loosely combined by small gravities and/or cohesions, has not been fully understood, although there are a few sets of experiments [3]. In this study, we conducted impact experiments to construct new scaling law for coarse-grained targets simulating the rubble-pile asteroid surfaces.

Impact experiments: We used two vertical guns in the Univ. of Tokyo and ISAS, for impact velocities 79 - 224 m/s and 1 - 6 km/s, respectively. We used polycarbonate projectiles 0.76 - 0.77 g for the former gun and 0.068 g for the latter gun. Pumice blocks (~7, 9, and 16 mm), basalt blocks (~ 10, and 18 mm) are used as boulder target simulants. The cross-section profiles were obtained by a laser profiler (Keyence, LJ-V). In order to observe the cross-section during cratering, we also conducted quarter-space experiments and recorded by a high-speed camera (NAC, Q1v).

Results and analyses: If target grain sizes do not influence cratering, crater sizes are the same sizes on sand targets. However, our results suggested that although high-velocity impacts (>4 km/s) formed similar crater sizes as sand targets, low-velocity impacts (<4 km/s) resulted in smaller craters than sand targets. This is because energy dissipation by target grains disruption is not negligible compared to excavation energy. The trend of our results can not be explained by the classic πscaling by [4]. Quarter-space experiments suggest that cratering on coarse-grained targets would be divided into two stages: an early disruption stage and a latter excavation stage. We modified the scaling law based on the quarter-space observation, assuming that the momentum of an impactor transferred to a contacted target grain immediately, that is when a target grain size is larger than an impactor size, the effective velocity that controls the excavation field would be smaller. Using the new modified scaling law, we can estimate crater sizes on real-sized bodies.

Implications for mass loss rate: For example, on Itokawa (average surface grain size of 2 m) impactors smaller than 1 m might result in smaller craters than sand targets by 5 times at most and impactors smaller than 0.1 m rarely cause crater because they do not have enough energy to disrupt surface grains. In contrast, impactor larger than 1 m could form craters as large as craters on sand targets. When an impactor can fully disrupt a target grain, a crater is at least several times larger than a crater on rigid bodies such as rocks. Thus, the cratering mechanisms on large continuum asteroids and small rubble-pile asteroids might be very different. The mass loss on cratering could be assessed by the classic scaling law if the latter excavation mechanism is the same as cratering on sand targets. The rubble-pile asteroids can lose their mass easily compared to the same-sized rigid bodies due to larger craters. Resent observations of the small-main-belt asteroids suggest that smaller asteroids are depleted from the steady distribution decided by the catastrophic disruption with the slope of -3.5 (e.g., [5]). The high efficiency of mass loss among rubble-pile asteroids might be responsible for the lack of small asteroids.

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