INCREASED MAGNETIC RESPONSE IN LUNAR REGOLITH SIMULANTS. M. C. Roth¹, V. G. Roux¹, E. L. Roux, ¹Off Planet Research, LLC (contact@offplanetreserch.com).

Introduction: As missions ramp up for the return to the Moon, so has the need for new technology and research that can help close Strategic Knowledge Gaps (SKGs). Just as the landing sites are diverse, so are the instruments, mobility and power systems, and processing equipment being developed to help meet mission goals. With the goal of a long-term, sustained presence on Moon, a better understanding of the various regolith properties, such as magnetic response, can lead to more efficient ISRU processes and better dust mitigation technologies and filtration systems to keep humans safe on the surface or inside habitats.

Replicating nanophase iron in lunar regolith simulants is difficult, expensive, and impractical on the large scale. However, there is a need for simulants that more closely match the iron content and properties seen on the Moon. Off Planet Research (OPR) has developed a process for producing simulants with an increased magnetic response as an alternative to help meet these needs.

Background: Terrestrial materials used for creating lunar regolith simulants do not contain nanophase iron and often have a much lower iron content in general compared to lunar regolith. This is particularly true of anorthosite, which is often a major component in simulants representing the highland regions.

In consultations with clients, OPR noticed the need for simulants with an increased magnetic response that could be used for testing how regolith will interact with ISRU benefaction processes, filtration systems, some remote sensing instruments, and dust adherence studies. This new range of simulants is intended to emulate the magnetic properties of a mature lunar regolith while maintaining as many of the physical properties of standard regolith simulants as possible.

While information is currently limited on the magnetic response of returned lunar samples, particularly highland samples, previous work indicates at least 50 wt% of the particles in a highland simulant should respond to a magnet [1],[2],[3]. This percent is based on previous testing that utilized a single or small number of magnetic field densities acting on complete mixtures of lunar regolith particle sizes.

There is limited documentation on magnetic testing or separation details for lunar regolith. Information from thin section images of mature lunar regolith, such the Figure 1, were used to inform the creation of these simulants with a higher magnetic response by approximating the ~50 micron iron-rich rim surrounding these regolith particles, including agglutinates.

Simulant Composition: The composition is determined through conversations with the client to find the ideal base simulant and percentage of added iron to meet specific research needs. The overall particle size distribution of this simulant normally approximates the average Apollo 17 samples as described in the Lunar Sourcebook unless requested otherwise by the client.

The final composition will be a combination of unaltered simulant particles and particles with adhered iron. To date, OPR has provided multiple simulants with increased magnetic response to clients, including several highland simulant compositions and Mare agglutinates. The process can be extended to the entire range of OPR general regolith simulants and agglutinates.

Simulant R&D: All OPR simulants undergo extensive research and development. In order to determine the original magnetic response of the base simulant, magnetic separation tests were conducted using a calibrated magnet and test fixture with adjustable heights. The total mass picked up for each magnet height was recorded; the magnetic field density (Gauss) for each height is known and the test results are plotted in terms of percent mass collected for both magnet height and increasing magnetic field density. The separation test continued until all of the sample was collected, or the lowest height increment was completed, leaving only the non-reactive material in the original sample behind. This provides controlled and repeatable test conditions to gauge both the effectiveness of the process and the characteristics of the simulant and/or simulant components. This testing was initially conducted on unaltered anorthosite and basalt.
feedstocks both by separate sieve sizes and all sizes mixed.

To be representative of lunar regolith, approximately 50% of the particles need to be picked up by the magnet. Due to the starting magnetic response of the anorthosite and basalt feedstocks, only some of the particles undergo a secondary process to adhere iron. The iron is adhered to individual particles without melting the base simulant or notably altering the particle morphology. The process did require several iterations to determine the best production method while reducing oxidation of the iron.

The altered particles undergo testing and adjustment may occur as needed. After assembling the final simulant, testing is conducted again to determine its resulting magnetic response.

**Findings:** During the first magnetic separation test, the complete simulant behaved differently than expected. It was picked up at lower magnet heights than was previously observed during testing of the individual size components and was in clumps rather than as a collection of particles. This issue did not occur while testing simulants with a more limited particle size distribution (ie. only larger or finer particles).

Possible explanations for this response include the increased friction between the particles within the mixed simulant (cohesion). This is similar to the behavior observed with OPR’s general simulants where the ultra-fine particles tend to cling to, and “hide” within, larger particles. This would increase the effective mass of the affected particles at any given range. It was determined that this behavior was significant and further testing was required.

It was decided to test the full simulant, and then sift out the simulant into parts (groups of related particle sizes) and test those parts separately; the data for the parts would then be compared to the whole to observe any hidden trends in the full simulant and to determine if the effects of the smaller particles accounted for a majority of the trends in the fully mixed simulant.

Graph 1 compares the results for testing the total combined simulant and the sum picked up by parts for each magnet height. These test results quantify the observations made earlier regarding the mixed simulant being picked up at lower heights than the components, as well as the components having a generally wider distribution of magnetic response.

**Conclusions and Recommendations for Future Work:** The addition of adhered iron greatly increased the magnetic response of the simulant and made it more applicable for use in processes that rely on the magnetic properties of lunar regolith.

The test results show that simulants display differing magnetic responses in bulk when compared to those that have been separated by particle size, such as in a benefaction process. Future studies into whether this phenomenon is present in lunar regolith may be beneficial.

As more data becomes available on the magnetic properties of lunar regolith, these mixtures can be tailored to more closely approximate actual mature lunar regolith properties of a particular region.

To fully understand the magnetic properties of this simulant, and the effects of cohesion, further testing may be conducted in a vacuum environment.

It should be remembered that this line of simulants is not intended for use as a mineralogical lunar regolith simulant and may not be suitable for certain types of testing. OPR works with all clients to discuss what type(s) of simulant may be well suited for their research or testing.

**References:**


