EXPERIMENTAL STUDY ON IMPACT CRATERS FORMED ON BASALT TARGET COVERED WITH WEAK MORTAR LAYER. M. Arakawa[1], K. Dohi[2], C. Okamoto[3], and S. Hasegawa[3], [1]Graduate School of Science, Kobe University (masahiko.arakawa@penguin.kobe-u.ac.jp), [2]Graduate School of Environmental Studies, Nagoya University, [3]JAXA.

Introduction: Impact craters are most common geological structure found on planetary bodies without atmosphere. A lot of small craters with the size less than 1 km on the moon was found to have several types of the crater morphologies, which formation mechanism could be controlled by the mechanical strength of subsurface layers. Their morphologies are categorized to be bowl type, flat floor type, and concentric type according to the previous study. This small size crater with complex shape was used to estimate regolith layer thickness on the moon. Oberbeck and Quaide [1] made cratering experiments on the layered target simulating the lunar subsurface with the regolith layer, and they found that the crater type changed at the critical ratio, *R*, of the crater diameter to the upper layer thickness. This result suggests the possibility to estimate the regolith thickness from the diameter necessary for the change of the crater type. But, it was not studied in details how the *R* depended on the material properties of the subsurface layer.

A layered structure is a very common structure on planetary surface, e.g. regolith layer on the moon and asteroids, and sediment layer on Mars and the earth. But, the thickness might not be so thick, thus the crater affected by the subsurface structure could not be so large. Actually, the small complex craters with the effects of the subsurface structure are found at the crater size less than 1km. In this smaller range, the crater formation could be controlled by the mechanical strength. Usually, not only sediment but also regolith layer compacted by self-gravity and impacts would have some degree of mechanical strength, so that at least a cohesive material is necessary to be used for the upper layer of the targets in a laboratory experiment. Thus, we studied the crater morphology for the target covered with the cohesive material such as mortar in this study.

Experimental Methods: Layered targets were prepared by covering a basalt block with a mortar layer. The size of the basalt block was from 5 to 30 cm and their surfaces were prepared to be flat by a diamond saw in order to set a mortar layer on it. The basalt block was originated from Kinosaki area, Japan, and the mean density is 2700 kg/m^3. The tensile strength was reported to be 19.3 MPa [2], and the bulk sound velocity was measured to be 1.93 km/s by our ultrasonic measurements. The mortar layer set on the basalt block had the thickness (T) from 2 to 30 mm. The physical parameters of the mortar layer important for the impact features were measured in the laboratory: they are the means density of 1730 kg/m^3, the tensile strength of 1.5 MPa, and the bulk sound velocity of 2.2 km/s.

Impact experiments were conducted by using a two-stage light gas gun set in Nagoya University and JAXA. In Nagoya University, a nylon cylindrical projectile with the size of 1.6 mm and the mass of 7 mg was launched at the impact velocity at 4 km/s and the same shape of the nylon projectile with the different size of 6.3 mm and the mass of 180 mg was impacted at 2 km/s. In JAXA, the cylindrical nylon projectile with the size of 7 mm and the mass of 300 mg was impacted at the velocity of 4 km/s. The direction of the projectile colliding on the target is normal to the surface. After the impact, the layered target and the impact fragments ejected from the crater were recovered from the sample chamber evacuated below 1 kPa. The impact crater formed on the recovered layered target was analyzed to measure the crater dimension such as diameter, depth and volume in addition to the cross section profiles of the crater. The crater profile was measured by means of a laser displacement meter with the resolution less than 1 μm scanning one-dimensionally.

Results: *Crater Types.* Three crater types were found on the layered target according to the experimental condition: they are bowl type, flat floor type, and concentric type. Figure 1 shows the photos showing these crater types, and each crater type has characteristic features. The bowl type is usually observed on the target with the thicker mortar layer. The flat floor type appears on the target with the appropriate thickness of the mortar layer. For this type of the crater, the crater depth is the same as the mortar thickness and the observed crater floor is an intact surface of the basalt block. The concentric type crater is the most impressive one: the small pit was formed on the basalt block surface in addition to a larger crater formed on the mortar surface. The small pit on the basalt could be formed by direct collision of the projectile on the basalt block: it means that the projectile does not decelerate through the mortar layer and it still keeps enough velocity to make a crater on the basalt. These experiments showed that the crater type changed with the impact velocity and the thickness of the mortar layer, so this systematic feature will be discussed in a next section.

