Experimental study on crater size scaling law of porous silica layer

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Recent planetary explorations and ground-based observations revealed that many small bodies in the solar system could have a large porosity: 80% for cometary nuclei and less than 75% for asteroids. For impact cratering phenomena on such porous bodies, a new crater formation mechanism dominated by pore collapse and compaction was proposed: it was recently classified as a compressive type crater. Impact craters are classically classified into two types: one is a crater formed in a gravity dominated regime and the other is one formed in a strength dominated regime. For these classical type craters, a π scaling law has been constructed and used to discuss various impact phenomena. However, the cratering model considering the effect of porosity was not fully constructed. Besides, the π scaling law applicable for porous asteroids is necessary for the impact experiment on asteroid Ryugu by a small carry-on impactor equipped on Hayabusa-2 spacecraft, because one of the surface models of Ryugu is a fine-grained porous layer.
In this study, we used commercially available amorphous silica dusts with the mean particle diameter of 0.5mm and the material density of 2.2gcm^{-3}(ρ_s), and we controlled the bulk porosity of the target from 50% to 78% by changing the degree of compression. The target was adhered by a Van Der Waals force with the tensile strength(Y_t) from 100 Pa to 10^4Pa. For the purpose of studying the effect of porosity on cratering phenomena, we conducted impact cratering experiments on this porous target by using two-stage light gas gun set at Kobe University. Spherical glass projectiles with the diameter of 1mm and 2mm, and the mass of 1.5mg and 10mg(m_p) was impacted at 0.8-6.5kms^{-1}. The target was set in a vacuum chamber evacuated at less than 20 Pa. First, the targets with the porosity from 50% to 78% were impacted at 3.6kms^{-1}. The crater morphology changed with the increase of the target porosity: the shallow dish type crater was observed on the target with the porosity of 50%, and as the porosity increased the spherical cavity was formed and grew below the shallow dish crater. The recovered target was cured by an epoxy resin and cut through at the center of the crater so that we could observe the cross section and measure the cavity radius (R), the depth of the crater (d) and the radius of the shallow dish crater (R_s). The relationship between distension $\alpha=\rho_s/\rho_{bulk}$ and the normalized cavity radius, $\pi_R=R(\rho_{bulk}/m_p)^{1/3}$, was found to follow the empirical equation of $\pi_R=1.9\alpha^{0.7}$, where ρ_{bulk} is a bulk density of the target, and the relationship between the distension and the normalized crater depth, $\pi_d=d(\rho_{bulk}/m_p)^{1/3}$, was found to follow the empirical equation of $\pi_d=3.0\alpha^{1.0}$. However, the radius of the shallow dish crater measured at the entrance of the cavity, $\pi_{Rs}=R_s(\rho_{bulk}/m_p)^{1/3}$, was found to be constant irrespective of the target porosity. Second, the targets with the porosity of 70% and 60% were impacted at 0.8-6.5kms^{-1} to study the velocity dependency. The crater morphology changed with the increase of the impact velocity: the carrot type penetration hole was observed below the shallow dish crater at the impact velocity of 0.8kms^{-1}, and as the impact velocity increased the spherical cavity was formed and grown. For the targets with the porosity of 70%, the relationship between π_{Rs} and another scaling parameter, $\pi_{Yt}=Y_t/\rho_{bulk}v_i^2$, was found to follow the empirical equation of $\pi_{Rs}=0.09\pi_{Yt}^{-0.27}$, where v_i is the impact velocity, and for that of 60% the relationship between π_{Rs} and π_{Yt} was found to follow the empirical equation of $\pi_{Rs}=0.20\pi_{Yt}^{-0.24}$. These empirical equations could be used to incorporate the effect of porosity on the scaling law.

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