Reinventing CEMENT: Carbonation-Enabled Mineralization to Engender Novel Technology

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Goal: To Synthesize Crystalline Calcium Silicate Cements

We are synthesizing low permeability, high chemical stability, and high strength materials using CO_2 and calcium silicates

Total project cost:	$1.18M
Current Q / Total Project Qs	9/12

TINA-Cement
Annual Meeting
October 13 & 14, 2021

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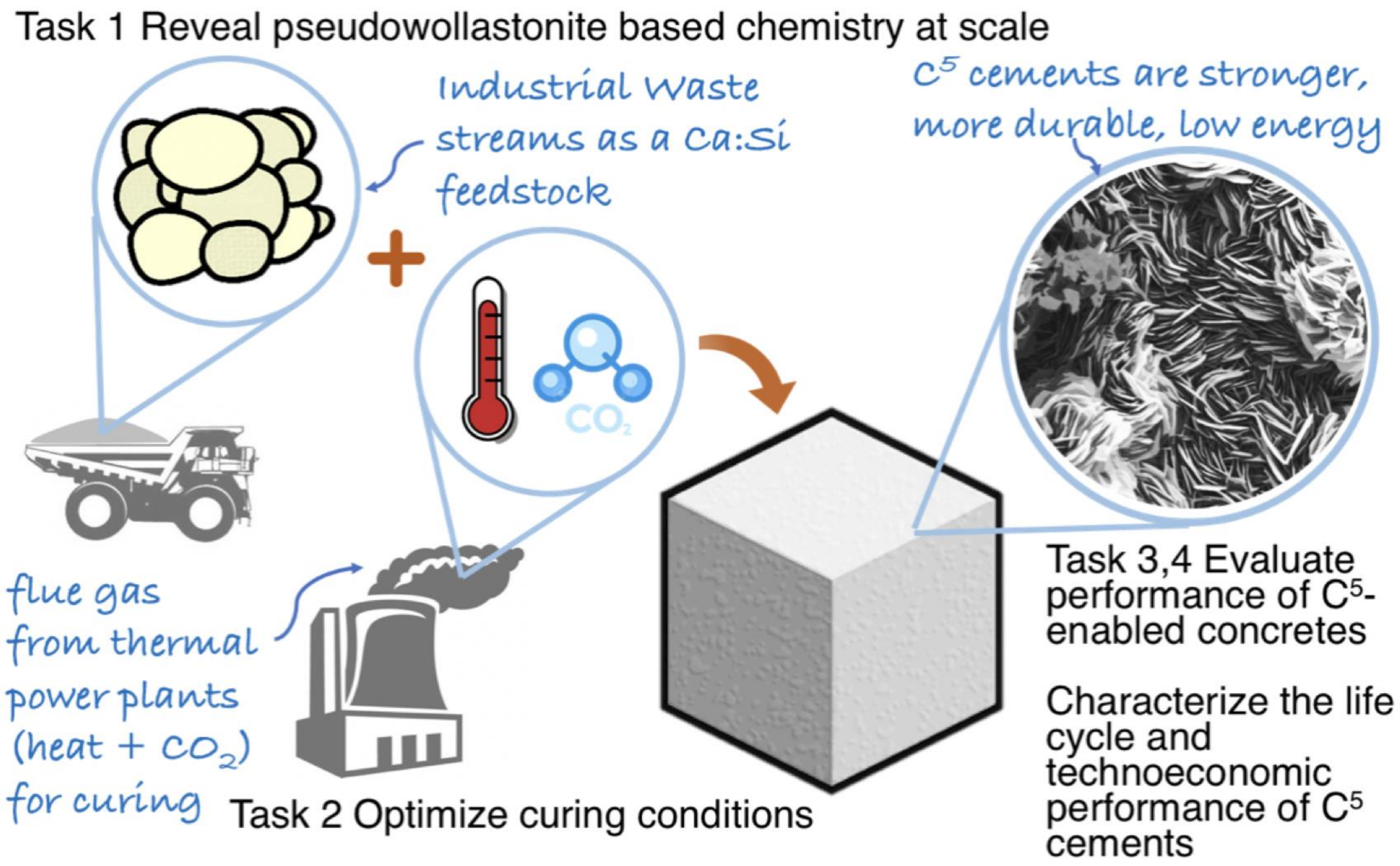
The Concept



Task 1 Reveal pseudowollastonite based chemistry at scale
Industrial waste streams as a Ca:Si feedstock
C5 cements are stronger, more durable, low energy
CO2
flue gas from thermal power plants (heat + CO2) for curing
Task 2 Optimize curing conditions
Task 3,4 Evaluate performance of C5-enabled concretes
Characterize the life cycle and technoeconomic performance of C5 cements

The Team

	Andres Clarens is a Professor of Civil and Environmental Engineering at the University of Virginia. He is an aqueous geochemist and expert in water/rock interactions. His work on geologic carbon storage led to the study of certain calcium silicate polymorphs and their possible application for inspiring low carbon cements. He has done complementary work on reactive transport in porous media and also maintains a modeling group that assesses the environmental sustainability of emerging technologies.
	Rouzbeh Shahsavari is the Founder and President of C-Crete Technologies, an adjunct-Professor at Rice University, and an internationally recognized expert on structure, mechanics and durability of cementitious materials, with a particular focus on CSH phases. His pioneering work on this subject has resulted in several national/international awards. At C-Crete, he has been a PI on several R&D and lab-to-market commercialization of new cementitious products.
	Elizabeth Opila is a Professor of Materials Science and Engineering at the University of Virginia. She is an expert in ceramic materials, especially oxides and silicates proposed for use in power and propulsion applications. Her work focuses on experimental determination of the thermodynamics and kinetics of high temperature reactions for life prediction of high temperature materials in extreme environments.

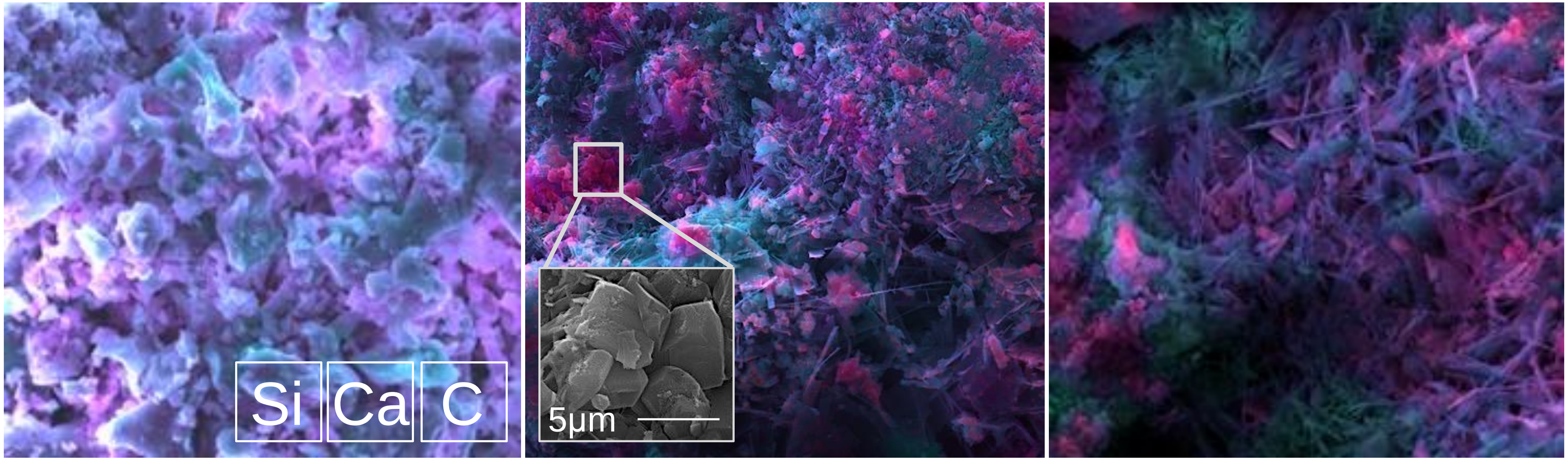
Project Objectives

- Characterize feedstock production and substitution methods
  - our understanding of the chemistry is being used to explore alternative low-cost feedstocks and formulations
- Optimize the manufacture of C^5 cements and pre-cast set-up
  - we are synthesizing mortars that will enable us to benchmark our formulations to competitors
- Optimize manufacture of precast concrete products
  - our curing conditions are still being refined to maximize the rate of production
- Meeting ASTM/ACI/AASHTO testing standards
  - first markets focused on pre-cast applications where chemical stability and/or low permeability is critical

