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# Cratering experiments on coarse-grained targets: application to the resurfacing age of a rubble-pile asteroid Itokawa

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**Introduction:** The crater-like morphologies on Itokawa are observed by the spacecraft Hayabusa (Hirata et al., 2009). The crater-retention ages on asteroids would provide valuable information on their dynamical evolutions. Because crater-retention age is influenced sensitively by crater size scaling, accurate age estimation requires an accurate crater scaling law. It is not obvious if cratering on rubble-pile asteroids, whose surface is composed of coarse grains, is controlled by material strength or gravity. Although crater experiments on coarse-grained targets have been conducted (e.g., Guettler et al., 2012; Holsapple and Housen, 2014), their results are not necessarily consistent to each other. Michel et al. (2009) estimated the crater surface age based on the strength crater scaling as 75Myr - 1Gyr. Furthermore,the cosmic ray exposure (CRE) ages and Ar degassing ages of returned samples show a variety of ages. To interpret these ages with linking to dynamical phenomena, the accurate crater scaling is needed for crater-retention age estimates. The purpose of this study is to experimentally examine what crater scaling rule should apply for estimating crater age on a possible rubble-pile asteroid Itokawa.

Experiments: The impact experiments were conducted at low velocities (70-200 m/s) and high velocities (1.5-5.3km/s): 10-mm diameter projectiles for low velocities and 4.6-mm diameter projectiles for high velocities. We used pumice as boulder simulants and loose 200$\mu$m glass beads as regolith simulant. Two types of targets were used: (1) two-layer targets with a block layer on a regolith substrate, (2) a uniform block layer. We measured the rim-to-rim (crest) diameters of craters.

**Mechanism of armoring:** There may be three mechanisms of armoring depending on impact energy. (1) If impact energy is low enough that the target grains are rarely disrupted, target grains move as receiving momentum from a projectile discussed by Guettler et al. (2012). (2) The energy slightly increase when the projectile disrupts only the surface grains because of the low impact energy, fragments are ejected without transferring momentum efficiently to grains deeper in the target and crater size increases only gradually. (3) When impact energy becomes large enough for the projectile to penetrate into a certain depth, the fragments from disrupted surface grains can also transfer their momentum to surrounding grains very efficiently, and resulting crater size approaches the gravity scaling.

Experiment results would predict the minimum size for craters formed on coarse surfaces; the minimum crater size is $\sim$60% of the gravity scaling on dry soils. Thus, the armoring effect suppresses the excavation energy by $\sim$40% at most.

**Discussion:** Our experimental results show that the crater sizes formed on the coarse surfaces are in between the gravity scaling and the gravity scaling with armoring (the 40% suppressed from the gravity scaling). Avoiding the effect of seismic shaking or other erasure processes, the formation of five of 100-m sized craters on Itokawa would take 0.4-8.4 Myr including statistical error of 50%. The crater retention age may be younger than the age estimate based on the strength scaling law (Michel et al., 2009) by more than an order of magnitude. Our age is rather close to the CRE ages of the returned samples (Nagao et al., 2011; Meier et al., 2014) and the space weathering age from spectra analysis (Koga et al., 2014) which suggest as young as $<$10 Myr. More recently an old $^{40}$Ar/$^{39}$Ar age (1.26$\pm$0.24 Gyr) was reported (Park et al., 2014), which probably corresponds to a catastrophic disruption of Itokawa's parent body. Take into account of these ages, our age can be interpreted on two scenarios. One is the resurfacing time scale by escape of the regolith which is suggested by Nagao et al. (2011) and another possible scenario is that Itokawa might be disrupted more than once and so our crater age may reflect the latest event age.

Keywords: asteroid, Itokawa, impact experiment, rubble-pile, crater, age estimation