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Influence of the Space Environment on Geopolymer Lunar Concrete

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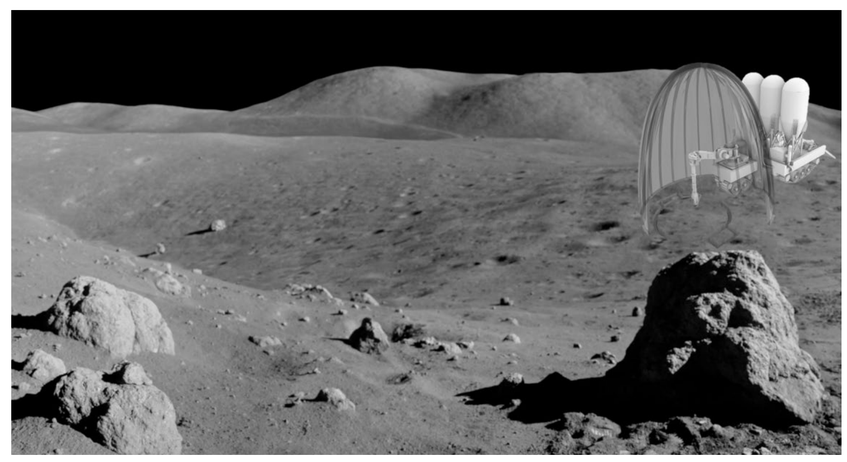
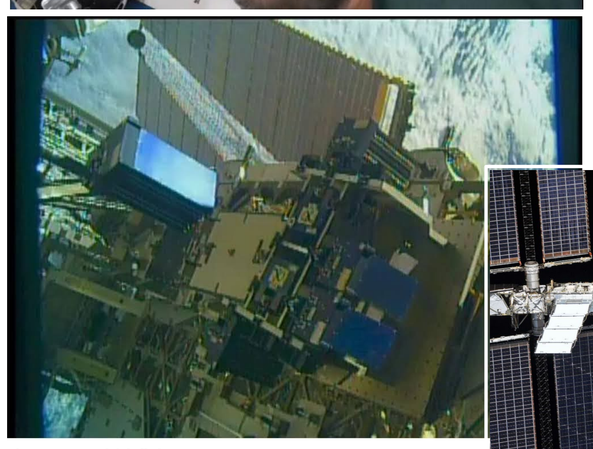
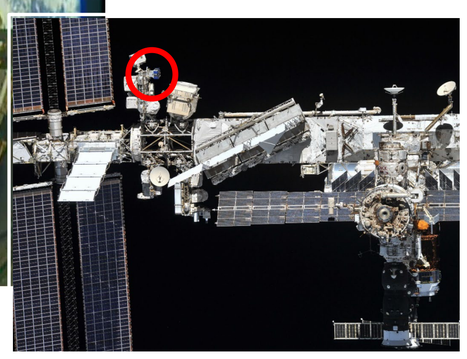
Motivation

NASA is set to embark on the next era of human space exploration with the Artemis program. An eventual goal of the program is to maintain a human presence on the lunar surface. With such a goal comes the challenge of providing durable infrastructure that is suitable for the Moon and utilizes the in-situ resources. Bringing materials from Earth poses a financial burden and increased safety concern. The composition of the lunar soil makes it advantageous to create a geopolymer concrete material. The lunar regolith can be used in the as found condition on the lunar surface and most of the mixing solution can be extracted from the regolith. It is envisioned that any concrete infrastructure would make use of additive manufacturing techniques with a temporary controlled environment enclosure to mitigate the harsh lunar conditions. Data is needed to benchmark how the material behaves once exposed to such an extreme environment so structural failures are mitigated.



Experimental Setup





Images: NASA

The lunar surface poses environmental challenges such as reduced gravity (1/6th of Earth's), atmospheric pressure of 3×10^{-15} ATM, radiation, and temperature ranges from -179°C to 116°C at the equator. Subjecting concrete samples to all the various environmental conditions found on the lunar surface simultaneously can be a challenge on Earth. The environment outside the International Space Station (ISS) is currently the best option to subject samples to such conditions all at once.

