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In-situ flash X-ray observation of impact crater formation in porous gypsum

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Introduction: In order to understand the impact histories related to the asteroid formation processes, it is very important to study the impact craters found on the surfaces of asteroids. So, we should study the crater formation mechanism and establish the formation theory of the impact crater based on the physical mechanism. From recent spacecraft explorations, many asteroids were found to have low density and be porous bodies [1]. Porosity has an important effect on the crater formation: the void spaces were crushed due to impact pressure and the large craters with a compaction layer below the surface were formed [2]. So, the crater formation mechanism on the porous materials is important to understand the impact history of asteroids. The target internal structure changing with time during the crater formation process has not been studied yet by laboratory experiments because it is difficult to observe the target interior by visible light. In some previous works, impact experiments were conducted by using the porous transparent silica aerojel to visualize the target interior [3]. In this study, we tried to visualize the interior of the target during the crater formation process by using a flash X-ray generator and studied the elementary processes of the crater formation, and observed the projectile penetration and the cavity expansion in the target.

Experimental method: We prepared the targets of porous gypsum having cylindrical shape with two different diameters of 34 and 64 mm. Impact experiments were conducted by a two-stage H_2-gas gun in ISAS/JAXA. The impact velocities were 1.9-2.4 km/s (low-velocity) and 5.4-6.1 km/s (high-velocity) by using three types of projectile, stainless spheres with diameters of 1.6 and 3.2 mm, and Al sphere with 3.2 mm. We set two flash X-ray generators to take two images at different times for one test. Multiple images were obtained from several tests at the same impact condition and the different trigger timing from 0 to 250 micron-s.

Results: From the analysis of X-ray images, we found that the crater shape of target depended on the impact velocity and the projectile type. In the case of low-velocity collisions, the stainless projectile penetrated through the target without deformation and the penetrated hole was formed while the Al projectile collided the target surface and the hemispherical cavity was formed. In the case of high-velocity collisions for stainless projectile, the projectile with a diameter of 3.2 mm deformed and the hemispherical cavity was formed in the target, accompanied with some narrow pits on the cavity front. When the projectile with 1.6 mm collided, the hemispherical crater was formed on the surface. We measured the penetration depth (d), cavity diameter on the target surface (D) and the maximum diameter in the target (D_{max}). In the case of penetration hole, the D was almost constant for projectile diameter while the d increased with time exponentially. In the cases of hemispherical cavity, all parameters increased with the time until 20 micron-s, however, the increases of d and D_{max} stopped at 20 micron-s. Beyond 60 micron-s, the behavior depended on the stainless projectile size. In the case of small projectile, the D became the maximum and the spalling occurred on the target surface. In the case of large projectile, the d increased due to the progress of some disrupted projectiles. Conclusively, all parameters increased because the target was disrupted and many fragments were ejected. We examined the drag coefficient (C_d) of projectile by using the deceleration model [3], and found that the C_d for penetration was about 0.9 while that for other cases was about 2-3. This high value might be caused by the deformation of projectiles [4].

Reference: [1] Veverka *et al.* (1999), Icarus 140, 3-16. [2] Housen and Holsapple (2003), Icarus 163, 102-119. [3] Niimi *et al.* (2011), Icarus 211,986-992. [4] Tamaki and Hinada (1966), Seisankenkyu 18, 219-221.

Keywords: impact crater, penetration, pit, drag coefficient, flash X-ray, H-gas gun