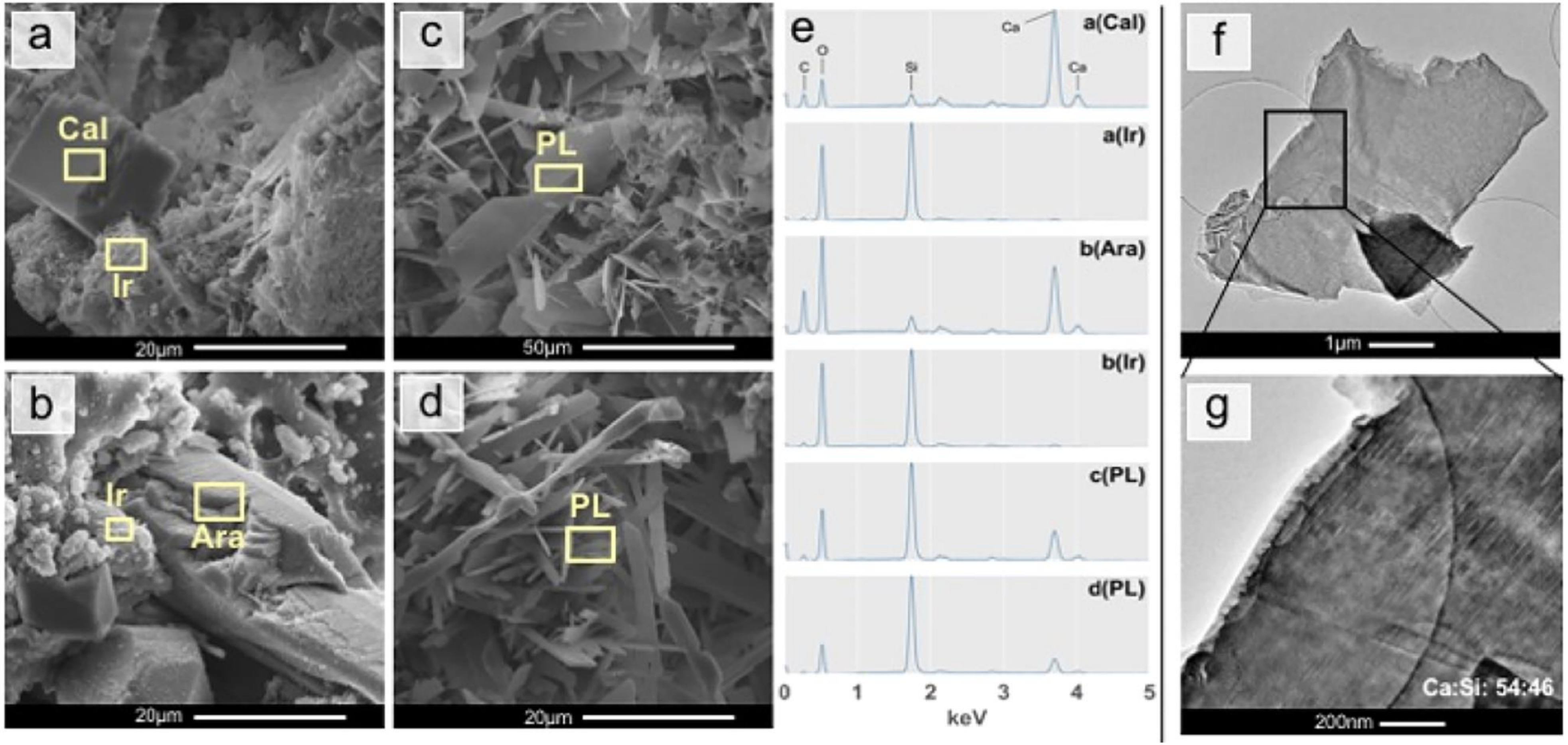
Results: carbonation of calcium silicates

