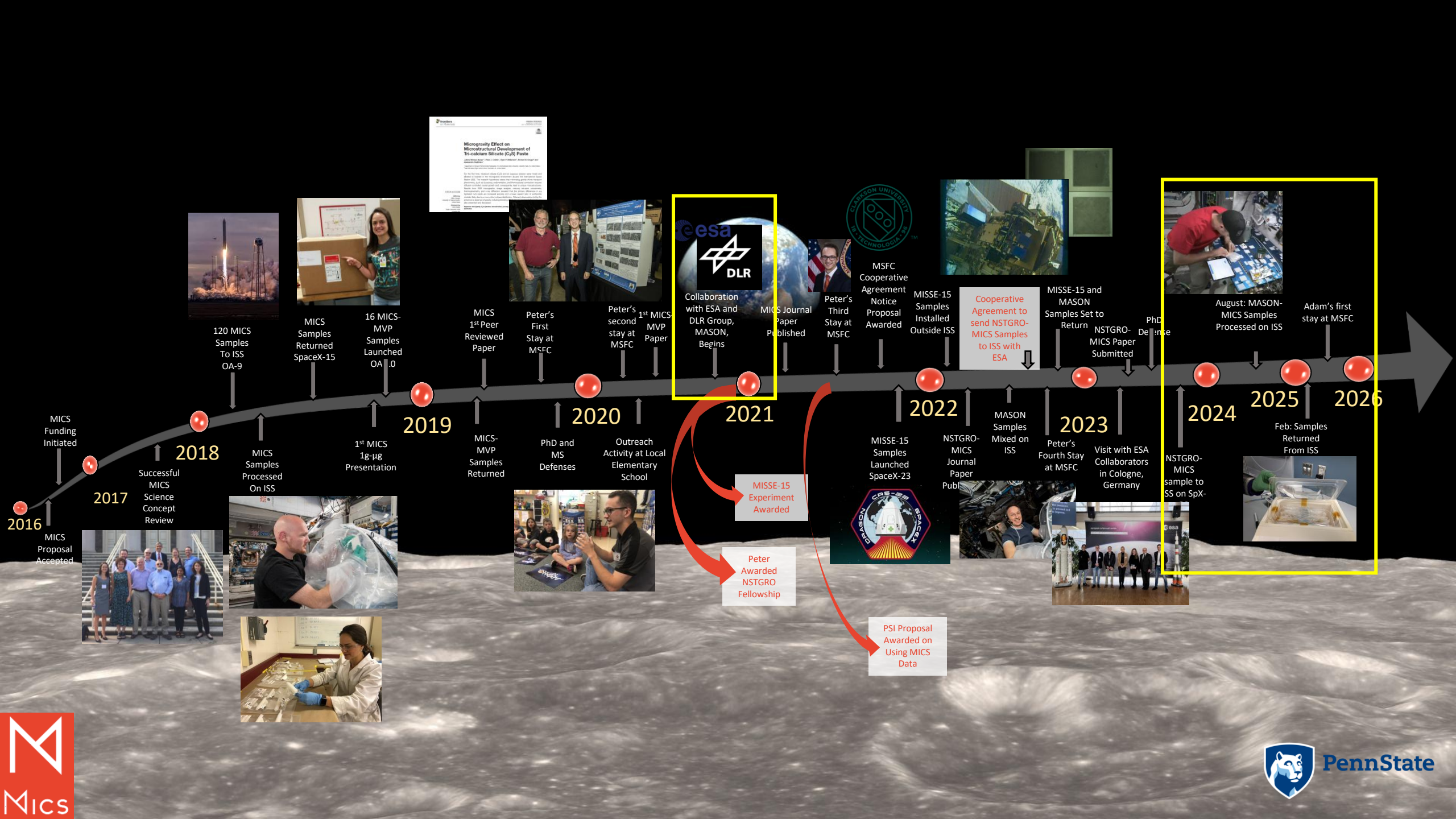
Investigation of Lunar-Inspired Geopolymer Concrete Formulations Mixed and Cured in Microgravity on the International Space Station (ISS)

Adam Johnson[1]
Louise Littles[2]
Aleksandra Radlińska[1]
Sven Bilén[1]

[1]*The Pennsylvania State University*
[2]*NASA Marshall Space Flight Center*

ASCE Earth and Space
April 16th, 2026


2016
MICS Funding Initiated
MICS Proposal Accepted
2017
Successful MICS Science Concept Review
2018
120 MICS Samples To ISS OA-9
MICS Samples Processed On ISS
MICS Samples Returned SpaceX-15
1st MICS 1g-µg Presentation
16 MICS-MVP Samples Launched OA-10
2019
MICS 1st Peer Reviewed Paper
MICS-MVP Samples Returned
Peter's First Stay at MSFC
PhD and MS Defenses
2020
Peter's second stay at MSFC
1st MICS MVP Paper
Outreach Activity at Local Elementary School
Microgravity Effect on Microstructural Development of Tri-calcium Silicate (C3S) Paste
esa
DLR
Collaboration with ESA and DLR Group, MASON, Begins
2021
MICS Journal Paper Published
Peter's Third Stay at MSFC
MSFC Cooperative Agreement Notice Proposal Awarded
MISSE-15 Experiment Awarded
Peter Awarded NSTGRO Fellowship
PSI Proposal Awarded on Using MICS Data
MISSE-15 Samples Launched SpaceX-23
2022
MISSE-15 Samples Installed Outside ISS
NSTGRO-MICS Journal Paper Publ
Cooperative Agreement to send NSTGRO-MICS Samples to ISS with ESA
MASON Samples Mixed on ISS
MISSE-15 and MASON Samples Set to Return
Peter's Fourth Stay at MSFC
2023
NSTGRO-MICS Paper Submitted
Visit with ESA Collaborators in Cologne, Germany
PhD Defense
NSTGRO-MICS sample to ISS on SpX-
2024
August: MASON-MICS Samples Processed on ISS
2025
Feb: Samples Returned From ISS
Adam's first stay at MSFC
2026
MICS
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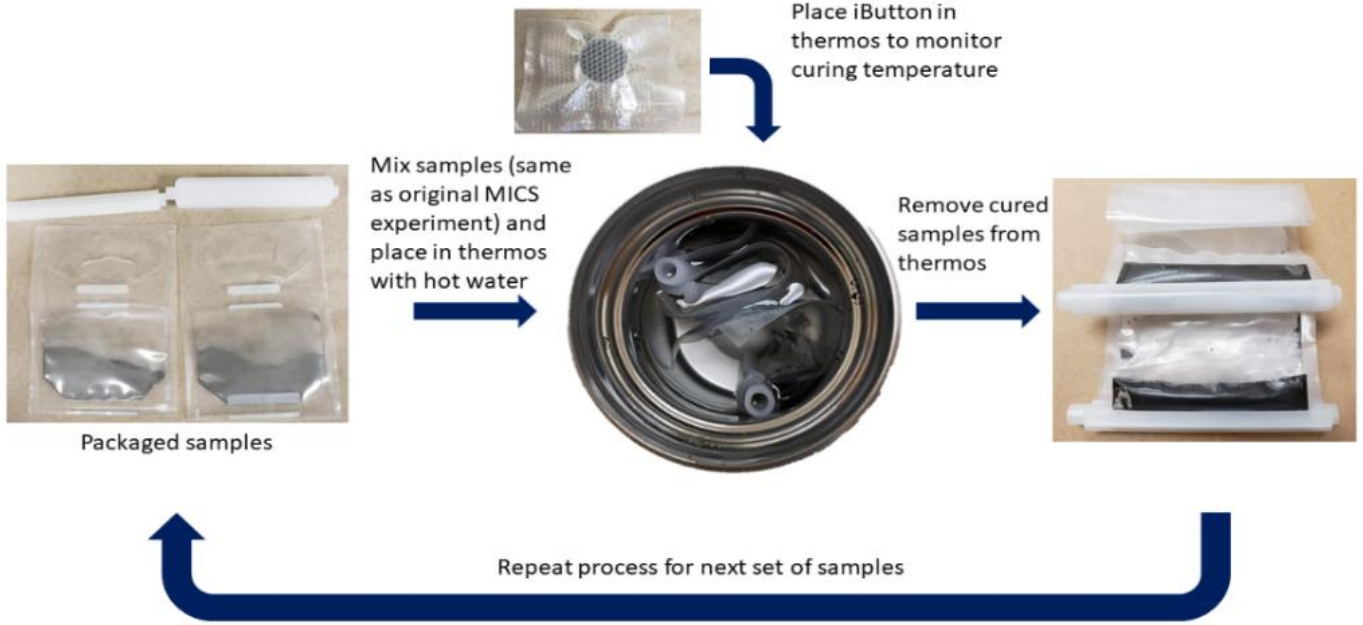
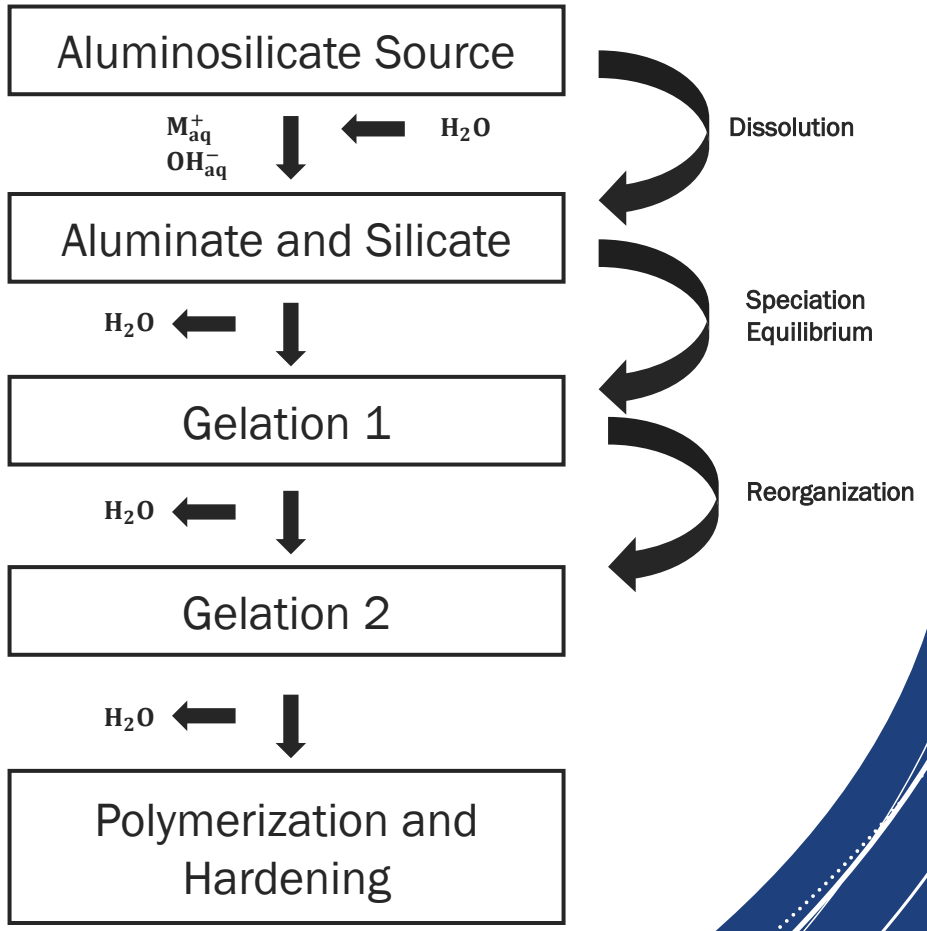
This research involves determining a viable material for long-term infrastructure with in-situ materials on the lunar surface, focusing specifically on geopolymer lunar concrete thermally cured.





