DEVELOPMENT OF A LUNAR AGGLUTINATE SIMULANT. Robert Gustafson¹, Brant White¹, Marty Gustafson², and Dr. John Fournelle³ ¹Orbital Technologies Corporation (ORBITEC), 1212 Fourier Drive, Madison, WI 53717, gustafsonr@orbitec.com, ²PLANET LLC, ³University of Wisconsin-Madison.

Introduction: ORBITEC is developing a process to create agglutinate-like particles from various materials, including JSC-1 lunar regolith simulant. The ultimate objective of this work is to develop a large-scale production process that can be applied any lunar regolith simulant material to create agglutinate-like particles that exhibit many of the unique features of lunar agglutinates. If successful, this process will significantly increase the fidelity of the existing and future lunar regolith simulants.

Definition of Lunar Agglutinates: Agglutinates are individual particles that are aggregates of smaller lunar regolith particles (mineral grains, glasses, and even older agglutinates) bonded together by vesicular, flow-banded glass. Lunar agglutinates have many unique properties, including: (1) a highly irregular shape, (2) presence of trapped bubbles of solar wind gases (primarily hydrogen) that are released when the agglutinates are crushed, (3) heterogeneous composition (due to the presence of individual regolith particles), and (4) the presence of metallic iron (Fe⁰) droplets that are often very fine grained [1].

Importance of a Lunar Agglutinate Simulant: Agglutinates, shown in Figure 2, make up a high proportion of lunar regolith, about 50%wt on average, although their abundances may range from a rare 5%wt to about 65%wt. Agglutinates contain an appreciable amount of metallic Fe⁰ in their glass. Two competing hypotheses regarding the mechanism of formation of Fe⁰ are currently being debated. The prevalent hypothesis holds that Fe-bearing phases (e.g., ilmenite) in the agglutinitic melt are reduced by the solar wind hydrogen implanted in soil grains [2]. The other hypothesis contends that the Fe⁰ forms from dissociation of Fe-bearing phases in a high-temperature (e.g., >3000 C) vapor produced by impacts followed by condensation of Fe⁰ globules on the surfaces of exposed grains in lunar soils [3].

Currently, the only widely available lunar regolith simulants (JSC-1 and JSC-1A) contains few particles that match the shapes and morphologies of lunar agglutinates [4]. The presence of agglutinate particles will have a significant impact on the mechanical properties of the lunar regolith/simulant. The geotechnical properties that are most affected by the agglutinate particles include:

Shear Strength: The particle shape and intragranular porosity have a profound influence on the shear strength of the lunar regolith. Under the low confining pressures found on the surface of the Moon, the highly irregular and reentrant agglutinate particles tend to interlock and produce unusually high shear strength [1].

Compressibility: Lunar regolith is more compressible than current simulants due to the crushing of agglutinate particles under load [1]. The compression index and recompression index can be used to measure this property.

The mechanical properties of the lunar regolith change significantly based on the history of the regolith. High applied loads can cause many of the agglutinate particles to be broken into smaller particles. This is not true of current lunar regolith simulants. In addition, the presence of agglutinate-like particles with “nanophase” Fe⁰ globules will significantly affect some of the thermo-physical properties of the simulant (including the absorption of microwave energy).

Current Status of the Lunar Agglutinate Simulant Development: Past efforts at producing synthetic agglutinates included plasma melting of MLS-1 lunar regolith simulant. This technique was evaluated using an in-flight sustained shockwave plasma (ISSP) reactor at the Mineral Resources
Research Center at the University of Minnesota. This testing concluded in products with unreacted mineral fragments, massive globular glass, and vesicular glass in a variety of textures that resemble some of the glassy components of lunar regolith. However, it failed to produce analogs of lunar agglutinates [5].

ORBITEC is currently developing two different methods to create agglutinate-like particles. Both methods attempt to mimic the fusion of individual grains that is observed in lunar agglutinates. The goal is to produce agglutinate-like particles that exhibit as many of the unique properties of lunar agglutinates as possible. Preliminary results are very promising, with the agglutinate-like particles having the same general size and shape as lunar agglutinates. Figure 2 shows some examples of the agglutinate-like particles produced by ORBITEC using JSC-1 lunar regolith simulant. Note how individual grains are bonded by in glassy melt regions.

When the surfaces of the agglutinate-like particles are examined closely, numerous “nanophase” Fe⁰ globules can be seen (see the bright spots in Figure 3). Note how the Fe⁰ globules tend to form in “trains” in both lunar agglutinates and the agglutinate-like particles. At least 50% of the Fe⁰ globules in lunar agglutinatic glass are entrained in flow lines and many smaller globules occur in clusters. Approximately 99% of the Fe⁰ globules in lunar agglutinates have a diameter of 1 µm or less [6]. In the agglutinate-like particles analyzed so far, the Fe⁰ globules range is size from 10’s of nanometers up to about 2 µm in diameter. The same Fe⁰ globules have been found extending into the glassy melt regions. Energy dispersive spectrometry (EDS) and wavelength dispersive spectrometry (WDS) have verified that the iron globules are nearly pure Fe⁰ and not iron oxide.

References: