Surface Soil Stabilization by Microbial Induced Calcite Precipitation

Junliang (Julian) Tao

Assistant Professor
Department of Civil Engineering
The University of Akron

NIEA, Oct 4, 2017

Microbe and Soil Cementation

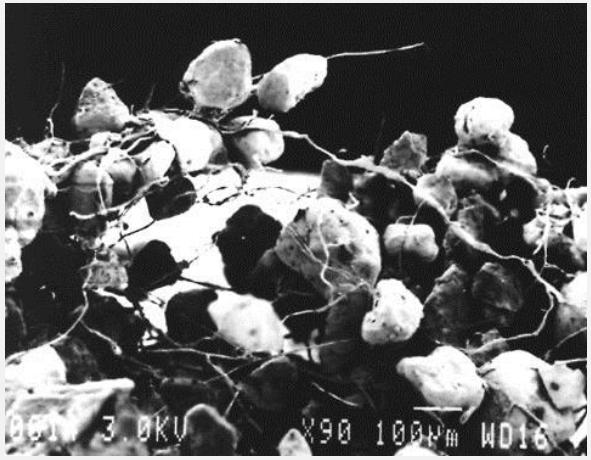
Bioinspiration

Termite Mound

https://static01.nyt.com/images/2015/03/03/science/03JPTERMITEs

***Microcoleus* in the Sonoran desert**

https://askabiologist.asu.edu/explore/desert-microbes



Closer look of a sandy crust

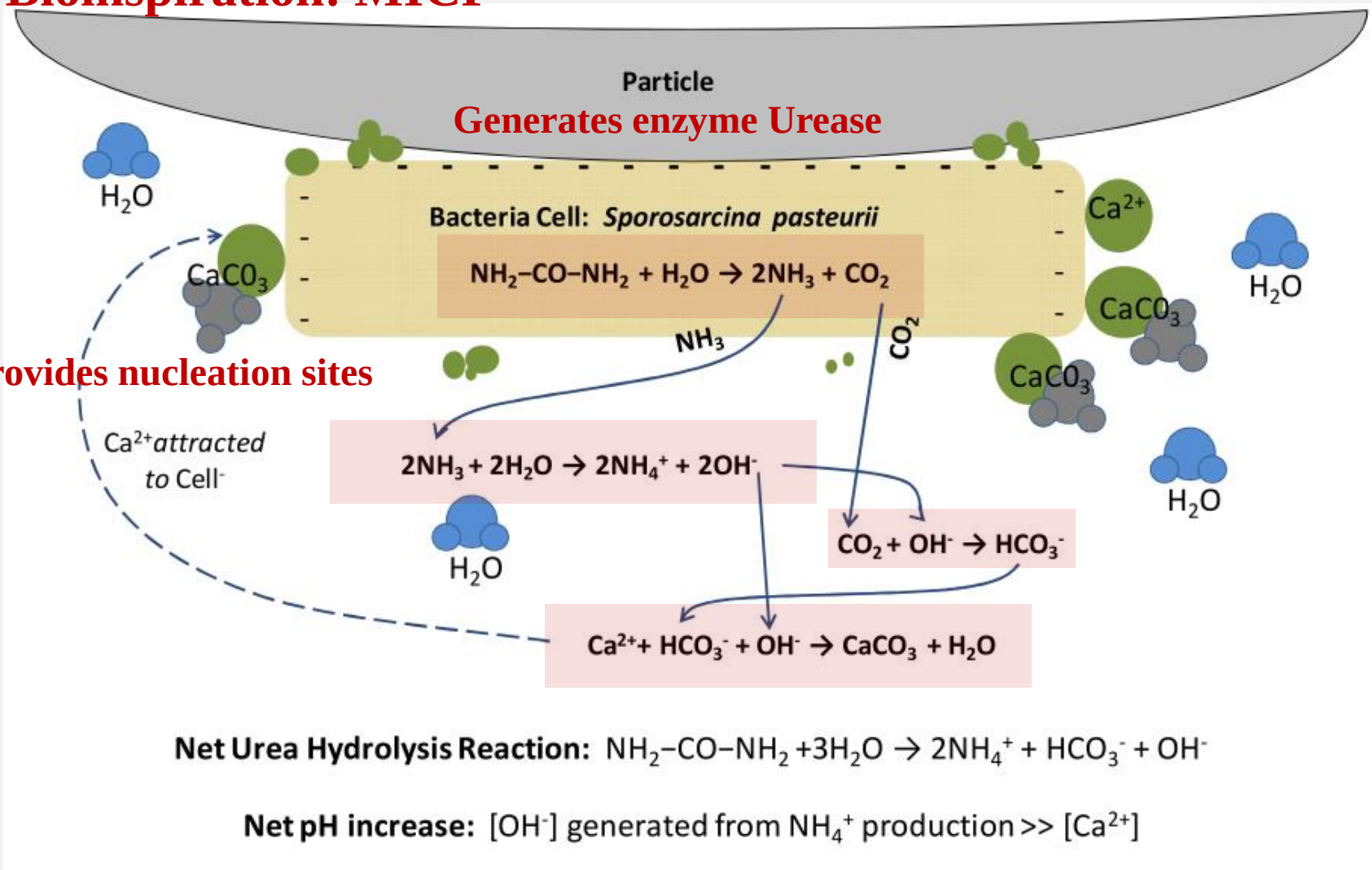
https://geochange.er.usgs.gov/sw/impacts/biology/crypto/

Stromatolites

http://stromatolites.weebly.com/morphology.html

Microbe and Soil Cementation

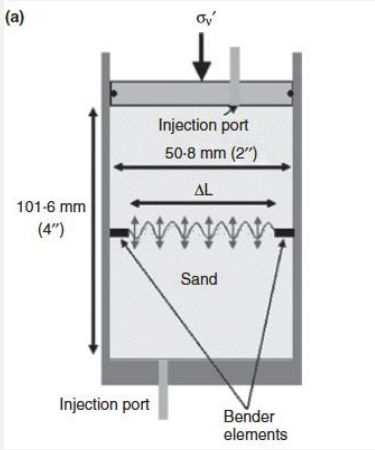
Bioinspiration: MICP



(Montoya 2012)

