MOON-OPOLY II

Employing Additive Manufacturing Technology for Lunar Construction with Waterless Concrete

A Continuation Project

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MOON-OPOLY I AND II

Year 2 of a Continuation Project.

Since NASA now has a "concrete" plan to create a permanent moon base, Space Mining and the utilization of in-situ lunar resources have developed into a major area of study. Colorado School of Mines, John Hopkins and other institutions have research groups competing for NASA funding and investigating both mining and lunar construction methods. With an internet search, I found that there is significant commercial energy being invested into this new area of discovery.

Moon-Opoly I (2022): For last year's Science Fair project, I wanted to create a version of waterless concrete by using only the materials available on the moon. I was able to demonstrate that by extracting sulfur from lunar rocks, recombining the sulfur with lunar regolith, and heating the mixture above 120°C (248°F), a useful building material could be created. When corrected for the effects of reduced lunar gravity, Lunar-Crete (as we called it) was comparably as strong as conventional concrete. I enjoyed some success with my proof-of-concept project, demonstrating that it is not only possible to manufacture waterless concrete on earth, but that this product is of a useful structural strength.

Moon-Opoly II (2023): I wanted to continue with my investigations of Lunar-Crete from last year's Science Fair. A question quickly came into focus - how might one actually use this material for lunar construction?

During my research, I discovered that NASA recently awarded a $57 million grant to a private company to work on this problem, using existing 3D printing technology for concrete. The construction industry (here on earth) has been successfully experimenting with concrete 3D printing over the last few years, and it is already an expanding industry. **However, in the videos I saw, this NASA Contractor demonstrated their product using a concrete/water mixture - not waterless concrete.** Water is difficult to access on the moon. I thought a better solution would be to use Lunar-Crete, so I decided to focus my project on 3D printing with my waterless concrete. This also aligned with my long-standing interest in 3D printing.

I began to look at various large-scale 3D printing systems that currently exist which print using regular concrete. These basic systems use either an overhead gantry system, or a stationary robot to 3D print. To print with Lunar-Crete (no water) would be a much different proposition. **For waterless concrete, a specialized 3D printer "hot end" and nozzle will need to be developed in order to heat the mixture of lunar regolith and elemental sulfur to the temperature required for it to fuse together at 120°C (248°F)**. My research suggested that no system currently exists for the 3D printing of waterless concrete, so I also decided to look into the possibilities of patenting the idea.

ENGINEERING QUESTION:

Could one accurately and reliably 3D print a structure on the Moon, using waterless concrete (Lunar-Crete) as the base material?

ENGINEERING GOAL:

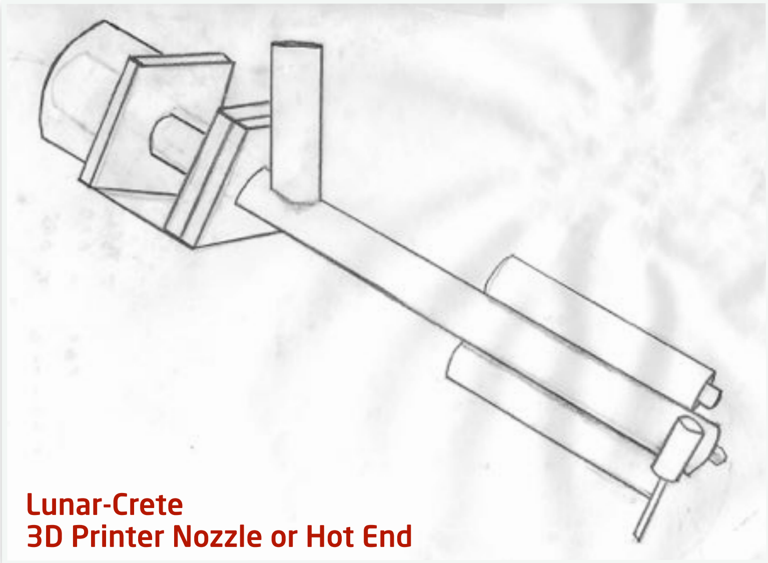
To design and build an extruder nozzle that would allow for the 3D printing of waterless concrete, and to test the compression strength of the resultant output in a commercial materials testing lab and compare it to last year's waterless concrete compression testing results.

METHODS

I focused on developing the “hot-end” or extruder for a large scale 3D printing system. My extruder, which I planned to prototype out of either steel or aluminum, consisted of a heated nozzle which melted the regolith/sulfur waterless concrete, and a screw or auger which fed the heated mixture into the nozzle.