- Hypothesis: Thermally-cured 3D printed geopolymer concrete using in-situ lunar regolith will be a viable method of construction for long term infrastructure for human habitation.

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The experiment consisted of three lunar regolith simulants with varying solution to simulant ratios.

Mix ID		Simulant	Simulant wt. (g)	Sodium Silicate and Sodium Hydroxide wt. (g)	Total mix wt. (g)	Solution to Simulant Ratio
1-1	1	OPRL2N	15	7.5	22.5	0.50
1-2	2					
2-1	3	OPRL2N		9	24	0.60
2-2	4					
3-1	5	OPRH2N		9		
3-2	6					
4-1	7	OPRH2N		7.5	22.5	0.50
4-2	8					
5-1	9	OPRL2N		8.25	23.25	0.55
6-1	10	OPRH2N				
7-1	11	JSC-1AF		7.5	22.5	0.50
8-1	12			9	24	0.60

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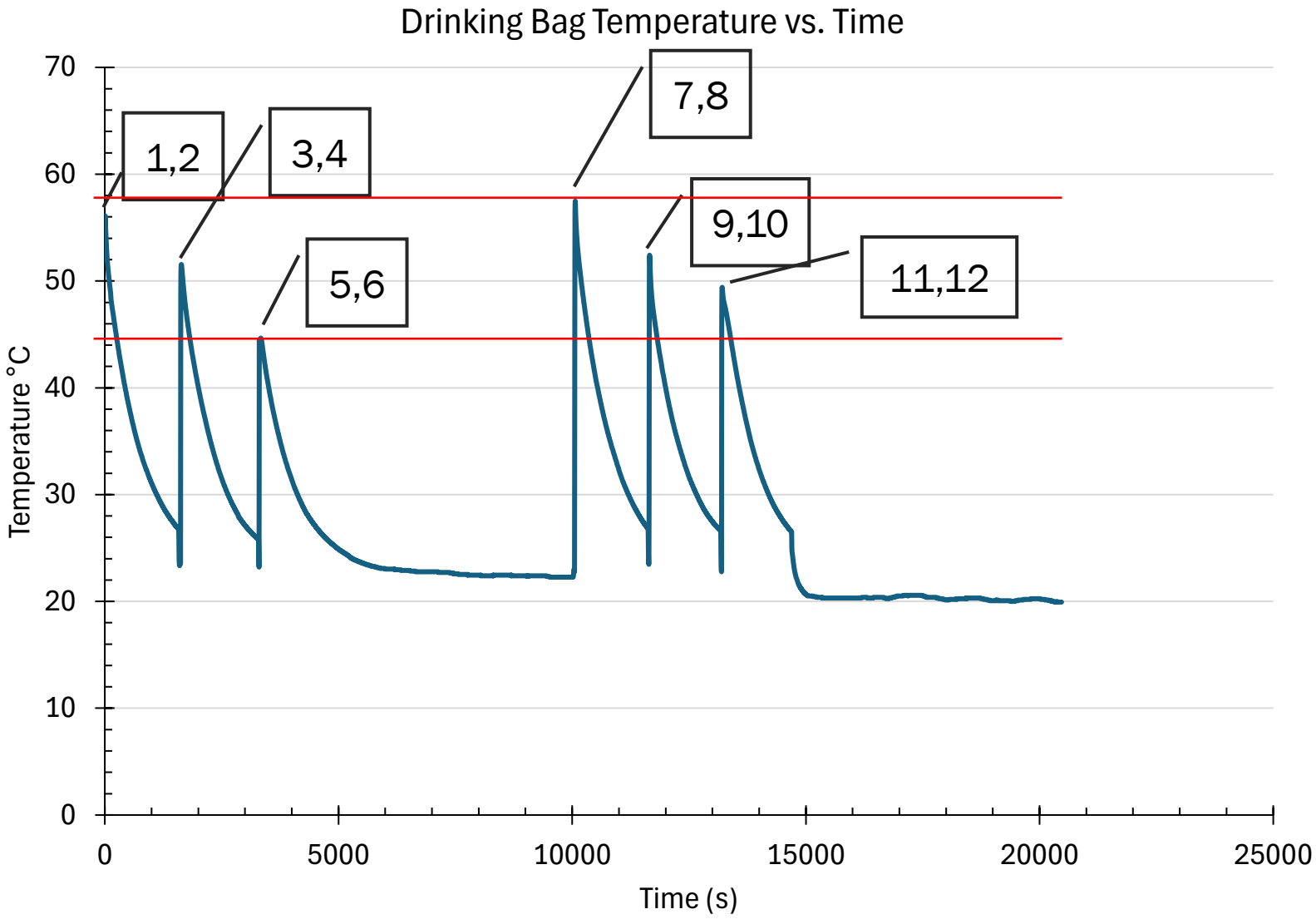
Samples were mixed and cured in pairs for 24 hours.



