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Impact experiments on granular targets with size frequency distribution similar to asteroid 162173 Ryugu

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Abstract

We carried out impact experiments on glass beads and fragile soil grains with the size frequency distributions similar to a rubble-pile asteroid in order to examine the erasure process of small crater on asteroid Ryugu. The impact cratering efficiency estimated by the crater scaling law for mixed glass beads was almost consistent with that for fragile soil grains at low impact velocity while it was smaller at the high impact velocity. The maximum acceleration of impact-induced seismic wave for our targets was smaller than those of single-sized glass beads and quartz sand at the distance far from the crater rim.

1. Introduction

On asteroid Ryugu, explored by the spacecraft Hayabusa2, several 100-m-sized impact craters are observed while those with a size of < a few meters are deficient [1]. There are two possible reasons for the deficiency of small craters. One is so called armoring effect: there are many large boulders on Ryugu so even if an impactor collided on Ryugu, the boulder was disrupted but the crater did not form. The other is the impact-induced seismic shaking, which erased the small impact craters due to the mass movement on Ryugu. In order to clarify the erasure process of small craters on Ryugu, we conducted impact cratering experiments on granular targets with the size frequency distribution similar to that of boulders on Ryugu and examined the effect of size frequency distribution on the crater size. Furthermore, we measured the acceleration induced by the impact of projectile and examined the impact condition occurring the impact-induced seismic shaking on granular targets.

2. Experimental Methods

We conducted cratering experiments by using one-stage light gas gun at Kobe University and two-stage light gas gun at ISAS, JAXA. We used mixed glass beads with the size frequency distribution similar to Ryugu from 0.1 to 10 mm and fragile soil grains called "Kanuma" grains having two kinds of size distributions of 1-4 mm (fine) and 10-40 mm (coarse). The static compressive strength of a glass bead is four orders of magnitude higher than that of a Kanuma soil. We used five types of 2 or 3-mm-sized projectiles with the density from 1.1 to 7.9 g/cm^3 for one-stage gas gun and the impact velocity ranged from 40 to 213 m/s at Kobe University. At ISAS, the aluminum projectile with a diameter of 1 or 2 mm was used and the impact velocity ranged from 1.2 to 4.3 km/s. Impact-induced seismic waves were measured by using three accelerometers with the specific frequency of 30 kHz setting at different positions from the impact point. To record the seismic data, a data logger was used with the sampling rate of 100 kHz.

3. Experimental Results

3.1. Cratering morphology

Figure 1 shows the photographs of impact craters formed on the targets of mixed glass beads and coarse fragile soil grains at the impact velocity of 4 km/s. The impact craters on both targets have similar morphology, that is, an irregular shape (not bowl shape) and an unclear rim. In the case of mixed glass beads, several 10-mm-sized glass beads were exposed on the surface of impact craters. These largest glass beads were buried at the subsurface before the impact,

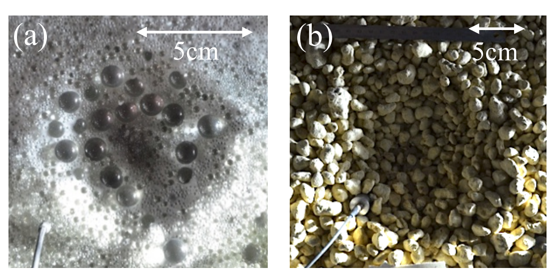

Figure 1: Photographs of impact craters on (a) mixed glass beads for 1-mm-sized aluminum projectile and (b) coarse fragile soil grains for 2-mm-sized aluminum projectile, at the impact velocity of 4 km/s.

and the other small glass beads were ejected away from the subsurface, then the largest beads were left after the impact.