$$CaSiO_{3(s)} + 2H^+ \leftrightharpoons Ca^{2+} + SiO_{2(am)} + H_2O$$

$$Ca^{2+} + CO_{2(aq)} + H_2O \leftrightharpoons CaCO_{3(s)} + 2H^+$$

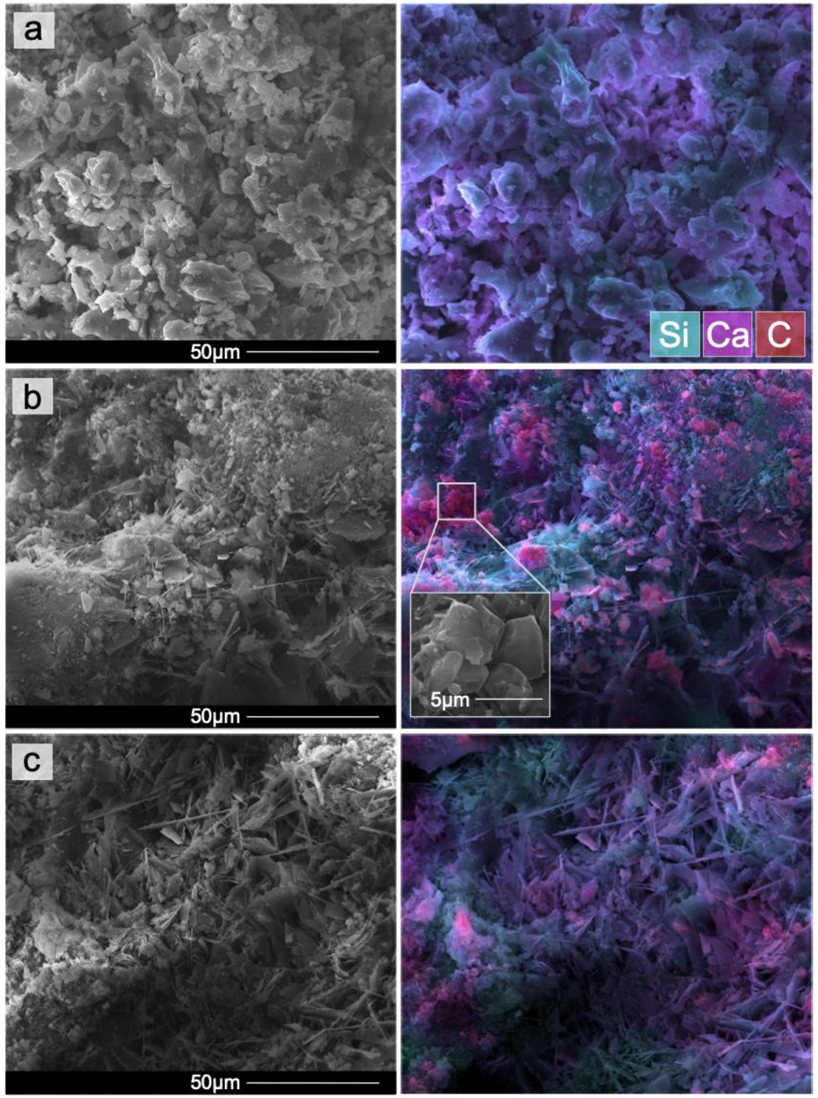


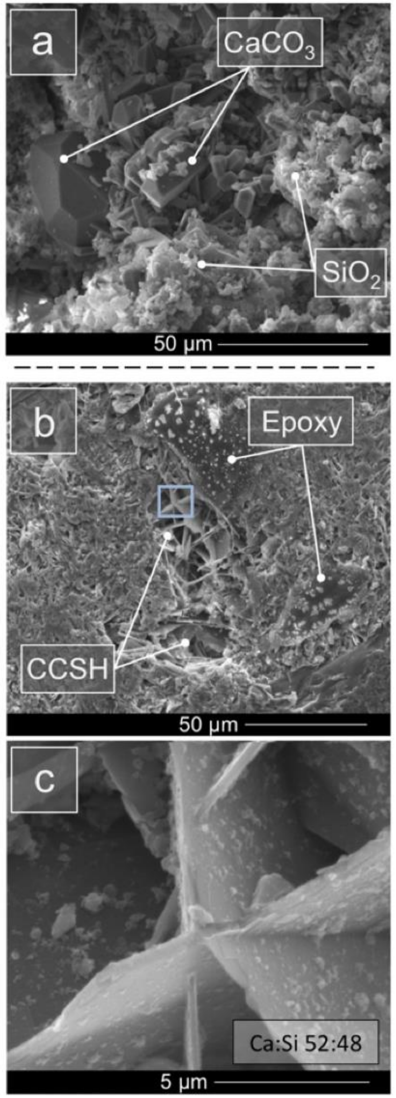
Multiple phases some crystalline

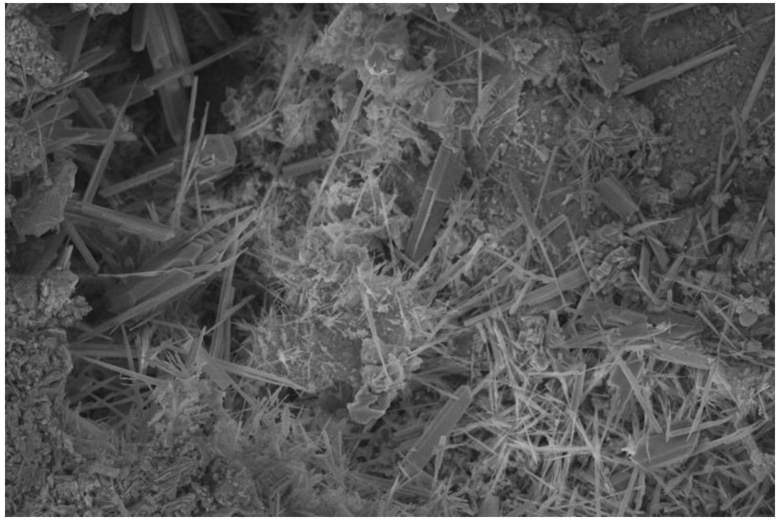


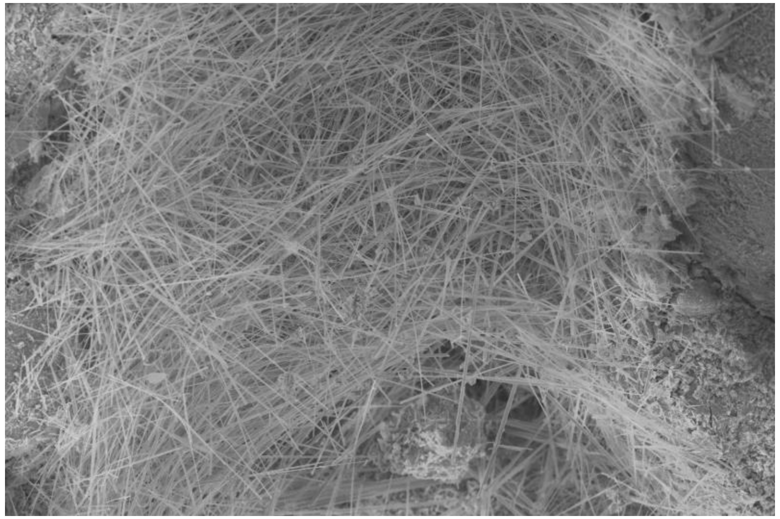
calcite (Cal), aragonite (Ara), and irregular silica phases (Ir)

CCSH phases are distinctive at continuous phase









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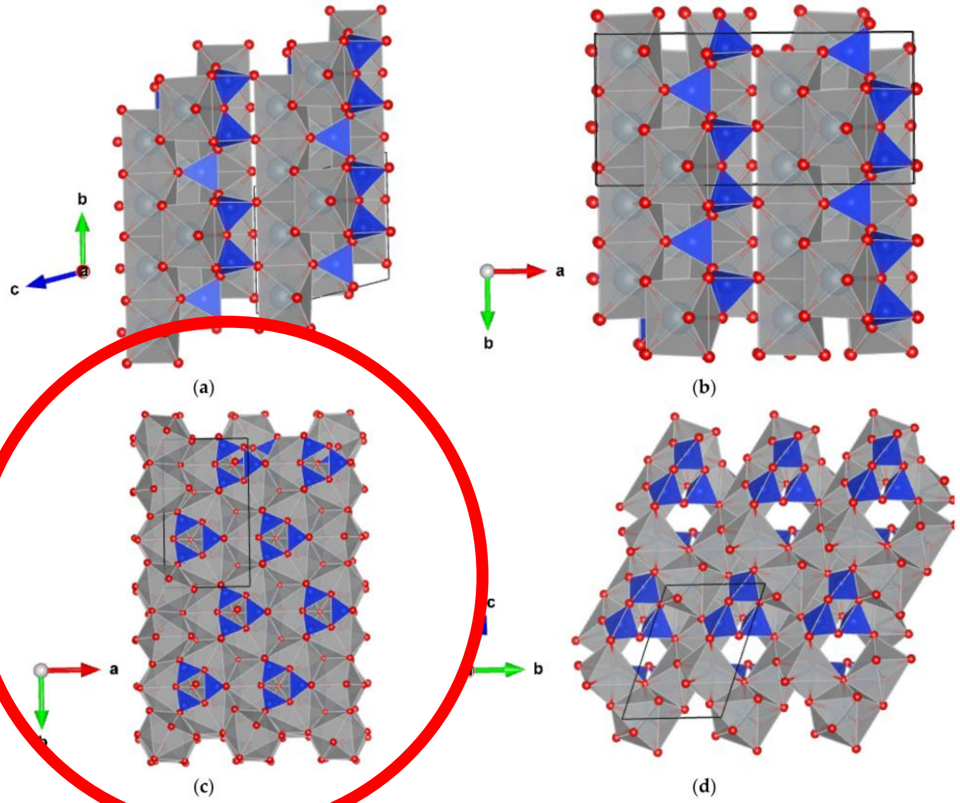
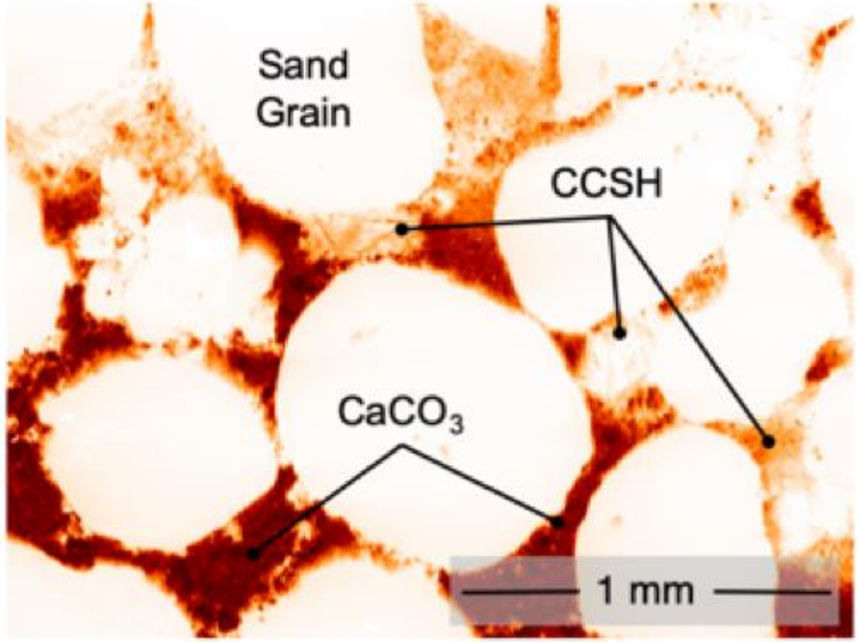
Unpacking the mechanistic underpinnings