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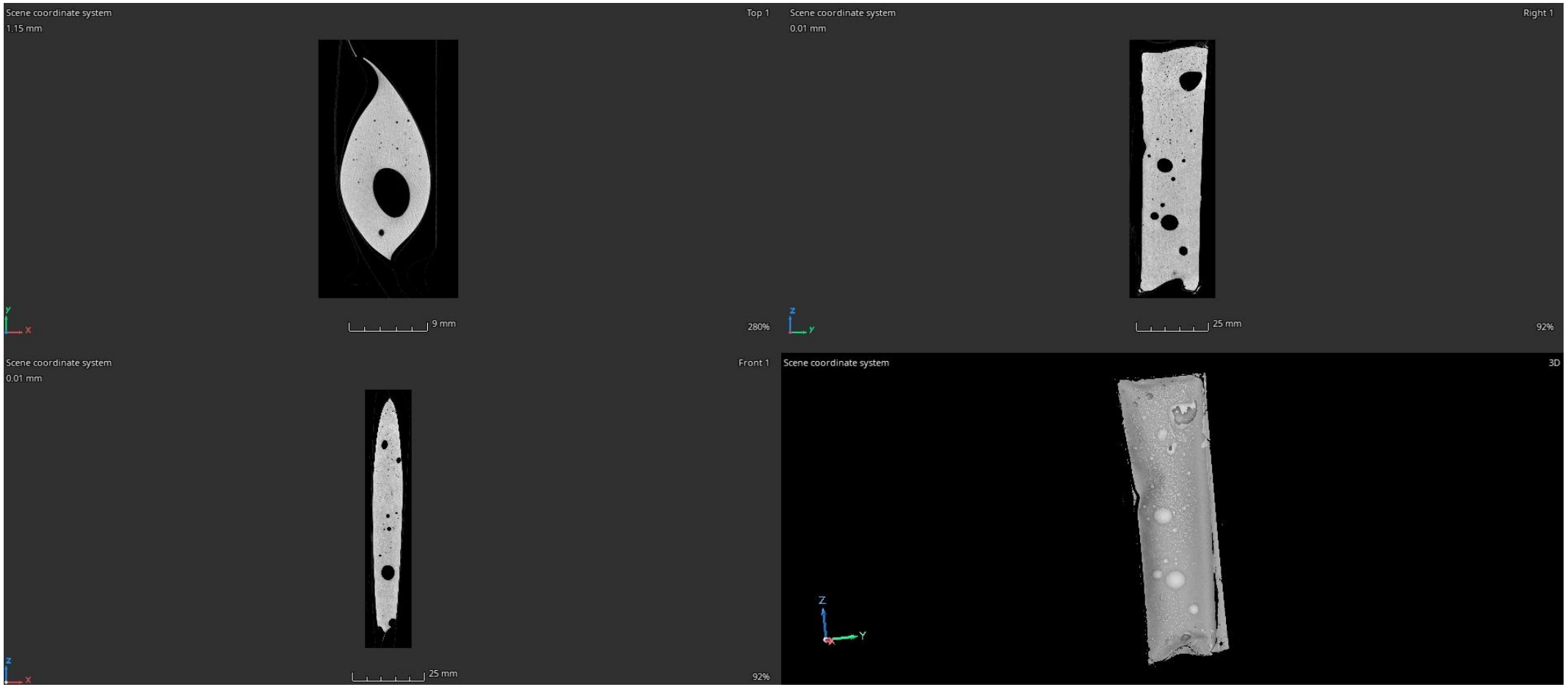
Micro-CT identifies internal features without damaging the specimens. Each sample was imaged at 25µm resolution.



Sample 10: OPRH2N simulant (15g) and sodium silicate and sodium hydroxide soln. (8.25g).

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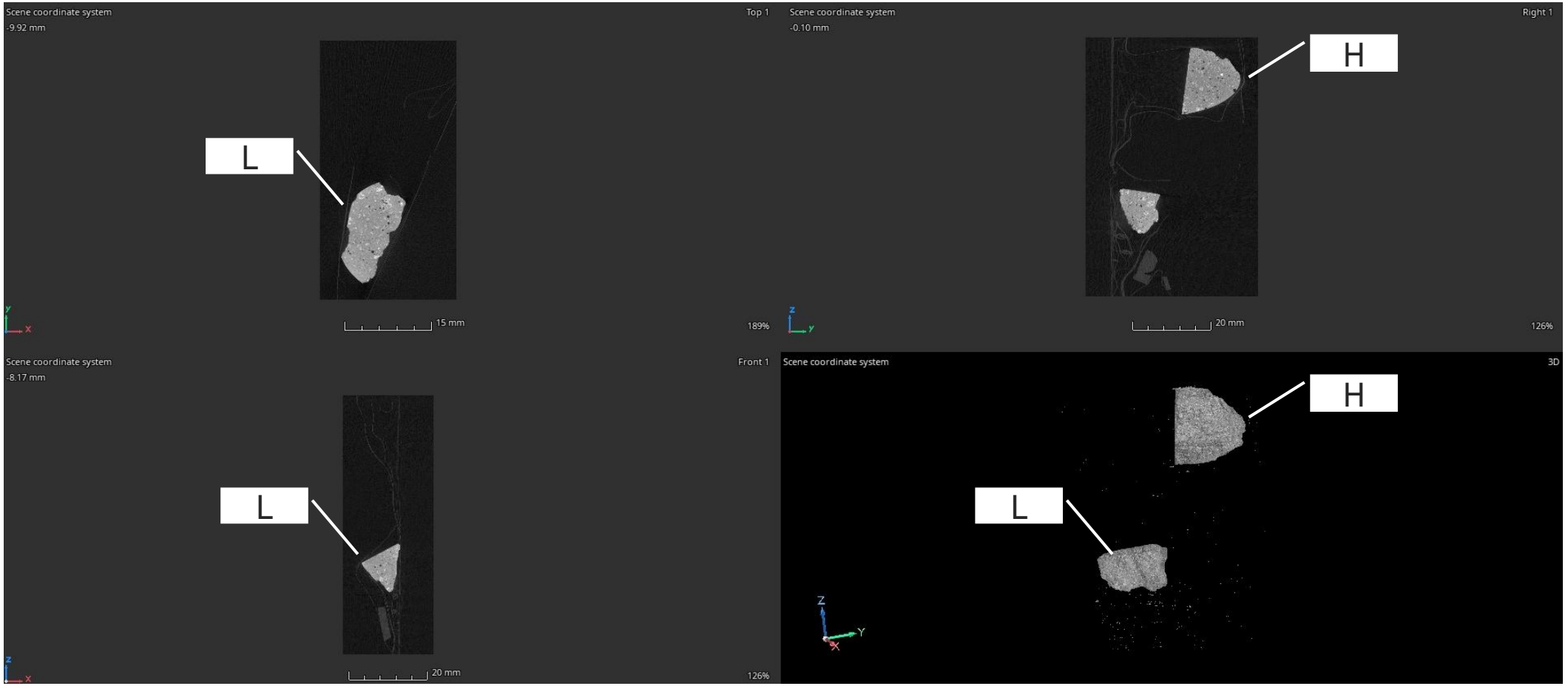
Micro-CT was also conducted on OPRH2N and OPRL2N composites mixed at 1.0 atm for pore reference



Samples H & L: OPRL2N and OPRH2N composites mixed in Earth's gravity.

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Helium gas pycnometery and mercury intrusion porosimetery (MIP) measure each samples density and porosity.

Flight Sample Information								
Sample	3	4	5	6	9	10	11	12
Simulant Type	OPRL2N		OPRH2N		OPRL2N	OPRH2N	JSC-1AF	
Solution (g)	9				8.25		7.5	9
Helium Gas Pycnometery								
Mass (g)	3.419	4.892	2.781	3.406	2.752	2.821	3.652	3.870
Volume (cm^3)	1.495	2.196	1.093	1.367	1.095	1.105	1.507	1.602
Density (g/cm^3)	2.288	2.228	2.544	2.491	2.514	2.554	2.424	2.415
Variance (%)	0.042	0.028	0.065	0.191	0.035	0.078	0.039	0.058
Mercury Intrusion Porosimetery								
Mass (g)	3.036	3.005	2.667	2.950	2.645	2.483	2.633	2.673
Porosity (%)	18.00%	18.64%	21.53%	21.50%	20.39%	23.18%	18.62%	18.51%

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Upon opening, samples showed visible excess moisture due to water leaving the system after polymerization, resulting in a darker color.

- Solvent exchange was conducted on samples.
- Samples appeared lighter after being dried under vacuum.

Sample 6: 15g OPRH2N, 9g solution.

