The University of Texas at Austin
Maseeh Department of
Civil, Architectural and
Environmental Engineering
Cockrell School of Engineering

July 2025

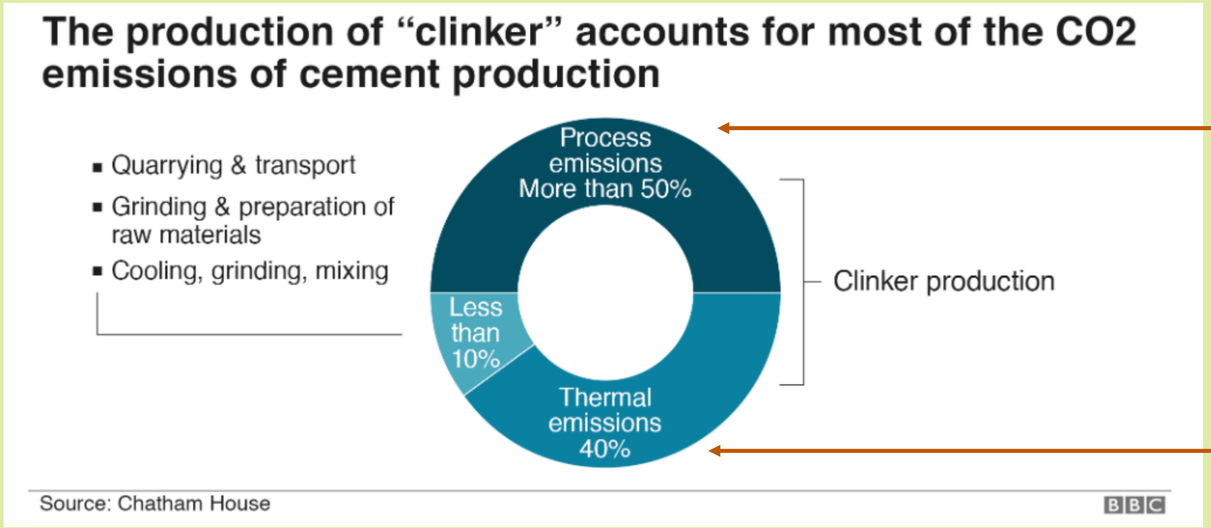
DEVELOPMENT OF NEW OR ALTERNATIVE CEMENTITIOUS MATERIALS

JCI-ACI 7th Joint Seminar
Morioka, Japan

MARIA C.G. JUENGER
Professor and Ernest Cockrell, Jr. Centennial Chair in Engineering #2, The University of Texas at Austin

Why new or alternative cements?

Environmental Considerations



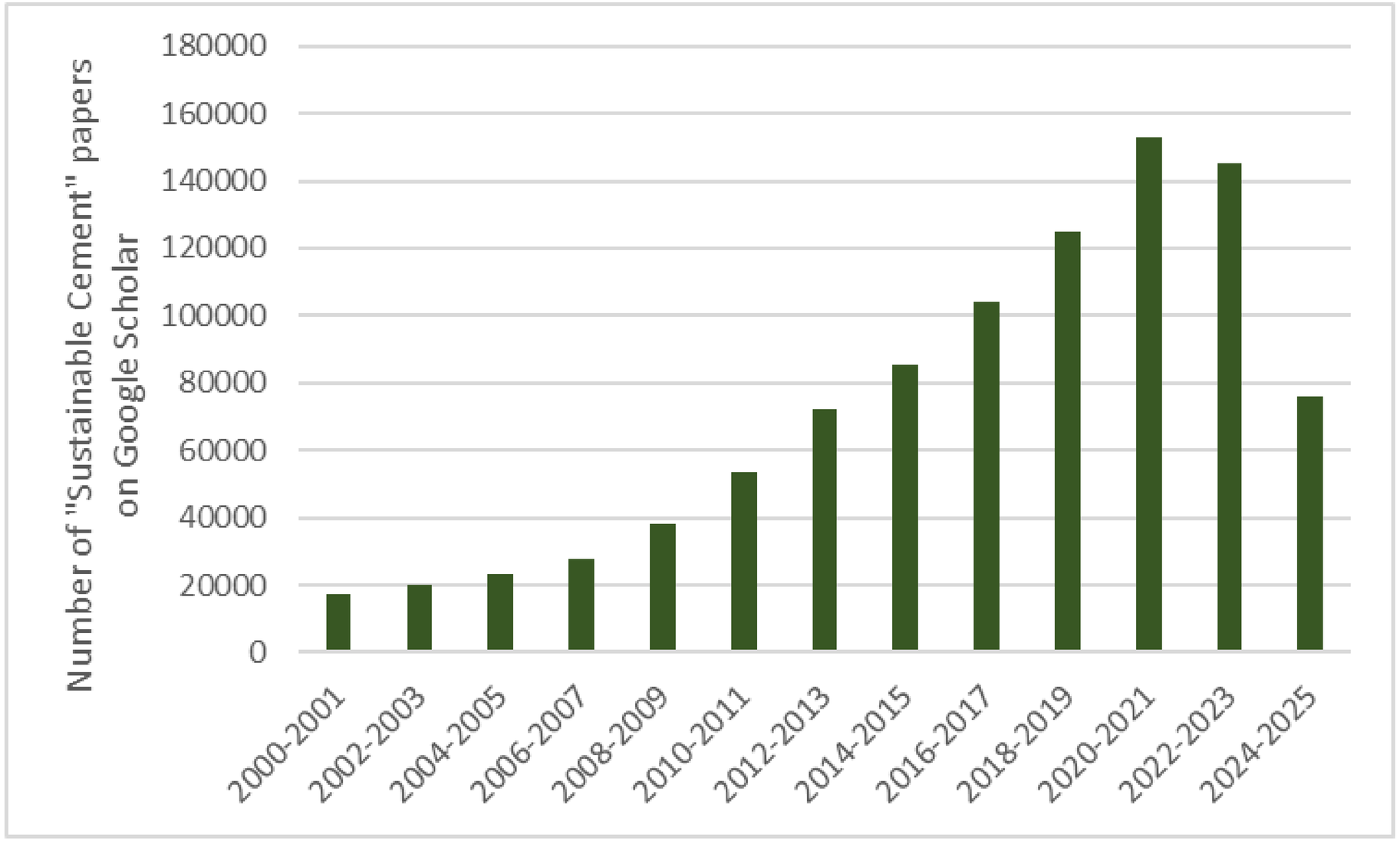
$3CaCO_3 + SiO_2 \rightarrow Ca_3SiO_5 + 3CO_2$

Fossil fuels burned to reach high temperatures (~1400°C)

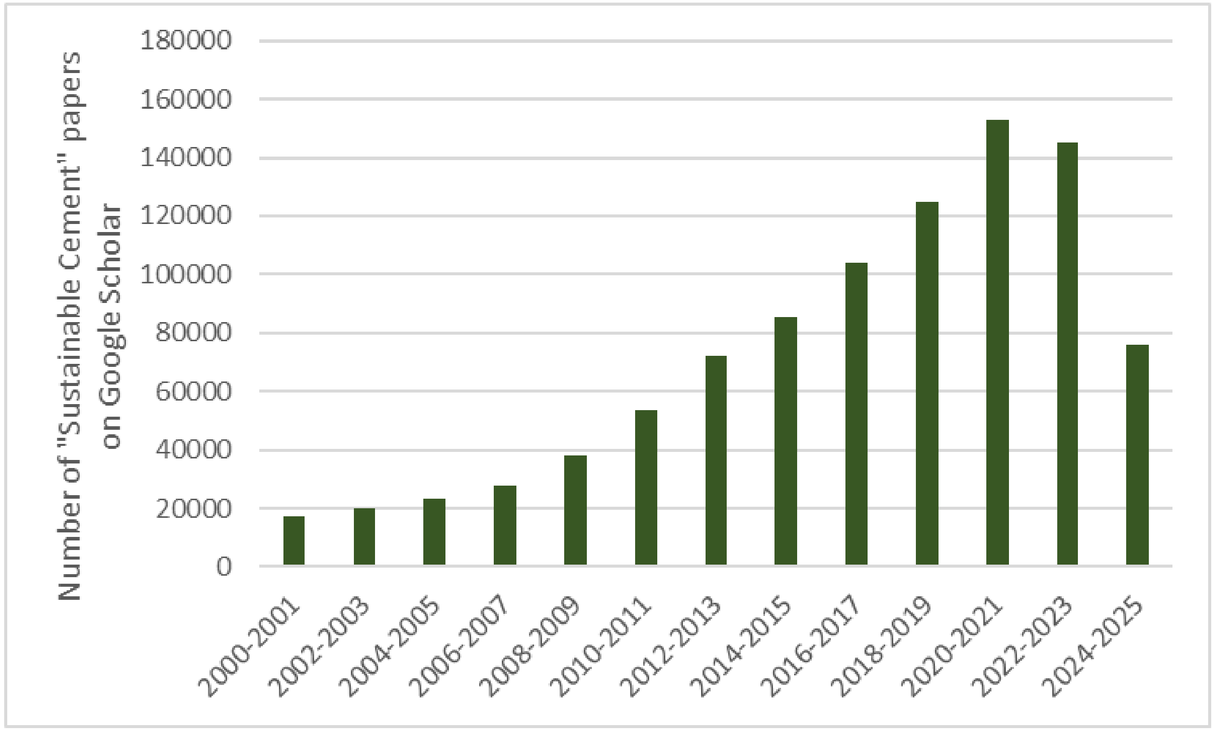
Performance Considerations

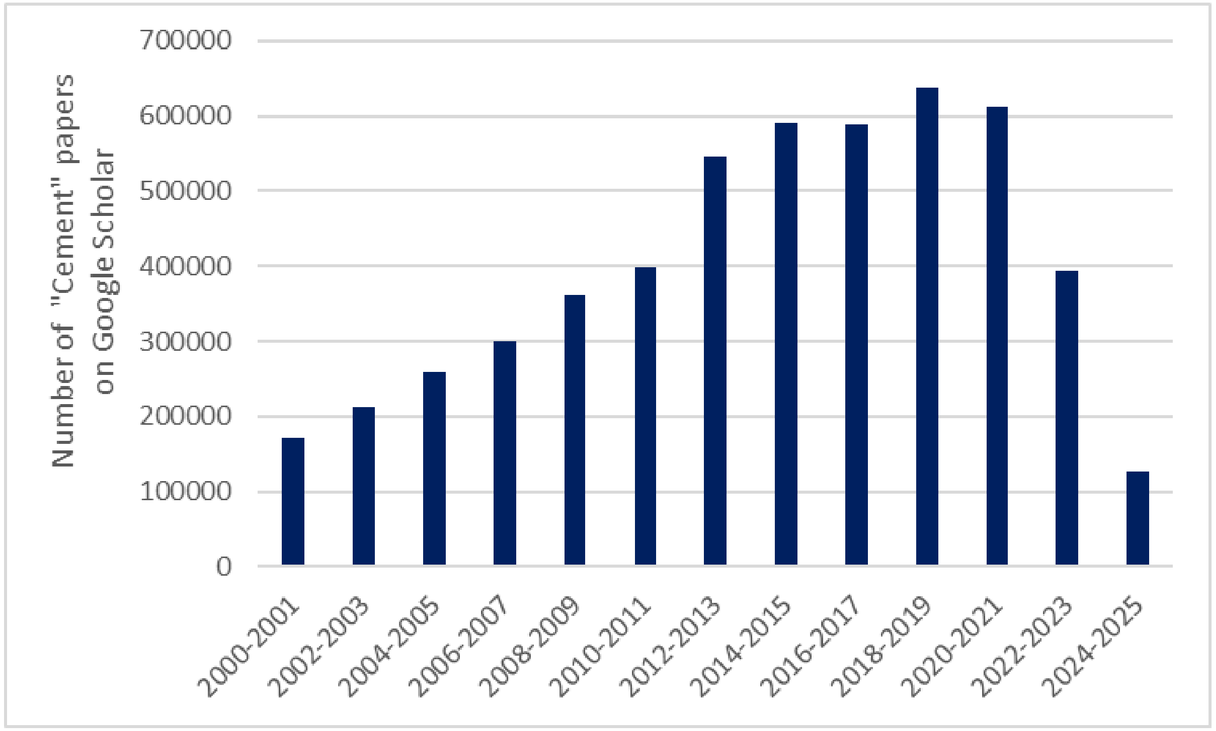
- **Rapid repair**
- **Acid resistance**
- **Sulfate resistance**

Interest in “sustainable cement”



Interest in “sustainable cement”





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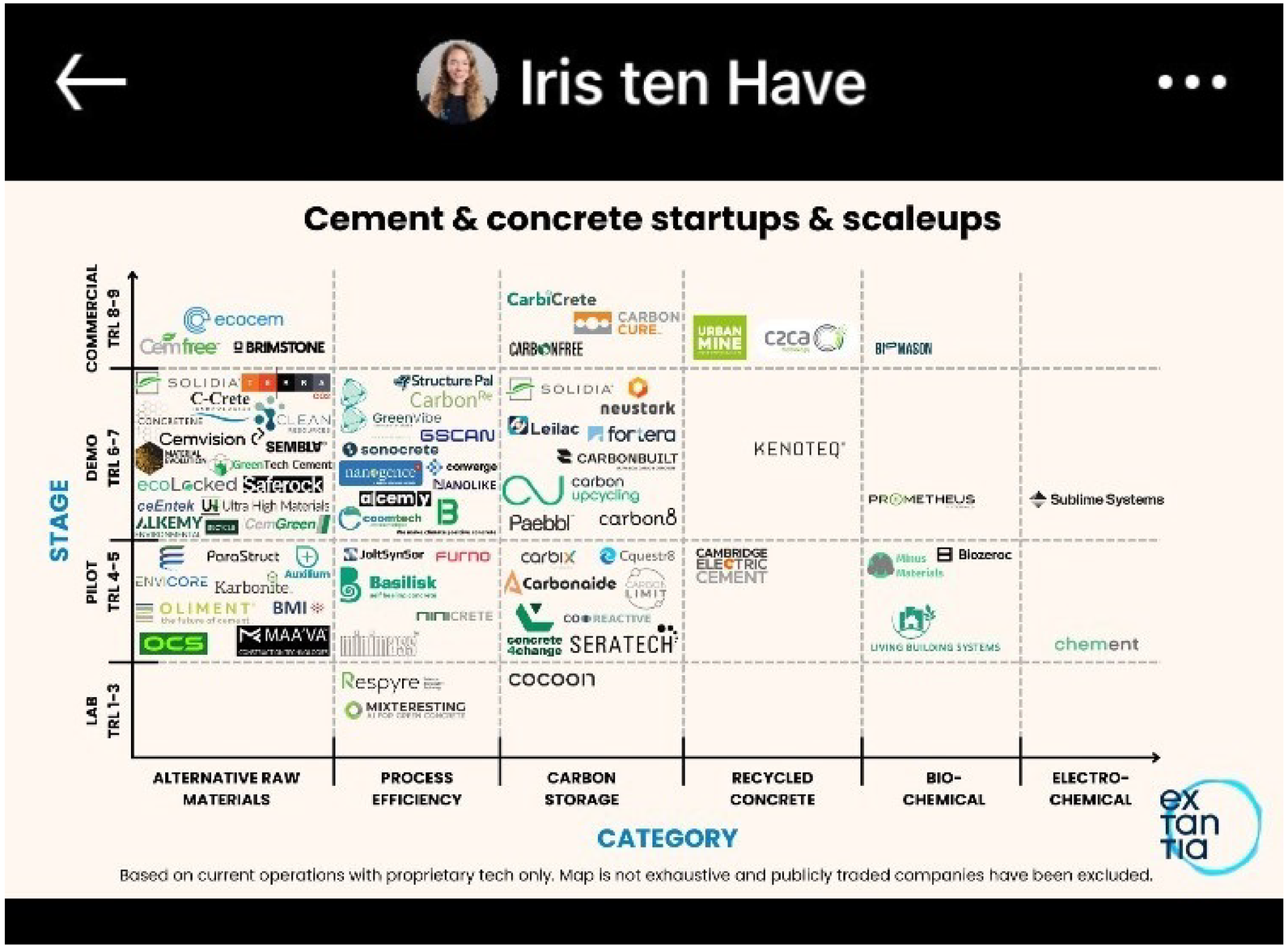
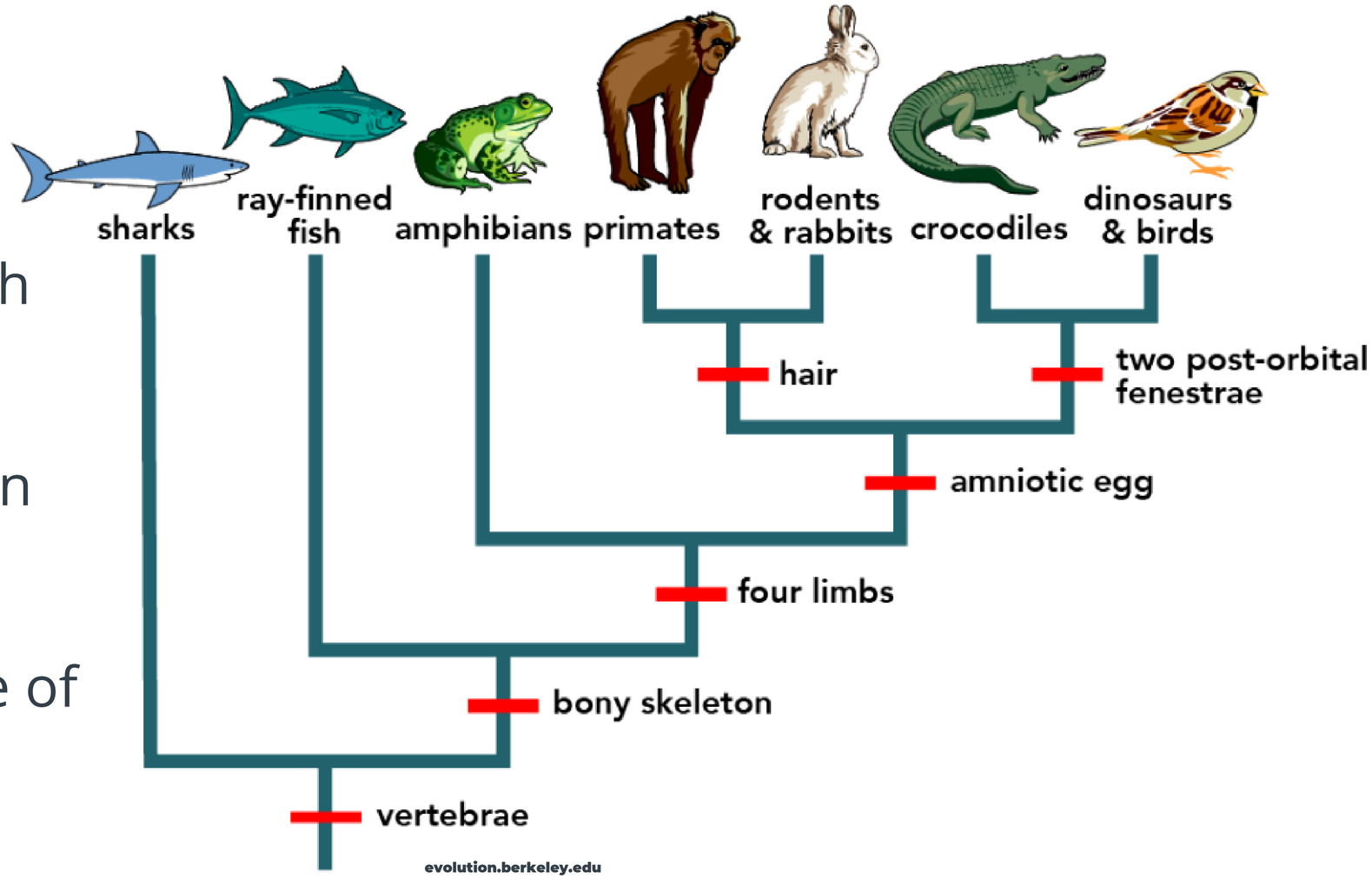
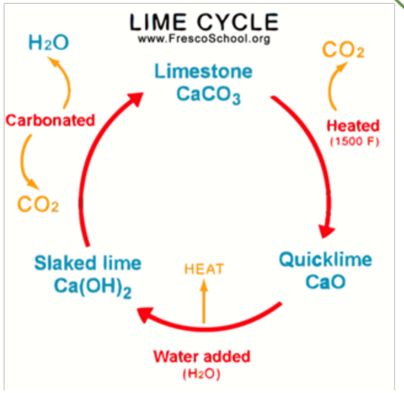


Can cement evolve?

- Evolution occurs through natural selection
- Some mutations result in better fitness
- End result is a multitude of species