$$CaSiO_{3(s)} + 2H^+ \leftrightharpoons Ca^{2+} + SiO_{2(am)} + H_2O$$

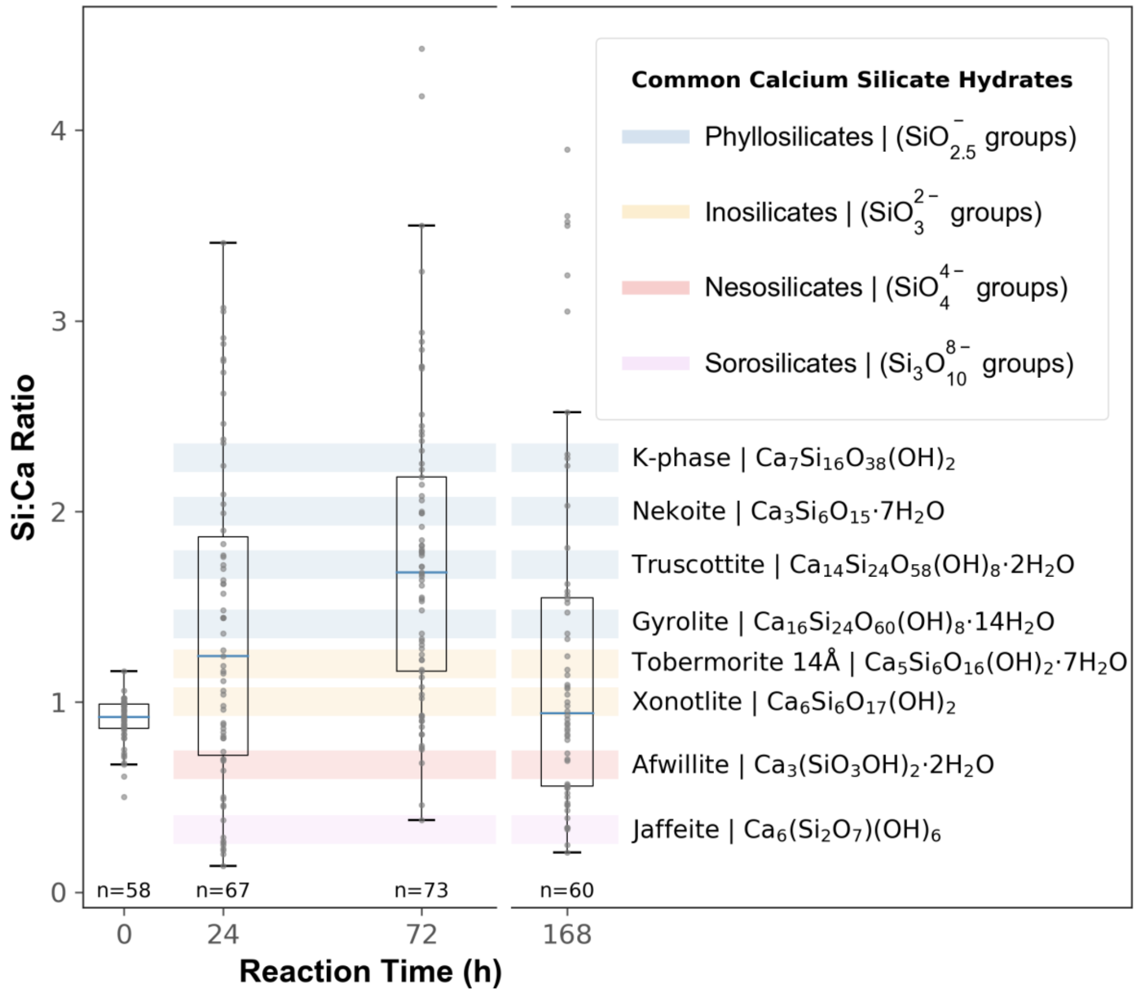
$$Ca^{2+} + CO_{2(aq)} + H_2O \leftrightharpoons CaCO_{3(s)} + 2H^+ + \textbf{CCSH}$$

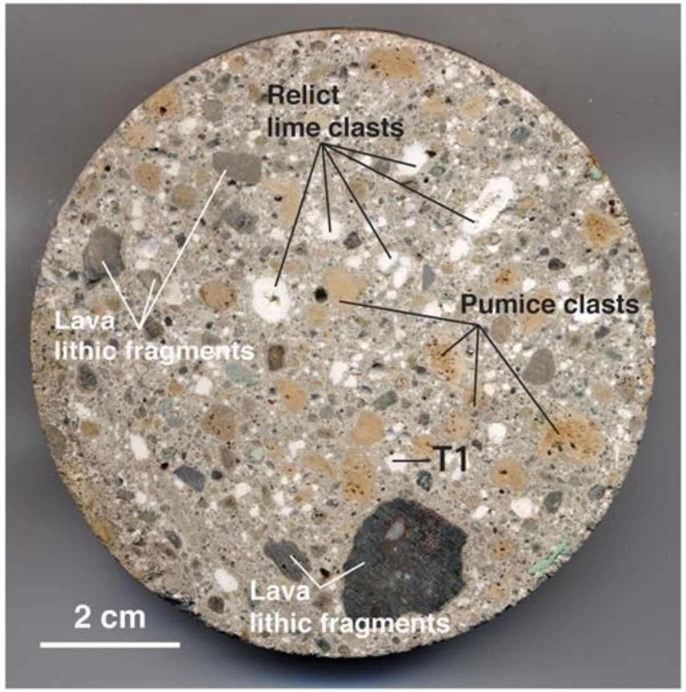




Milani, S.; et al. Crystal Structure Evolution of CaSiO3 Polymorphs at Earth's Mantle Pressures. Minerals 2021, 11, 652.