I approached this design by first looking at current designs similar to what I was trying to create. In the 3D printing world they traditionally use “filament”, a long plastic string wrapped around a spool. But for larger 3D print jobs, some may use a pellet 3D printer, which melts larger pellets of plastic held in a “hopper”. This seemed somewhat similar to the 3D printer I was going to try and extrude, so I studied their design and created a prototype with a similar idea.

I constructed a screw-based extruder, with heating elements surrounding it to raise the temperature enough to melt the regolith/sulphur mixture. Heating was provided by 4 x commercial cartridge heaters, operating at 120V AC, and the mixture was fed into the delivery by a 1” steel screw, driven by a geared motor. This is a relatively simple design, and my custom extruder nozzle can attach to and be controlled by a commercially available, gantry or robotic 3D printer. I don’t plan to build the 3D printer itself, since the designs already exist.



Lunar-Crete
3D Printer Nozzle or Hot End

Illustration: Nathaniel Ellis

MATERIALS

Lunar-Crete. For this experiment I used the most successful Lunar-Crete mixture I made last year, the 65 / 35 mix of Lunar regolith simulant / elemental sulfur.

Extruder. The nozzle and body of the extruder were made of steel, with the ceramic/ stainless steel cartridge heaters purchased online. The screw/auger was purchased at Home Depot, and the geared DC motor and controller were retrieved from our motor collection.

The materials were relatively inexpensive and easy to obtain.

BUILDING


Wheels allow linear motion for nozzle
Frame
Auger Motor Control
Extruder nozzle, with auger inside
VARIAC: controls AC voltage
Heater Cartridges

TESTING

Testing varying extruder temperature by varying AC voltage on VARIAC.

Adjusting set screws to remove internal auger for cleaning.

Removing internal auger.

RESULTS

I collected data on how to control the extruder's temperature, by adjusting the AC voltage of the cartridge heaters, using a VARIAC. I also varied the DC voltage of the motor to adjust the speed of the auger, which controls the extruded output. Later I switched to a variable speed drill for more power and simplicity. Lastly, I varied the ratio of sulfur to lunar regolith. More sulfur created a smoother output.

The extruder successfully output molten Lunar-Crete. The trials below were conducted, and higher temperatures, along with additional sulfur and higher auger speed created the best output. However, the samples I created at this point were not sufficient to compression test in a commercial lab, based on my compression testing experience from last year.

Output: 1cm3/30 sec. - 5cm3/30 sec.

Voltage	80V	100V	120V	140V
Temperature	250° F	350° F	400° F	450° F
30% Sulfur/ 70% Regolith	1	2	3	4
35% Sulfur/ 65% Regolith	3	3	4	5
40% Sulfur/ 60% Regolith	3	4	5	5

Four Examples of Extruded Lunar-Crete

CONCLUSION

In conclusion, my results show that is practical to 3D print Lunar-Crete on the surface of the moon. The engineering goal was to see if it is possible to create a 3D extruder and nozzle assembly that will successfully fuse together lunar regolith and elemental sulfur through heat, and extrude it in a linear deposit. This part of my experimentations were successful. However, at this point I was unable to manufacture a sample appropriate for conventional compression strength testing, as I had last year with my Lunar-Crete cylinder shapes.

Further research and experimentation is needed to understand the following:

- Need a more powerful auger motor.
- How extruder nozzle diameter may affects layer strength.
- How 1/6th gravity might affect layer adhesion.
- How 3D Printing in the vacuum of the moon might affect output.
- How lunar temperatures and temperature swings might directly affect output.

APPLICATIONS

This project is very applicable to current events, considering NASA's mandate to return to the moon and create a permanent colony. Initially, they might employ some type of inflatable habitat. But eventually they will need to build more permanent structures using the materials available on the moon.

Extruded Lunar-Crete might be used to manufacture the outer shell of habitable structures, shielding them from radiation. In addition, it might be used to make landing pads for rockets, roads, and any other sort of infrastructure required for a lunar base.

I see extruded Lunar-Crete as being the future for construction on the moon, as it is strong, simple to make, and only requires materials already on the moon. Last year's project showed that Lunar-Crete was viable for use on the moon, and was sufficiently strong for many applications. This year's Extruder project demonstrates an accurate and convenient method of actually creating things with Lunar-Crete.

Lunar-Crete could be used for a variety of lower-grade applications, such as:

- Shielding for living quarters
- Shielding for takeoff and landing pads
- Bases and flooring
- Where smooth surfaces are required - runways, roads, and walkways

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All photos taken/courtesy of Michael Ellis

Graphs/Chart created in google sheets by Nathaniel Ellis. Illustrations by Nathaniel Ellis.