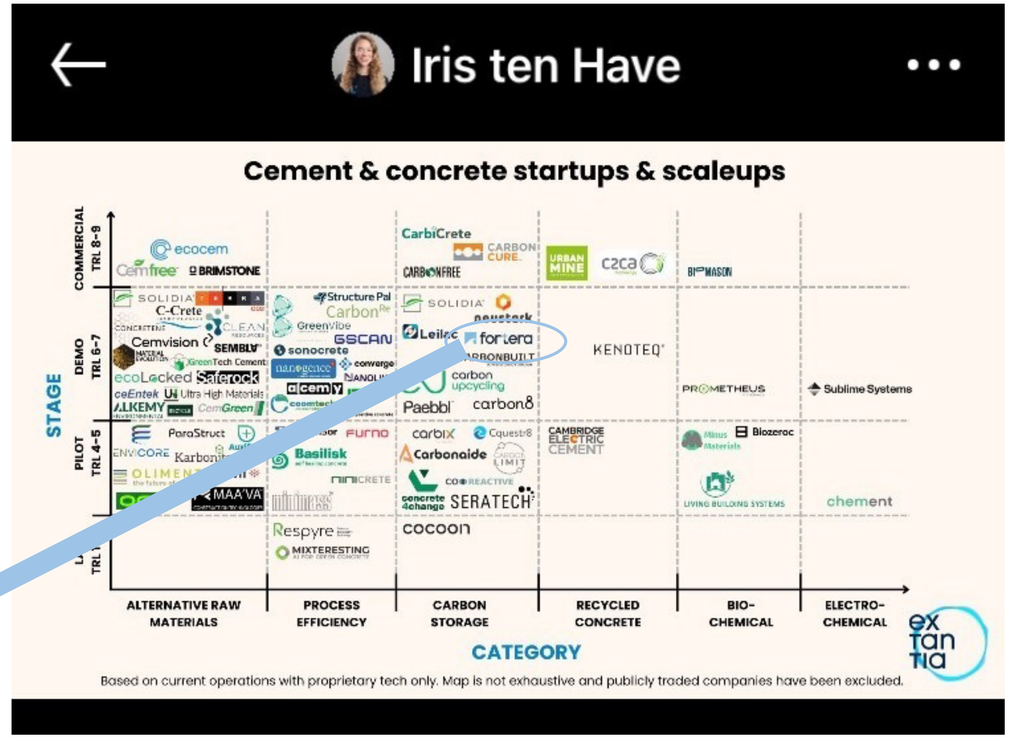
The evolutionary tree of cement



Roman hydrated lime

- +SiO2/Al2O3 → Roman hydraulic lime
  - +SO3 → Ordinary portland cement
    - +SiO2/Al2O3 → OPC + SCMs
      - +CaCO3 → Portland limestone cement
      - +CaCO3 → Limestone calcined clay (LC^3)
    - Low energy processing (Sublime)
    - Low CO_2 raw materials (Brimstone)
    - +SO3 → Calcium sulfoaluminate → Low CO_2 raw materials (Cemvision)
  - +Na/K (-Ca) → Alkali-activated
  - +SO3 → Supersulfated
- +Al2O3 → Calcium aluminate
- Swap Ca for Mg → Reactive magnesium oxide
  - +PO4 → Magnesium phosphate
  - +Cl → Magnesium oxychloride
  - +SO3 → Magnesium oxysulfate
- No water → Carbonated lime (Fortera)
  - +SiO2 → Carbonated wollastonite (Solidia)
  - +SiO2/Al2O3 → Carbonated CaO + SCM (CarbonBuilt)

Carbon utilization and storage



fortera

ReAct™

Blend →

ReAct™ Blend is a performance enhancing supplement to Portland Cement. It's fineness and morphology are highly engineered to increase packing efficiency, accelerate cement hydration, and improve workability.

- Low Clinker Blend
- Ample Surface Area for Nuclear Effect
- Improved Particle Packing
- Faster Strength Gain
- Strong Reactivity with Alumina

ReAct™

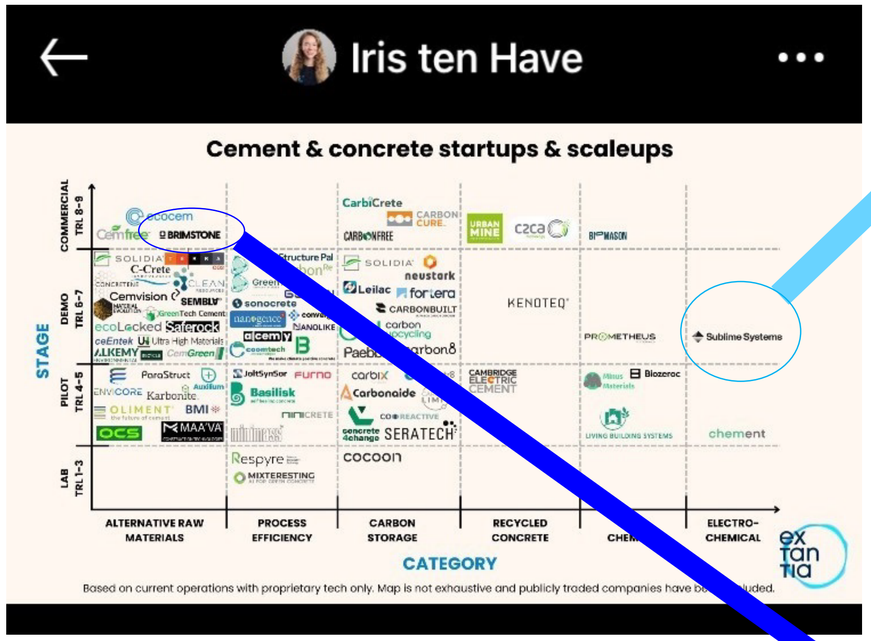
Pure →

ReAct™ Pure is a 100% replacement for Portland Cement, that is a reactive form of calcium carbonate known as vaterite. A binder based on the transformation of vaterite to aragonite or calcite, which has been successfully utilized to manufacture building materials.

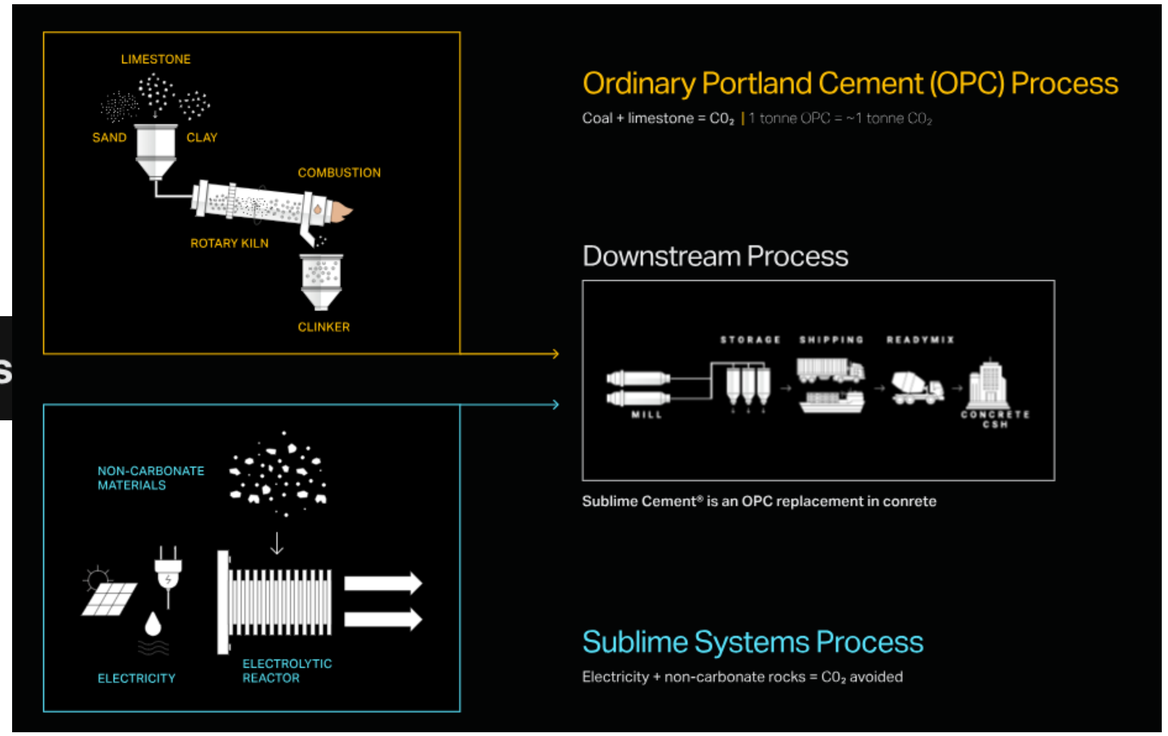
- High CO_2 Avoidance
- Strength to Weight Ratio
- Rapid Curing at Elevated Temperatures
- Dimensionally Stable
- Superior Whiteness

New Technologies

Sublime Systems



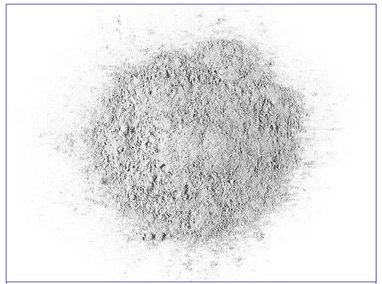
BRIMSTONE



we start with a common, carbon-free rock

CONVENTIONALLY MADE CEMENT USES LIMESTONE, **ACCOUNTING FOR 60% OF TOTAL EMISSIONS.**

The Brimstone process **replaces limestone with carbon-free, calcium-bearing silicate rocks.** These highly abundant rocks are **found on the surface of every continent,** enabling us to make our products efficiently, economically, and sustainably—virtually anywhere.