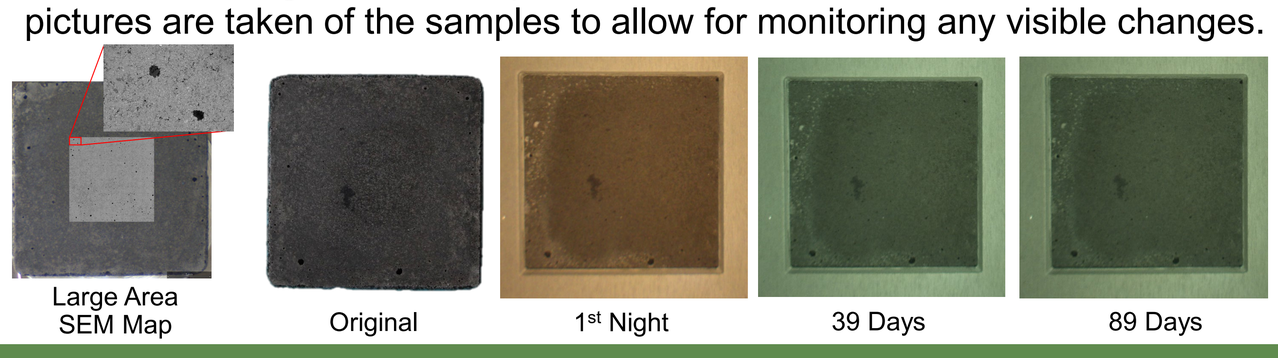
1 **Experiment:** The Materials International Space Station Experiment Flight Facility (MISSE-FF) outside the ISS provides the opportunity to subject samples to a hard vacuum environment, extreme temperature changes, and radiation all at once. The zenith direction (pointing above and away from the ISS) has environmental conditions most like the lunar surface as it maximizes the solar radiation exposure and limits atomic oxygen exposure. The samples were placed outside the ISS in January 2022 for a six-month exposure period.

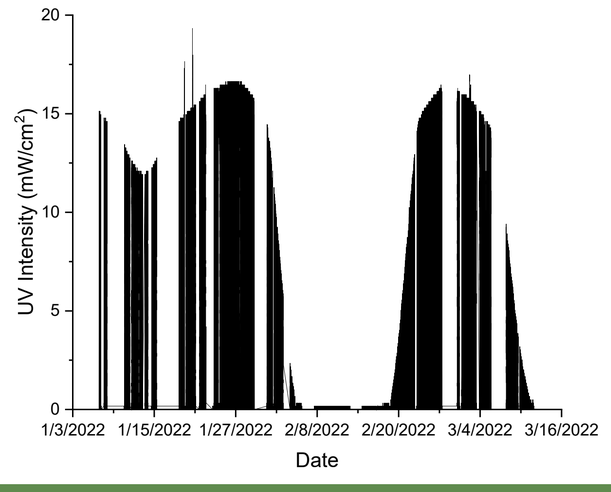
2 **Sample Design:** Eight one-inch square samples are currently sitting outside the ISS on MISSE-15. Two of the eight samples are an ordinary portland cement mixture with a water-to-cement ratio of 0.4 (one includes basaltic fibers). The remaining six are geopolymer lunar concrete. JSC-1A, a lunar regolith simulant, was mixed with a sodium silicate and sodium hydroxide solution at a ratio of solution to simulant of 0.35 and heat cured at 60°C for three days. The composition of the solution was varied by adjusting the molarity of the sodium hydroxide. Two of the six geopolymer lunar concrete samples included basaltic fibers.

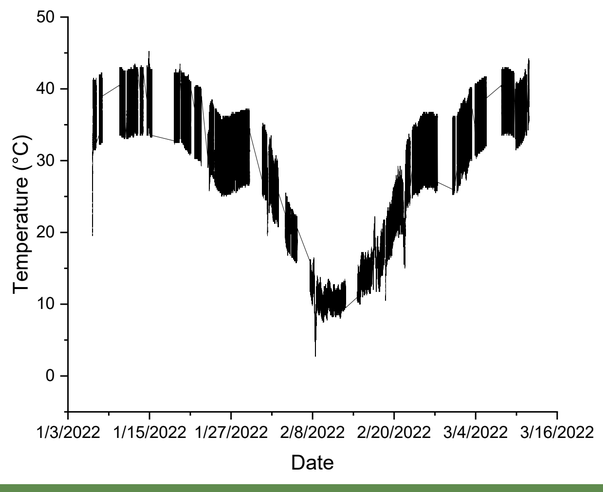
Sample Analysis and Current Observations

Benchmark Data: Prior to the samples being sent to the ISS, data was collected to set a benchmark to compare to once the samples return. This included a large area scanning electron microscope (SEM) map, camera photographs, weights, and dimensions. The same data will be collected upon the return of the samples. Overlaying the recollected SEM map to the original one will show any degradation to the microstructure from the exposure to the space environment.

ISS Collected Data: The temperature and ultraviolet intensity is continuously monitored throughout the sample's time outside the ISS. Once a month pictures are taken of the samples to allow for monitoring any visible changes.







Outlook

- Geopolymer lunar concrete is a promising material for building infrastructure on the lunar surface.
- The samples exposed to the space environment outside the ISS are collecting necessary data on how the material behaves in an environment like the lunar surface.
- The samples have shown no major signs of degradation in the first three months and still have three more months of exposure time left.
- Some samples exhibit minor discoloration which is likely due to efflorescence.
- A detailed analysis is still to be conducted on the samples once they return to Earth.

Acknowledgements

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