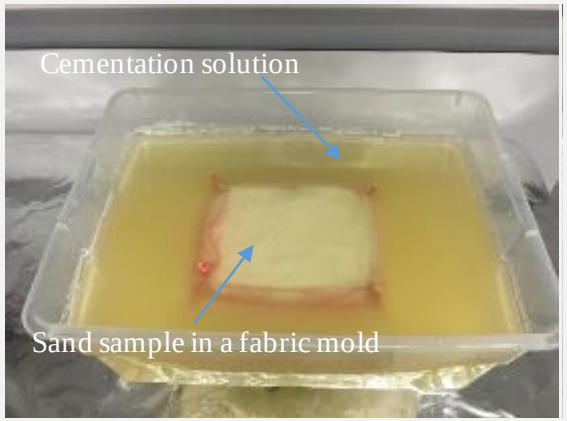
Microbe and Soil Cementation

Existing Treatment Schemes



(Mortenson et al. 2011)

(van Paassen et al. 2010)



(Bao et al. 2016)

Multiple Phase Injection

- ✓ Most studied
- ✓ Similar to existing grouting techniques
- ❑ Special Equipment
- ❑ Multiple step, tedious
- ❑ Hard to control
- ❑ Extraction wells needed for field applications
- ❑ Low efficiency due to waste of materials

Immersing

- ✓ Uniform treatment
- ✓ One step method
- ❑ Low efficiency due to waste of materials
- ❑ Limited to laboratory studies

Microbe and Soil Cementation

MICP for surface erosion control

Desired features:

- ❑ **Can be applied from the surface**
- ❑ **Create a crust with a controllable thickness**
- ❑ **Both strong and tough**

Microbe and Soil Cementation

MICP for surface erosion control

Infiltration problem:

L: infiltration depth

Soil Properties:
e: *void ratio*
θ: *volumetric moist content*
ψ: *wetting front suction*

Fluid properties:
K: *hydraulic conductivity*
γ_p: *unit weight*
μ: *viscosity*

Richard's equation

$$\frac{\partial q}{\partial t} = \frac{\partial}{\partial z}\left[K(q)\left(\frac{\partial y}{\partial z}+1\right)\right]$$

Green-Ampt equation

$$L(t)\,\mathrm{D}q = K(q)t + y\,\mathrm{D}q\ln\left(1+\frac{L(t)}{y}\right)$$

$$L(t)\,\mathrm{D}q = K(q)t$$

Infiltration depth and time can be controlled by tuning the permeability of the solution in the porous soil.

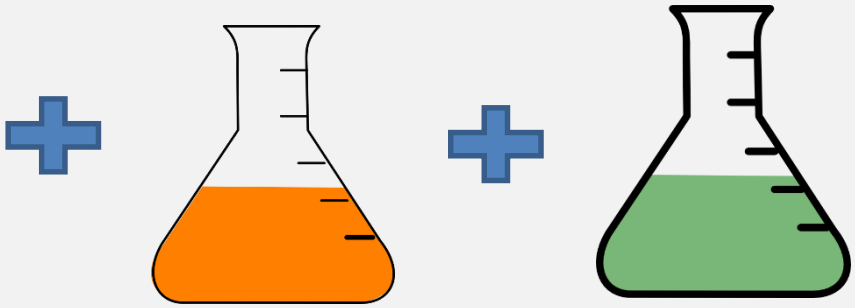
Permeability

$$K = C_s\left(\frac{g_p}{m}\right)\frac{1}{S_0^2}\left(\frac{e^3}{1+e}\right)S^3$$

Modification of the viscosity of the cementation solution might be a viable way to control the treatment depth.

Microbe and Soil Cementation

1 Concept Proof



Sand **Bacteria solution** **Cementation solution**

Sand: ASTM standard graded sand (Ottawa, IL)

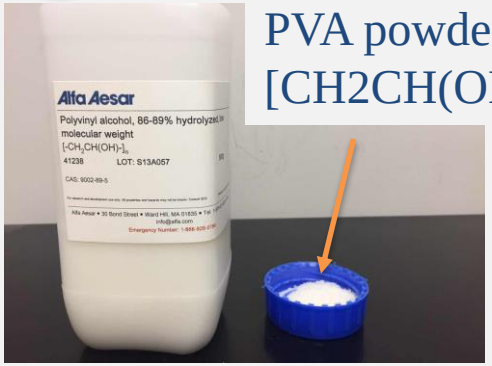
Bacteria solution: *Sporosarcina pasteurii* (ATCC 11895), Nutrient broth;

Cementation solution: Water **or Polymer additives**, Urea, $CaCl_2$, NH_4Cl, $NaHCO_3$, Nutrient broth;

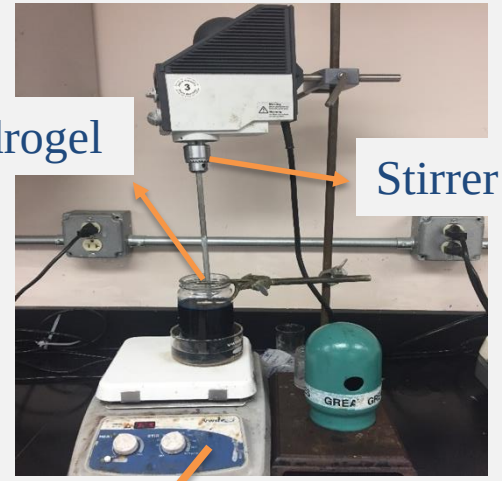
Dye: Methylene Blue

Microbe and Soil Cementation

1 Concept Proof



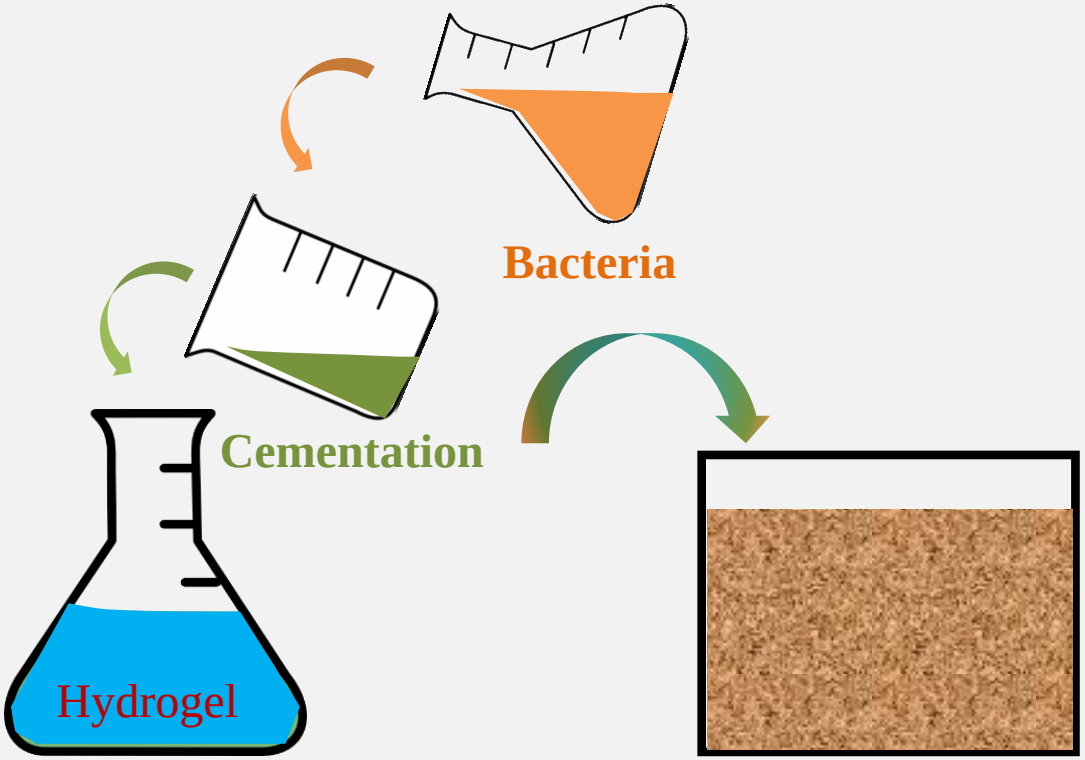
PVA powder
[CH2CH(OH)]n



Hydrogel

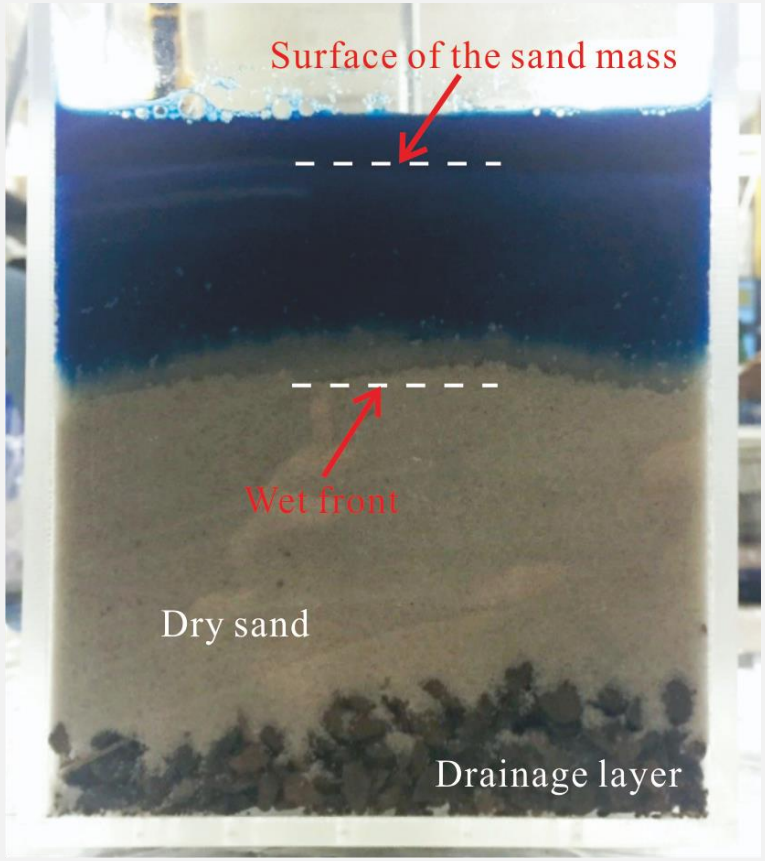
Stirrer

Heater



Microbe and Soil Cementation

1 Concept Proof



Hydrogel: Slow, uniform infiltration

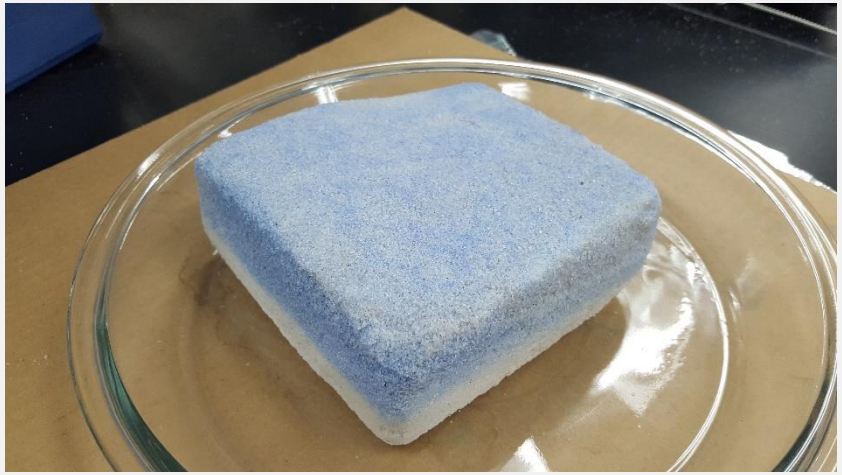
Water: Fast, non-uniform infiltration

Microbe and Soil Cementation

1 Concept Proof

	Observed		Estimated	
	Hydrogel	Water	Hydrogel	Water
Infiltration time (s)	>2400	≅60	≅4166	≅277
Infiltration depth (cm)	≅5	3~8	≅5	≅5

