CHARACTERIZING DETAILED GRAIN SHAPE AND SIZE DISTRIBUTION PROPERTIES OF LUNAR REGOLITH.

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Introduction: As the nation prepares to return to the Moon, there is an increasing need for testing tools, instruments, and equipment in simulated environments on Earth to ensure successful operations during lunar missions. Regolith will affect all aspects of future lunar missions, from plume interactions during landing to space suit and tool design [1]. Because of this, it is important to understand the grain shape and size properties of lunar regolith and how those influence regolith behavior in order to prepare for these missions. This knowledge is also vital to create more accurate lunar regolith simulants for testing equipment in a lunar environment. While particle size analyses have been performed on most Apollo soils using simple sieving, shape has only been crudely addressed [2]. This work analyzes 4 lunar regolith samples to provide a better understanding of these size and shape parameters and will provide a more accurate baseline of data to create high-fidelity lunar regolith simulants.

Methods: New technologies exist today that are capable of measuring size and shape simultaneously for hundreds of thousands of particles in a single measurement. We conducted a rigorous analysis of the particle size distribution (PSD) as well as the size-dependent 2D and 3D shape parameters of lunar regolith samples of different compositions and maturity levels. This analysis was done using a Microtrac SYNC which provides a unique combination of tri-laser diffraction and Dynamic Image Analysis (DIA).

Sample Selection. Four regolith samples were selected for analysis based on maturity level and lunar terrain type:

- 10084 – Mature high-Ti mare regolith
- 15601 – Immature low-Ti mare regolith
- 64501 – Mature highland regolith
- 67461 – Immature highland regolith

Sample Analysis. After receiving the samples, each sample was imaged with an optical microscope (Figure 1). To obtain 2D and 3D particle size and shape, 0.1 g of each sample was then added to the SYNC for analysis, which outputs more than 30 size and shape parameters for each individual grain as well as the complete size distribution from 0.01-2000 μm by blending laser diffraction and DIA together. For the 0.1 g sample masses requested, ~100,000 grains per sample were captured by DIA.
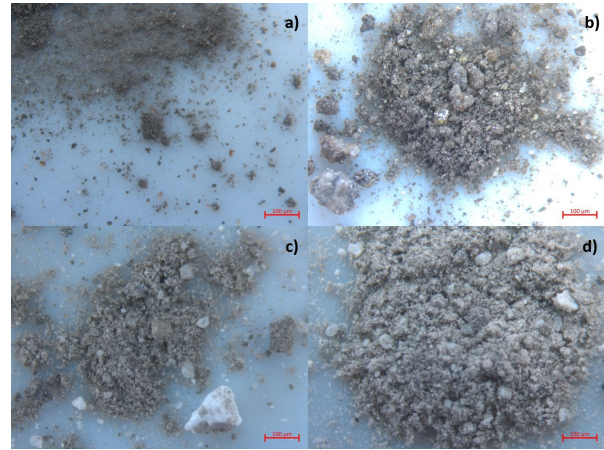

Figure 1. Microscopic images of regolith samples 10084 (a), 15601 (b), 64501 (c), and 67461 (d). Red scale bar is 100 μm.

Results: From the PSD analysis, it can be seen that the average particle size of 10084 is ~24.5 μm which is much smaller than the average particle size of the Apollo sample collection (~72 μm) [3], while the average particle size of samples 15601, 64501, and 67461 are larger than the Apollo sample average at ~106 μm, ~103 μm, and ~118.5 μm respectively.
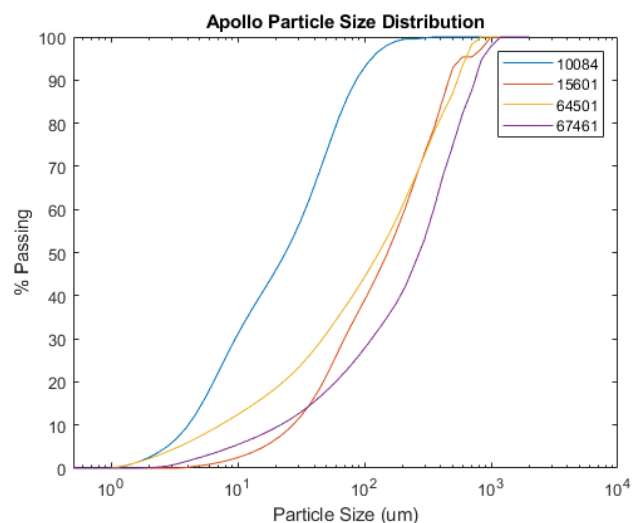

Figure 2. PSD graph for each of the four lunar regolith samples.

