Experimental study on the ejecta-velocity distributions caused by low-velocity impacts on quartz sand

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Introduction: Regolith formation on asteroids is caused by successive impacts of small bodies. The ejecta velocity distribution during the crater formation process is one of the most important physical properties related to the surface-evolution process, and the distribution is also necessary to reconstruct the planetary-accretion process among planetesimals. The surface of small bodies, such as asteroids and planetesimals in the solar system, could have varying porosity, strength, and density, and the impact velocity could vary across a wide range from a few tens of m/s to several km/s. Therefore, it is necessary to conduct impact experiments by changing the physical properties of the target and the projectile in a wide velocity range in order to constrain the crater-formation process applicable to the small bodies in the solar system.

Housen and Holsapple (2011) compiled the data of ejecta velocity distribution with various impact velocities, porosities, grain sizes, grain shapes, and strengths of the targets, and they improved their ejecta scaling law. But the ejecta velocity data is not enough for varying projectile densities and for impact velocities less than 1 km/s. In this study, to investigate the projectile density dependence of the ejecta velocity distribution at a low velocity region, we conducted impact experiments with projectile densities from 1.1 to 11.3 g/cm^3. Then, we try to determine the effect of projectile density on the ejecta velocity distribution by means of the observation of each individual ejecta grain.

Experimental methods: We made impact cratering experiments by using a vertical-type one-stage light-gas gun (V-LGG) set at Kobe University. Targets were quartz sand (irregular shape) and glass beads (spherical shape) with the grain size of 500 µm (porosity 44.7 %). The target container with the size of 30 cm was set in a large vacuum chamber with air pressure less than 10^3 Pa. The projectile materials that we used were lead, copper, iron, titanium, zirconia, alumina, glass, and nylon (11.3–1.1 g/cm^3). The projectile shape was spherical with a diameter $2a = 3$ mm. The projectile was launched at the impact velocity, V_i, from 24 to 217 m/s. We made impact experiments using 8 types of projectiles and observed each ejecta grain by using a high-speed digital video camera taken at 2000–10000 FPS. Then, we measured the ejection velocity and ejection angle of each grain varying with the initial position. We successfully obtained the relationship between the initial position and the initial ejection velocity for the quartz sand grains and the glass beads.

Results: From the high-speed camera observation, we found that, for higher projectile density, the angle of ejecta curtain from the horizontal plane increases from 50° for nylon to 58° for zirconia. The ejection angle of each grain was observed to change with the initial position, x, from 50° near the impact point to 40° near the crater rim, and this relationship does not depend on the projectile density. Thus, the ejection angle of each grain cannot explain the change in the angle of ejecta curtain for each projectile. When the ejecta velocity distribution, V_e, is written in the form of $V_\mathrm{e}/V_\mathrm{i} = c(x/a)^{-b}$, c is seen to somewhat change in each projectile. Meanwhile, b depends on the projectile density, and it was revealed that, for increasing projectile densities, b decreases from 0.43 of nylon to 0.68 of zirconia. It is assumed that b depending on the projectile density could cause the difference of ejecta curtain formed by each projectile.

When comparing the results of Housen and Holsapple (2011), who made experiments for a quartz sand target at high speeds of 1000–1900 m/s, with the results of this study for quartz sand or 500 µm glass beads target at low velocities of 24–217 m/s, the two sets of results were found to be consistent, even though our velocity range was an order of magnitude smaller than their velocity range. In addition, when the velocity distributions are written in the form $V_\mathrm{i}/\sqrt{gR} = k(x/R)^{-b}$, where R is a crater radius, g is the gravitational acceleration of planet, k is obtained to be approximately a constant of 0.78 ± 0.17, irrespective of projectile density. Our results in low-velocity experiments for 500 µm glass beads target are also roughly consistent with the results for the quartz sand target. In other words, we found that the shape of the target grain does not affect the velocity distribution so much, and the current scaling law can explain the effect of the impact velocity.

References: Housen, K. R. and Holsapple, K. A., Ejecta from impact craters, *Icarus* 221, 856–875.