Sample after Soaking and Rinsing

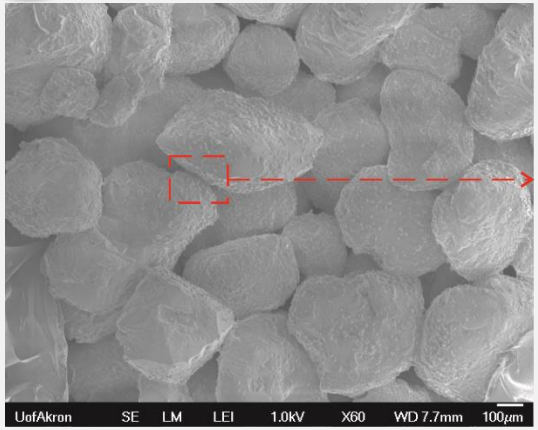


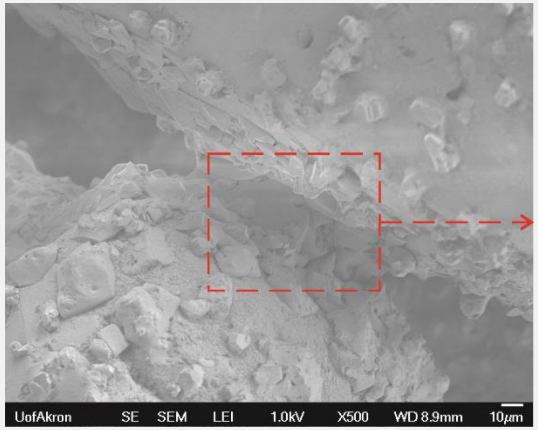
Hydrogel

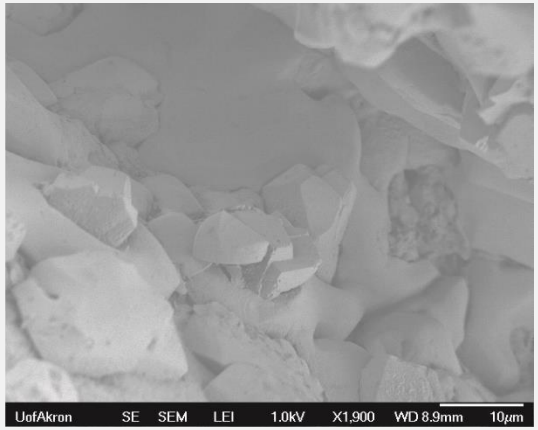
Water

Microbe and Soil Cementation

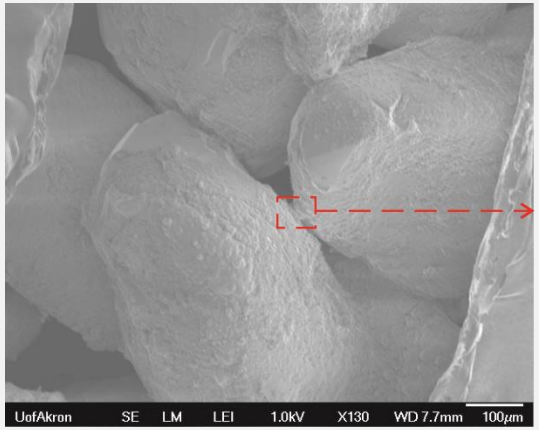
1 Concept Proof_SEM

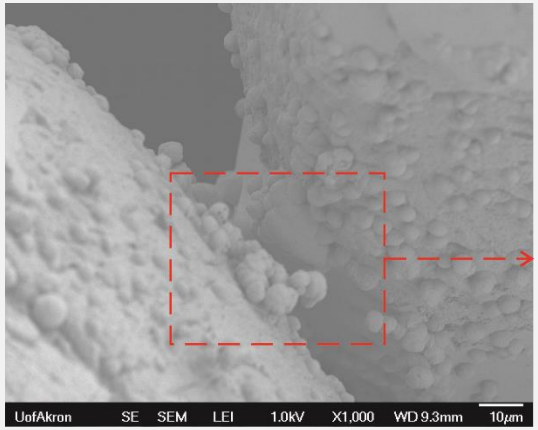


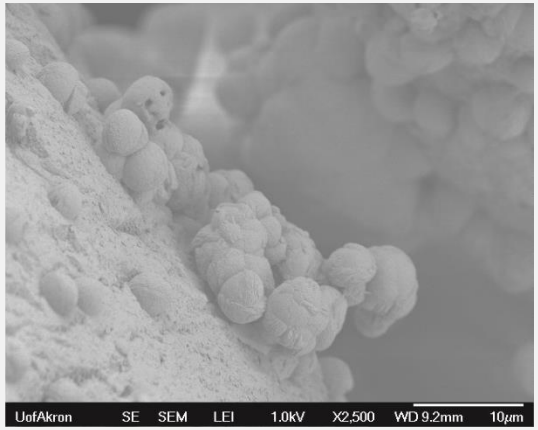




Water







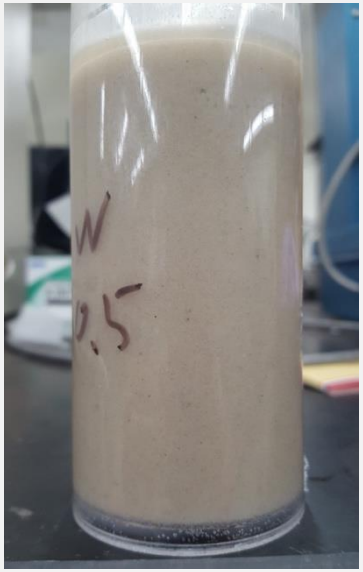
Hydrogel

Microbe and Soil Cementation

2 Optimization

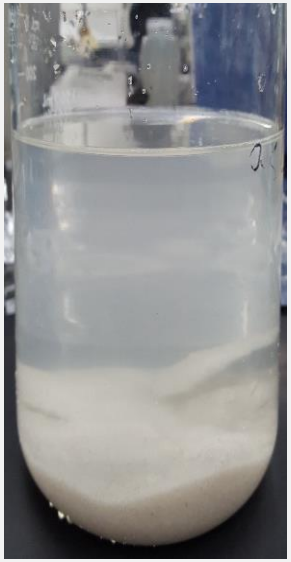
Summary of the recipes for tests in plastic molds

Group number	Specimen number	Formula	$[CaCl_2]$ (M)
1	1-6	Hydrogel cementation solution + Bacteria	0.5
2	7-12	Hydrogel cementation solution + Bacteria	1
3	13-18	Hydrogel cementation solution + Bacteria	1.5
4	19-24	Dyed Hydrogel cementation solution + Bacteria	1
5	25-30	Hydrogel cementation solution only	1

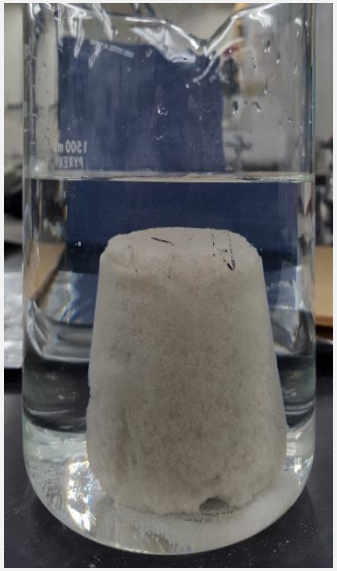


Pre-treatment

Post-treatment



Soaking-w/o bacteria

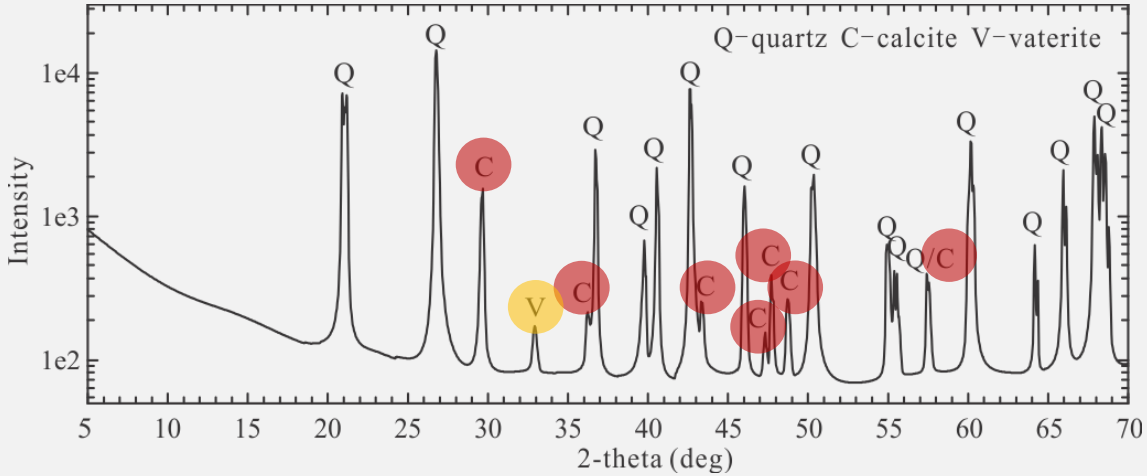


Soaking-w/bacteria

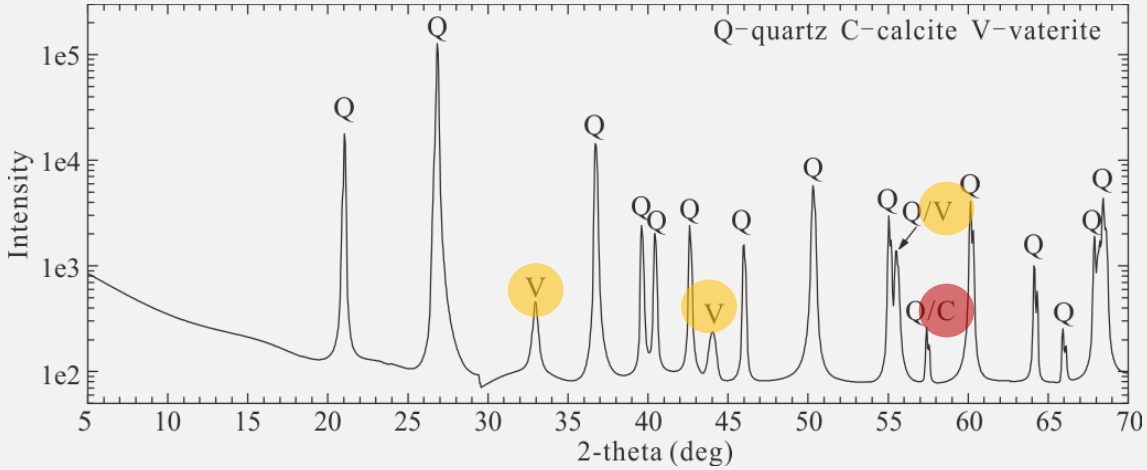
Microbe and Soil Cementation

1 Concept Proof_XRD

Water

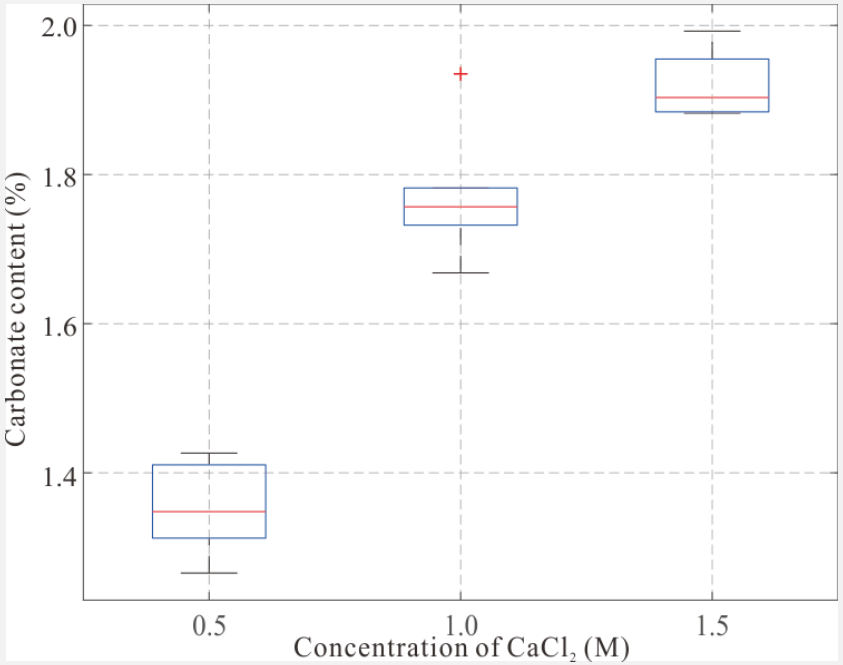


Hydrogel

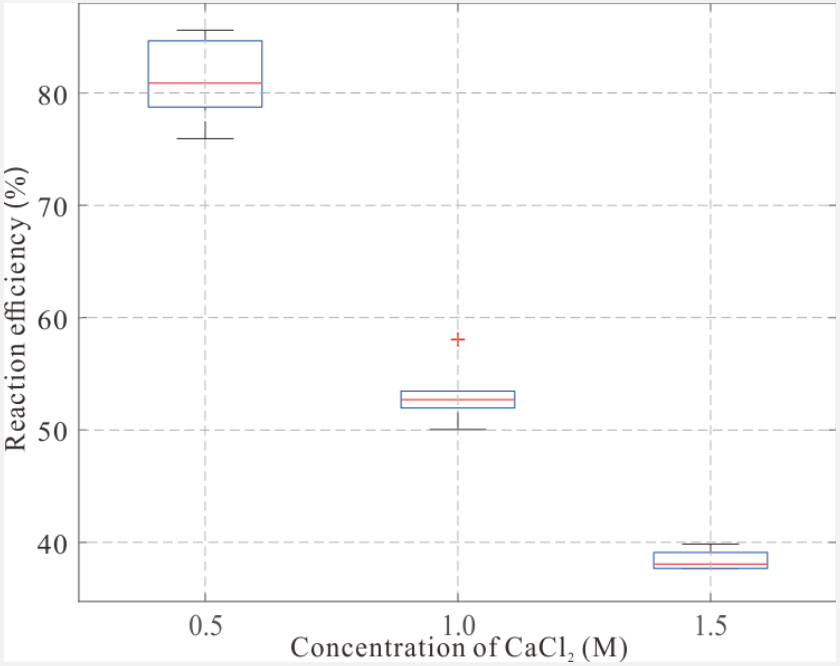