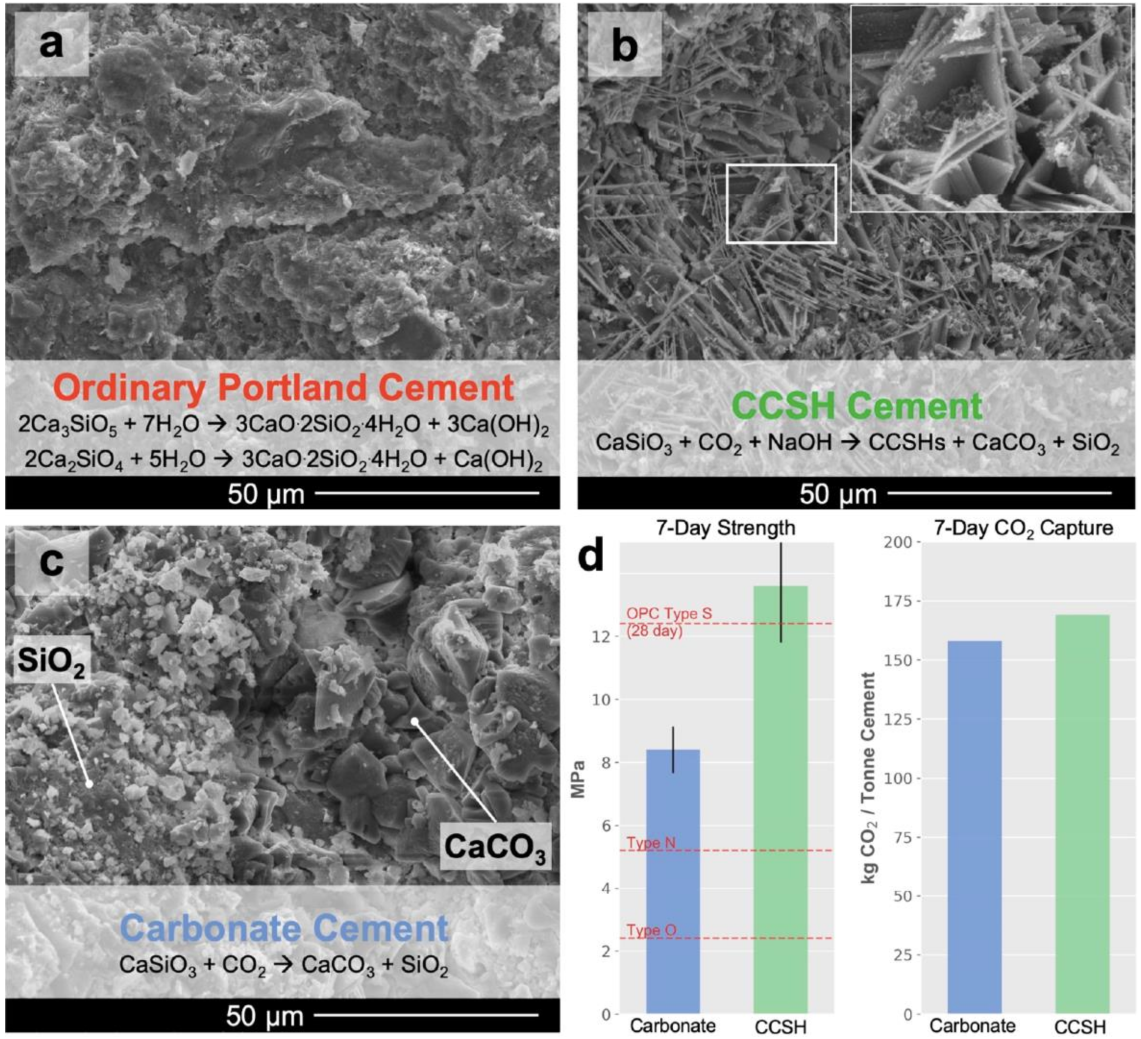
Composition of CCSH phases

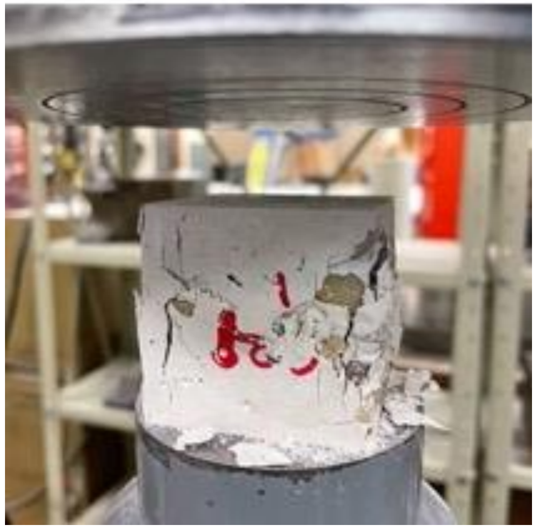


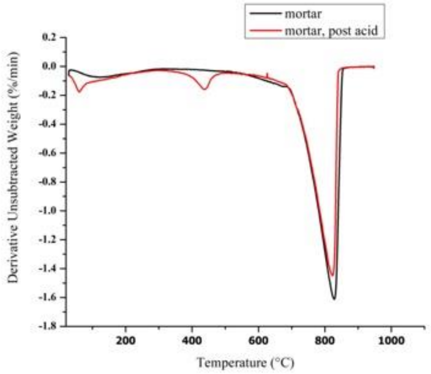


American Mineralogist (2013) 98 (10): 1669–1687.

