Relation among the permittivity, density, and volume fraction of crack around craters formed by laboratory impact experiment

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The lunar subsurface geological condition was investigated from the measurements of density of core sample [e.g., Carrier et al., 1991] and seismic velocity [e.g., Cooper et al., 1974] in Apollo site. These measurements suggests that the lunar subsurface density decreased with decreasing the depth, which is because there are more impact-induced cracks in the shallow media than in the deep media [e.g., Cooper et al., 1974]. Recently, in order to investigate lunar geological condition, the bulk permittivity of lunar subsurface layer was investigated based on the data from the Lunar Radar Sounder (LRS) onboard the SELENE (KAGUYA) spacecraft [Ishiyama et al., 2013]. Based on the empirical relation among the bulk permittivity, the bulk density, and the porosity, Ishiyama et al. [2013] suggested that the porosity of the lunar subsurface layer was ~19%. However, according to effective medium theory [e.g., Kärkkäinen et al., 2000], the direction of cracks in media can change the relation between the bulk permittivity and bulk density. In this study, we evaluate how the actual crack distribution around impact crater produced in the umpact experiment affect the bulk permittivity, and verify the validity of the estimation method of the porosity and bulk density from the permittivity measured in radar observations.

We performed the impact experiment by using the two-stage light-gas gun at JAXA. First, in order to produce two impact craters, the spherical stainless projectiles with a diameter of 0.32 cm, and mass of 0.133 g at the velocities of ~3.5 and ~5.5 km/s were impacted on two basalt targets with a size of 20 cm×20 cm×10 cm. Next, in order to investigate the influence of anisotropic cracks on permittivity, we drilled two core samples with a diameter of 2.5 cm and length of 8-10 cm along horizontal and perpendicular directions to its impacted surface from basalt target. Finally, we sliced the core sample, and produced sliced sample with a thickness of 3-4 mm. In order to identify the crack distribution on the surface of slice sample, the surface was polished.

In this study, we measured the bulk permittivity, bulk density, and volume fraction of crack of sliced sample. The permittivity of sliced sample was measured at 5 MHz, which is the same with center frequency of the LRS, by using the permittivity measurement system (TOYO Technica Corporation, Type-1260 impedance analyzer and Type-12962A interface). The density of the sliced sample was derived from the measurements of its mass and volume, and the volume fraction of crack of sliced sample was estimated from the ratio of the crack area to the total surface area of the sliced sample. The crack area was identified by applying an image processing to the picture of the surface of the sliced sample.

With the increase of radial distance from crater center, the volume fraction of crack decreased, and the density and permittivity increased. These parameters (i.e., permittivity, density, and volume fraction of crack) strongly depended on the characteristics of the crack distribution around impact crater. In addition, we could confirm difference between the permittivities of sliced samples including the cracks in different directions based on the comparison of slice samples from two core samples along horizontal and perpendicular directions to the surface impacted by the projectile at velocity of ~5.5 km/s. This difference of the permittivity could be explained by the effective medium theory [e.g., Kärkkäinen et al., 2000]. However, since the difference was enough small with respect to the deviation in the measurement of the permittivity of Apollo samples, we could conclude that the estimation method of the porosity and bulk density from the permittivity measured in radar observation was valid.

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