CHARACTERIZATION AND DISCRETE ELEMENT MODELING OF ICY LUNAR REGOLITH UNDER COMPRESSION J. Badal[1] and Q. Chen[2], [1]Glenn Department of Civil Engineering, Clemson University, Clemson SC, Email: jesusb@g.clemson.edu. [2]Glenn Department of Civil Engineering, Clemson University, Clemson SC, Email: qiushi@clemson.edu.

Introduction: The prospective utility of icy lunar regolith (ILR) within the permanently shadowed regions (PSRs) of the Moon is the focus of many of NASA's research efforts and ongoing exploratory missions (Artemis) [1]. As such, the accessibility of H2O and other volatile deposits in lunar PSRs [2] will be essential to advancing human knowledge and its presence in our solar system. The design and application of tools and in situ resource utilization (ISRU) systems needed to excavate and process these essential reserves will require the application of terrestrial civil/geotechnical engineering concepts [3], an understanding of the currently unknown subsurface mechanical properties of ILR within the PSRs [4][5], and its correlation to the tool regolith interactions under lunar conditions. This study uses characterization data of LHS-1 Lunar Highlands Simulant [6] in molding ILR specimens for temperature monitoring and dielectric permittivity testing of various moisture contents at room temperature and frozen in developing a discrete element model (DEM) for ILR. DEM simulations of the unconfined compressive strength (UCS) test are then conducted and validated using the mechanical strength test data of ILR reported in the literature [7]. The resulting model will be used in a sensitive study on the stress-strain behavior of LHS-1, Black Point-1 (BP-1), and Lunar South Pole Simulant-2 (LSP-2) ILR at various moisture contents and the design of DEM-simulated tool-IR interaction.

Technical Approach: Laboratory test specimens were prepared following the methods outlined in Atkinson and Zacny 2018 [7] in which predetermined masses of oven-dried LHS-1 are prepared with moisture contents (wt%) of 1%, 3%, 5%, and 12%. Each specimen was placed in a sealable plastic bag, mixed to allow the moisture to be evenly distributed, and stored in a sealed container to cure for a minimum of 12 hours. Cured samples were molded in aluminum containers with an internal height and a diameter of 7.6 cm and 8.3 cm, respectively, and tamped in three layers to obtain a density of 1.6 g/cm^3. A thermocouple wire was inserted in each specimen during the molding process to monitor core temperature changes during cryogenic freezing, and the molded specimens were placed in the standard chest freezer to pre-cool for at least 12 hours to a temperature of -20° before testing. Precooled specimens were then placed in an LN2 bath to reduce the internal temperature of the specimens to near lunar PSR temperatures of -196 °C. The core temperature of each specimen was monitored using a data acquisition (DAQ) system to observe the changes as they relate to each moisture content. Other cured samples were created using the previously listed moisture content and molding method in plastic containers with a height-to-diameter ratio of 2:1 and were subjected to dielectric permittivity tests at room temperature. Similar specimens were precooled in a standard chest freezer to obtain a temperature of -20° and were subjected to dielectric permittivity tests to determine the relative dielectric permittivity of IR specimens at low temperatures and moisture contents before testing at cryogenic temperatures. Dielectric permittivity tests were also conducted on pure ice specimens to set a benchmark for specimens at 100% moisture content. Laboratory characterization tests were conducted on BP-1 and LSP-2 to obtain their mechanical properties and other parameters needed to simulate the

Figure 1. *Laboratory characterization, Temperature monitoring, and dielectric permittivity testing*

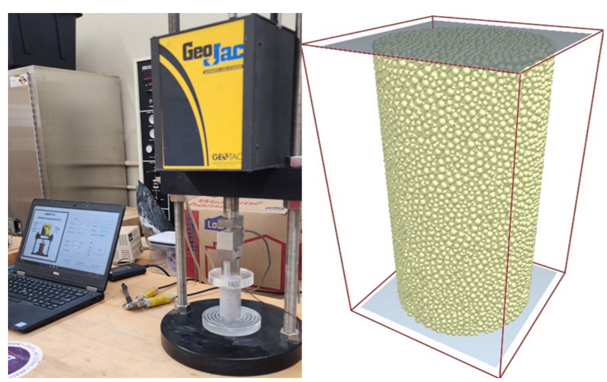

Figure 2. *Laboratory experimental UCS tests and DEM simulated UCS tests*

behavior of these regolith simulants as icy regolith specimens during UCS tests.

DEM Model: Simulated unconfined compression tests were designed to function similarly to a typical laboratory UCS test using the commercial code EDEM. In the model, a cylindrical single-sphere bonded particle assembly is generated with a height and diameter of 6.35 cm and 2.54cm, respectively. The particle assembly consists of 2 mm spherical particles set between a pair of platens with the bottom platen fixed in place and a top platen applying the load by a velocity-controlled mechanism. A Hertz-Medlin (no slip) base model and a standard rolling friction model are coupled with a bonded contact model [8] to simulate the ice-cemented bonds of ILR that break at a given maximum normal and tangential shear stress.

UCS Simulation: ILR cylindrical single-sphere particle assemblies are generated using the known parameters of JSC-1A at moisture contents of 3%, 5%, and 12%. Each specimen is compressed between the top and bottom platen at a rate of 0.00024 m/s until failure or until 15% strain is achieved. The stress-strain behavior of each specimen is compared with the mechanical strength test data as part of the calibration and validation process. Once validated, the known parameters of LHS-1, BP-1, and LSP-2 will be used as inputs in the model to determine the UCS of these ILR simulants at the given moisture contents. The resulting stress-strain behavior will be compared to the laboratory experimental data as part of the sensitivity study.

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