EPSC Abstracts
Vol. 13, EPSC-DPS2019-127-1, 2019
EPSC-DPS Joint Meeting 2019

EPSC
EPSC-DPS Joint Meeting 2019
15–20 September 2019 | Geneva, Switzerland

In-situ observation of catastrophic disruption of asteroid analogues using flash X-ray photography

Masahiko Arakawa (1), Minami Yasui (1), Masashi Okazaki (1), Masato Nakamura (1), Sunao Hasegawa (2),
(1) Graduate School of Science, Kobe University, Japan (masahiko.arakawa@penguin.kobe-u.ac.jp)
(2) Institute of Space and Astronautical Science, Japan Aerospace Exploration Agency, Japan

Abstract

High-velocity impact experiments were conducted for asteroid analogues to study the impact strength in a gravity regime. The catastrophic disruption of asteroid analogues with different tensile strength and porosities were observed by using flash X-ray photography, and the relationship between the impact fragment mass and the ejection velocity was obtained. The median velocity, V^*, which is an upper limit of ejection velocities of fragments with a half of the original target mass was derived from this relationship and it was found to increase lineally with the energy density but it was independent of the tensile strength. While the $V^*$was drastically affected by the porosity, the V^* of the non-porous target was more than 3 time larger than that of the porous targets. These V^* of various targets allowed us to estimate the impact strength of asteroid analogues in the gravity regime.

1. Introduction

The impact strength of small bodies such as asteroids and planetesimals is one of the most important physical properties to clarify the planetary accretion processes and the formation processes of proto-planets and asteroids. The impact strength in the strength regime ($Q_S{}^*$) applicable to planetary bodies with a size smaller than 100 m has been mainly studied by laboratory experiments [1]. However, the impact strength in the gravity regime ($Q_D{}^*$) applicable to planetary bodies larger than 100 m has been studied only by numerical simulations [2], and their results were not consistent each other. Furthermore, recent numerical results conducted by Jutzi [3] showed us that the material properties such as friction, cohesion, and porosity affected the impact strength drastically in the gravity regime. Therefore, we conducted laboratory impact experiments to elucidate the material dependence on the impact strength in the gravity regime.

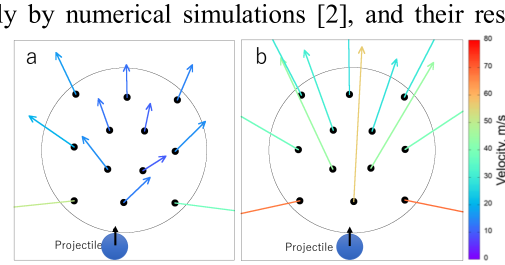

Figure 1: Velocity vectors of 12 steel balls obtained from the displacement observed by flash X-ray. (1) 5000 J/kg, (b) 10000 J/kg. The color index shown at right side is the speed of the vectors.

2. Experimental Methods

Impact experiments were conducted by using a two-stage light gas gun set at ISAS/JAXA. A polycarbonate projectile with the diameter of 7 mm was launched at the impact velocity from 2 to 5 km/s, and it was impacted on the spherical target with the size of 6 cm at the head-on collision. We used frozen clay targets with 3 different water contents, 25, 35, and 45 wt.%, and the tensile strength changed from 1.1 MPa for 45 wt.% to 2.2 MPa for 25 wt.%. We also used porous gypsum targets with the porosity of 50% and the tensile strength of 2 MPa. All targets were catastrophically disrupted, so the largest fragment mass was always less than 0.2. The twelve steel balls with the diameter of 3 mm were set as a tracer in the targets on the same plane passing though the center. These steel balls were observed during the catastrophic disruption by three X-ray pulses generated by three flash X-ray tubes. The first pulse was discharged to recognize the impact point and the following two pulses were discharged simultaneously from the different direction with the angle of 90° to observe steel ball positions. We could measure the velocity vectors of these steel balls comparing with their initial position (Fig. 1), so if we assume that the impact fragments were ejected at the same velocity as the nearest steel ball, we could estimate the fragment velocity-mass distribution for each experiment. As a result, we could determine an upper limit of ejection velocities of fragments with a half of the original target mass, and defined this upper velocity as a median velocity of V^*. So, we studied how V^* depended on the energy density, tensile strength, and porosity.

