Development of simplified lunar regolith simulants for resource explorations

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Several space agencies and private companies have announced new lunar missions focusing on lunar resources, further increasing the demands for lunar simulants. Preparation of lunar regolith simulants has become an essential part of a mission for appropriate developments of instruments and designs of rovers and landing systems. Previously, many types of lunar regolith simulants have been developed (e.g., Mckay et al., 1994; Linke et al., 2020), including those used as a standard for general purposes as summarized in Planetary Simulant Database at the Center for Lunar and Asteroid Web page. There is a long history of debates on simulant developments in terms of chemical compositions, mineralogy, particle size distributions, other engineering properties, and thus, a simulant made for one purpose may be entirely unsatisfactory for another (Taylor et al., 2016). Obviously, if soil compositions are adjusted similarly to Apollo landing sites, they are not representing those of the other areas, such as a highland. Satisfactory levels of physical properties, such as grain sizes, shapes, and microvesicles, can vary significantly. Under these constraints, simulated materials with wide ranges of adjustable parameters, including mineral abundances and textures, particle size distributions, particle shapes and surface textures, and chemical composition, could be the most convenient at an earlier stage of mission design. Hence, in this research, we develop simplified lunar regolith simulants with the availability of adjustable specific parameters. Particularly, we aim to develop a production scheme to simulate chemical compositions and mineral abundances of specific regions of the Moon.

To develop rough and simple simulants for the specific areas, including target sights for future explorations, we first constrain the bulk mineral abundances and chemical compositions of target areas from remote sensing data (e.g., Wöhler et al., 2011). We follow the following procedure to develop prototypes: (1) preparing raw materials, which appear to have mineral textures similar to lunar regolith particles, (2) crushing and sieving raw materials to satisfy the particle size distribution, (3) mixing raw materials with appropriate mixing ratio to adjust chemical composition. Raw materials were selected based on the major element, texture, and mineral assemblage. The particle size distribution is determined by compiling data from Apollo soil samples (Graf, 1993). Using a Jaw crusher and stamp mill, we crushed the raw materials into fine powders with angular shapes and jagged surface textures, as seen in the lunar samples. The crushed raw materials were mixed in the optimized ratio to be close to the chemical composition of the regolith in the simulated region.

We compared the elemental compositions of the targeted areas with our prototype simulants. As a result, the elemental compositions of our simulants are within 2.7 wt% difference for ten major elements (Si, Ti, Al, Fe, Mn, Mg, Ca, Na, K, and P) of each target site. We also confirm that the mechanical properties of simulants prototypes (e.g., poured density, tapped density, Hausner ratio, true density, angle of repose) are within those measured values of the samples obtained from the lunar surface (Heiken et al., 1991). The production scheme developed by this study may be used to assist future Japanese missions, including LUPEX and TSUKIMI (Lunar Terahertz Surveyor for KIlometer-scale MappIng) missions.

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