Cratering experiments with spherical targets: The curvature effects on the cratering efficiency

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Recent planetary explorations revealed that the surfaces of small bodies are covered by a large number of craters. Impact cratering processes on small bodies are expected to be largely different from those on terrestrial planets mainly because of the following two reasons. The first one is their relatively-low surface gravity. The local material strength rather than gravity is subject to control the crater size on small bodies. All the craters on the asteroids smaller than a few km in diameter are possible to be in the strength-controlled regime (Jutzi et al., 2015). Another reason is the target curvature. Thus, the understanding of the cratering processes on curved surfaces in the strength-controlled regime is essential to investigate the collision environment of small bodies through their histories.

The curvature effects on the cratering processes, such as the cratering efficiency, have not been investigated systematically, although Fujiwara et al. (1993, 2014) have produced distinctive-shaped impact craters mainly on cylindrical targets with a wide range of its radius in a laboratory, and reported the crater diameter/depth/mass increase with and the target curvature. In this study, we performed a series of impact experiments using spherical targets with different diameters. The three-dimensional topography of the produced craters on the spherical surfaces were measured in 0.2 mm/pixel, allowing us to investigate the crater dimensions as a function of the target curvature. Then, we constructed a simple model to describe the effects of target geometry on the increase of the crater radius.

Impact experiments were performed by using a two-stage light-gas gun at the facility of ISAS/JAXA. The gypsum targets were cubes with 9 cm and 15 cm on a side, and spheres with 7.8 cm, 10.9 cm, 17.0 cm, and 24.8 cm in diameter. The bulk density and tensile strength of the target were 1.08 g/cm^3 and 2.4 MPa, respectively. A nylon sphere with 3.2 mm in diameter impacted into the target at ~3.4 km/s. The ratio of the radius of projectile and target (the normalized curvature) are 0.013-0.041. The targets were placed in a styrofoam box, and the target and their fragments were collected from the box in each shot. The spherical surface including a resultant crater was scanned by a high resolution 3-D geometry measurements system (COMS MAP-3D). The volume and depth of the crater was measured with the deviation from the pre-impact surface determined by the topographic data around the crater. The radius of a circle having an area equal to the area occupied by craters on the pre-impact surface was defined as the crater radius.

The resultant craters consist of a circular pit and a spall region around the pit. A larger target curvature led to a broader the spall region. The volume and diameter of the crater increase with the target curvature, although the depth of the crater is almost constant. The volume of spall region and the crater profiles also show that the spall region gets broader and deeper with the target curvature. The volume increase in the spall region mainly contributes to the volume increase of the crater.

We developed a model focusing on the normal component of the force to the target surface without taking into account of the interference zone. The experimental results fell in the area constrained by model curves with reasonable parameters (the radius of the isobaric core and the attenuation rate of the impact induced pressure) on the diagram of the ratio of the crater radius to those on plane surface and

the target curvature. Namely, the distance from the equivalent center to the target free surface is shorter for higher curvature, which mainly contributes to the increase of the crater diameter and volume with the target curvature. The curvatures for some largest craters on the asteroids are within the range of the curvature in this study. The increase of the crater radius originated from the curvature might have to be considered for spall craters in their size range.

Keywords: impact craters, impact experiments, small bodies, morphology, two-stage light-gas gun