Sintered Regolith: *For Martian, Lunar, and Terrestrial Construction*

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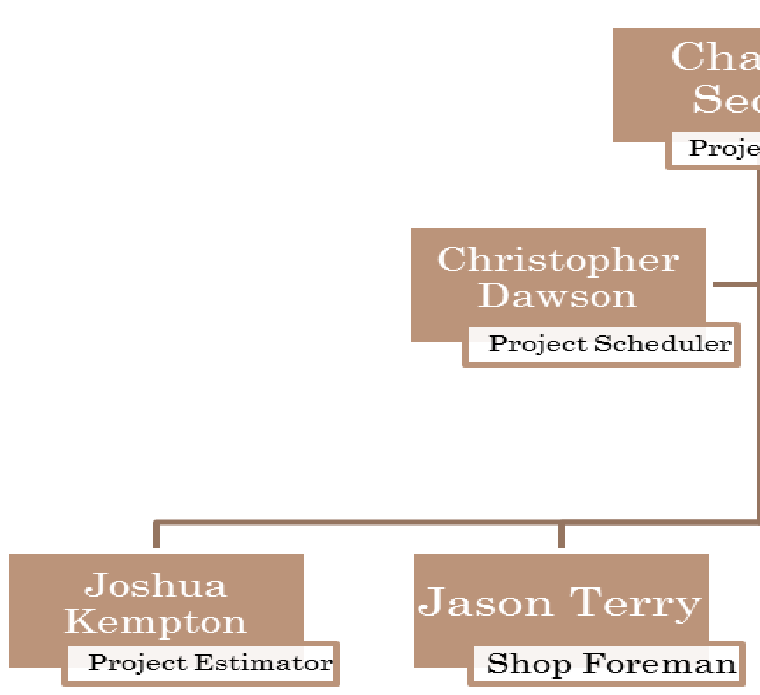
Abstract

This project proposes laboratory flexural and compressive testing of sintered regolith samples to determine the material's mechanical properties in support of the Surface Systems research at NASA and Florida Tech's Buzz Aldrin Space Institute. The Surface Systems group at NASA's Kennedy Space Center is researching In-Situ Resource Utilization (ISRU) technologies, including the potential for regolith as a construction material on Mars. This project will also examine the possibility of sintered regolith as a sustainable innovation in construction materials on Earth. However, data regarding the engineering properties of sintered regolith simulant are currently insufficient and those that are available have yet to be laboratory tested. This project involves the fabrication and testing of samples composed of sintered planetary regolith simulant, as well as design and modeling of conceptual construction methods which might be applied to buildings, launch pads, roadways, ablative heat shields, and other Martian, Lunar, and Terrestrial infrastructure. Compression, splitting tensile and flexural testing of the sintered regolith samples will yield various mechanical attributes such as compressive strength, flexural strength, and splitting tensile strength. The same testing will be carried out with Quikrete No. 1004 concrete specimens serving as an experimental control. The information from this project shall aid in the development innovative construction methods which show promise as building methods for the Earth, Moon, and Mars. Therefore, the proposed research is critical in order to effectively engineer equipment and structures for Martian Infrastructure and beyond by exploring the sintering process and testing.

Work Cited: Mueller, Robert P., et al. "Additive Construction using Basalt Regolith Fines". NASA. 2014. Web, 2015.

Research Team

From Left to Right: Chris Dawson, Joshua Kempton, Charles Sedor, Jason Terry, Amro Aledresi, & Edward Lopizzo**.**



The Regolith Research Team consists of six seniors in Construction Management in the Organizational Structure at left.

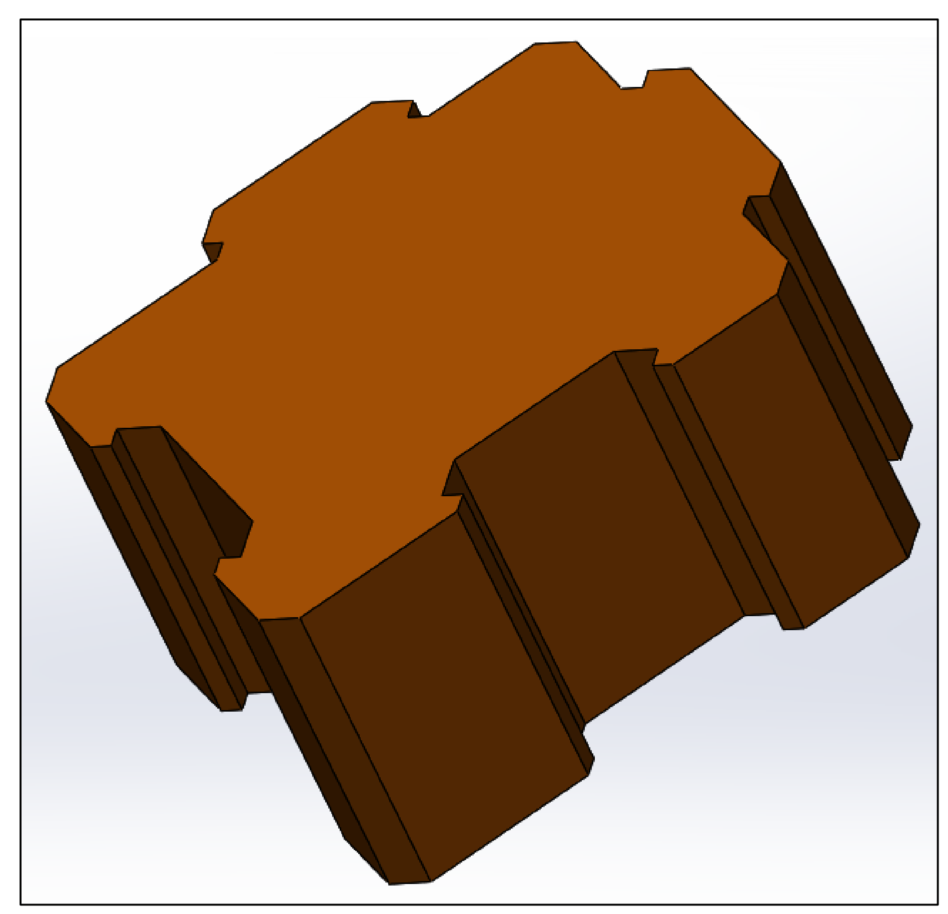
Problem Statement

There appears to be a gap in the technical data available regarding the engineering properties of sintered regolith, a material that shows promise as an innovative construction material. This project will:

- Provide data to bridge this gap and aid in the research of future sintered regolith technologies.
- Explore the possible applications of sintered regolith for:
  - Modular Construction, using mortar less Sintered Regolith Masonry Construction
  - Additive Construction, or 3D printing

Sintered Regolith Masonry Unit

The scarcity of water on Mars means that masonry construction must be done without mortar. Therefore, the team designed the Sintered Regolith Masonry Unit with the ability to interlock to create structures. This block is 8" x 10" x 6", not counting the shear keys extending 1" beyond the face of the block. These blocks would be fabricated on Mars from sintered regolith, either by extrusion or additive construction (3D printing).



In order further engineer this construction technique, the team must carry out testing in order to determine certain physical properties of sintered regolith. This information will also be helpful when designing equipment for additive construction. The team designed a model robotic arm to demonstrate principles that will be used for 3D printing regolith structures.

Methods

Testing specimens will be composed of Quikrete No. 1004 concrete, and two planetary regolith simulants, as shown in table below. These simulants were formulated using low-cost components to mimic the regolith environments of the Moon and Mars. The level of iron-oxides and aluminum-oxides vary in Regolith Research Team (RRT) Simulant A and Simulant B in order to determine the effect of iron and aluminum oxide content on the strength of sintered regolith.

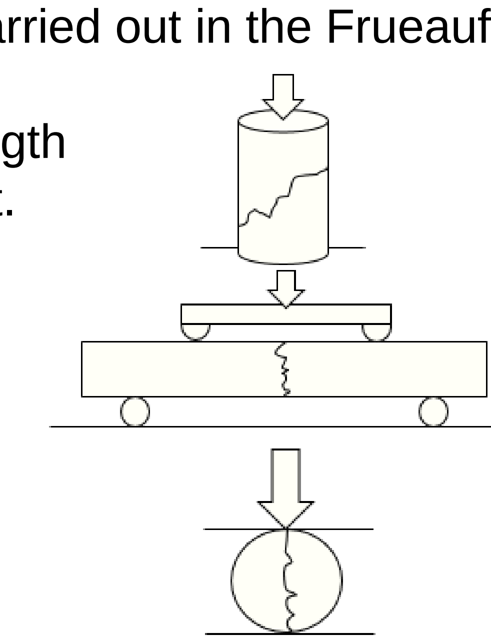
Regolith Simulant

Research Simulants (mass%)		
Component	Simulant A	Simulant B
Sand	50	50
Fe2O3	20	10
Basalt Rock	20	20
Al2O3	10	20

Table 1 (above) shows the composition of the team's Martian regolith simulants. **Table 2** (right) shows the team's simulants compared to planetary regolith and other common simulants.

Regolith Composition (mass%) by Planet							
	Mars			Moon	Arizona, Earth		
Oxide	JSC Mars-1 Simulant	Pathfinder	Viking Lander	Mare	BP-1 Lunar Simulant	RRT Simulant A	RRT Simulant B
SiO2	**43.7**	**43.8**	**44.7**	**46.7**	**47.2**	50.6	50.6
TiO2	3.8	0.7	0.9	1.7	2.3	-	-
Al2O3	**23.4**	10.1	5.7	**13.2**	**16.7**	10.00	20.00
Fe2O3/FeO	**15.3**	**17.5**	**18.2**	**16.3**	**12.1**	20.97	10.97
MnO	0.3	0.6	-	0.21	0.21	0.03	0.03
MgO	3.4	**8.6**	**8.3**	10.9	6.5	0.43	0.43
CaO	6.2	5.3	5.6	10.4	9.2	1.12	1.12
Na2O	2.4	3.6	-	0.38	3.5	-	-
K2O	0.6	0.7	0.3	0.23	1.1	0.35	0.35
P2O5	0.9	1	-	0.16	0.52	0.31	0.31
SO3	-	5.4	7.7	-	-	-	-
Cl	-	0.6	0.7	-	-	-	-

Concrete specimens are prepared and submerged in water to cure prior to testing. Regolith specimens must reach at least 1200˚ Celcius in order to be sintered (Mueller). The energy-intensive aspect of the sintering process has proven to be the team's largest obstacle. Even with a propane fired foundry, the team found it necessary to add sodium bicarbonate to the mixture to lower the melting temperature. If the team is able to produce or to obtain sintered samples from NASA, the following tests shall be carried out in the Frueauff Lab.



- **Compression Test**

The compression test yields the compressive strength of a 4" diameter, 8" length cylinder standing upright.

- **4-Point Flexural Test**

The Flexural Test yields the flexural strength of a of a 2' long, 3" thick beam laying on its wide side

- **Splitting Tensile Test**

The splitting tensile test yields the splitting tensile Strength of a 4" diameter by 8" length cylinder placed on its side and compressed until rupture.

The data gathered through these tests, along with the insight gained through the team's own concepts for using sintered regolith, will be a valuable contribution to the growing field of in-situ resource utilization.