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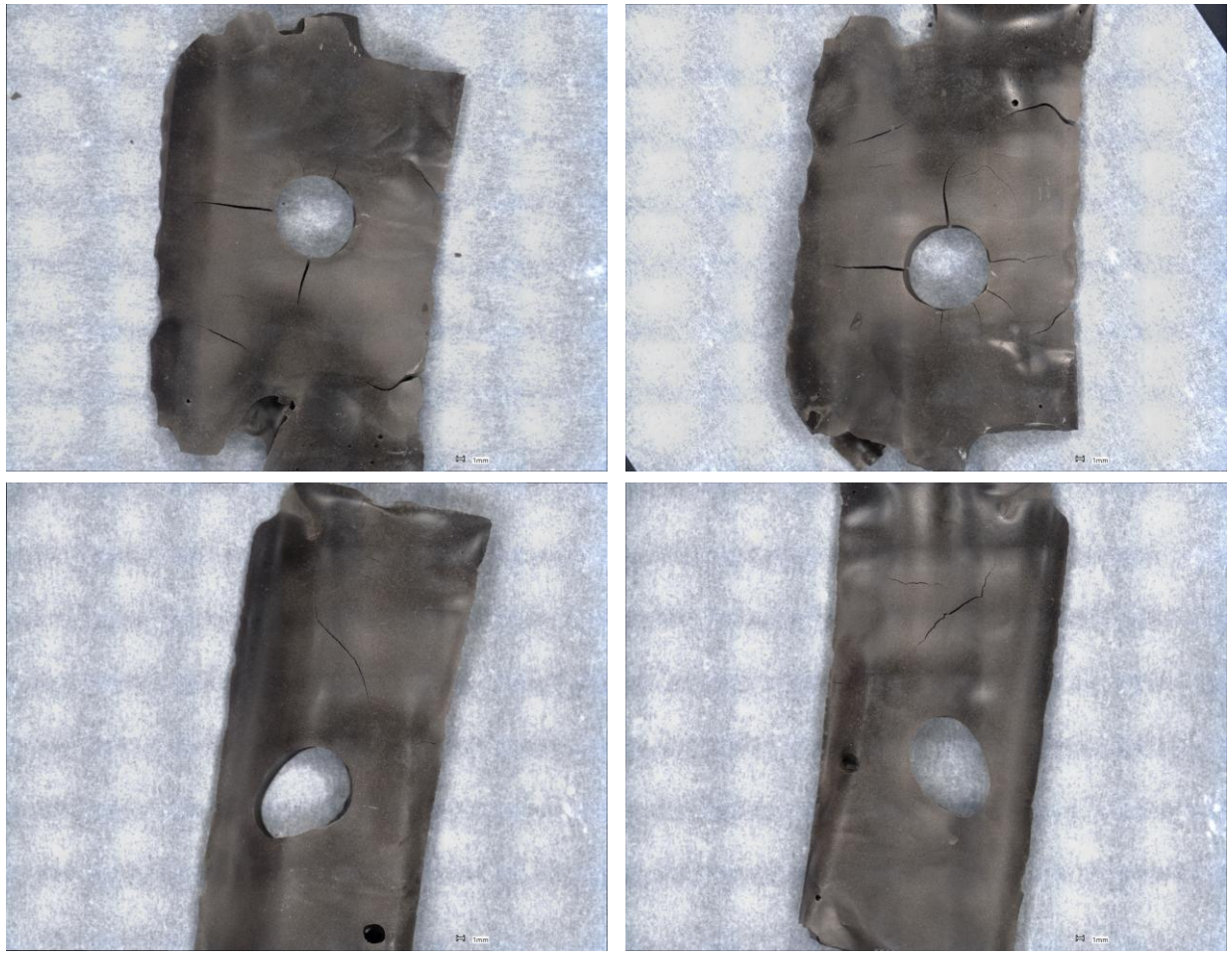
Optical Microscopy was conducted to document surface cracking on two specimens.



Sample 3 (top) and Sample 4 (bottom): 15g OPRL2N 9g solution

- Each image is a stitched 7x7 montage at 20x magnification on a VHX-7000 digital microscope

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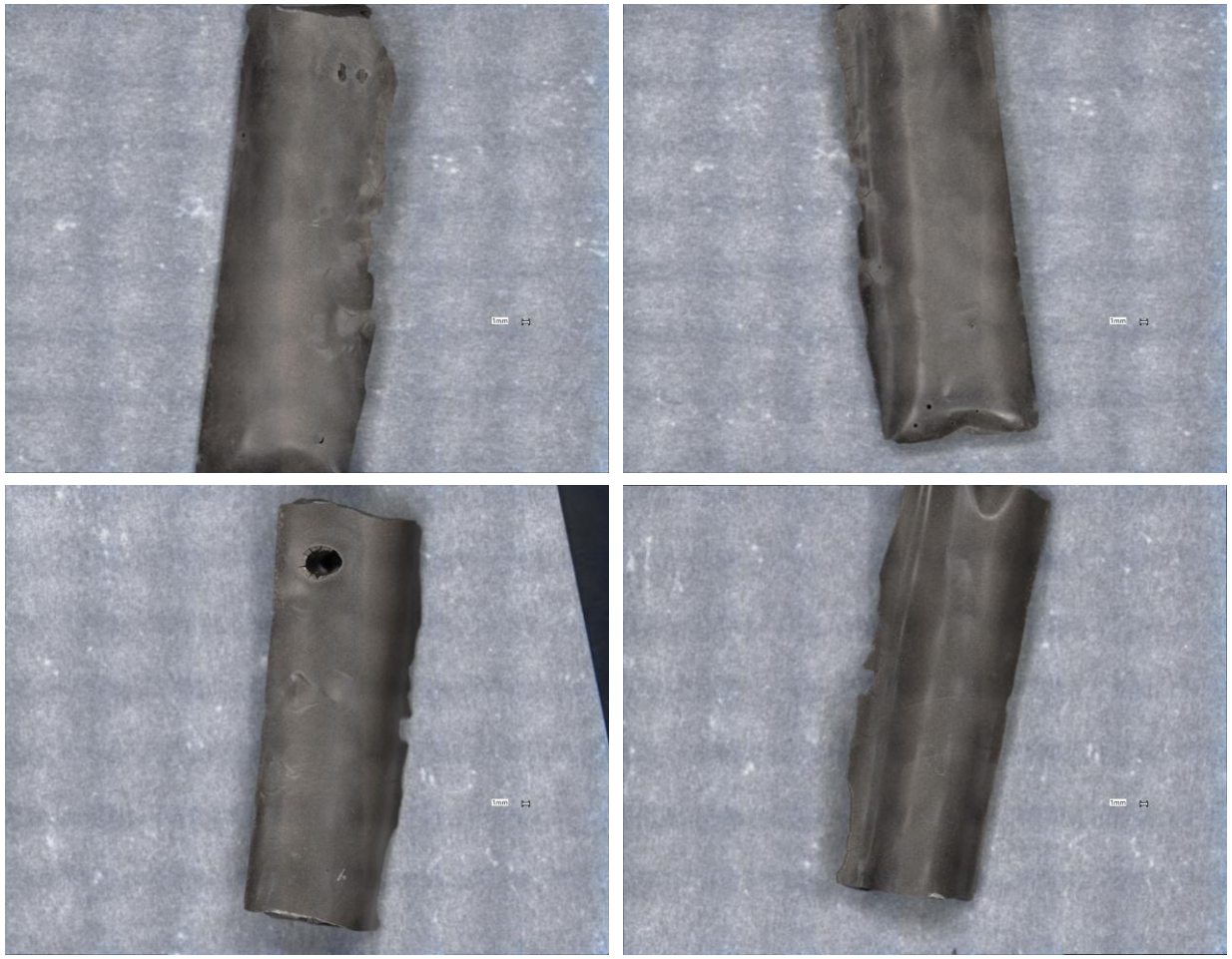
Each sample was imaged to identify causes of surface cracking.



