CASTING LUNAR REGOLITH FOR MANUFACTURING CONSTRUCTION MATERIALS

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Photo Credit: Kyla Edison

Introduction

- Manufacturing materials on the Moon will require a lot of energy.
- 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 adapted in space:
  - Sintering
  - Additive Manufacturing (AM)
  - Casting
- Casting Lunar regolith has not been as widely researched as sintering and AM.

Basalt Research
PISCES Hawai'i

Can a durable construction material be produced from basalts of varying chemical compositions?

- Open air kiln
- Characterization of quarries and analog sites samples through:
  - Location,
  - Lava flow & age of the flow,
  - Volcano of origin,
  - EDXRF/XRD chemical/mineral analysis.

Photo Credit: PISCES Hawai'i

Basalt Sintering

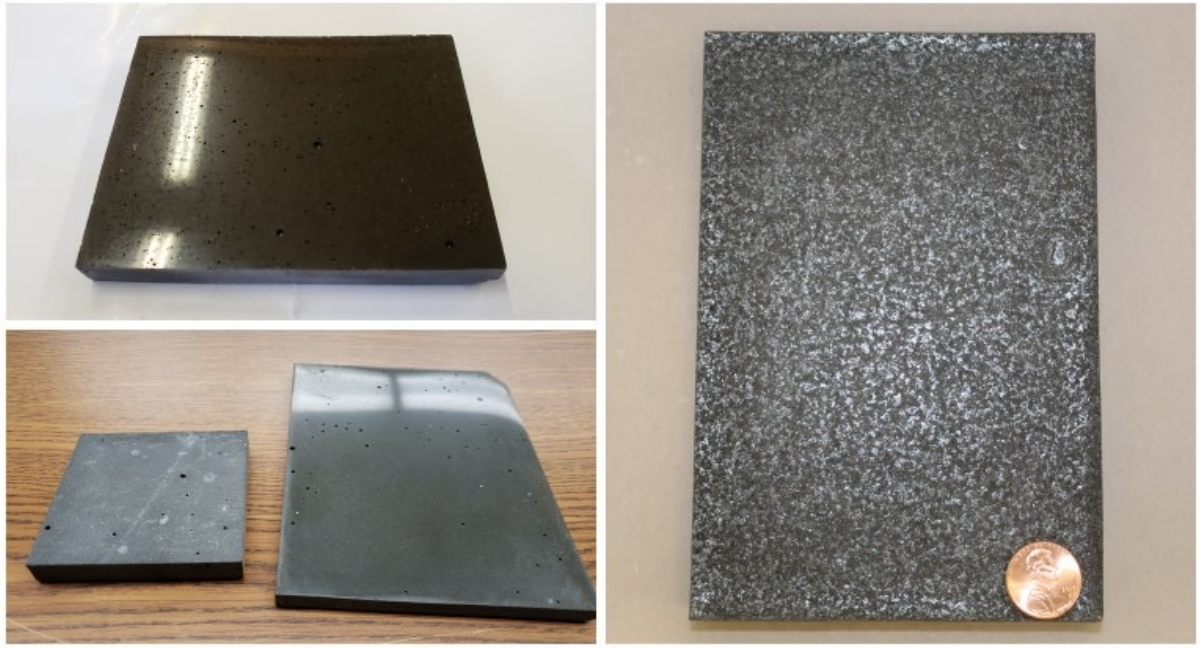

Photo Credit: PISCES Hawai'i

- Required ramping temperature to 1,180 °C,
- Hold at temperature for 2-3 hours depending on tile size and then allow for slow cooling,
- The entire sintering process takes 3.5 days,
- Required ceramic molds and a mold release agent,
- Could not sinter complex shapes,
- Tiles typically had several surface pores,
- Tiles could be made to have varying surface textures / could be polished.

PISCES
Pacific International Space Center for Exploration Systems

Basalt Research *PISCES Hawai'i: Materials Testing*

Sintering Hawaiian basalts have shown to create materials that have a high strength tolerance; however, this is reliant upon the chemical and mineral composition of the parent rock.