Compressive strength tests show high strengths for mortar







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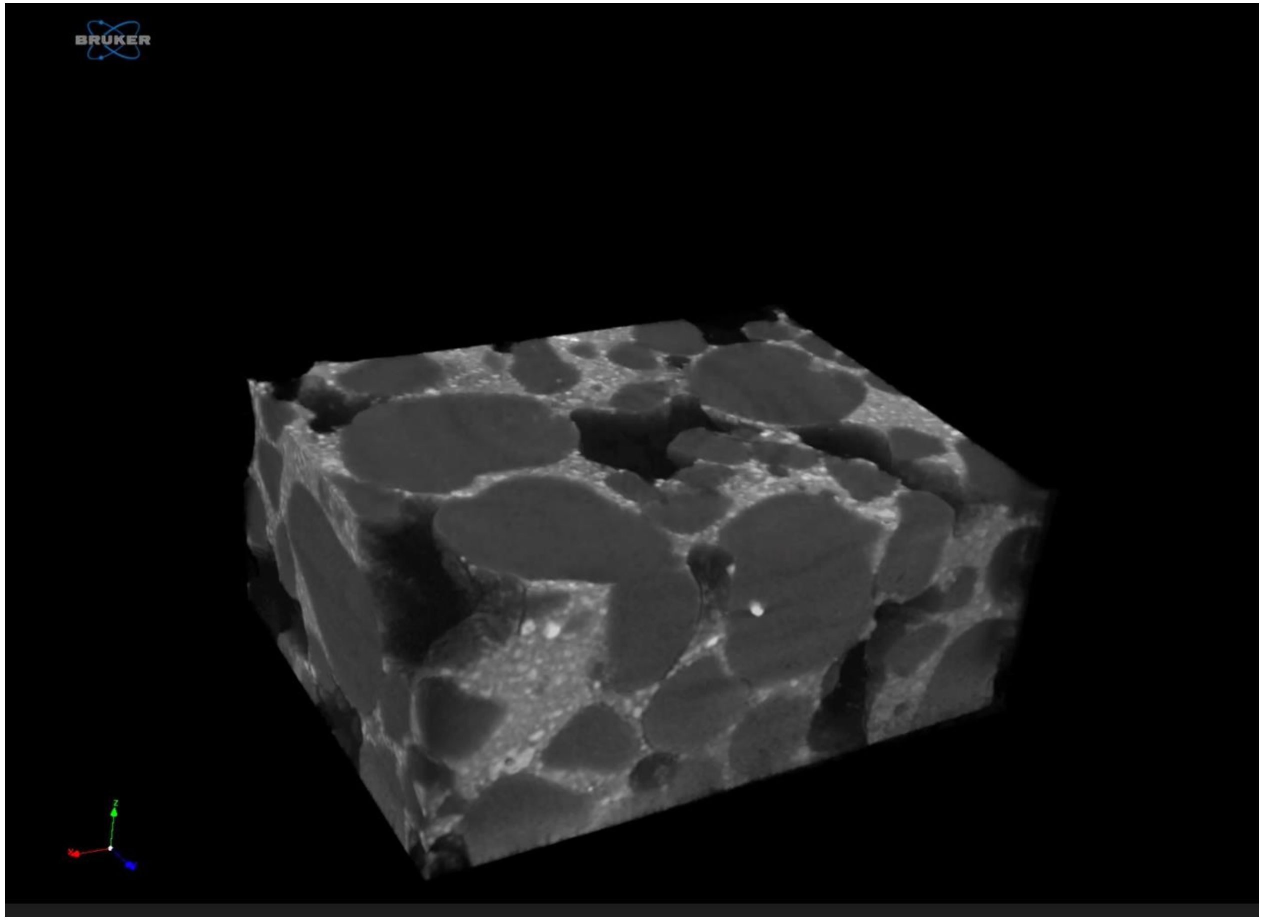
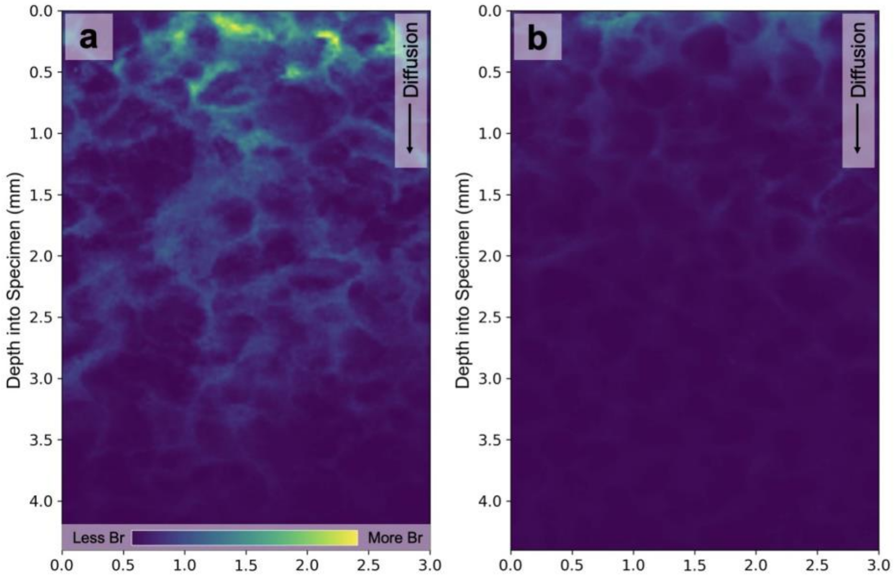
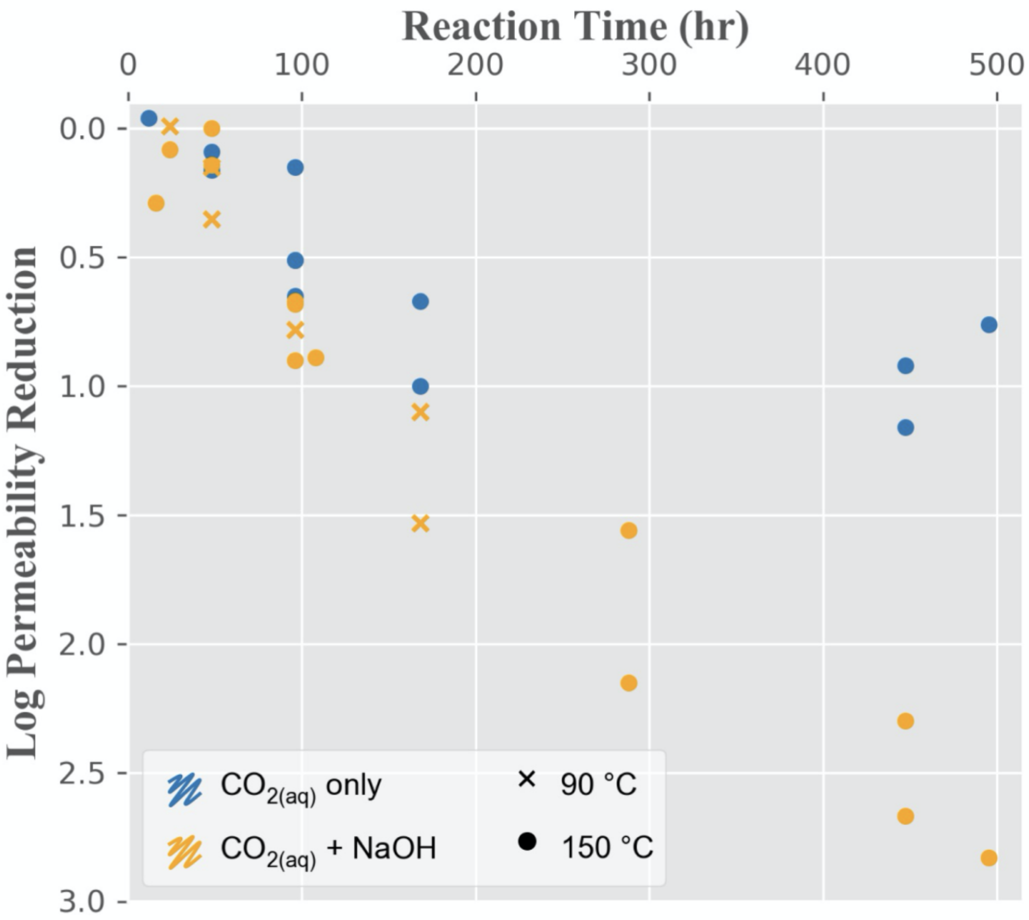
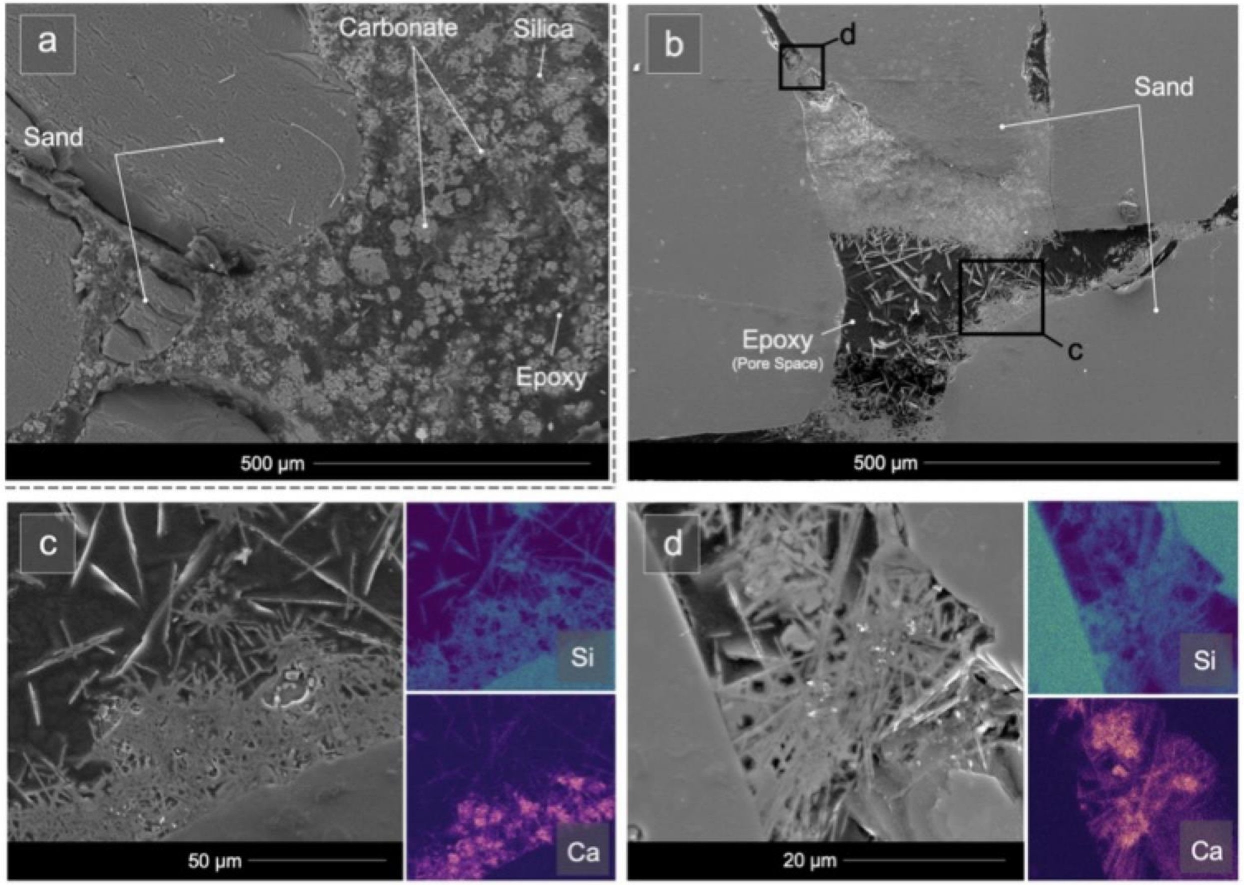
Permeability – Strength Connections