Sample 11 (top) and Sample 12 (bottom): 15g JSC-1AF, 7.5g & 9g solution

- Visual differences in sample shape compared to Samples 3-5
- No surface cracking visible at 20x magnification
- Sample thickness and voids influence cracking from arresting hydration

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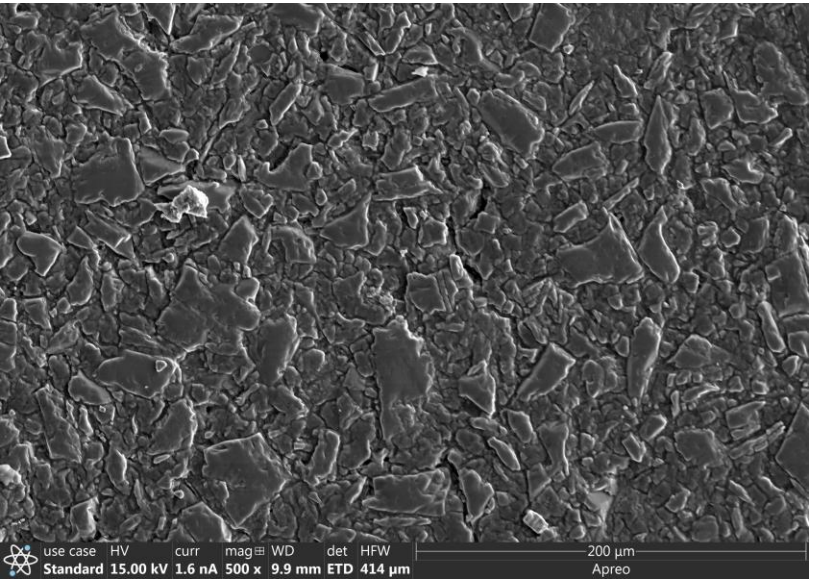
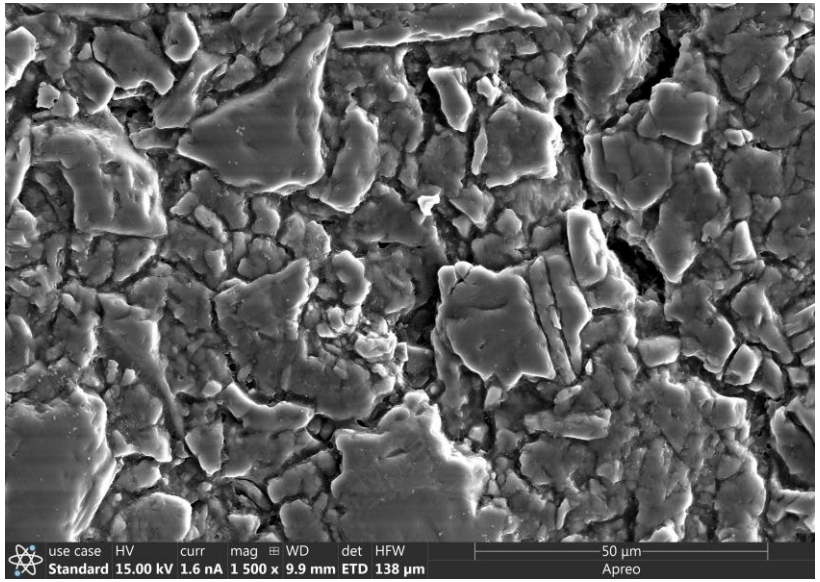
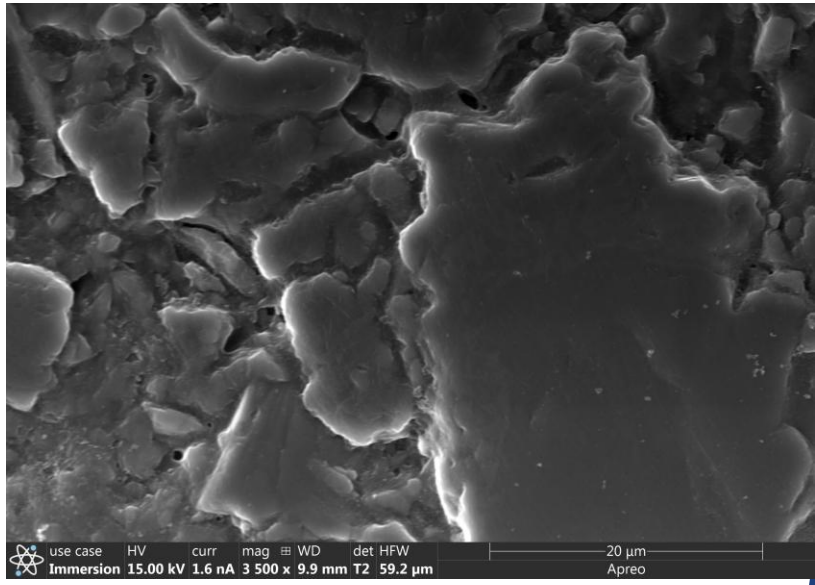
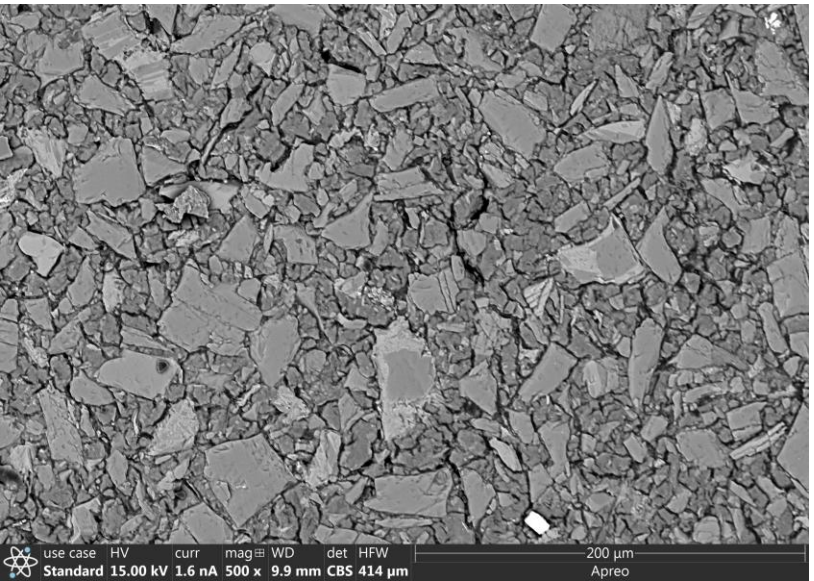
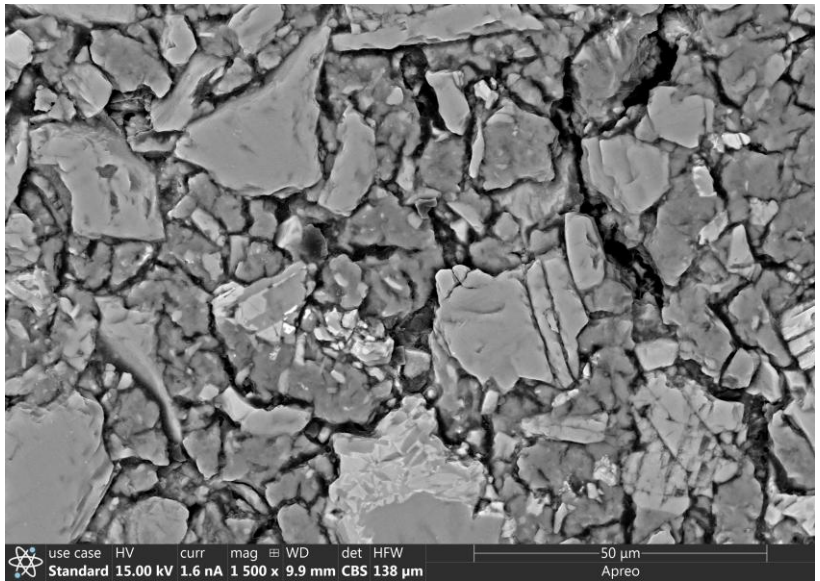
SEM was conducted to analyze the reaction product network and air void inclusions from a diffusion-controlled reaction.