Concentric Crater. The most interesting morphological feature observed for the concentric crater is a pit formed on the basalt. Then, the pit depth was measured for each crater and they are shown in Fig. 2 as the relationship between the mortar thickness and the pit depth. There are three data sets in Fig. 2: they have a different projectile kinetic energy with different projectile velocities or projectile masses. The pit depth linearly decreases with the increase of the mortar thickness in all of the data sets: it means that the impact velocity of the projectile on the basalt through the mortar layer gradually becomes small with the increase of the mortar thickness. The relationships of the pit depth corresponding to each data set have an order, which is the same as that of the projectile kinetic energy.

Discussion: The simple theoretical model of the projectile penetration into the mortar layer was considered to estimate the impact velocity on the basalt block. The following equation of motion of the projectile penetrating through the mortar layer was assumed to derive the decelerating velocity of the projectile in the mortar layer.

$$m\frac{dv}{dt} = -k \cdot v^n, \quad (1)$$

where m is the projectile mass, v is the projectile velocity, k and n are parameters to characterize the penetration. Eq. 1 can be solved easily as follows,

$$v = \left(V_0^{\,2-n} - \frac{k(2-n)}{m} T \right)^{\frac{1}{2-n}}, \quad (2)$$

where v_0 is an initial projectile velocity. The projectile velocity colliding on the basalt surface after penetrating through the mortar layer can be estimated by using Eq. 2, and the pit depth can be obtained by using the empirical equation of the depth vs. the projectile kinetic energy for the intact basalt without mortar layer if we assume that the upper mortar layer does not affect the pit formation on the basalt. The empirical equation for intact basalt was obtained by the previous study [3], and also by ourselves as follows, d_{b0}[mm]=3.4E_k[J]$^{0.36}$. Therefore, the pit depth was estimated by combining Eq. 2 and the above equation for pit depth on basalt, so that it is described as follows,

$$\frac{d_b}{d_{b_0}} = \left(1 - \frac{T}{l}\right)^{\frac{0.7}{2-n}}, \quad (3)$$

where the characteristics length, l, was defined to be $l = mv_0^{2-n}/k(2-n)$, and the physical meaning of l is the penetrating depth when the projectile completely stops. This equation can be used to fit the data set shown in Fig. 2 and it is possible to obtain parameter n and l, so the most feasible n was derived from fitting each data set and it was 1.3. Then, the l for each data set was also obtained simultaneously. The obtained l is compared with the crater depth formed on the uniform mortar target. Thus, the l is estimated to about 80 % of the each crater depth formed on the uniform mortar layer. It may help our understanding for the formation mechanism of the concentric crater. It is well known that the projectile deeply penetrates into non-cohesive targets like sand but the penetration depth for the cohesive target is not well understood yet.

References: [1] Oberbeck, V. R. and Quaide W. L. (1967) *JGR, 72,* 4697–4707. [2] Nakamura A. M. et al. (2007) *JGR, 112*, E02001. [3] Gault D. E. (1973) *The Moon, 6*, Issue 1-2, 32–44.

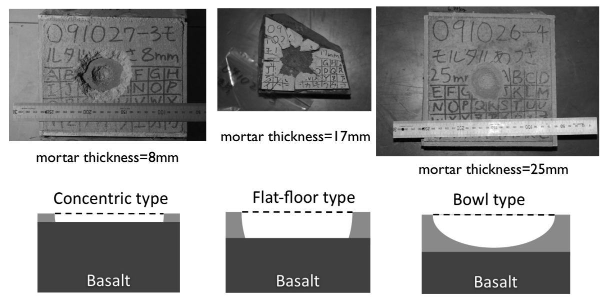

Figure 1: Crater type formed on the basalt target covered with mortar

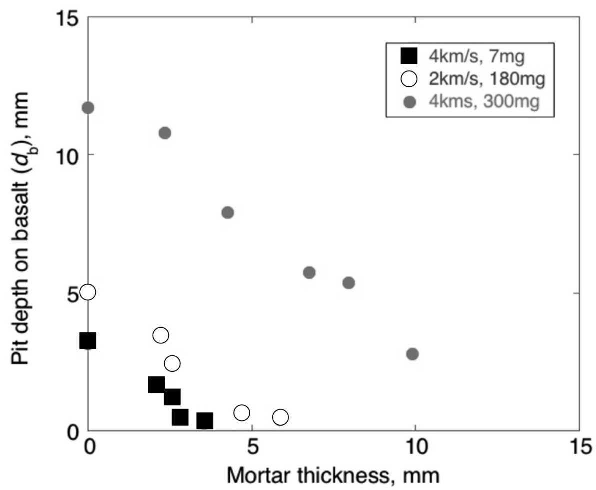

Figure 2: Relationship between pit depth and mortar thickness