Microbe and Soil Cementation

2 Optimization



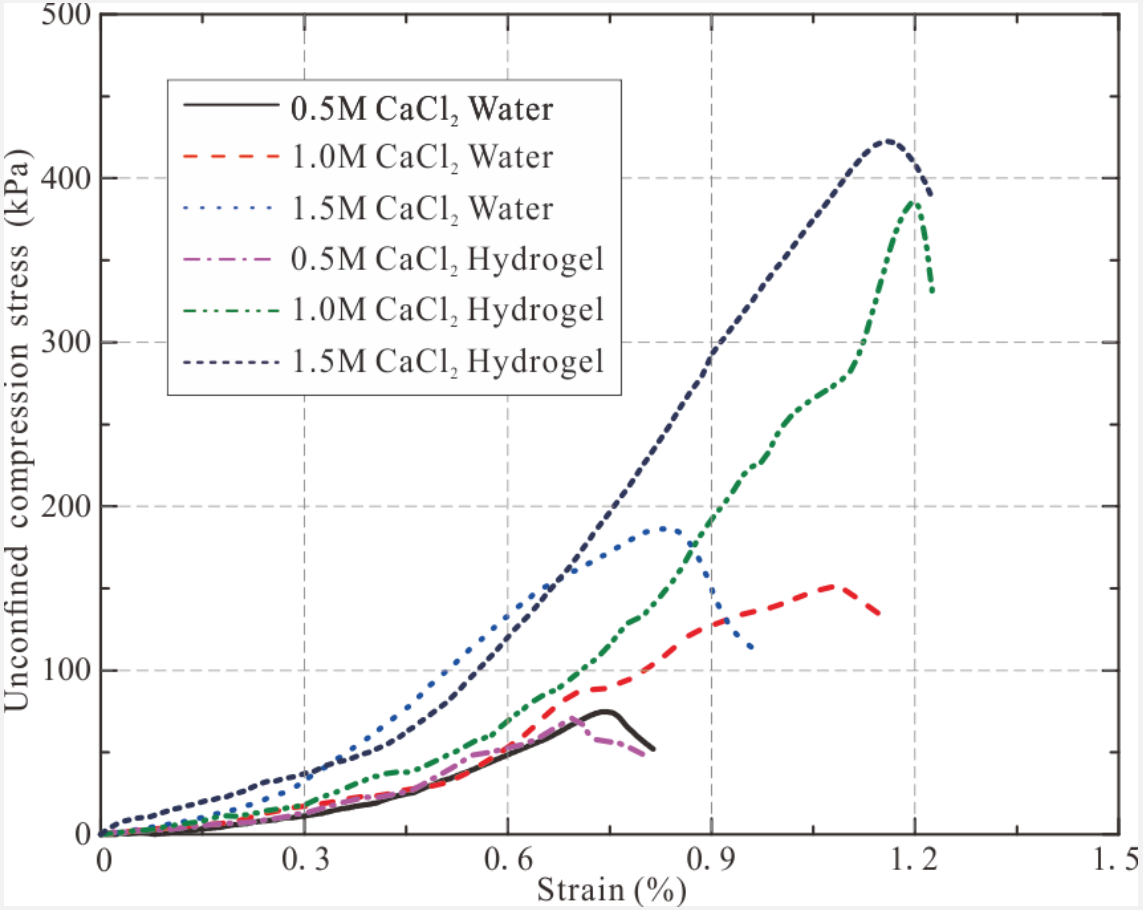
$CaCO_3$ content



Reaction efficiency

Microbe and Soil Cementation

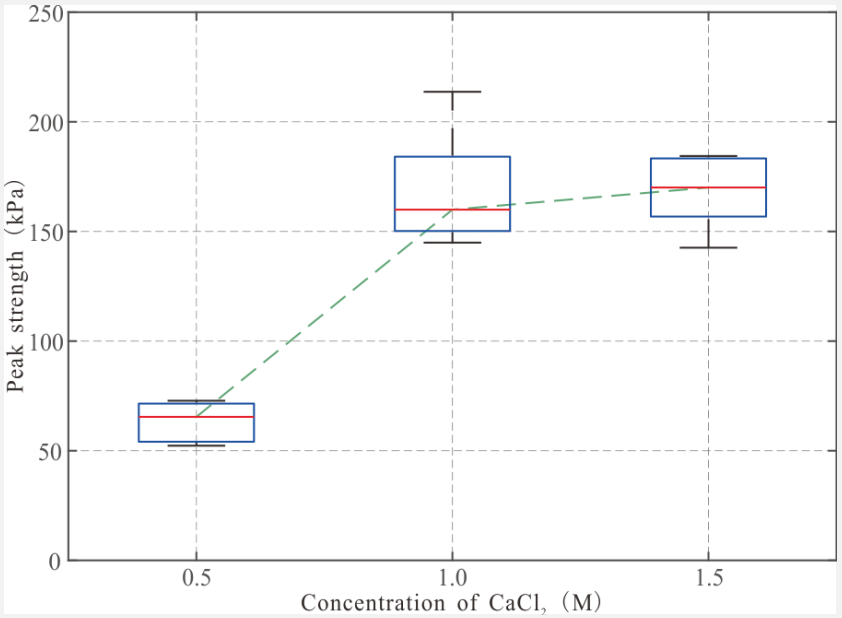
2 Optimization



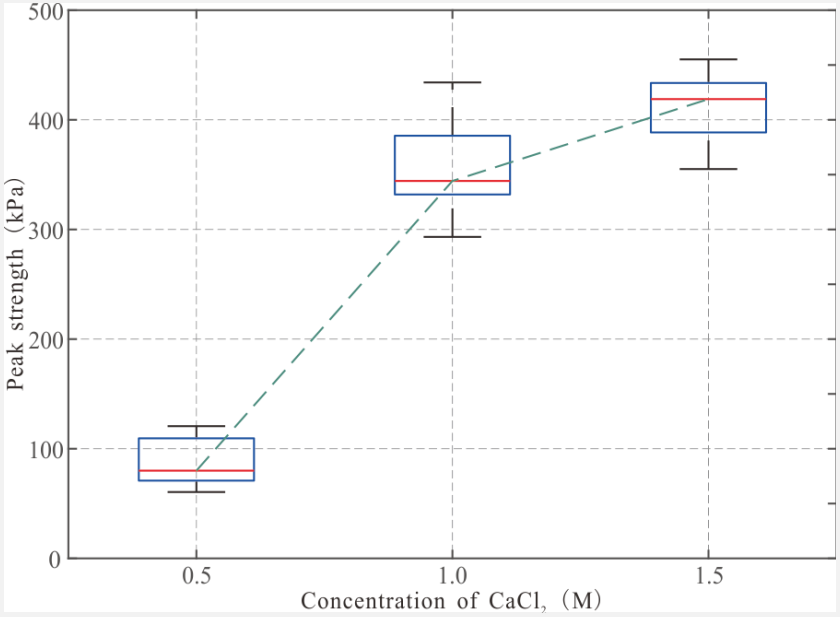
Unconfined compression test

Microbe and Soil Cementation

2 Optimization



Water

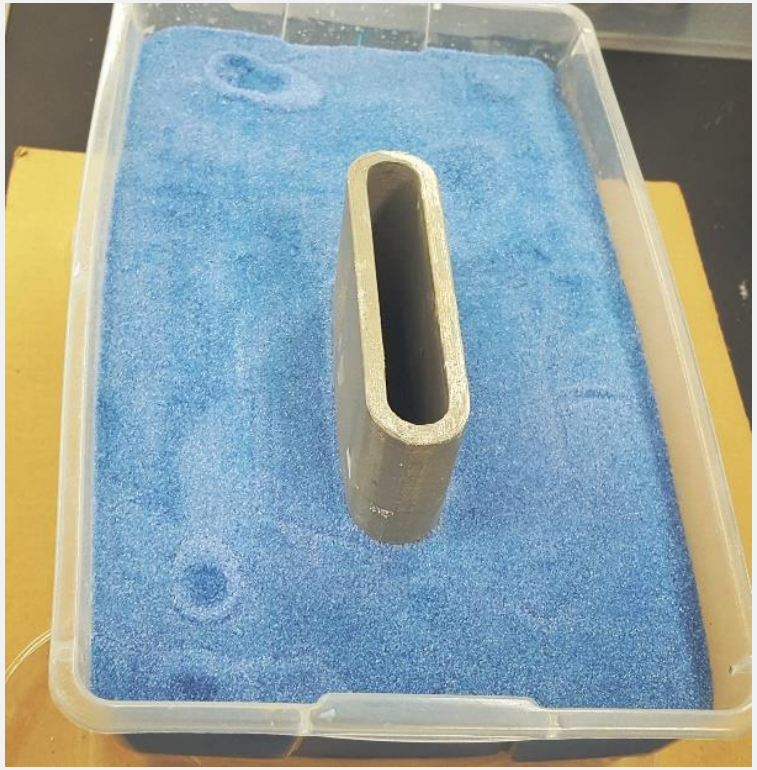


Hydrogel

Unconfined compression test

Microbe and Soil Cementation

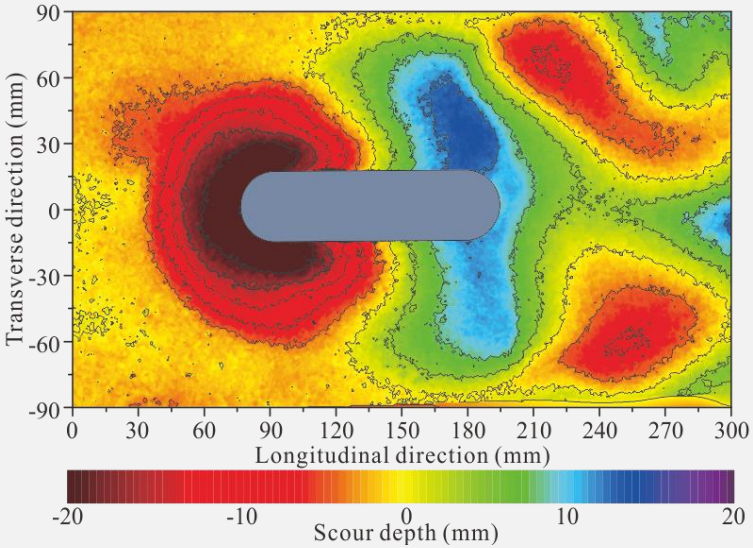
3 Laboratory validation

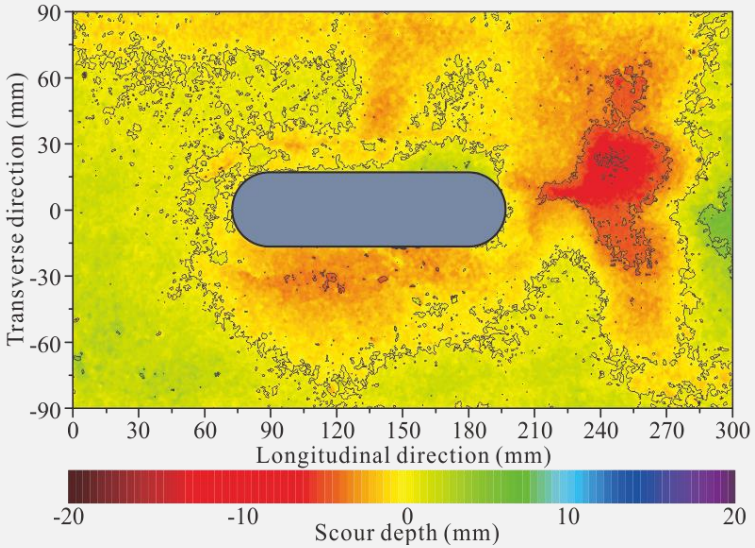


Hydrogel-based MICP around a bridge pier model

Microbe and Soil Cementation

3 Laboratory validation





