MOON-OPOLY

Utilizing In-Situ Resources to Create Lunar Concrete

Nathaniel Ellis
Durango High School
Durango, CO
USA

MATS032

INTRODUCTION

Over the past year, I've been curious about what it would take to live on the moon, which included a secret desire to become a lunar Real Estate Mogul!

The Colonization of other planets in our Solar System may become critical to the survival of our species. The moon has been identified by NASA as the first location they will attempt colonization, and it will be used as a learning lab. Once we can prove some of the concepts we need to survive on the moon, we could use it as a springboard to colonize other planets, including Mars.

If we're going to set up some kind of long-lasting lunar base, we will need to utilize the resources that we find there to keep our astronauts (and visitors) alive. NASA is calling this group of activities In-Situ Resource Utilization (ISRU). Fortunately, the Moon may have a lot to offer in terms of resources that are already available.

The focus of my Science Fair project centers around the construction of Lunar Concrete using material currently available on the moon. I initially investigated two methods - making concrete from lime, and making concrete from sulfur.

Research Question: Can a viable building material be created using materials on the moon, such as lunar regolith?

Progress in the field: Sulfur-based concrete is currently made on earth before, and is used for highly acidic conditions where conventional concrete does not last. Investigations have been made using lunar regolith and sulfur to make concrete, but its viability as a building material on the moon has not been conclusive.

HYPOTHESIS

Lunar regolith (simulant) will, when combined with elemental sulfur and heated above 140 degrees celsius, form a concrete-like substance, and resist compression and shear stresses at a level similar to normal concrete.

METHODS

A regolith simulant was purchased online. I chose the LH-1 Lunar Highlands Simulant manufactured by Exolith Labs. This material is a high-fidelity, mineral-based simulant appropriate for an average highlands location on the Moon. The simulant is not made of a single terrestrial lithology, but accurately captures the texture of lunar regolith by combining both mineral and rock fragments (i.e., polymineralic grains) in accurate proportions. The particle size distribution of the simulant is targeted to match that of typical Apollo soils.

Elemental sulfur was also purchased online. Differing from previous experiments conducted with sulfur concrete, I weighed and cold-mixed the sulfur and simulant, shaking the ingredients for 5 minutes. These samples were then poured into molds (2" diameter) and placed in a convection oven at 140 degrees C, and heated for one hour. All three molds were removed and allowed to cool. Finally, the Lunar-crete samples were removed from the molds. Two mixtures were created, one with a 65/35 regolith/sulfur mix, and the other 65/35 mix with the addition of 5% fiberglass by weight.

Identically sized conventional concrete (sandcrete) samples were also made and prepared for testing.

All samples were then cut to a similar length for testing purposes. Compression testing was conducted in a Geophysical Testing Facility, and data was recorded in a format consistent with the compression testing of conventional concrete. Data is presented below.

RESULTS

The Lunar-crete samples I created successfully resulted in a concrete-like material.

When tested for compressive strength, the Lunar-crete mixture was approximately half as strong as the conventional concrete sample.

However, when fiberglass (5% by weight) was added to the Lunar-crete, one of the samples proved stronger than conventional concrete.

This is significant as it shows a 65:35 mixture of regolith to sulfur is half as strong as standard concrete, which may be sufficient in the 1/6th gravity of the moon. When reinforced with lightweight fiberglass, it could be stronger than conventional concrete.

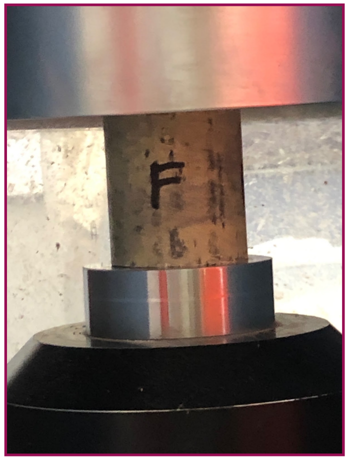
My compression testing results results were similar to experiments done by Toutanji, Evans and Grugel in "Performance of Waterless Concrete" (2010).

What I did differently in my experimental procedure was to dry-mix the ingredients and then heat them - instead of adding regolith to already molten sulfur.

