Experimental investigation for cavity dimensions of highly porous small bodies

T. Okamoto[1], A. Nakamura[1], and S. Hasegawa[2]

[1]Department of Earth and Planetary Sciences, Kobe University
[2]Institute of Space and Astronautical Science, JAXA

Small bodies were probably very porous during the formation of the solar system. In order to understand the surface evolution of highly porous bodies, it is necessary to investigate the impact process for targets with such high porosity. In this study, impact experiments with sintered glass-bead targets of 87 and 94 % porosities were conducted. Growth of cavities with time and the final cavity dimensions were analyzed and compared with previous studies of porous targets.

Impact experiments were conducted using a two-stage light-gas gun at ISAS, Japan. The projectiles of a few millimeters were composed of titanium, aluminum, nylon, and basalt. The impact velocities ranged from 1.8 to 7.2 km s^{-1}. In order to observe the inside of the targets, we used a flash X-ray system and a micro-X-ray tomography instrument.

The track shape was found to be divided into two types, elongated 'carrot' shape and short 'bulb' shape [1]. The figures on the left and right present a transmission image of the bulb shape track and a sketch of a cross section of the cavity, respectively. The results of the final maximum diameter, D_{max} and the final entrance-hole diameter, D_{ent} show that both dimensions tend to increase with impact velocity and decrease with target porosity. We adopted the scaling law of crater diameter [2] for our analysis of D_{max} and D_{ent}. The following empirical relations are obtained for targets with porosity ≥ 87 %:

$$\frac{D_{\mathrm{max}}}{d_{\mathrm{p}}}\left(\frac{\rho_{\mathrm{t}}}{\rho_{\mathrm{p}}}\right)^{0.4} = 10^{-1.52\pm0.27}\left(\frac{Y}{\rho_{\mathrm{t}}{v_0}^2}\right)^{-0.49\pm0.07}, \tag{1}$$

$$\frac{D_{\mathrm{ent}}}{d_{\mathrm{p}}}\left(\frac{\rho_{\mathrm{t}}}{\rho_{\mathrm{p}}}\right)^{0.4} = 10^{-2.12\pm0.39}\left(\frac{Y}{\rho_{\mathrm{t}}{v_0}^2}\right)^{-0.53\pm0.11}, \tag{2}$$

where $d_{\mathrm{p}}, \rho_{\mathrm{t}}, \rho_{\mathrm{p}}, Y,$ and v_0 are the projectile diameter, target density, projectile density, target compressive strength, and the impact velocity, respectively. The results of the depth from the entrance hole to the maximum diameter of the cavity, L_{max}, shows that L_{max} decreases with impact velocity and increases with target porosity. If we assume that a projectile decelerates by inertial drag [1], the characteristic length L_0, which is the depth from the surface where the kinetic energy of the projectile becomes 1/e of the initial energy, is described as follows:

$$L_0 = \frac{2\rho_{\mathrm{p}}}{3C_{\mathrm{d}}\rho_{\mathrm{t}}}d_{\mathrm{p}}, \tag{3}$$

where C_{d} is the drag coefficient that increases with dynamic pressure normalized by tensile strength of the projectile [1]. We found that $L_{\mathrm{max}}/d_{\mathrm{p}}$ increases with L_0/d_{p}. It indicates that L_{max} depends on the degree of projectile deformation or disruption through the drag coefficient and also depends on the projectile-target density ratio. We will also discuss the growth of the cavity volume, maximum diameter, and depth of the cavity with time using dimensionless parameters of crater scaling [3].

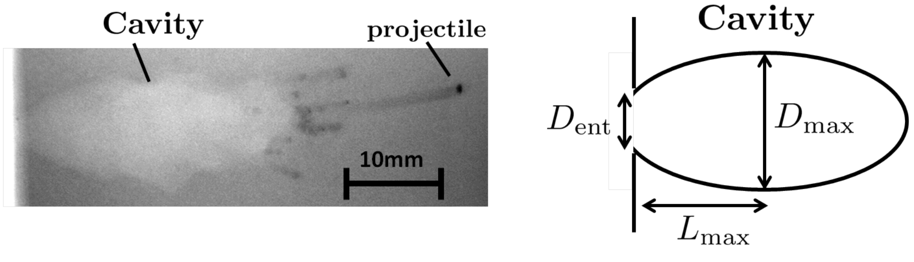

Figure: Left: A transmission image of the bulb shape track. The titanium projectile impacted the targets with a porosity of 94 % at an impact velocity of 6.7 km s^{-1}. The deformed projectile is observed at the end of the track. Right: Schematic illustration of cavity dimensions.

References: [1] Okamoto et al. (2013), Icarus 224, 209–217. [2] Housen and Holsapple. (2003), Icarus 163, 102–119. [3] Schmidt and Housen. (1987), Int. J. Impact Eng. 5, 543–560.