CRATERING EFFICIENCY REDUCTION DUE TO ARMORING ON THE COARSE-GRAINED TARGETS.
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Introduction: A rubble-pile asteroid Itokawa is covered by coarse-grains, including many cm-m sized gravels [1] and possesses the crater-like depressions [2] (Fig. 1). If those features are impact craters, crater retention age can be estimated. However, the apparent size distribution of these features is substantially different from impactor size distribution. Large crater-like features are near empirical saturation level, but the density of small features (<100 m) is very low [2]. One possible explanation to this depletion is the armoring effect: when a meteorite hits the asteroid, the gravel hit by the meteorite absorb the kinetic energy of the impactor through its disruption.

Because crater retention ages on planetary bodies are estimated based on crater statics, the crater size scaling influences the age sensitively. However, it is not obvious which scaling law should be applied for such coarse-grained surface. For example, Michel et al. [3] shows the crater retention age based on the strength scaling would yield 75 Myr – 1 Gyr for Itokawa. If gravity or other mechanism such as armoring controls crater size instead, crater retention age on Itokawa would be younger by more than one order of magnitude [4]. Accurate age estimation requires an accurate crater scaling law. Only a limited number of experiments have been done and their results do not necessarily agree with each other yet [5,6]. In this study, we conduct cratering experiments on coarse-grained targets over a wide velocity range. Then we examine what crater scaling rule should be used for estimating crater age on Itokawa and evaluate the cratering efficiency reduction due to the armoring mechanism.

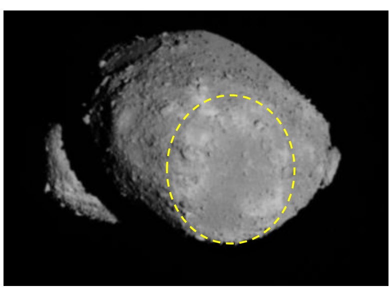

Fig. 1 A crater-like morphology on Itokawa. This is the second largest depression, Arcoona. ST_2424222537

Experiments: The impact experiments were conducted with a vertical single-stage gas gun range at Univ. of Tokyo for low impact velocities (70 – 200 m/s) and a two-stage light-gas gun at for high impact velocities (1 – 6 km/s) at JAXA/ISAS. Polycarbonate impactors 10 mm in diameter were used for low velocities and 4.7 mm for high velocities. Target were

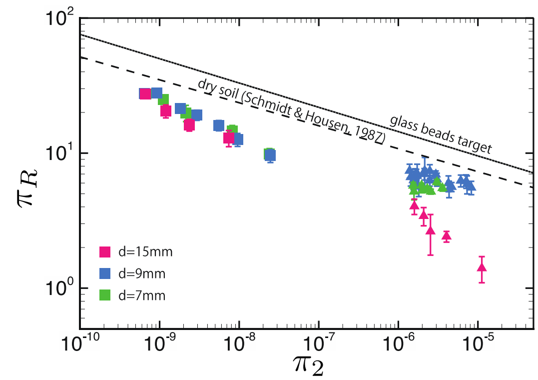

Fig. 2 A π-scaling plot for the coarse-grained surface with different grain sizes.

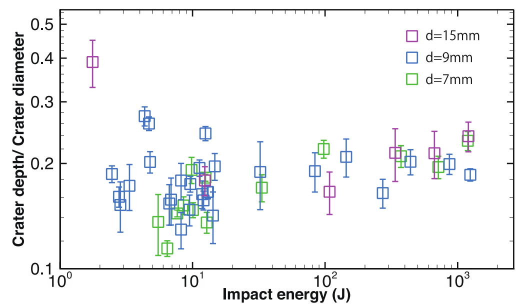

Fig. 3 The depth/diameter ratios of the craters formed on coarse-grained target. The ratios are same as craters formed on fine-grained targets.

pumice gravels of three sizes; the average grain sizes were 7, 9 and 15 mm, and the weights were 0.10, 0.23 and 1.3 g. Note that the compressive strength of pumice is less than 1 MPa, but the energy required for disruption is comparable to that of basalt [7]. We measured rim-to-rim crater diameters and depth with a laser profiler (Keyence, LJ-V).

Results: Fig. 2 compares the sizes of the craters formed on coarse-grained targets with different grain sizes in our experiments and those on fine dry soil and glass beads in $\pi_2 - \pi_R$ space, where $\pi_2 = ag/U^2$ and $\pi_R = (\rho_t/m_p)^{\frac{1}{3}}(R_c/a)$. The ratio of the crater depth and the crater diameter is shown in Fig.3. These results show that the crater size on coarse-grained surface is comparable to the size of dry soil gravity scaling [7] when impact velocity is high enough and slightly reduced at slower velocities. In order to evaluate the reduction in cratering efficiency, we introduce the scaled impact energy $\xi = \frac{1}{2} m_p U^2 / Q_D^* m_t$, where Q_D^* is the catastrophic disruption energy for unit mass of the target grain, vs. the cratering efficiency χ defined as the ratio of actual crater size to that estimated-size based on the gravity scaling. Fig. 4 shows previous results of glass-beads targets [5] and our coarse-grained experiments. Fig. 4 suggests that there may be three regimes; I: $\xi < 1$, II: $1 \lesssim \xi \lesssim 10^2$ and III: $10^2 \lesssim \xi \lesssim 10^4$.