PORTLAND CEMENT

ASTM C150	Brimstone cement meets or exceeds ASTM C150 standards for portland cement, the most widely used cement in the world.		
TRICALCIUM SILICATE CONTENT	>60%	**28 DAY STRENGTH**	>6000 PSI

SUPPLEMENTARY CEMENTITIOUS MATERIALS

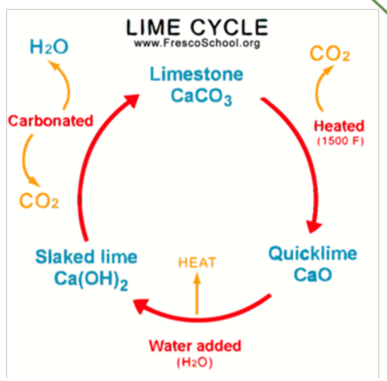
ASTM C618 CLASS N	Brimstone SCM meets the physical and chemical requirements of ASTM C618 Class N.		
R3 HEAT RELEASE	>200 J/g	**28 DAY STRENGTH ACTIVITY INDEX**	>100%

SMELTER GRADE ALUMINA

INDUSTRY SPECIFICATIONS	Under development		
ALUMINA CONTENT	>99%		

Both are making OPC… but not as usual

The evolutionary tree of cement



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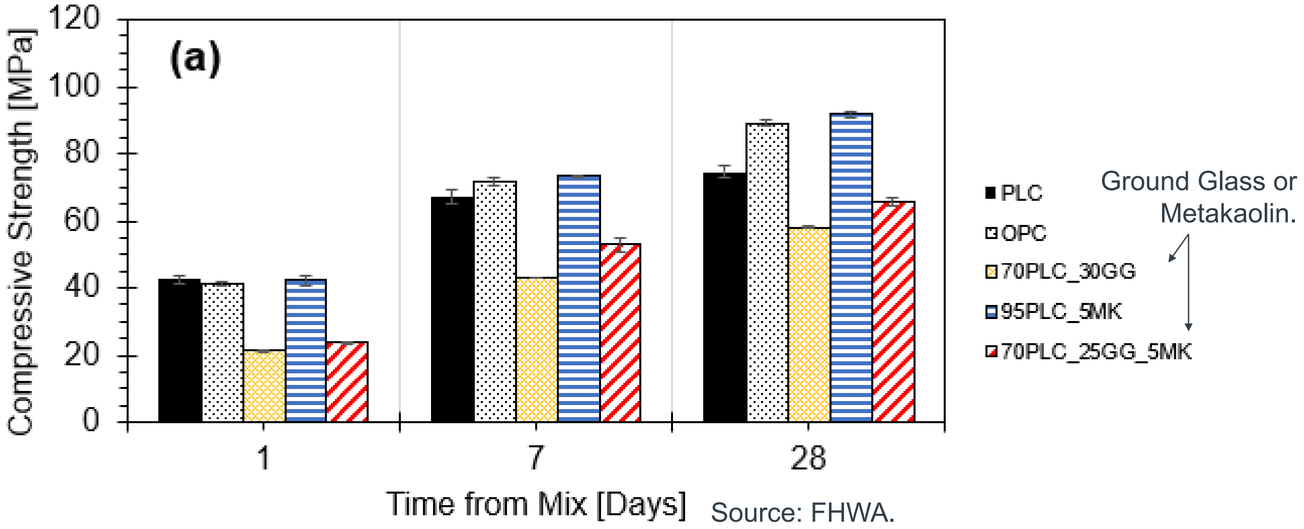
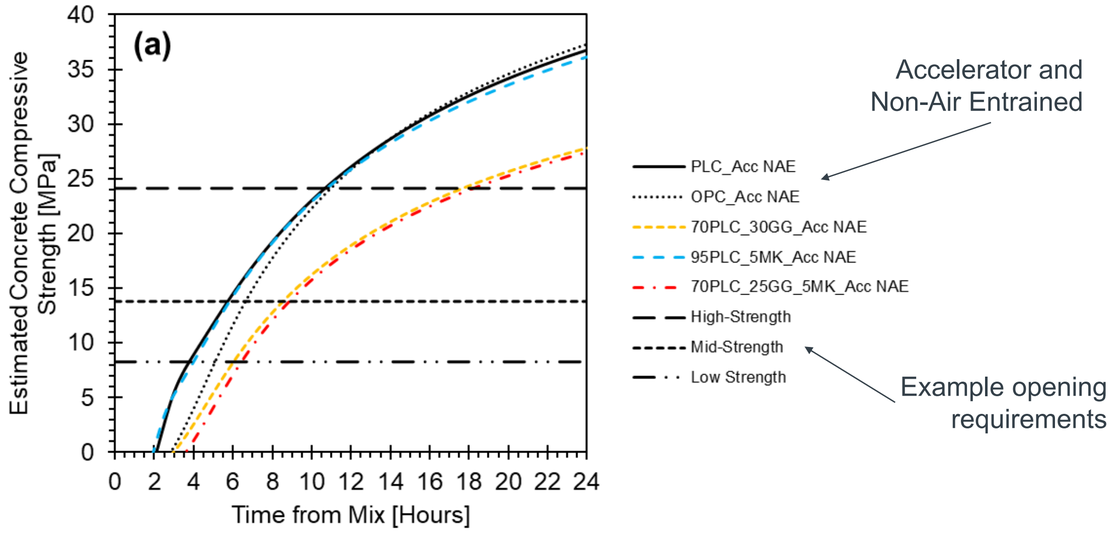
Portland Limestone Cement

- PLCs in the US are also called Type IL and have up to 15% limestone
- Concerns over early strength have led to the use of higher cement contents in some concrete mixtures
- When manufactured properly, PLCs have good early strength, comparable to OPC
- You can use PLCs to make high early strength concrete for pavement repair applications



Source: FHWA.