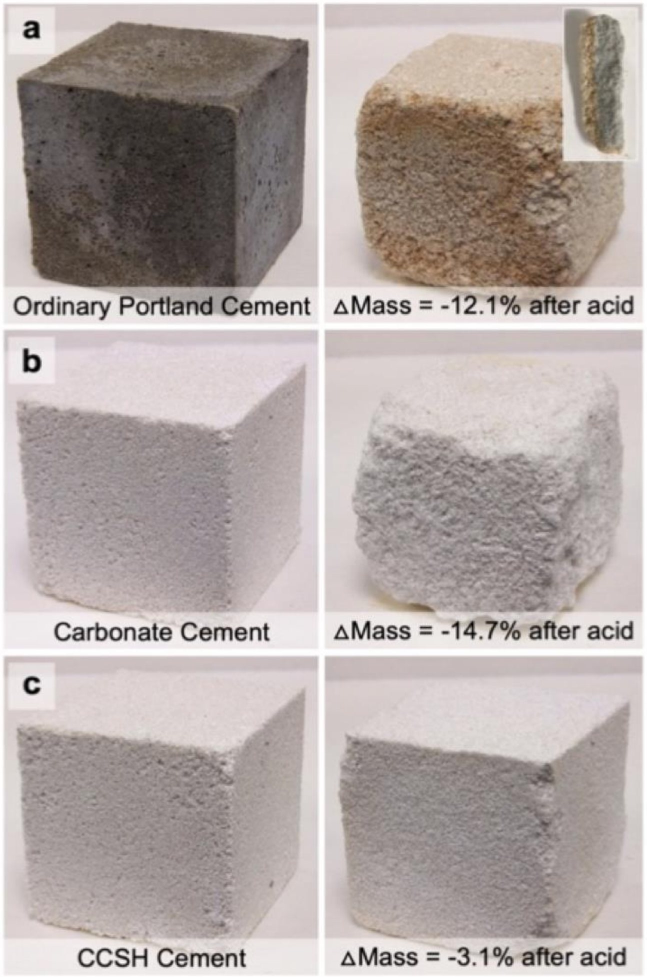


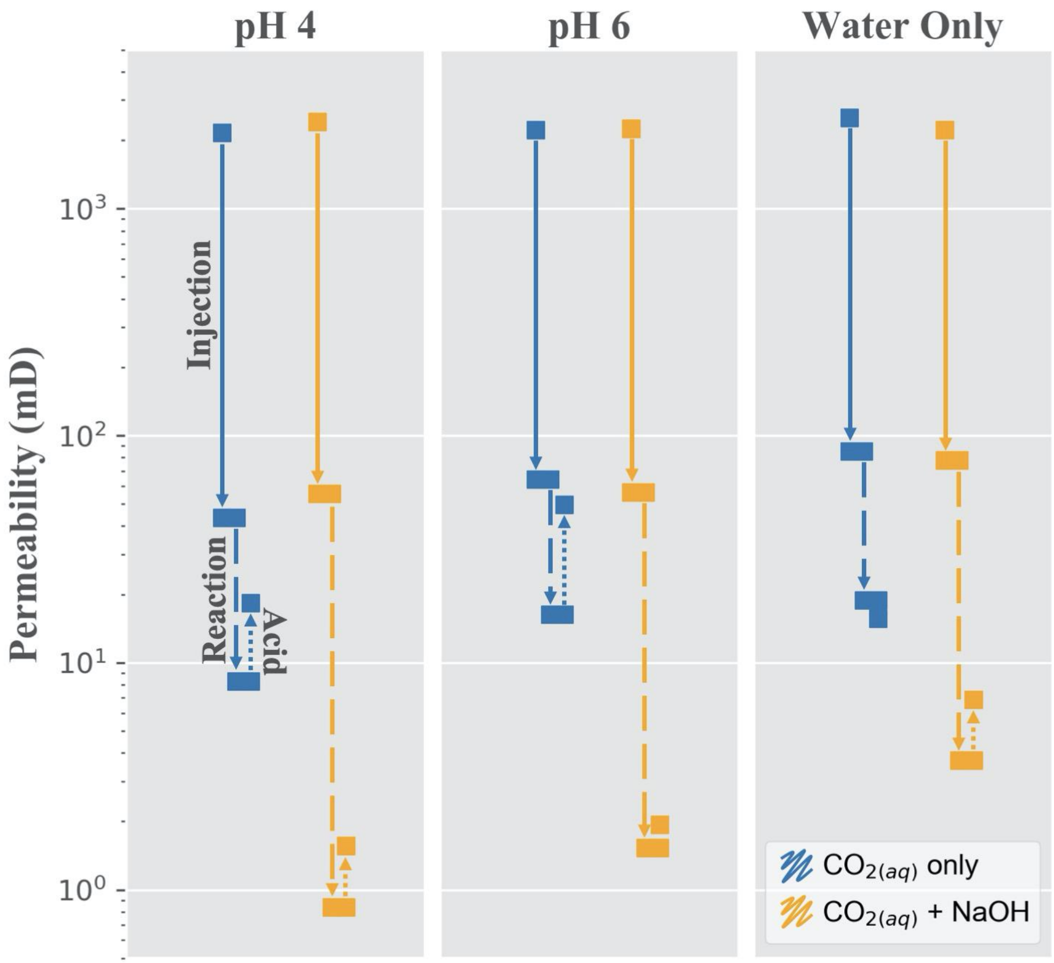
Permeability effects in C5 cements



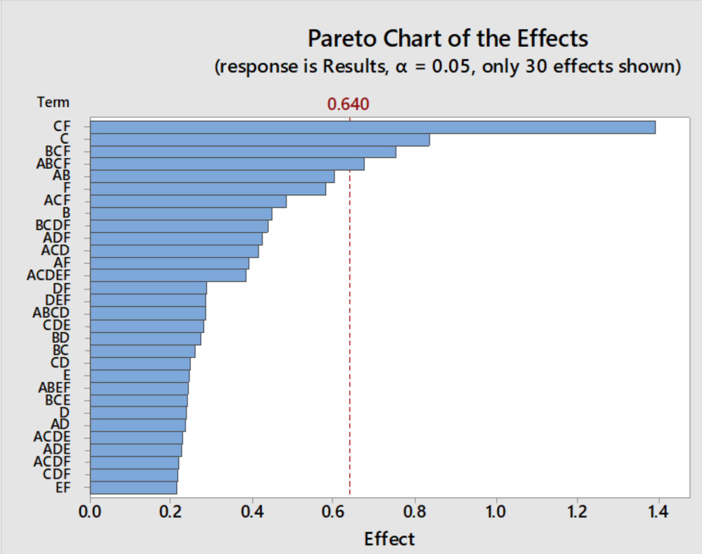


Chemical stability of C5 cements encouraging

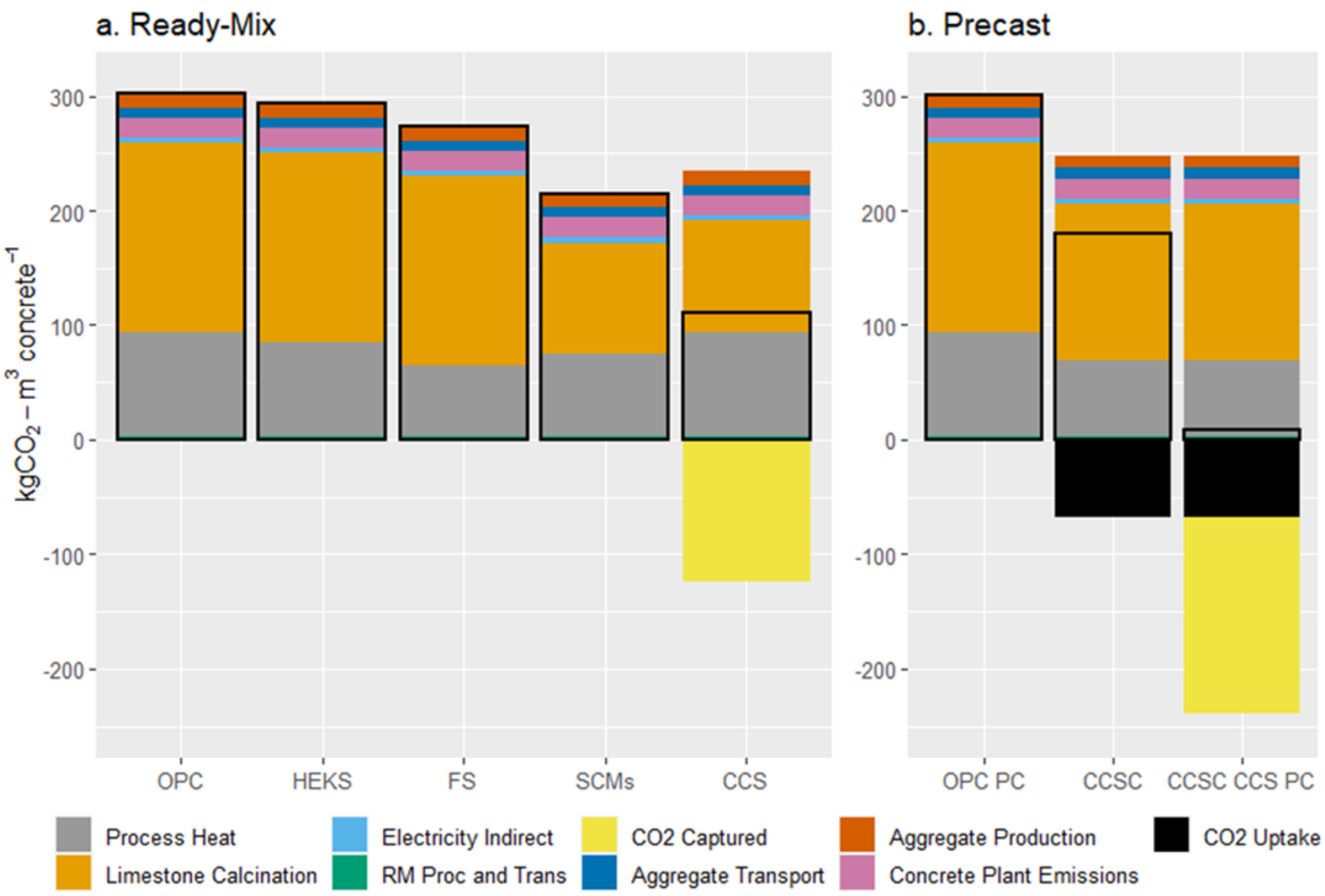




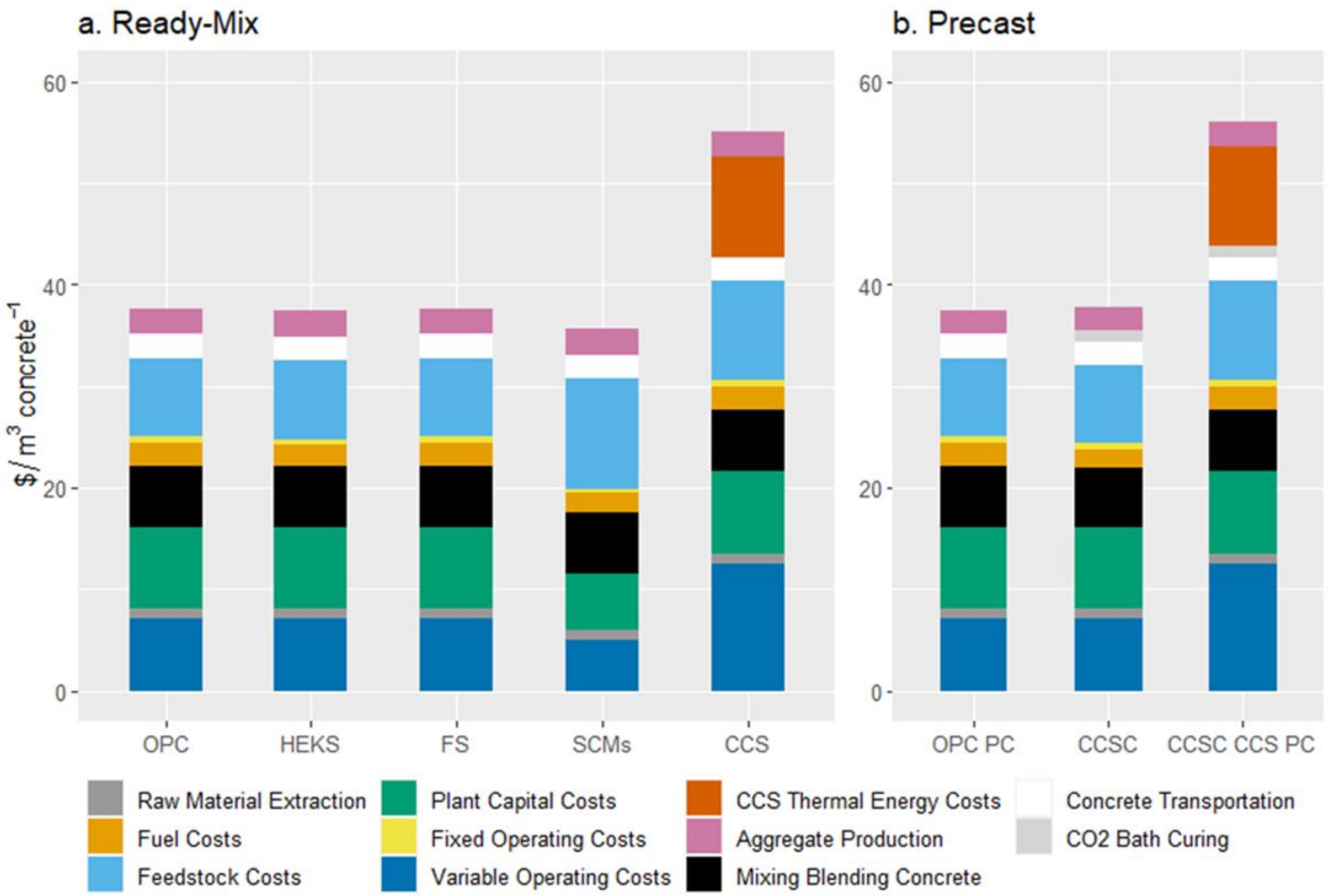
Compressive strength tests show high strengths for concrete



Life cycle analysis



Techno-economic analysis



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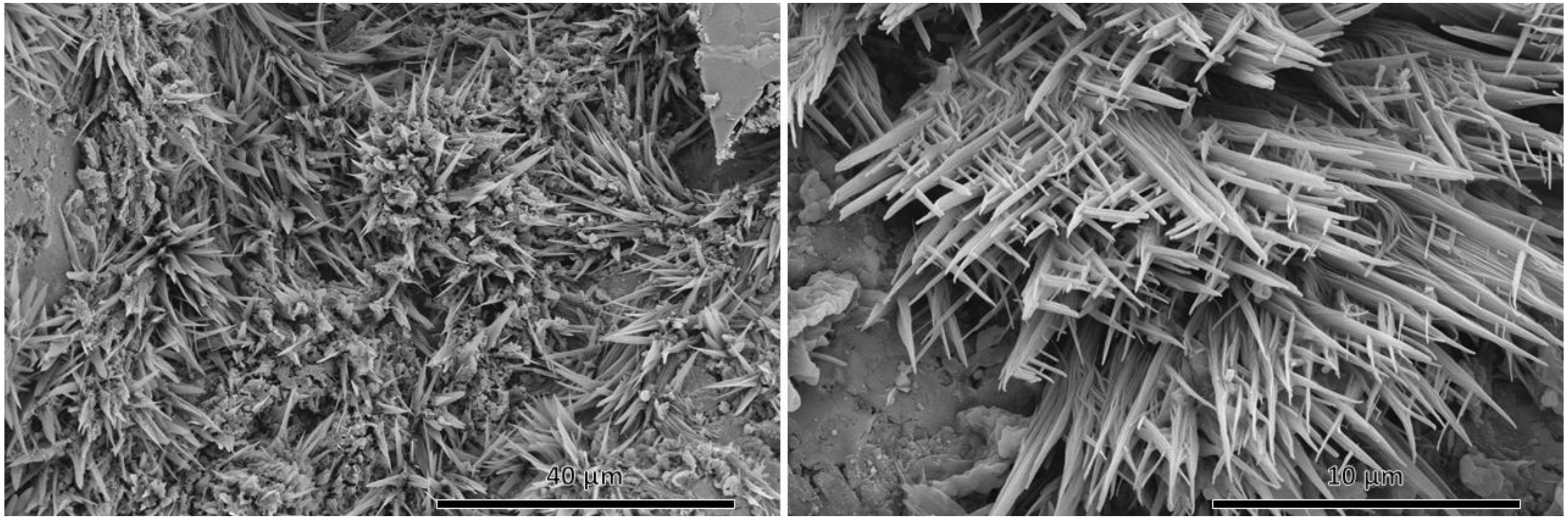
Challenges, Risks and Potential Partnerships

- Complex chemistry
  - Working to define cause-and-effect relationships for commercialization
- Translation of our mechanism
  - Identifying novel feedstocks that can accelerate commercialization



Technology-to-Market

- Partnered with C-Crete Technology
- Performing prototype scaling of larger scale concrete samples
- Carrying out Standard Tests
  - Mechanical properties ASTM
  - Durability properties ASTM/AASHTO
  - Developing a product datasheet
- We are looking for partners across the supply chain

C-Crete
TECHNOLOGIES

Summary Slide

- We are developing a flexible means to produce materials with much in common (both chemically and mechanically) with ancient Roman cements - high strength, low permeability, and low reactivity cementitious materials
- Our objective is to produce pre-cast prototypes
- We are using a range of analytical techniques to reveal the fundamental chemistry that would enable us to apply this approach broadly and in inexpensive ways
- Techno-economic and life cycle modeling suggest our approach could produce materials with much lower footprint than OPC or other pre-cast competitors
- Final year of our project focused on standards testing and tech-to-market activities.

  - We would love to talk with you!
    - andres@virginia.edu

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