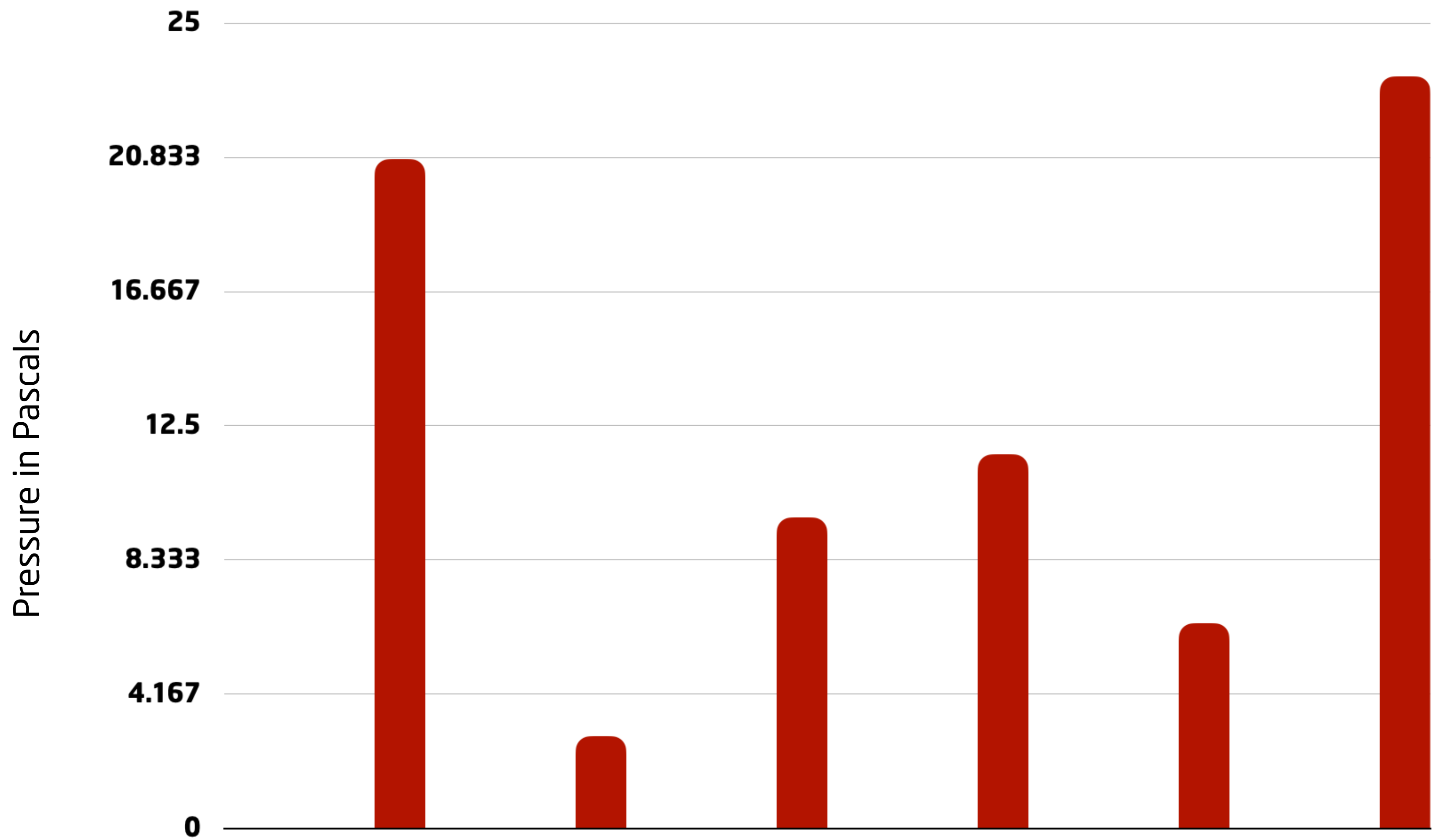
Photo by Michael Ellis of Nathaniel Ellis and Greg Jadrich (photo releases on file).