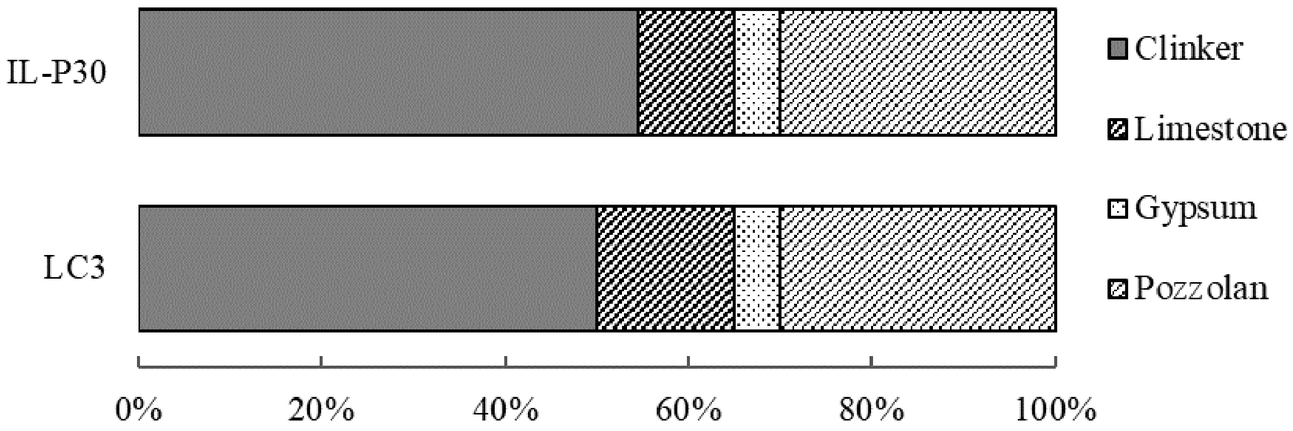


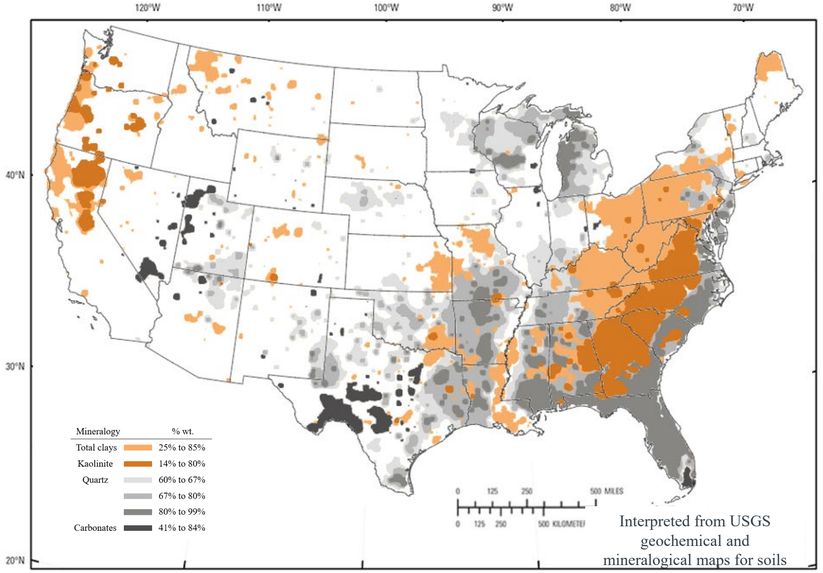
Source: FHWA.

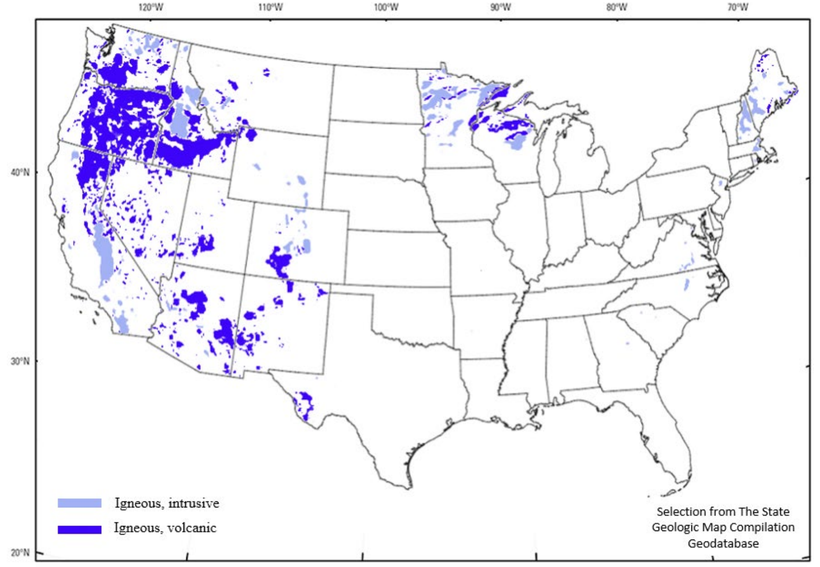
Montanari, Helsel, Hosseini, and Juenger, “Evaluation of early age strength and porosity of binary and ternary mixtures incorporating portland limestone cement and a set accelerator,” submitted to ACI Materials Journal.

LC³ Cements in the US

- We have portland limestone cements
- We have natural pozzolans and calcined clays
- Can we combine them to make readily available limestone-calcined clay cement (LC³)?



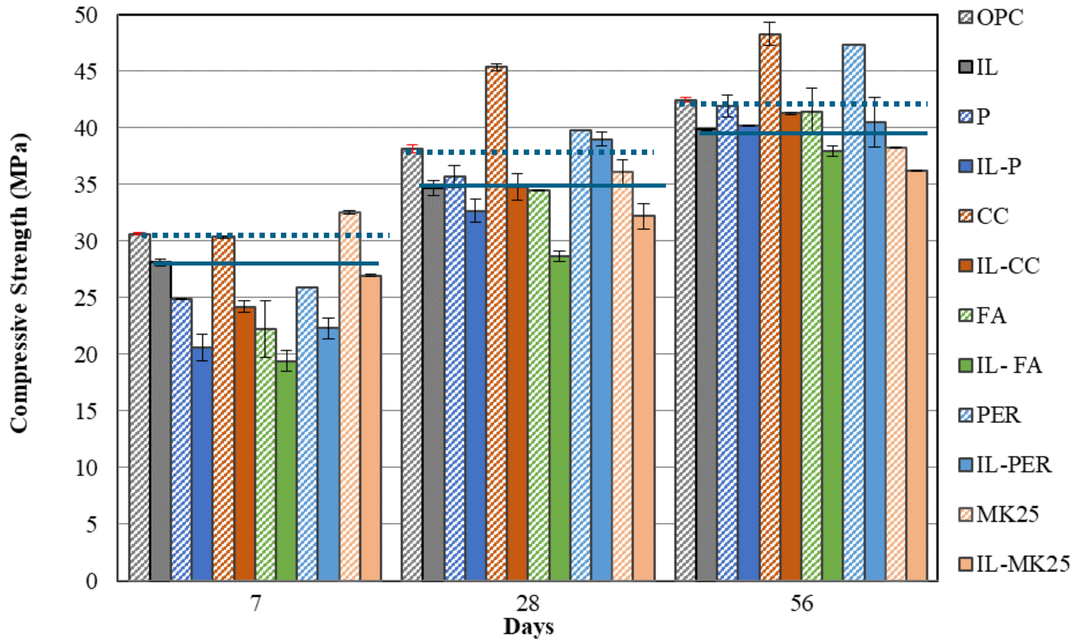




O'Quinn, Juenger, & Bernal "MAKING LC³-ADJACENT CEMENTS BY COMBINING PORTLAND LIMESTONE CEMENTS WITH SUPPLEMENTARY CEMENTITIOUS MATERIALS" submitted to Construction & Building Materials.

