RESEARCH AND DEVELOPMENT APPLICATIONS OF LUNAR REGOLITH SIMULANTS WITH INCREASED MAGNETIC RESPONSE. M. C. Roth[1], V. G. Roux[1], E. L. Roux, [1]Off Planet Research, LLC (contact@offplanetreserch.com).

Introduction: Understanding how the iron component of lunar regolith can affect technology and the behavior of regolith during benefaction for ISRU operations is critical for the success of lunar missions and a future lunar economy. The iron content of standard terrestrially-derived lunar regolith simulants is critically different from their related lunar regoliths in both chemical form and physical distribution within and on the regolith grains. This leads to difficulties using standard lunar regolith simulants for certain types of research and development. Lunar regolith simulants with an enhanced magnetic response can improve development and testing of lunar technologies and help assure more successful missions through better approximation of the magnetic properties of lunar regolith.

By looking at the physical distribution of very fine iron particles close to the surface of regolith grains in mature lunar regolith, these enhanced simulants can better approximate the magnetic response of lunar regolith. Simulants with a more realistic magnetic response have research and development applications in many fields including ISRU and dust mitigation. The electro-magnetic effects of this iron content can be helpful in understanding how lunar regolith may affect the transmission and reception of radio signals and the performance of wireless devices on the Moon, the removal of dust from surfaces, and the beneficiation of lunar regolith to produce other commodities.

Background: Analysis of larger regolith particles showed they develop and retain an iron-rich rim about 50 nanometers thick which imparts a magnetic response. The iron content in these rims varies with maturity as more mature regolith appear to have more implanted iron. As regolith particles break down from impact gardening, they become more mono-mineral in nature, with a range of magnetic reactivity.

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. Off Planet Research (OPR) has a line of lunar regolith simulants with an increased magnetic response for clients with specialized research.

OPR's earliest productions of simulants with increased magnetic response were focused on highland simulant variations since they are primarily composed of anorthosite, which terrestrially has very little iron content. However, there has become an increasing interest in how technology may be affected in regions with the highest iron content. These regions are typically Mare patches where returned samples show an iron content of over 20 wt% [1]. To meet this need, OPR has broadened the scope of simulant types that can be enhanced with iron.

Simulant Composition: To represent a mature Mare regolith with an iron content of 20 wt%, the simulant is composed of unaltered and altered particles. The iron content includes both the iron already present in the feedstock materials and iron added to the feedstocks. OPR's objective with this approach is to replicate the distribution of magnetic response within the different particle sizes of mature lunar Mare regolith.

It should be noted the iron is not added in as a stand-alone feedstock or its resulting magnetic response would be independent of the other regolith particles. Rather anorthosite and basalt grains are altered so iron creates a rim on the particles as seen in Figure 1.

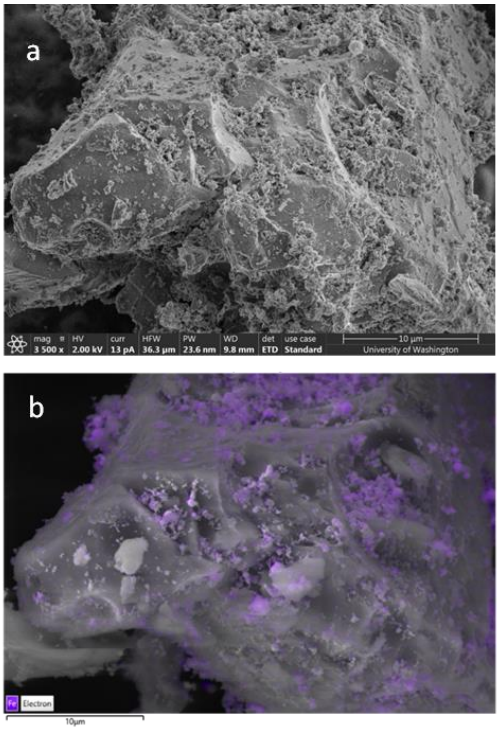
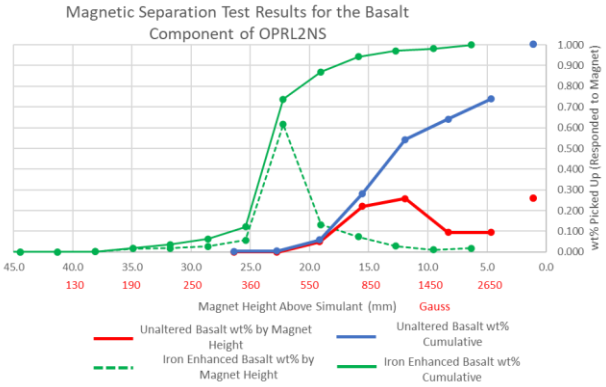