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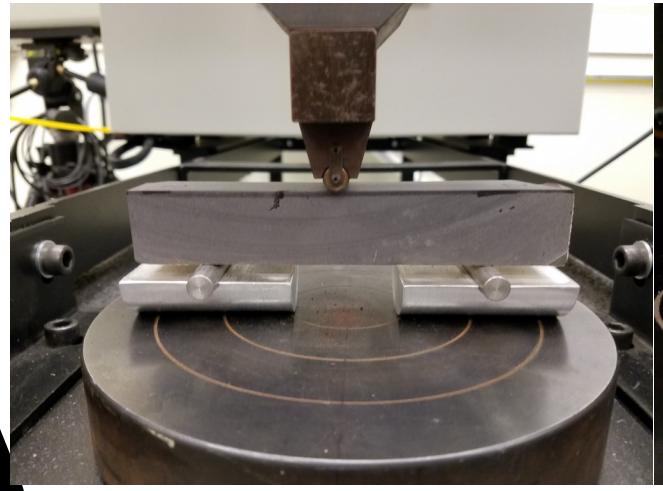

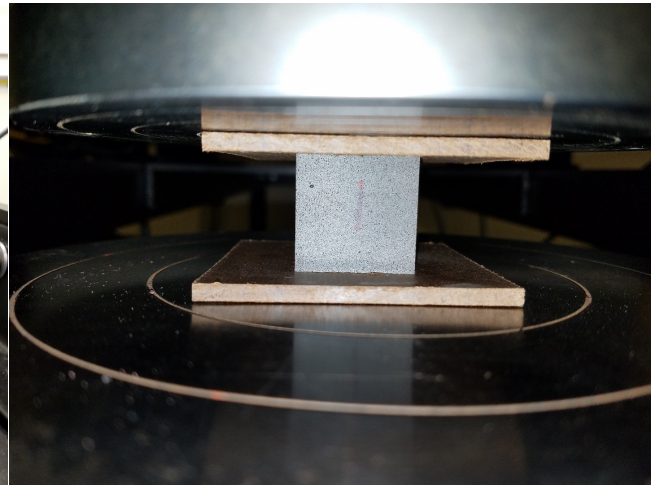

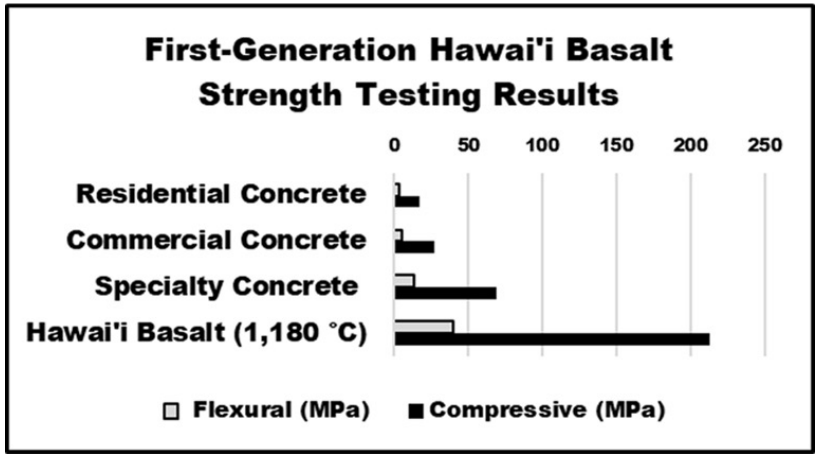

Test	Residential Concrete	Hawai'I 1,150 °C	Commercial Concrete	Specialty Concrete	Hawai'I 1,180 °C
Flexural Stress (Mpa)	3.44	4.93	5.51	13.79	40.35
Compressive Stress (Mpa)	17.24	21.48	27.58	68.95	212.5
Density (g/cm^3)		1.7			2.64

Anorthosite & Basalt Casting for Space Resources

Anorthosite Casting

- *The moon is ~83 % Highlands made up of a silicate rock known as anorthosite,*
- Melting temperature: *1,553 °C*
- Pouring temperature: *~ 1,653 °C*
- Crucible type: *Silicon Carbide (SiC)*
- SiC melting temperature: *2,730 °C and used in casting steel.*
- *Not much if any research on casting anorthosite.*

Basalt Casting

- *The moon is ~ 17 % Mare made up of a silicate rock known as basalt,*
- Melting temperature: *960 °C – 1,260 °C (dependent on basalt composition),*
- Pouring temperature range: *1,060 °C – 1,360 °C,*
- Crucible type: *Graphite (C),*
- C melting temperature: *~3,600 °C,*
- *Casting Earth basalt is common but not common for space applications.*

Cast Basalt

Cast Basalt is formed by "Melting and Recrystallizing" naturally occurring basalt rock. Slow controlled cooling forms finely crystallized ceramic.