RESULTS

Sample ID	A	B	C	D	E	F
Sample Material	Sand-Crete	Sand-Crete	35% Sulfur/65% LH-1	35% Sulfur/65% LH-1 + 5% Fiberglass	35% Sulfur/65% LH-1	35% Sulfur/65% LH-1 + 5% Fiberglass
Aggregate Size	.06 to 2.0 mm	.06 to 2.0 mm	50 um	50 um	50 um	50 um
Structural Additive	NA	NA	NA	NA	NA	Fiberglass
Cylinder Age (cure-hrs.)	72	24	72	2	72+	2
Date Tested	3/21/22	3/21/22	3/21/22	3/21/22	3/21/22	3/21/22
Cylinder Height (mm)	73.025	73.025	69.85	55.5625	73.025	57.15
Cylinder Diameter (in)	50.8	50.8	50.8	50.8	50.8	50.8
Cylinder Area (mm^2)	2026.83	2026.83	2026.83	2026.83	2026.83	2026.83
Cylinder Weight (kg)	0.326	0.315	0.226	0.213	0.287	0.267
Total Load (kg)	4295.52	594.206	1945.911	2399.504	1315.418	4826.2228
Comp. Strength (MPa)	20.79459	2.87511	9.645765	11.61077	6.36386	23.35944
Type of Fracture	Type 4	Type 4	Type 3	Type 4	Type 4	Type 4



RESULTS



A	B	C	D	E	F
Sand-Crete	Sand-Crete	35% Sulfur/65% LH-1	35% Sulfur/65% LH-1	35% Sulfur/65% LH-1	35% Sulfur/65% LH-1
			+ 5% fiberglass		+ 5% fiberglass
20.79459	2.87511	9.645765	11.61077	6.36386	23.35944

Samples Labeled

DISCUSSION

These results suggest that Lunar-crete is feasible on the moon, but could require some fiberglass reinforcement in areas that bear more load.

Possible errors include incorrect measure of crushing force, improper formation of the concrete, slightly different sample sizes and use of different materials than stated.

The result did match the expected result, as an alternative to conventional concrete was successfully formed which was stronger than normal concrete.

It is possible that the strength difference with unreinforced Lunar-crete is insignificant, as there are lower gravities on the moon which means that the forces the Lunar-crete would be subjected to are weaker.

The use of fiberglass in Lunar-crete might be impractical on a large scale, as transporting it to the lunar surface would be prohibitively expensive. Perhaps it could be recycled from non-functioning components to provide strength in areas which require it.

CONCLUSION

The results show that Lunar-crete may be practical for use on the moon. The results support my hypothesis, as a form of concrete (Lunar-crete) was successfully formed, and in one situation was stronger than conventional concrete. To continue this project, I would repeat the experiment multiple times, and experiment with the use of a lunar rock simulant instead of a lunar sand simulant. Conventional concrete is stronger when made with rock instead of sand, so I would suggest that Lunar-crete might follow a similar pattern.

In conclusion, by extracting sulfur from lunar rocks in the form of the mineral Troilite, subsequently recombining the sulfur with lunar regolith, then heating the mixture and allowing it to cool for several hours, a structural material was successfully created, and illustrates the viability for use for future lunar colonization.

Further research is needed to fully understand the effects that the temperature fluctuations on the moon may have on Lunar-crate, the forming of the Lunar-crete in a vacuum, and the effect of reduced gravity.

BIBLIOGRAPHY

https://en.wikipedia.org/wiki/Geology_of_the_Moon accessed 2/13/2022

https://www.nasa.gov/specials/artemis/ accessed 2/13/2022

https://earthsky.org/space/io-sulfur-volcanoes-hot-so2-cold-so2/ accessed 2/13/2022

lpi.usra.edu/publications/books/lunar_sourcebook/pdf/Chapter06.pdf accessed 2/13/2022

https://www.sciencedirect.com/topics/earth-and-planetary-sciences/mare-basalt accessed 2/13/2022

https://www.sciencedirect.com/topics/earth-and-planetary-sciences/mare-basalt accessed 2/13/2022

http://www.pas.rochester.edu/2010blackman/ast104/moon_surface.html accessed 2/13/2022

http://www.meteorites.tv/content/55-Lunar-mare-basalts-lunar-mare-gabbros-composition accessed 2/13/2022

https://patents.google.com/patent/DE3713089A1/en accessed 2/13/2022

https://pubs.acs.org/doi/10.1021/ie300450e accessed 2/13/2022

https://en.wikipedia.org/wiki/Leaching_(chemistry) accessed 2/13/2022

https://www.sciencedirect.com/science/article/abs/pii/S0378381211004201https://ntrs.nasa.gov/api/citations/19980001900/

https://civilengineeringbible.com/article.php?

https://www.vector-construction.com/sulfurcrete