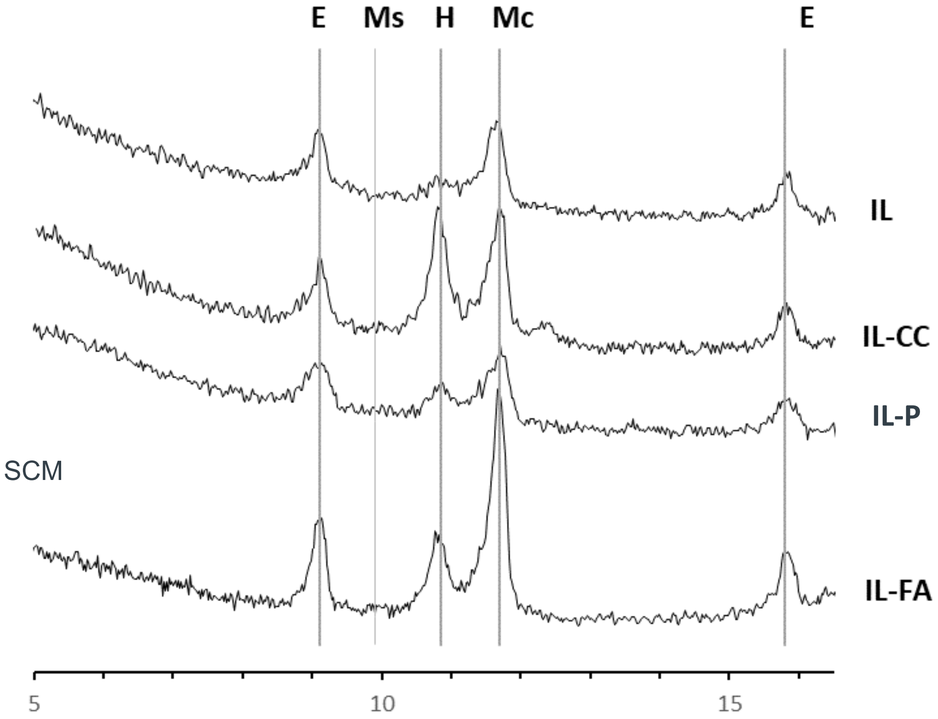
LC³ Cements in the US

- Formation of carboaluminates is not limited to calcined clay – limestone blends
- Pozzolan-limestone blends can perform just as well as calcined clay limestone blends, allowing for regional optimization



CC= Calcined Clay
P = Pumice
FA = Fly Ash
PER = Perlite
MK25 = 25% Metakaolin SCM

Ettringite (E)
Hemicarboaluminate (H)
Monosulfaluminate (Ms)
Monocarboaluminate (Mc)



O'Quinn, Juenger, & Bernal "MAKING LC³-ADJACENT CEMENTS BY COMBINING PORTLAND LIMESTONE CEMENTS WITH SUPPLEMENTARY CEMENTITIOUS MATERIALS" submitted to Construction & Building Materials.

And about carbonation…

Atmospheric Environment 70 (2013) 263–266

Contents lists available at SciVerse ScienceDirect

Atmospheric Environment

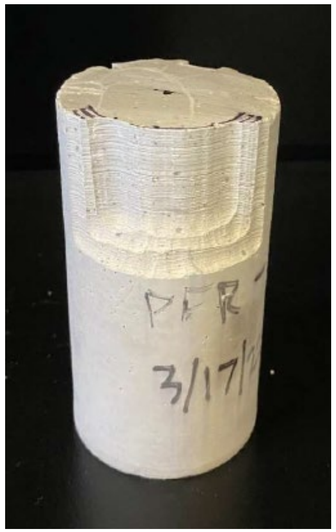
journal homepage: www.elsevier.com/locate/atmosenv

Technical note

Impact of cement renders on airborne ozone and carbon dioxide concentrations

Sarah C. Taylor-Lange [a,*], Maria C.G. Juenger [a], Jeffrey A. Siegel [a,b]

- Thermogravimetric analysis of pastes allows for quantification of $CaCO_3$ formed and CO_2 bound
- Metakaolin densifies pore structure, reducing expected CO_2 ingress



C = neat cement
MK = 15% metakaolin
1 & 28 = days of curing prior to exposure

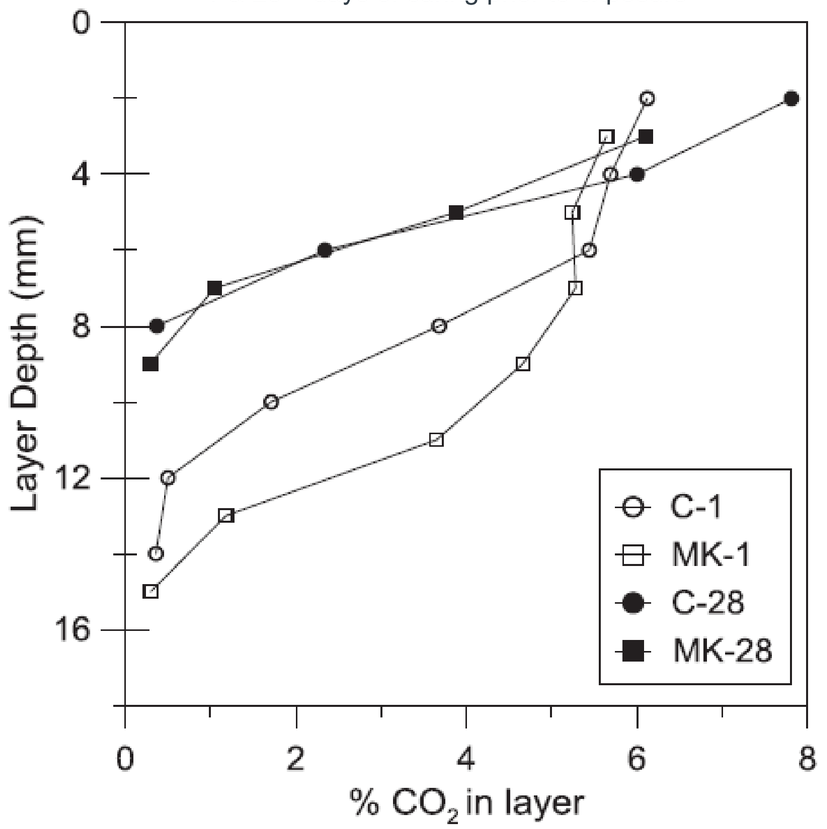


Fig. 1. The layer depth tested from the sample profile grinding as a function of the percent of carbon dioxide contained in each layer to provide a profile of the carbon dioxide penetration.

Calcined clay purity affects carbonation rate

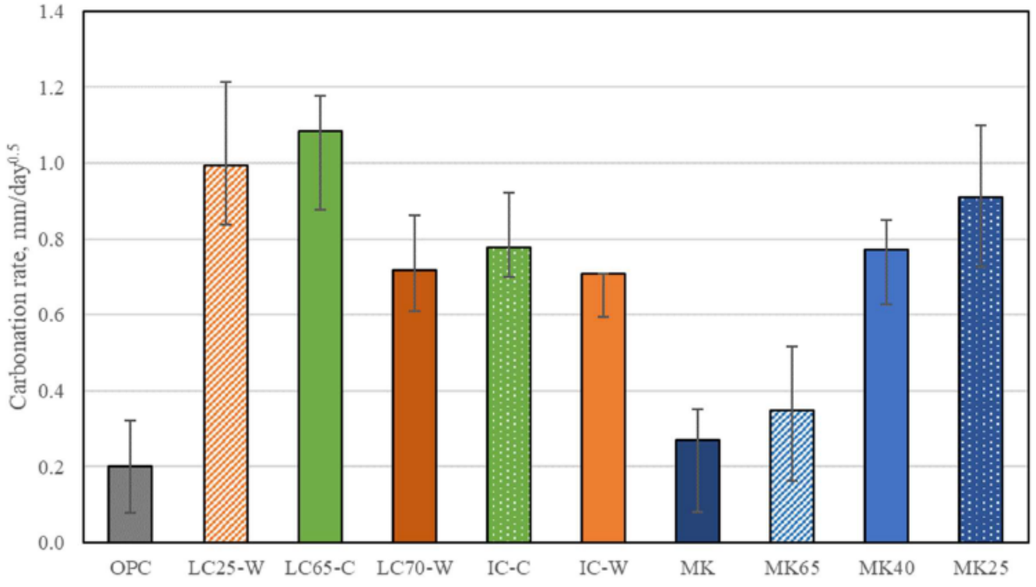


Figure 23: Carbonation rates after 28 days of exposure of the mortars containing OPC and calcined kaolinite clays

