

Impact strength of small hydrated rocky planetesimals with core-mantle structure in gravity-dominated regime

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The asteroid Ryugu, visited by the Hayabusa2 spacecraft, is a rubble-pile object. From observations and analysis of collected samples, the parent body is expected to have been a hydrated planetesimal with a viscous core experienced hydrous alteration and a high-porous mantle. Such layered bodies are thought to form diverse asteroids through repeated collisional disruption and re-accumulation. Therefore, in order to clarify the formation process of various asteroids, it is necessary to consider the evolution of internal structure of parent bodies.

Impact strength Q^* , defined as the energy density Q at which the largest fragment mass is half of the original target mass, has been used to understand the impact phenomena that occur during the early evolution of asteroids. This Q^* is determined by the re-accumulation of impact fragments due to gravity for objects larger than 100 m in size, and it is called the impact strength Q_D^* in the gravity-dominated regime. This Q_D^* has been estimated only by numerical simulations so far, but since the Q_D^* shown in previous research differs greatly for each model, it has been said that laboratory experiments are necessary. In order to obtain Q_D^* in laboratory experiments, it is necessary to determine the mass-velocity distribution of all fragments generated by impact. Conventional methods of tracking fragments using high-speed cameras have been difficult to determine the velocity of all fragments because they could only measure fragments ejected from the target surface.

Therefore, in this study, in order to obtain the impact strength Q_D^* , impact experiments were conducted using a target with layered structure simulating a hydrated planetesimal. And the mass-velocity distributions of all impact fragments, including particle velocities inside the target, were investigated using a tracer method using flash X-rays and a digital image correlation method (DIC).

Impact experiments were carried out using horizontal two-stage light gas guns at Kobe University and ISAS/JAXA. The projectiles used were polycarbonate spheres with diameters of 4.7 mm and 7 mm, and the impact velocity V_i was 1.5-6.2 km s⁻¹. To simulate a hydrated planetesimal, the mantle was prepared by mixing sand and gypsum with a mass ratio of 2:1 or 8:1 (tensile strength of 770 kPa and 101 kPa, respectively, and porosity of 37%). For the core, a mixture of bentonite and silicone oil with a viscosity of 10 Pas at a mass ratio of 3:1 was prepared. That is, we prepared two types of layered targets with different strengths of mantle. The core diameters were 30 mm and 50 mm, and the mantle diameter was 60 mm. For comparison with the layered target, we also prepared a homogeneous target consisting of only mantle material. In the DIC method, a hemispherical target was used and the cross section was randomly dotted. Also, the projectile collided with the side of the cross section. In the tracer method, a whole target was used and 12 iron balls (3 mm in diameter) were placed on a single plane within the target. The movement of the iron balls was analyzed using flash X-ray imaging immediately after impact.

As a result of investigating the 2D velocity-time distribution inside the target using the DIC method, it was found that in the layered target, the separation of the core and mantle was promoted by the shock wave reflected from the boundary between the core and mantle. We also found that the deformation and movement of the core makes the velocity of the mantle near the antipodal point faster than that of the homogeneous target.

Next, we determined the internal velocities of the target from the flash X-ray images and correlated them with the mass of nearby fragments to investigate the cumulative mass distribution of the fragment velocity.

Then, the fragment velocity (intermediate velocity v^*) when the accumulated mass becomes half of the original target mass was obtained, and the relationship with the energy density Q was investigated. As a result, it was found that v^* increased with increasing the Q and the v^* did not depend on the mantle strength. In addition, it was found that v^* was larger in the layered target than in the homogeneous target, and that v^* became larger as the core size increased. Then, by comparing this intermediate velocity with the escape velocity of the target body, we estimated the impact strength Q_D^* in the gravity-dominated regime, and discussed the effect of the internal structure on the impact strength of the hydrous planetesimals.

Keywords: impact experiments, Digital Image Correlation, flash X-ray, gravity-dominated regime, impact strength, differentiated bodies