A Novel Method for Icy Lunar Regolith Production. Daniel K Johnson[1], Chris Dreyer[2], and [3]George Sowers, [1]Colorado School of Mines 1500 Illinois St, Golden, CO 80401, dkjohnson@mines.edu, [2] Colorado School of Mines 1500 Illinois St, Golden, CO 80401, cdreyer@mines.edu [3]Colorado School of Mines 1500 Illinois St, Golden, CO 80401, gsowers@mines.edu

Introduction: Creating representative regolith simulants is critical to the testing of rovers, excavators, constructors, and other activities performed in permanently shadowed regions of the Moon. These simulants typically aim to replicate one or more characteristics of the parent body, including mechanical, thermal, and chemical properties. Many lunar regolith simulants exist currently which successfully imitate these properties to varying dergees, with two major compositional differences being lunar highlands and lunar mare simulants. The challenges of creating lunar regolith simulants are further complicated when attempting to replicate icy lunar regolith, which is believed to exist in permanently shadowed regions of the lunar poles. The above mentioned properties have been determined for dry lunar highlands and mare regolith, which significantly aids the design of their simulants, however no in-situ overvations have been made of icy regolith, so it is compositionally an enigma. It is unknown whether the ice forms thick sheets or glaciers, if it acts as a matrix cementing regolith grains together, or if it is loosely mixed with minimal bonding to regolith grains. One thing that is clear, however, is that liquid water has never existed on the lunar surface, and therefore the previous attempts to create icy lunar regolith simulants are unlikely to be representative.

Currently, work in icy lunar regolith simulants have focused around a procedure in which liquid water is mixed into a lunar highlands simulant. The prepared sample is compacted using vibration and a weight, then is frozen. Resulting compressive strengths of samples made according to this method are comparable to concrete, and have prompted players in the industry to drive excavator designs which incorporate high-strength tooling such as jackhammers and drills to overcome this strength. In reality, there is no technical basis for this method of creating icy regolith, and serious doubts to its efficacy exist due to the use of liquid water in its creation. At Colorado School of Mines, this problem is being approached by creating icy granular regolith mixes and applying pressure via a press to cause some degree of fusion between the ice grains and regolith grains. This approach allows a bearing strength to be specified by a combination of water content and applied pressure. In this way, the gap in strength between loose granular regolith and fully-fuzed permafrost-style regolith may be bridged, populating the range of possible mechanical properties that may be seen on the Moon.

Regolith Sample Creation Methodology: In an effort to populate the spectrum of possible material types and strengths, a series of samples have been created which vary by water wt. % and applied pressure. First, a granular mix of ice and regolith simulant is created. Ice is shaved then sieved to below 500 μm. It should be noted that all activites take place in a freezer as fine ice particles melt immediately if exposed to room above-freezing atmosphere. The sieved ice is then mixed with the correct amount of CSM-LHT lunar regolith simulant to achieve the desired wt. % of water. The mixture in then placed in a cup and pressed at a prescribed isostatic pressure level for a duration of 10 minutes. After pressure is relieved, a 10 mm diameter flat head penetrometer was used to measure the maximum load achieved during 10mm of penetration.

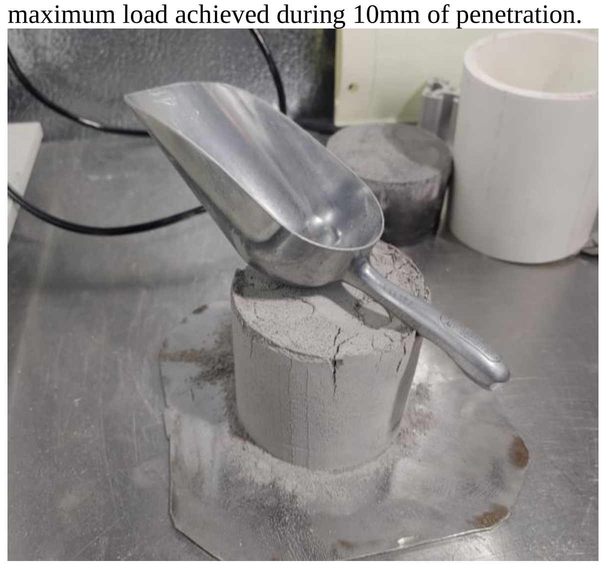

Figure 1: Pressed icy regolith sample extracted from the sample cup, shown supporting a trowel.

The test matrix can be seen in Table 1. At least three repeat measurements were taken for each condition.

Results: The test

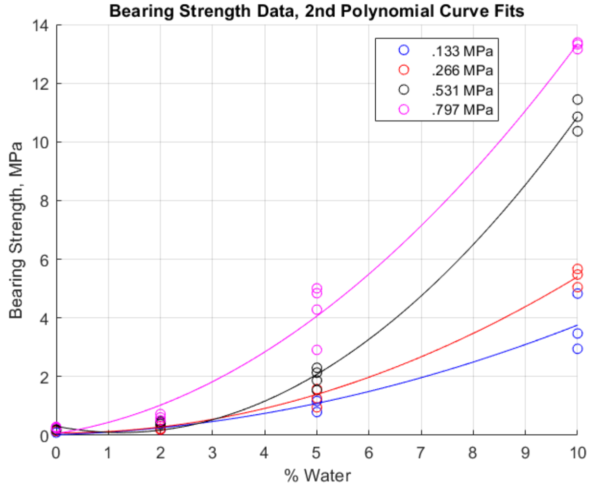

Figure 2: Bearing strength penetrometer data of fused granular regolith penetrometer measurements. 2nd order polynomial cruve fits included.

Table 1: Curve fit coefficients for curves seen in Figure .

Load, MPa	***A***	***B***	***R^2***
.133	**.2516**	**.2708**	**.9079**
.266	**.2916**	**.2922**	**.9789**
.533	**.3117**	**.3554**	**.9951**
.797	**.9131**	**.2686**	**.9727**

In Figure 2 it can be seen that larger amounts of ice content lead to significant increases in bearing strength as measured by penetrometer. Additionally, samples pressed to higher pressures exhibit higher bearing strengths as well. Due to the uncertainty of the actual morphology of icy regolith on the Moon, this plot is an example of the range of strength values that can be expected for a particular wt. % of ice. It can be seen that for wt. percentages below about 3% the difference in regolith bearing strength for different amounts of applied isostatic pressure become minimal. It is only at higher water percentages that drastic increases in strength are seen. In this way, water content data can be used to infer a range of mechanical properties.