Laboratory experiments of impact crater formation on surface with layered structure

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Introduction: We can find several types of impact craters on the lunar surface. Especially, tiny craters with the size smaller than 1km are classified into three types, which is called as a bowl, a flat-floor, and a concentric crater. These crater shapes are vary sensitive to the subsurface structure, so that Oberbeck and Quaide (1967) made impact cratering experiments on two layer targets with a substrate covered with a sand layer to study the formation conditions of the crater types found in the lunar tiny craters. As a result, they obtained the impact conditions and the relationship between the thickness of an upper sand layer and the crater diameter corresponding to the morphology change of the craters. They estimated the thickness of the lunar regolith layer by using their experimental results applied to the lunar tiny craters. Their criterion of the morphology change could strongly depend on the physical properties of the substrate. Therefore, it is necessary to study the impact crater made on the two-layer target with different substrates, which simulates lunar compressed regolith and bedrock beneath regolith.

Experimental methods: We made impact experiments by using a single stage light gas gun at high-speed range and by using free fall method at low-speed range. In the high-speed impact experiments, we prepared two-layer target with the substrates of clay, brick and wet sand, which water content was 1 to 10 wt.%, and the upper layer was dry sand with the thickness from 2 to 15mm. These two-layer targets were set at a bottom of a glass box with the size of 40cmx22cmx20cm. The substrate properties were characterized by the indentation strength and it was varied from 136kPa to 2MPa for these substrates. We used a glass ball projectile with the size of 3 and 5 mm and it was accelerated from 30 to 110m/s. In the low-speed impact experiments, a glass ball with the size of 5 to 25mm was dropped from an appropriate height to accelerate the ball from 1 to 3.3m/s. The substrates were brick, granite, and wet sand with 6 wt.% water.

Results: The crater morphology changes from bowl to flat-floor and more to concentric with the decrease of the sand layer thickness at a constant velocity. The criterion of the morphology change is described to be R which is defined as the ratio of the crater diameter to the sand layer thickness. The R_{b-f} corresponding to the boundary of bowl to flat-floor crater was obtained to be 5 for the strengthen substrates of granite and brick, on the other hand, the R_{b-f} obtained for the substrates of wet sand with various water contents was changed from 8.6 to 4.5 according to the substrate strength. The R_{f-c} of the boundary between flat-floor to concentric crater was also changed from 13 to 7 for the wet sand substrates and it depends on the wet sand strength, that is, R_{f-c} decreases with the increases of the wet sand strength. The crater diameter (D) of the flat-floor crater was measured for the wet sand substrate of 6 wt.% in detail and the relationship between the D and the projectile kinetic energy (E_k) was examined to compare it to that of usual bowl crater. As a result, the D of the flat-floor was described by the following equation,

$$D \text{ (mm)} = 15\, h^{0.37}\, {R_{b-f}}^{0.37}\, E_k \text{ (J)}^{0.17},$$

where h is the thickness of the sand layer. The exponent of E_k, 0.17, is rather smaller than that of typical bowl crater, 1/4 and we can notice that the sand thickness and R_{b-f} have the same power law dependence on the crater diameter.

Oberbeck ,V. R., and W. L. Quaide, J. Geophys. Res., 72, 4697-4704, 1967.