The size and shape measurements for the samples output ~30 parameters, four of which were focused on for this study: sphericity, aspect ratio, roundness, and concavity (Figure 3). However, after analyzing the plots it was found that only sphericity and aspect ratio showed differences between the samples. These two parameters are measured on a scale from 0 to 1, with 1 being a perfect sphere with equal dimensions. The results show that the sphericity values are slightly higher for the mature samples 10084 and 64501 (~0.96) than they are for samples 15601 and 67461 (~0.95) (Figure 4). The aspect ratio values are slightly lower for samples 64501 (~0.7) and 67461 (~0.74) than they are for samples 10084 (~0.76) and 15601 (~0.8) (Figure 5).
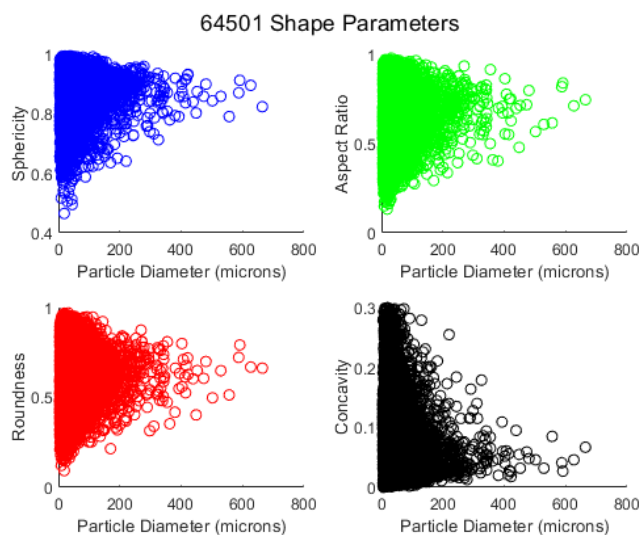

Figure 3. Sphericity, aspect ratio, roundness, and concavity values for the 64501 regolith sample.
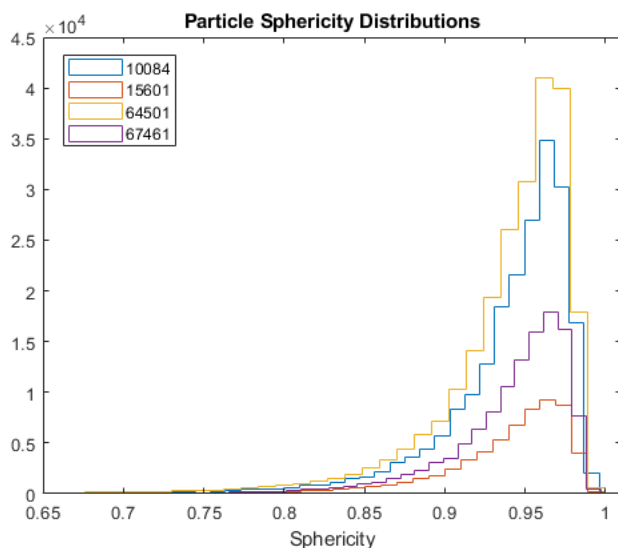

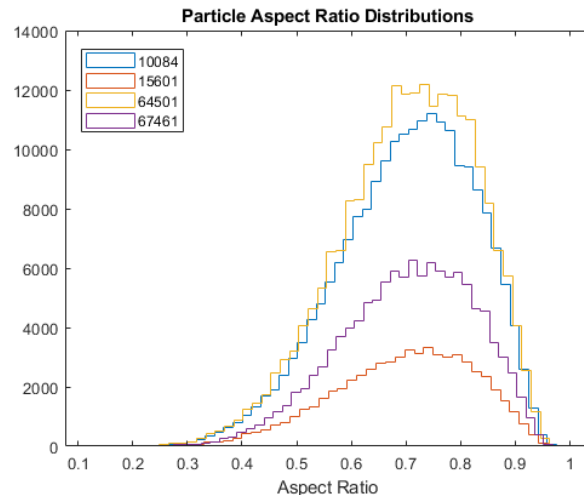**Figure 4.** Particle sphericity distributions for each sample.

Figure 5. Particle aspect ratio distributions for each sample.

Discussion: Mature regoliths are those that have been exposed to micrometeorite and solar wind bombardment for long periods of time, breaking up particles and causing them to become more rounded [4]. Therefore, the smaller particle sizes and higher sphericity values for samples 10084 and 64501 are expected due to their higher maturity level compared to 15601 and 67461. However, the aspect ratio values are not dependent on maturity and are instead dependent on terrain type. The lower aspect ratio values for the highland samples is potentially due to the higher plagioclase content, which occurs in elongated particles and does not break down as easily as the pyroxenes or olivines that are present in the mare.

Conclusion and Future Work: The results of this work provide a baseline of high-quality data that will contribute to the creation of high-fidelity lunar simulants and will greatly benefit NASA's efforts of establishing a human presence on the Moon. Future work includes performing unsupervised image classification on the ~10^5 particle images per sample in order to identify different classes of grains. These grain classes can then be linked to detailed shape properties, and the relative abundance of each class in the samples can be compared.

References: [1] Taylor, L. A. et al. (2005) *AIAA #2510*. [2] Katagiri et al. (2015) *ASCE*. [3] Carrier III, W. D. (2005) *Lunar Geotech Institute Tech Report*. [4] McKay, D. S. et al. (1991) *The Lunar Sourcebook, Chapter 7*.