Flume erosion test result: bridge scour

Microbe and Soil Cementation

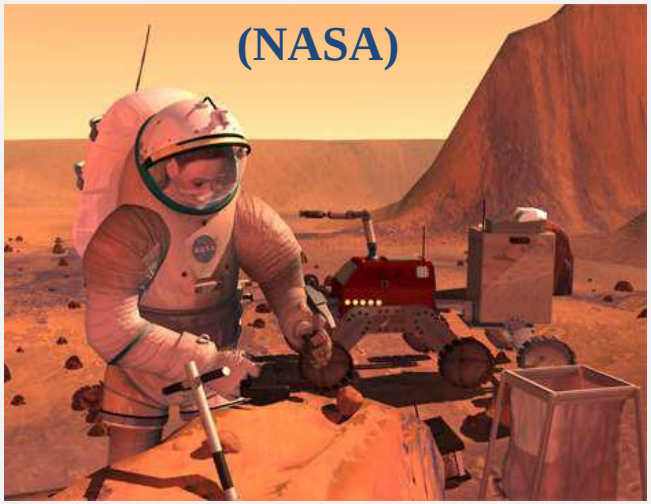
SUMMARY

- ✓ **Surface treatment of loose sand can be achieved via a hydrogel-based MICP**
- ✓ **Hydrogel significantly affects the precipitated $CaCO_3$**
  - ✓ **Crystal Polymorph**
  - ✓ **Morphology**
  - ✓ **Crystal Size**
- ✓ **Hydrogel-based MICP significantly decreases erodibility of loose sand**

CURRENT/FUTURE WORK

- ❑ **Fundamental mechanism**
- ❑ **Tunable design**
- ❑ **O/I hybrids**
- ❑ **Scaling up, QA/QC**

Microbe and Soil Cementation



Extraterritorial *in situ* resource utilization

- Bio-brick factory?
- Surface soil stabilization for dust control?
- Soil stabilization for underground habitat?
- 3D printing?

Martian soil		Lunar soil		
Formula	Composition (wt %)	Formula	Composition (wt %)	
			Maria	Highlands
SiO_2	45~50%	SiO_2	45.40%	45.50%
FeO, Fe_2O_3	~17%	Al_2O_3	14.90%	24.00%
Al_2O_3	~9%	CaO	11.80%	15.90%
MgO	~8%	FeO	14.10%	5.90%
CaO	~7%	MgO	9.20%	7.50%
SO_3	~5%	TiO_2	3.90%	0.60%
Na_2O	~3%	Na_2O	0.60%	0.60%
TiO_2	~2%			

- ✓ Soil compositions and particle size distributions are suitable
- ✓ Calcium rich regolith
- ✓ CO_2 rich in Martian atmosphere
- ✓ Human waste (urine) can be reutilized
- ✓ Bacteria duplicate fast
- ❑ Survivability in ambient environment (Temperature, radiation)?
- ❑ Biocontamination?

Thank you!