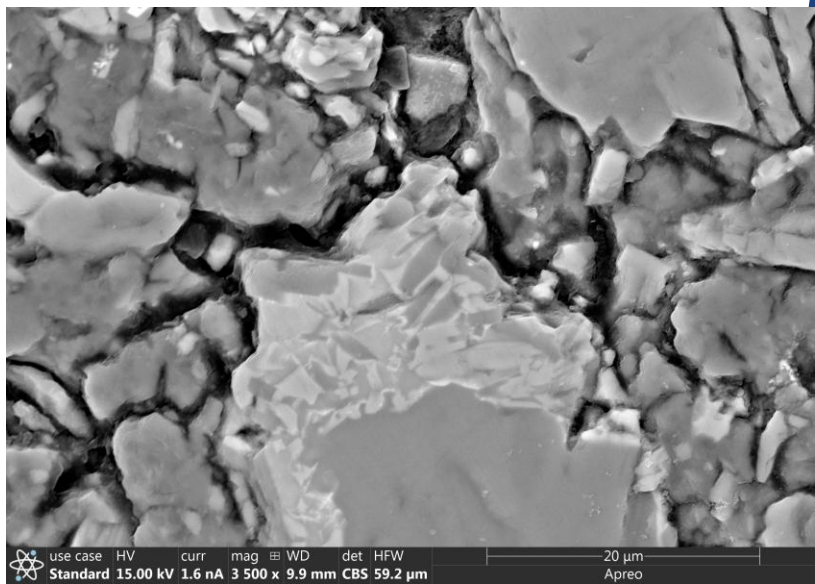




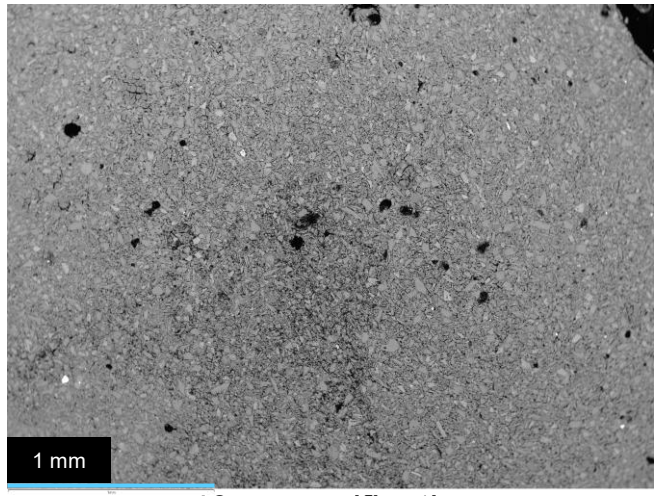




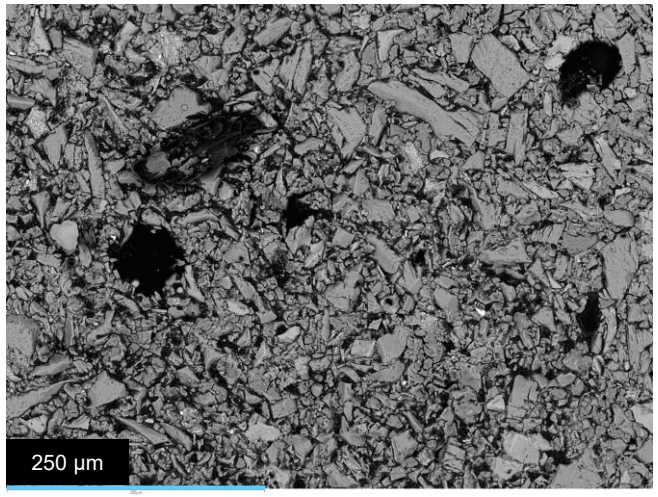




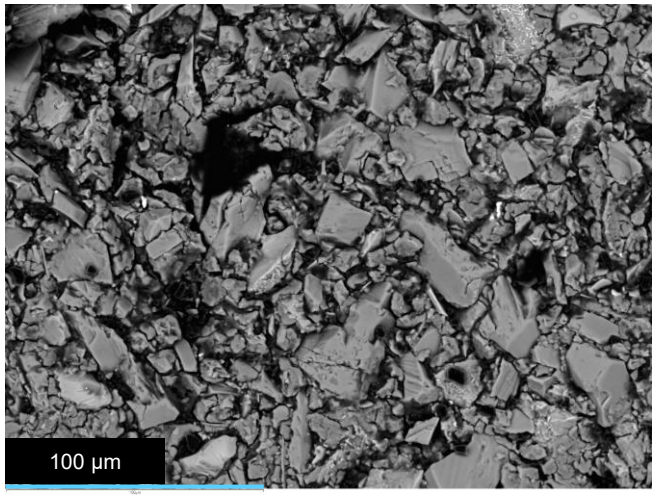
SEM of Sample 5: 15g OPRH2N and 9g soln.



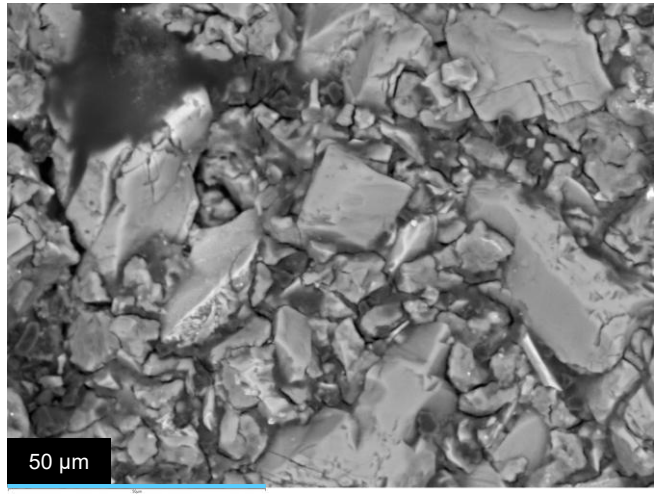
40x magnification



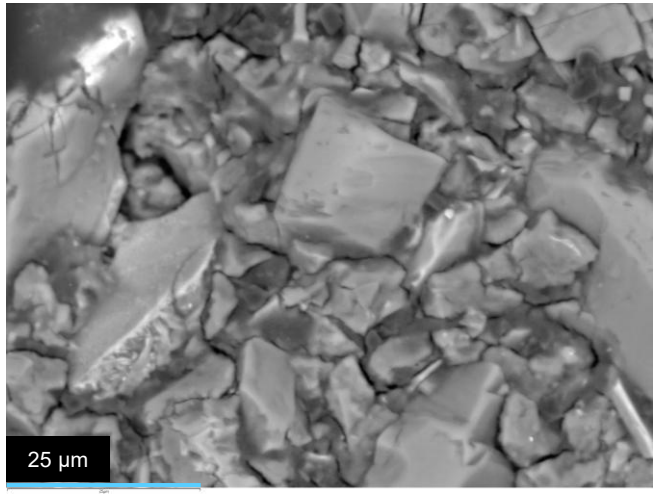
200x magnification



500x magnification



1000x magnification



1500x magnification

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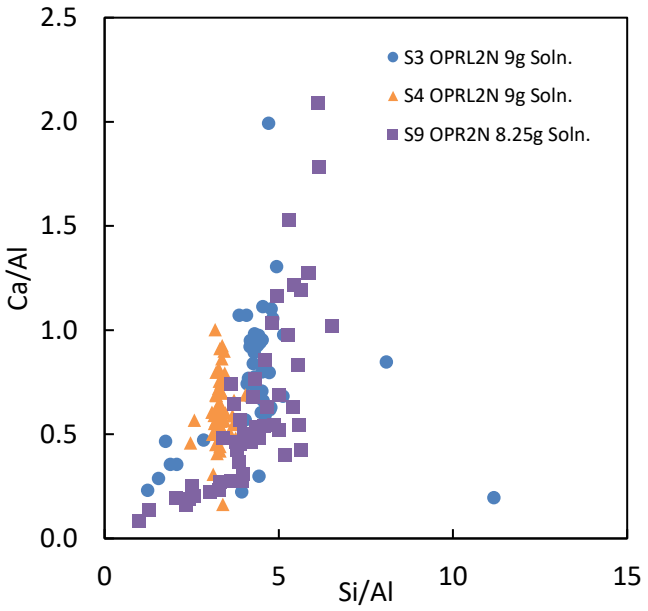
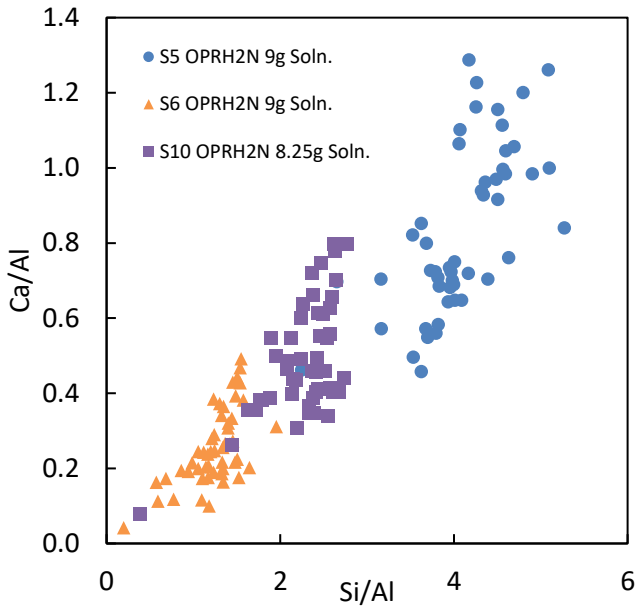
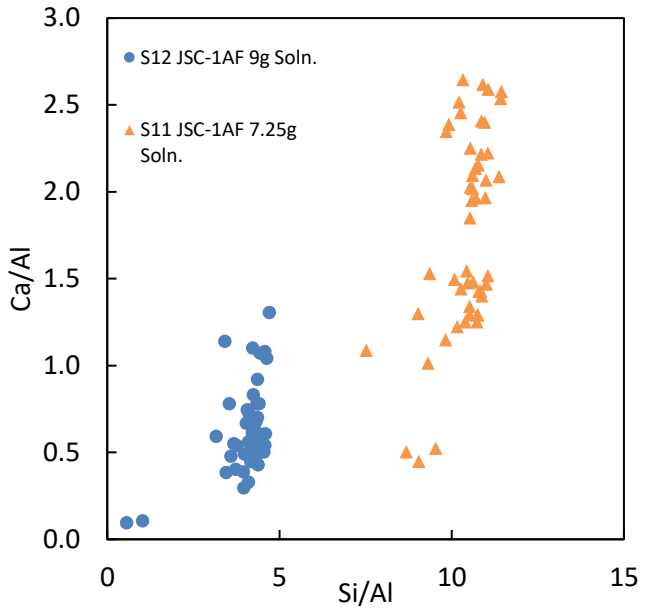
50 EDS point spectra surveys were taken of each specimen to investigate correlation between hydration products and solution to simulant ratio.







