Synthesis of Regolith Bricks in application to In-Situ Resource Utilization on Extraterrestrial Surfaces. J. C. Barton[1] P. A. Rupar[2] J. E. Bara[3] M. Fiske[4] and J. A. Cartwright[1], [1]Department of Geological Sciences, University of Alabama, Tuscaloosa, AL 35487, USA. [2]Department of Chemistry and Biochemistry, University of Alabama,. [3]Department of Chemical and Biological Engineering, University of Alabama. [4]Jacobs Space Exploration Group jcbarton3@crimson.ua.edu

Introduction: Growing interest in Mars as a target for future NASA exploration presents an emerging challenge of space travel and extraterrestrial habitation, as technologies must be responsive in foreign environments. Additionally, financial restrictions associated with space travel and transporting equipment as mission payloads limit what can and cannot make it off the Earth's surface for use on another planetary surface. With the Moon an active return target locality for NASA with the Artemis Base Camp [1], Mars is a further step into the Solar System. Through the process of in-situ resource utilization (ISRU), the collection, processing, and storage of materials found or manufactured on extra-terrestrial surfaces acts to replace those that could be brought from Earth, thus eliminating financial constraints and enhancing practical means for habitation. This is particularly relevant for Mars, given the exponential costs associated with its distance to Earth.

As no samples have been returned from Mars (yet) and Martian meteorites are rare, it is not possible to use 'true' Martian materials to develop ISRU. Instead, Martian analogues, composed of specially selected, delithified terrestrial materials, are used to replicate chemical and mechanical properties of Martian regolith for experimentation regarding in-situ resource construction. By combining a Martian Regolith Simulant (MRS) with an epoxy-resin, experimentation performed may synthesize a stable Martian regolith brick to serve as an introductory, yet fundamental component for advanced development and sustainment of Martian habitation by means of ISRU.

Objectives: This study looks to establish a composite regolith brick offering the following practicality and stability parameters: (1.) Use of an epoxy ratio that hardens in a timely manner (<8 h) without causing extensive exothermic reactions, which would harm the structural viability of the sample or mold; (2.) Creation of a solid material, with enhanced structural integrity under the differing pressure, atmosphere, tectonic, and solar conditions of an extraterrestrial terrain; (3.) Consideration of required shielding from solar radiation; (4.) Low porosity and permeability for a habitat brick; and (5.) Use of the maximum weight percentage of regolith in the epoxy/analogue brick, to off-set the costs of using Earth-based materials. In reaching these objectives, a regolith brick may be formed that: (1.) Cures in the fastest time, leading to the quickest pace of extraterrestrial development; (2.) Provides maximum safety measures against the environment of an extraterrestrial planet; and (3.) Is financially viable.

Martian Regolith Simulant: To construct a Martian Regolith Brick, Martian Global Simulant (MGS-1) created by Exolith Labs and commercially available has been selected as the functioning analogue. MGS-1, developed based on quantitative mineralogy from the MSL Curiosity Rover, serves as a mineralogical standard for basaltic soils on Mars [2]. Mineralogy inclusion and corresponding weight percentage, are as followed: plagioclase (27.1%), glass-rich basalt (22.9%), pyroxene (20.3%), olivine (13.7%), Mg-sulfate (4.0%), ferrihydrite (3.5%), hydrated silica (3.0%), magnetite (1.9%), anhydrite (1.7%), Fe-carbonate (1.4%), and hematite (0.5%) [2].

Epoxy-Resin System Determination: Volatility of polyfunctional binding agents is an essential consideration for epoxy-resin systems in an extra-terrestrial environment, where low pressures on the Martian surface could cause damage to the materials. The low-volatizing polymer, polyethylenimine (PEI), has resultingly been chosen to function as a binding agent for Hexion EPON 828 General Epoxy, to form a solid, non-volatizing thermosetting material [3], and our experimentation with this combination has resulted in viable solid resins.

Fig. 1. Epoxy-resin experiments performed in the lab detailing varying epoxy-resin ratios and a cured, thermoset system.