Figure 1: Images of Iron-Enriched Simulant OPRL2NS. (a) SEM image shows broad distribution of 25nm iron particles across feedstock grain. (b) Layered EDS image shows iron nanoparticles in purple. Some clumping is observed. Image Credit: Scott Braswell, University of Washington Molecular Analysis Facility

Simulant Magnetic Response: OPRL2NS is composed of 90 wt% basaltic cinder and 10 wt% anorthosite with both unaltered and altered components. Graph 1 shows a comparison of the unaltered basalt component of OPRL2NS (red and blue lines) with the altered basalt component that has been enhanced with iron (green and green dashed lines). The altered basalt is fully picked up and did so at a lower Gauss than the unaltered basalt. At approx. 450 Gauss, 75 wt% of the altered basalt responded to the magnet while only a negligible amount of the unaltered basalt did. Even at 2650 Gauss, which was the strongest the magnet was during the test, 25 wt% of the unaltered basalt particles still did not respond.



Graph 1: Comparison of the unaltered and altered (iron enhanced) basaltic cinder used in OPRL2NS. Anorthosite components not shown.

Current Work on Iron Content in Lunar Regolith: The Chinese Academy of Science recently announced that the agglutinates in the returned Chang'e-5 samples contained notably larger amounts of ferric iron (forms of oxidized iron) than previously known [2]. Critics of lunar simulants have been concerned that the iron should be entirely elemental. The Chang'e-5 discovery suggests that lunar regolith simulants with increased magnetic response from both oxidized and metallic iron may be more capable of approximating some qualities of lunar regolith, such as magnetic and electro-magnetic responses, than previously expected.

Researchers at the University of Washington have conducted experimental research using wireless power transfer with magnetically coupled resonators (MCR) in the presence of various standard lunar simulants, iron-enriched simulant, and metallic iron powders. Their results for wireless power transfer efficiency, thermal response, and frequency response demonstrated that the metallic iron and particle size of the lunar simulants and iron powder samples are critical factors affecting the coupling of the incident magnetic field [3].

Conclusions and Recommendations for Future Work: The University of Washington results reported in both Garmen et al. (2023) and their 2023 LPSC Abstract 1781 demonstrate that iron content and its particle size play an important role in the EM coupling between a MCR-based WPT field and lunar regolith [3, 4]. Continued exploration of simulant variations with increased magnetic response and how those compositions will respond to various types of testing and test conditions will be important for a number of lunar technologies.

Further analysis of current returned samples as well as future returned samples from new geologic locations will broaden our understanding of the metallic iron content and how this will impact technology. Additional findings from the Chang'e-5 samples and future samples can help better define the forms of iron found in lunar regolith.

It should be noted that this line of simulants may not be suitable for certain types of testing due to the composition alterations. OPR works with all clients to discuss what type(s) of simulant may be well suited for their research or testing.

Acknowledgements:

We would like to acknowledge Shanti Garman and Joshua Smith with the University of Washington for collaborating on the analysis and development of OPRL2NS; their work was funded in part by the NASA Tipping Point program under award 80LARC21CA001.

References:

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[3] Garman S. M. et al. (2023) *Magnetism and Magnetic Materials* (under review).

[4] Garman S. M. and J.R. Smith (2023) *LPSC*, Abstract #1781.