3.2. Crater size scaling law

To compare the results of glass beads with those of fragile soil grains at various impact conditions, we applied our results to the crater size scaling law. The crater size scaling law related to the crater rim radius, R_{rim}, (a half of a rim-to-rim diameter) is proposed as $\pi_{\mathrm{R}} = a \cdot \pi_2{}^{-b}$ and the non-dimensional scaling parameters, π_{R} and π_2, is defined as $R_{\mathrm{rim}}(\rho_{\mathrm{t}}/m_{\mathrm{p}})^{1/3}$ and $gr_{\mathrm{p}}/v_{\mathrm{i}}{}^2$, respectively, where ρ_{t} is the target density, m_{p} and r_{p} are the projectile mass and radius, v_{i} is the impact velocity, and g is the gravitational acceleration [2].

Figure 2 shows the relationship between the π_{R} and π_2 for our targets and glass beads with a diameter of 0.1 mm and quartz sand with a diameter of 0.5 mm [3]. At the π_2 larger than 10^{-7} (low impact velocity), the π_{R} for all targets were almost consistent with each other. The data for fine soil grains was a little scattered in this range because the projectile impacted directly on the grain so the crater radius became smaller at the kinetic energy of projectile of 0.1-1 J. On the other hand, the π_{R} for soil grains was higher than that for mixed glass beads while it merged well with the data for quartz sand at the π_2 smaller than 10^{-8} (high impact velocity).

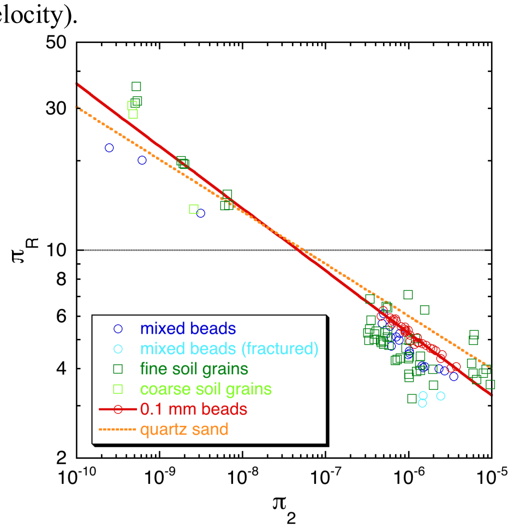

Figure 2: Relationship between the π_{R} and the π_2. "mixed beads (fractured)" represents the results of glass beads when the projectile impacted on the 10-mm-sized glass bead. Two other results are shown, 0.1-mm-sized glass beads obtained in this study and 0.5-mm-sized quartz sand [3].

3.3. Impact-induced seismic wave

In this study, we observed the impact-induced seismic wave at different distances from the impact point at the impact velocity of >1 km/s and examined the maximum acceleration of the first upward peak on the waveform.

Figure 3 shows the maximum acceleration, g_{max}, and the distance from the impact point normalized by the crater rim radius, x/R_{rim}, for our targets and glass beads with a diameter of 0.2 mm [4] and 0.5-mm-sized quartz sand [3]. The g_{max} of mixed glass beads and fragile soil grains were roughly consistent with each other at the x/R_{rim} smaller than 5, but all of our results were smaller than those of single-sized glass beads and quartz sand. Therefore, the impact-induced seismic shaking for targets with the grain size frequency distribution similar to Ryugu could occur in a quite limited area surrounding the impact crater, compared with the targets with a single-sized grains.

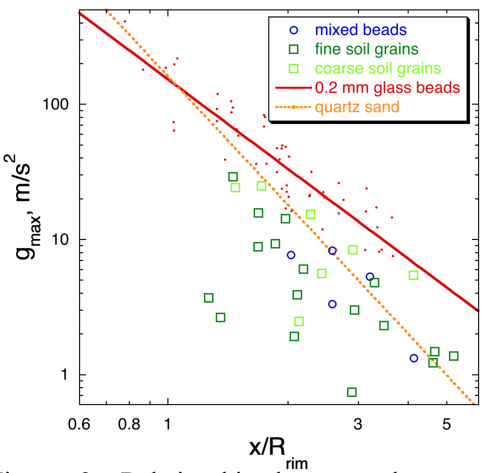

Figure 3: Relationship between the maximum acceleration g_{max} and the normalized distance x/R_{rim}. Two other results are shown, 0.2-mm-sized glass beads [4] and 0.5-mm-sized quartz sand [3].

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