Discussions: The regime I ($\xi < 1$), where the target grains are not disrupted, is the same condition for the experiments by [5]. On Itokawa, cratering occurs under the condition where the projectile is smaller than the target grain size and the impact energy is higher than the disruption energy of one target grain (the regime II and III). A previous study [9] on catastrophic disruption experiments of both basalt and alumina spheres, indicates that only ~ 2 % of the initial kinetic energy is transferred to the large fragments of targets, but the translation momentum transferred to large fragments is almost twice as the initial impact momentum. This process could be viewed as conversion from a hypervelocity impact of a small projectile to a slow impact of large projectile(s) at the very first target grain.

Here, such conversion could be described with kinetic energy transfer efficiency α and the momentum multiplication factor β. They are the fraction of energy and momentum of impact transferred to large target fragments, respectively. Representing the scale of impact by the point source measure $aU^{\mu}\delta^{\nu}$, β is derived as a function of impact velocity $\beta = 1 + KU^{3\mu-1}$[10].

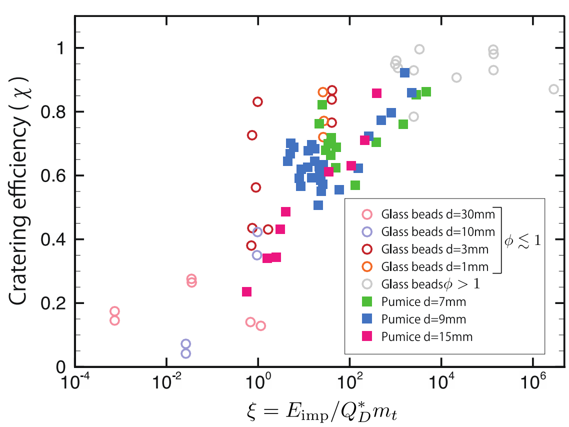

Fig. 4 The cratering efficiency, the ratio of actual crater size to that predicted by gravity scaling law estimated gravity scaling crater size; our results (squares) the previous study [2] (circles). The ϕ is the impactor/target grain size ratio. As long as the disruption of the surface grains occurs (ξ>1), the efficiency is reduced, but only by 70 – 50% at most. When the scaled energy is much higher (ξ >10^4), the crater efficiency is comparable to the gravity scaling (χ~1). Note that the crater efficiency tends to be higher than overall trend between 1 and 10^2 of ξ; this regime might have different mechanism of armoring.

Assuming that after the collision between the projectile and the surface target grain, the energy and the momentum transfer are given by

$$\begin{cases} m_t^* v^2/2 = \alpha m_p U^2/2 \\ m_t^* v = \beta m_p U \end{cases},$$

where m_t^* is the mass of large fragments that carry kinetic energy and momentum. This gives $m_t^* = (\beta^2/\alpha)\, m_p$ and $v = (\alpha/\beta)U$. If the final crater size is determined by the fragments mass $m_t^* = \left(\frac{4}{3}\right) \rho_t \pi r_t^{*3}$ and velocity v, the gravity scaling would predict that the crater size on the coarse-grained targets would be

$$\pi_R \propto \hat{\pi}_2^{-0.17} = \left(\frac{g r_t^*}{v^2}\right)^{-0.17}$$
$$= \pi_2^{-0.17} \left(\frac{\beta^{8/3}}{\alpha^{7/3}}\right)^{-0.17},$$

and this leads to the cratering efficiency:

$$\chi = \left(\beta^{8/3}/\alpha^{7/3}\right)^{-0.17}.$$

In the previous disruption experiments [9] on basalt target were conducted under ξ~10. Using α=0.02, β=2, as suggested by [9], we have $\chi \sim 0.15$, which approximately coincides with the efficiency reduction with Fig. 4. However, further experiments for α and β are needed to examine this model more in detail.

Implications: Our results suggest that the crater size on coarse-grained surface might be described as the modified gravity scaling with the energy and momentum transfer efficiency. Thus, the depletion of crater size caused by armoring would be only a few times smaller at most. This leads the younger surface age as < O(10Myr) of Itokawa than the previous estimation based on the material strength scaling by an order of magnitude. This young age is consistent with the cosmic exposure age [11,12] of samples and space weathering age from spectra analysis [13].

References:

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