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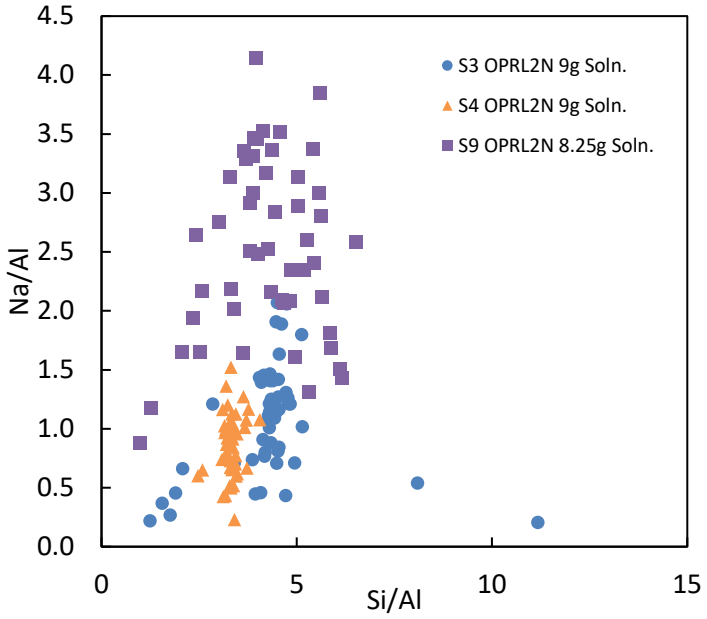
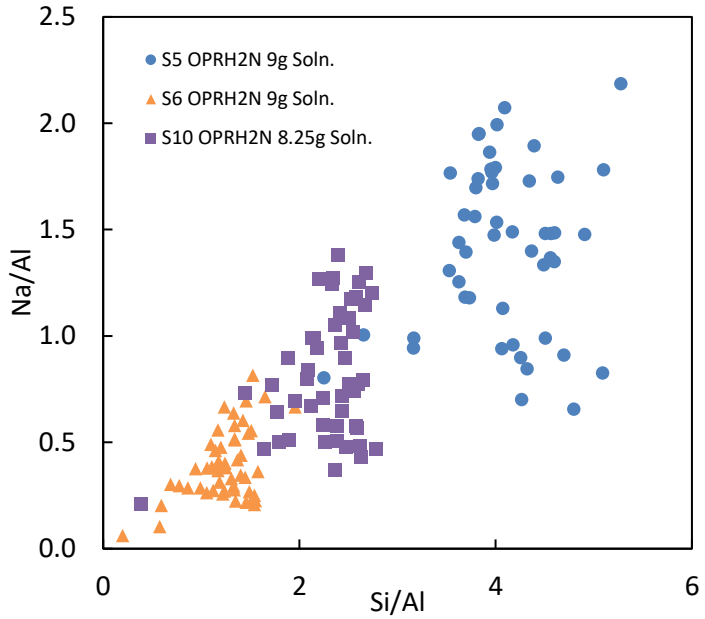
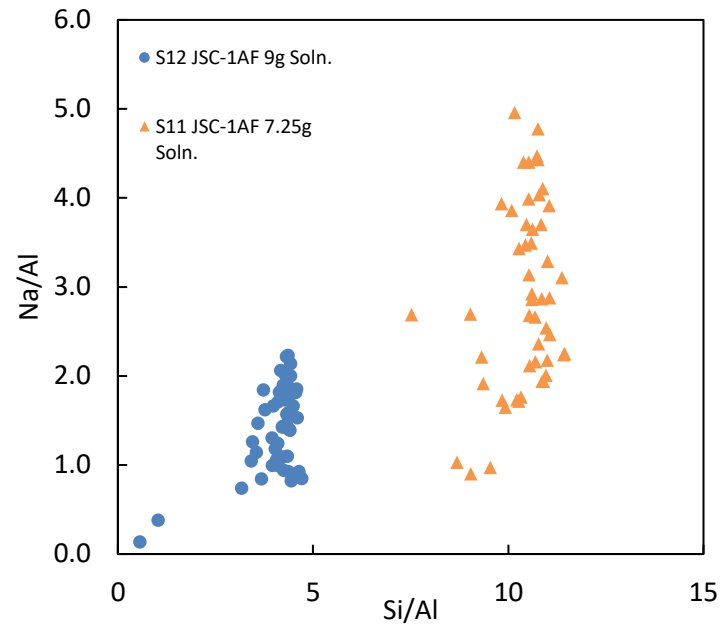
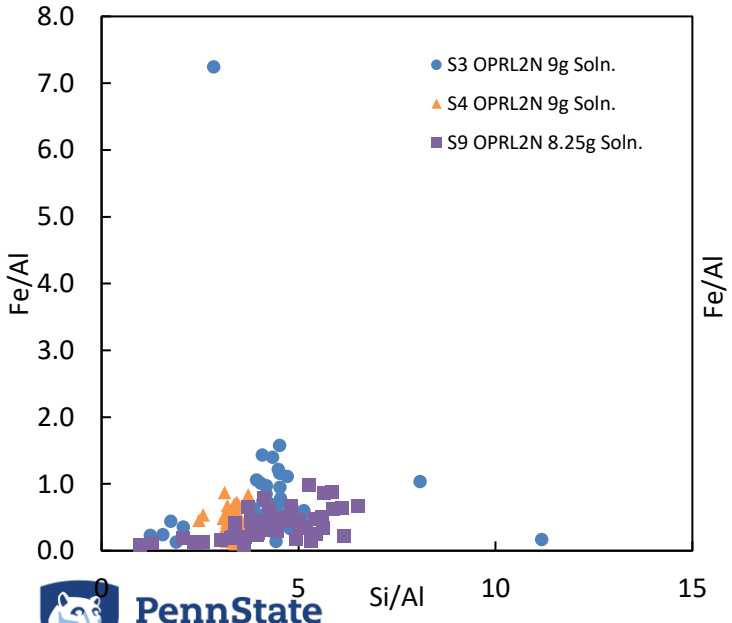
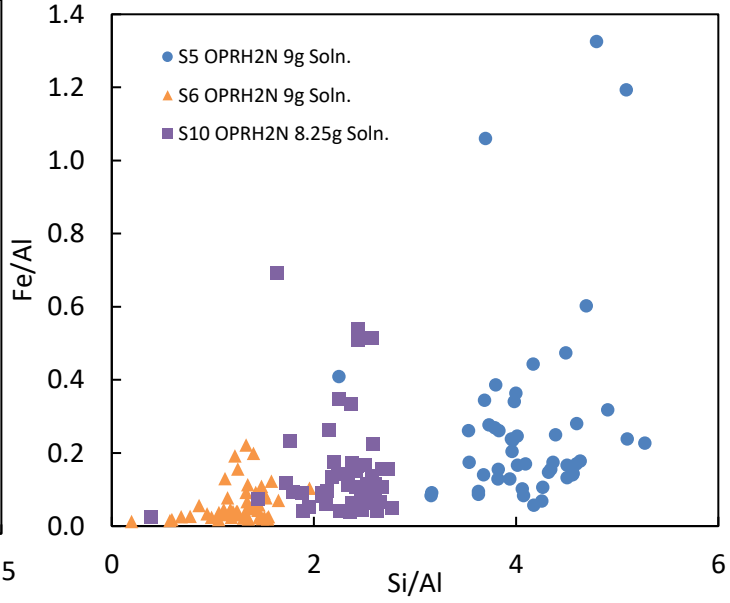
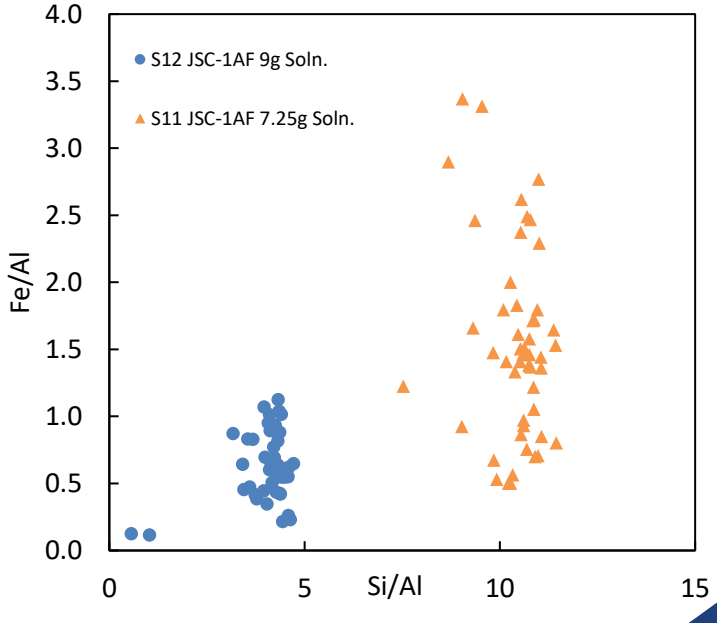

