CASTING LUNAR REGOLITH FOR MANUFACTURING CONSTRUCTION MATERIALS. K. Edison[1] and, K. M. Cannon[1,2]. [1]Colorado School of Mines Space Resources Program, Golden CO, 80401. kedison@mines.edu. [2]Colorado School of Mines Department of Geology and Geological Engineering, Golden CO, 80401.

Introduction: Manufacturing materials on the Moon will require a great deal of energy. In-situ resource utilization (ISRU) is the means by which to reduce payload and mass costs for crewed missions to the Moon and later Mars. Costs can be brought down by using regolith as a resource for creating construction materials and extracting volatiles. Habitation on the Moon and Mars will require materials for launch/landing pads, infrastructure, and shielding. There are currently several existing techniques that are being adapted for manufacturing in space, examples of which include sintering, additive manufacturing, and casting. Each technique requires significant amounts of energy and time which translates to high costs. It is desirable to find ways to make these techniques more efficient. Casting seems like it could be the most energy intensive because it requires fully melting regolith so it can be poured into a mold, rather than heating it just enough to bond regolith grains like in sintering [1]. However, sintering has been demonstrated by PISCES to be timely. To sinter one basalt tile required ramping the temperature to 1,180 °C, holding for 2-3 hours depending on tile size, and then allowing for a slow cool. In all the process took 3.5 days, leading to a high energy demand, likely exceeding casting [1].

The lunar regolith is divided between the mare which is mostly composed of basalt (plagioclase, pyroxene and olivine dominant) and the highlands mostly composed of anorthosite (90-100% anorthite plagioclase, 0-10% mafic minerals) [2]. This may pose a challenge for casting on the Moon as both rock types have high melting ranges. Depending on basalt composition its melting range is between 960 ℃ to 1,260 ℃, and anorthite, the main constituent of anorthosite melts at ~ 1,553 ℃ [2]. This will require a significant amount of energy. Although the energy needs are high there is still good reason to investigate lunar regolith casting. For approximately one hundred years, the Czech Republic in particular has shown great success in producing cast basalt materials like piping and tiles that are wear resistant and temperature resistant up to 400 ℃. Casting in space has been proposed in the past, with some melt experiments and thought experiments [3,4], however, casting lunar regolith as a potential means to develop construction materials has not been widely investigated for space applications in the same way as sintering or additive manufacturing.

Methods: We are undertaking a series of casting experiments to validate its applicability on the Moon or Mars. The objective of these experiments is to identify the ideal melting and pourability conditions for various regoliths, material strengths as a function of composition and solidification rates and mixing molten metal or silicate binders with unmelted regolith to drive the energy needs down. Previous work by the lead author at Hilo Hawai'i has demonstrated that sinterability and material strength were reliant upon regolith chemical and mineral compositions [1]. This is expected to also be true of casting [3]. Fig. 1 shows sintered products produced by PISCES Hawai'i of various basalt aggregates and compositions from various quarries from the Big Island.

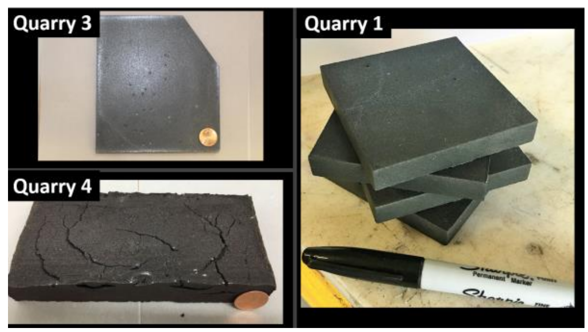

Fig. 1. Sintered materials from various basalt aggregates sintered at 1,180 C, but due to composition there is a variation in results on sinterability.

Our planned casting experiments include 1) casting basalt and anorthosite, then mixtures thereof; 2) casting basalt into a mold with a porous framework of unmelted clasts to reduce energy costs. 3) casting molten aluminum (available as surplus from spacecraft) into a mold with silicate grains, the aluminum acting as a binding agent. The experiments will take place at Colorado School of Mines foundry hot shop and will use a gas-powered furnace and graphite crucibles. Graphite is selected for its high heat tolerance of approximately 3,000 ℃. Green sand molds will be used, which include clay and water or sometimes oil to bond the grains of sand together. This is typically done in a metal flask with a pattern to create the cast shape; the sand can be reused. We are starting with green sand but may later choose to try other molding methods such as metal, regolith or ceramic to determine the best molding methods. Figs. 2 & 3 shows the Mines foundry in full operation, and an example of sand molds being used to cast aluminum.

Fig. 2. Foundry in full operation at the Colorado School of Mines.

Fig. 3. Open mold showing the cast aluminum after solidification.

The first castings will be simple shapes including small rectangular coupons. It will be necessary to understand melting times, pouring temperatures, solidification and overall pourability before moving on to more complex shapes. Measured quantitative data will include flexural and compressive strengths, porosity, heat capacity and thermal conductivity. These data will give valuable insight into the materials' ability to function in extreme conditions.

Conclusion: There are several viable techniques to manufacture materials in space, but none of which have been effectively developed for space-based applications. The experiments described herein will test the viability of casting construction materials on the Moon and Mars and if it can be done in an energy-efficient way, without sacrificing quality.

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