- Basalt casting has been done for over 100 years.
- Mastered for the last ~70 years
- Uses include:
  - Pipework,
  - Chutes,
  - Ash slurry pipework,
  - Coal bunkers,
  - Cylinders,
  - Tile,
  - Hoppers.

Photo Credit: Eutit.com

Properties of Cast Basalt Include:

- Resistance to abrasion surpassing that of steel,
- Enhanced durability,
- Resistant to most acids and lyes,
- Hardness of 8 on the MOH's scale.

Aluminum Binder Experiment

To cast molten aluminum (available as surplus from spacecraft) into a mold with silicate grains, the aluminum would act as a binding agent.

- Experimentation and casting will be done at the Colorado School of Mines foundry.
- 2 wax patterns created:
  - 3D printed
  - Paraffin wax cast into toilet paper tube.

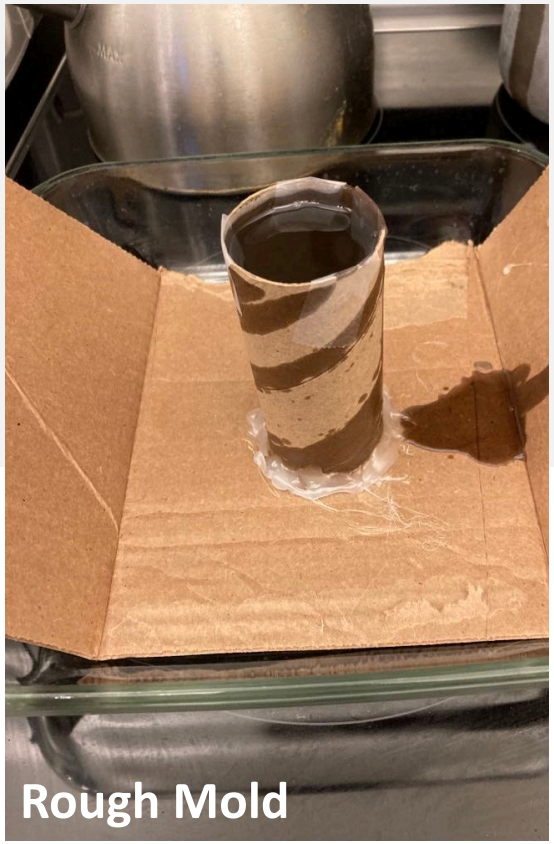

Photo Credit: Kyla Edison

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Aluminum Binder Experiment

- 3D printed mold ~1 mm too big for casting flask, so paraffin pattern was used,
- Solid investment cast around the wax pattern to create casting mold,
- Wax burnt out using a kiln, grains placed into the mold cavity and placed back into the kiln at 260 °C for 30 minutes.


Photo Credit: Kyla Edison

Aluminum Binder Experiment

- Commercially pure aluminum was melted at ~760 °C for ~ 30 minutes,
- Mold was placed into a vacuum chamber while aluminum was cast into the mold, in hopes of pulling the molten aluminum through the grains,
- Once aluminum was cast the mold was placed back into the kiln for slow cooling.

Aluminum Binder Experiment Results

Moving Forward:

- Heat aluminum for longer,
- Use larger grain-size,
- Heat the grains for longer at a slightly higher temperature,
- Larger 3D printed wax pattern,
- Sand mold.


Opened Flask Mold


Failed Material

Photo Credit: Kyla Edison

Future Work

1) Casting basalt and anorthosite (Lunar regolith simulant), then mixtures thereof,
2) Casting basalt into a mold with a porous framework of unmelted clasts to reduce energy costs,
3) Continue and refine the aluminum binder experiment,
4) Materials created will be compared to the PISCES tiles sintering process and materials properties,
5) Materials testing will include:
   - Flexural and compressive strength testing,
   - Heat capacity,
   - Thermal conductivity,
   - Thermal expansion,
   - Thermal shock,
   - Rocket blasting?

Photo Credit: Kyla Edison

Future Work Continued

Other tests that will be conducted:

1. Fluidity testing of molten basalt & anorthosite,
2. Solidification time of molten material,
3. Testing of various mold materials such as:
   - Sand,
   - Ceramic,
   - Metal.

Photo Credit: Kyla Edison

References

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