Weight percentage ratios 1:1-1:25 of PEI and resin respectively were assessed qualitatively in regard to curing rate and thermodynamic response (Fig. 1). Sample reactions favorable for ISRU processes feature fast curing rates (< 8 h) in a thermally controlled way.

After introducing MRS to the epoxy-resin system, compositional percentages of analogue and epoxy were assessed for optimal structural integrity while utilizing maximum simulant quantity, as to increase applications of practicality associated with ISRU. Constructed simulant regolith bricks thus exist as an assortment, with variable hardener-resin ratios and MRS amounts.

Mold Variation: We developed two mold systems for curing of the PEI and Hexion EPON 828 General Epoxy system after incorporation of MRS. The first is a single use, additive manufactured polylactic acid (PLA)

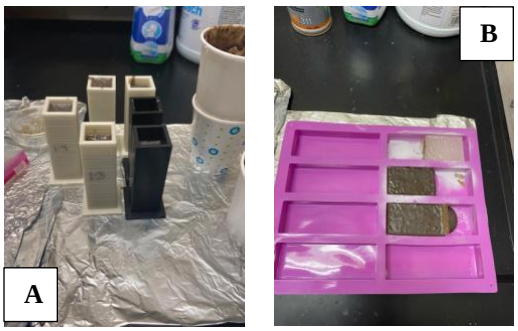

Fig 2: Polylactic Acid and Silicone Molds with varying epoxy-resin ratios and MRS quantities.

mold (Fig. 2A), while the second is a reusable silicone mold (Fig. 2B). After curing, PLA molds are submerged in tetrahydrofuran (THF) for a 24 h duration, allowing for mold dissipation and brick retrieval. Regolith bricks cured in silicone molds are removed after an 8 h period. The beneficial characteristics associated with additive manufacturing, the opportunity for automated brick creation, and the reusable nature of our two molds offer practical application for regolith brick production on Mars.

Preliminary Results: The successful formation and retrieval of regolith bricks using MRS and an epoxy-resin system incorporating a non-volatizing polymer has been noted through experimentation. Thermosetting of the MRS-epoxy system has occurred in both PLA and silicone molds.

Fig 3. Regolith bricks composed of MRS in varying epoxy-resin ratios post-dissipation of polylactic acid molds in THF.

Epoxy-resin systems, initially including ratios of 1:1-1:25 have been narrowed to three individual ratios of 1:2.5, 1:4, and 1:8 that offer rapid curing rates with low thermodynamic response. Lower ratios were accountable for high enthalpy responses (note clear dark yellow color of resin in Fig. 1B) while high ratios accountable for low rate of curing.

With the incorporation of MRS to epoxy-resin systems, our preliminary analogue weight percentage has reached 34.9% in silicone molds and 27.00% in PLA molds. Viability of increasing MRS quantities in both PLA and silicone molds has occurred independently of varying epoxy-resin ratios. We plan to continue to experiment to increase the analogue wt% of the bricks in our further experiments.

Future Work: After production and retrieval of regolith bricks, analyses will be performed to test structural integrity, radiation shielding, and porosity. This will include flexural testing, hardness testing, and water absorption testing. Porosity of the samples will be characterized at NASA/MSFC using a Germann Instruments Rapid-air system. Imaging using standard microscopy and a scanning electron microscope (SEM) within the Alabama Analytical Research Center (AARC) will also be performed to characterize microstructural components of the bricks, which can be assessed statistically. SEM will also allow us to gain information about the chemical properties of the composites created, as well as information about the distribution of analogue throughout the brick. As regolith bricks are predicted to have varying properties in correlation to varying epoxy-resin systems and analogue weight percentages, a range of resulting data is expected. Optimization of regolith bricks will succeed said analyses with incorporation of maximum MRS quantities.

Following established procedure for Martian regolith brick creation through ISRU, adaptation of similar experimentation can be applied to other analogue materials, including Lunar Highland Regolith, to help correlate our findings with previous studies (e.g., [4]).

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