3. Experimental Results

3.1. Velocity-mass distribution

The impact strength in the strength regime ($Q_S{}^*$) was obtained for the frozen clay and the porous gypsum targets, and it was obtained to be 700 J/kg for the frozen clay with 25 wt.%, 200 J/kg with 45 wt.%, and 763 J/kg for the porous gypsum, respectively. The velocity-mass distribution is shown in Fig. 2; it represents the relationship between the normalized cumulative mass of the fragments and the fragment velocity in the center-of-mass system. The fragment mass with higher velocities increased with the increase of the energy density (Q) for the frozen clay, but the fragment mass with high velocities drastically decreases for the porous gypsum target, compared with the frozen clay impacted at the same Q.

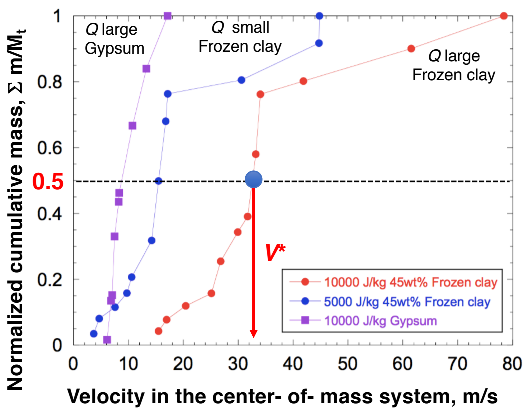

Figure 2: Fragment velocity-mass distribution shown by the relationship between the normalized cumulative mass of the fragments Σ and the velocity in the center of mass system for frozen clay and porous gypsum targets. The V^* means the median velocity at the $\Sigma = 0.5$.

3.2. Median velocity and $Q_D{}^*$

We found that V^* of the frozen clay increased with the energy density, but it was almost independent of the tensile strength because the V^* of three types of frozen clay targets with different tensile strength were well merged (Fig. 3). The V^* of the porous gypsum also lineally increased with the energy density, but we found that the V^* strongly depended on the target porosity: when the V^* of the porous gypsum was compared with that of the frozen clay with the similar tensile strength but without porosity, it was found that the V^* of the porous gypsum reduced to be 1/3 of that of the frozen clay. These V^* of various targets allowed us to estimate the impact strength of asteroid analogues in the gravity regime, so we speculate $Q_D{}^*$ according to our results of the V^*. The $Q_D{}^*$ for the target with a radius, R, could be derived from the simple assumption that V^* was equal to the escape velocity of the target body with a radius, R. We noticed that $Q_D{}^*$ was independent of the tensile strength for frozen clay and it strongly depended on the porosity, and these material dependencies are consistent with the numerical results obtained by Jutzi [3] very well.

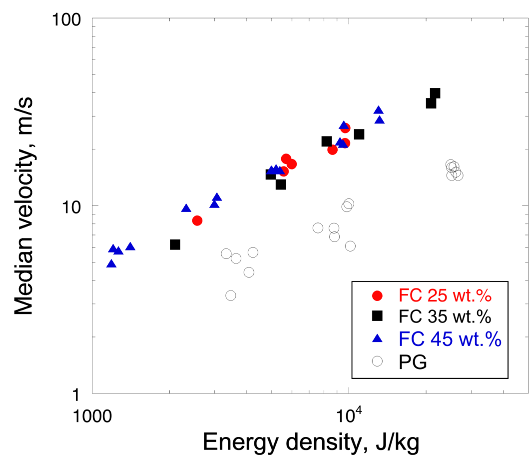

Figure 3: Median velocity (V^*) obtained from each velocity-mass distribution of frozen clay targets with different water contents (FC25, FC35, FC45 wt.%) and porous gypsum target (PG).

References

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