S3 OPRL2N 9g Soln.
S4 OPRL2N 9g Soln.
S9 OPRL2N 8.25g Soln.
Na/Al
Si/Al


S5 OPRH2N 9g Soln.
S6 OPRH2N 9g Soln.
S10 OPRH2N 8.25g Soln.
Na/Al
Si/Al


S12 JSC-1AF 9g Soln.
S11 JSC-1AF 7.25g Soln.
Na/Al
Si/Al


S3 OPRL2N 9g Soln.
S4 OPRL2N 9g Soln.
S9 OPRL2N 8.25g Soln.
Fe/Al
Si/Al


S5 OPRH2N 9g Soln.
S6 OPRH2N 9g Soln.
S10 OPRH2N 8.25g Soln.
Fe/Al
Si/Al


S12 JSC-1AF 9g Soln.
S11 JSC-1AF 7.25g Soln.
Fe/Al
Si/Al

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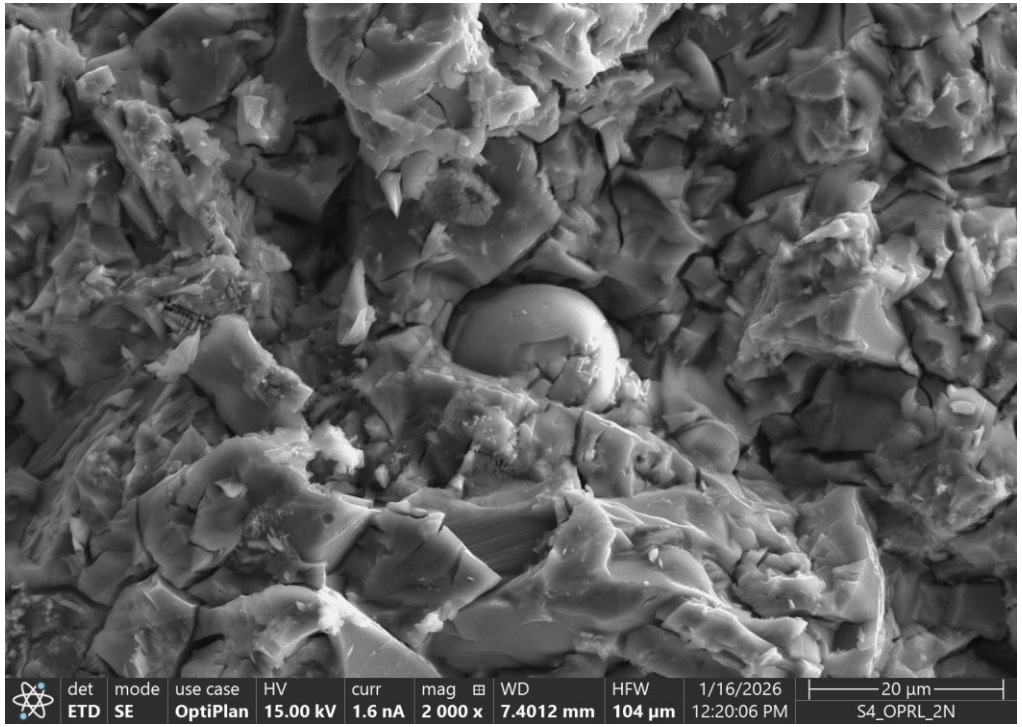
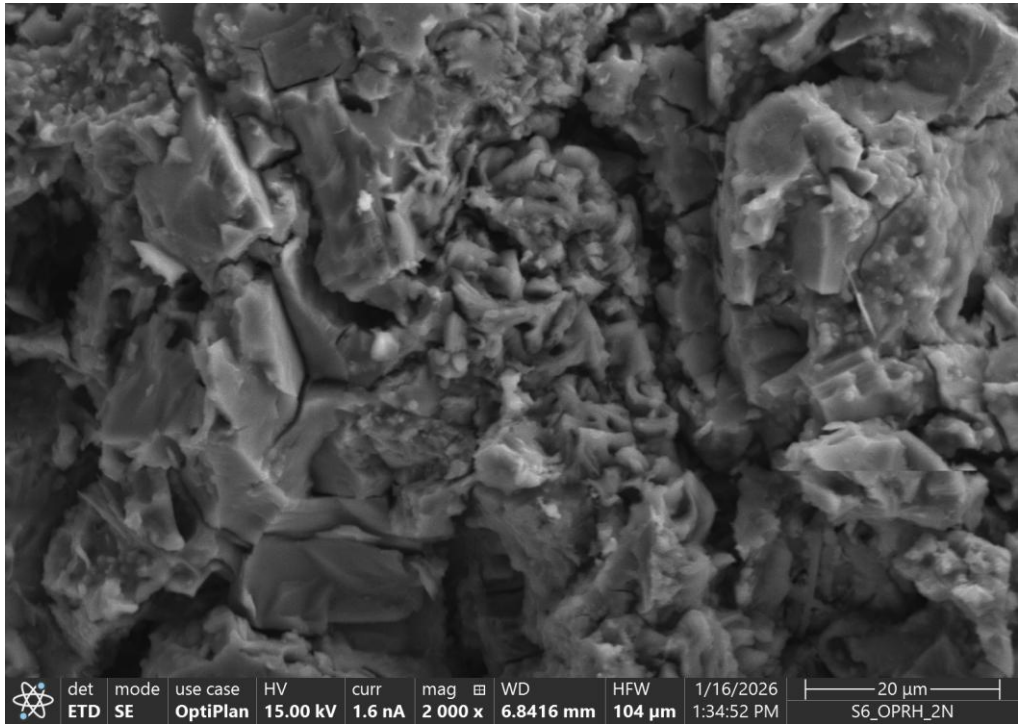
Samples were sent to Lublin Technological University for further SEM imaging and microcomputed tomography.



15g OPRL2N, 9g soln.



15g OPRH2N, 9g soln.

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Mixing and curing of geopolymer lunar concrete was successfully done on the ISS. Takeaways from analysis thus far include:

- Composites formed successfully
- Temperature impacted curing
- Cracking is a result of shrinkage
- Samples have entrapped air voids due to diffusion-controlled hydration
- Sample 3 and Sample 4 voids through entire sample are due to iButton temperature logger

The 8 MASON-MICS samples will have further testing conducted as well as machine learning applications for analysis

- Ground sample analysis is currently being conducted at PSU
- Samples are currently at Clarkson University for nanoindentation and
- Deconvolution of nanoindentation results using a bivariate Gaussian Mixture Model in MATLAB
- Machine learning can be used to optimize solution to simulant ratio for intended strength and elastic modulus

Acknowledgements

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- AddCon Lab at Penn State
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