Natural clays calcined in lab

Commercial calcined clays

Diluted metakaolin

Carbonation rate decreases with increasing kaolinite content in calcined clay because of refined pore structure

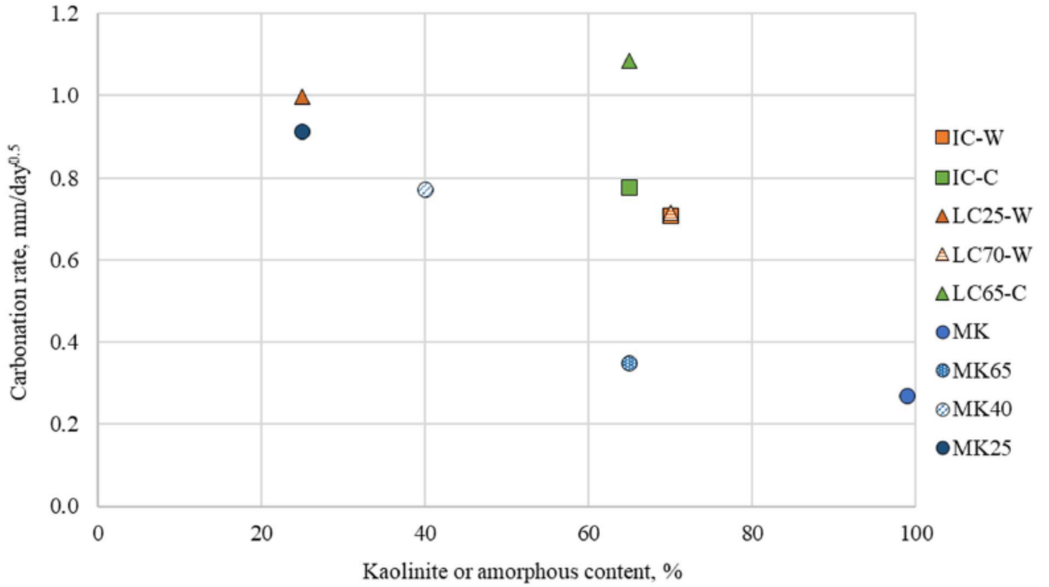


Figure 25: Carbonation rate of mortars containing OPC and calcined kaolinite clay after 28 days of accelerated exposure

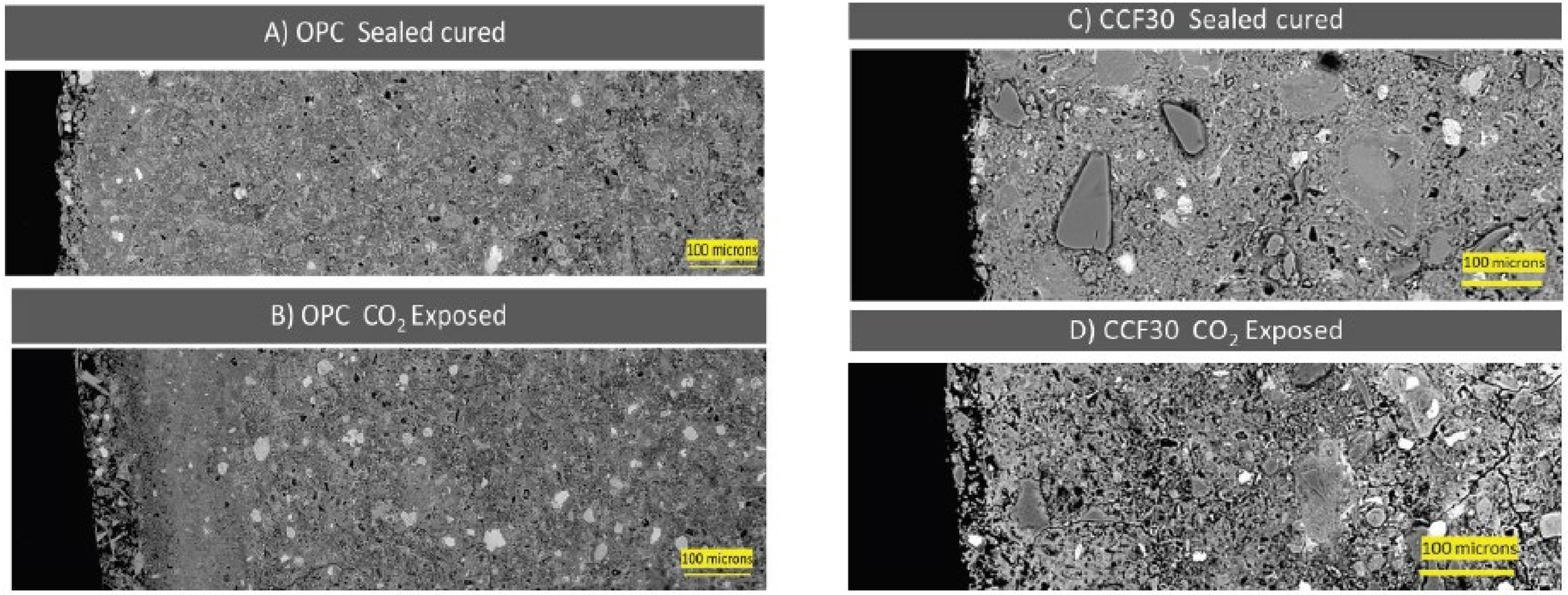
O'Quinn, Bernal & Juenger unpublished data. **[Confidential]**

Do we really want carbonated concrete?

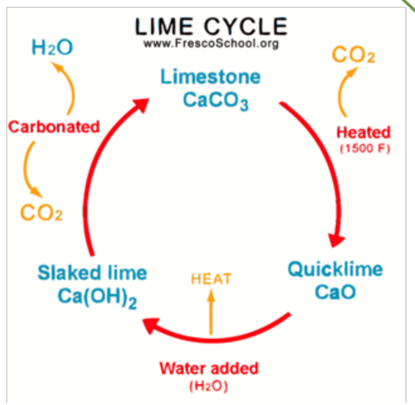
The 16th International Congress on the Chemistry of Cement 2023 (ICCC2023)
"Further Reduction of CO_2 -Emissions and Circularity in the Cement and Concrete Industry"
September 18–22, 2023, Bangkok, Thailand

Elucidating the carbonation front in blended calcined kaolinite clays binders using analytical techniques

Y. Dhandapani[1], L. Black[2], M. C. G. Junger[3] and S. A. Bernal[4]



The evolutionary tree of cement



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Geopolymers: Self-healing

- Self-healing can be hard to measure – we chose to use water permeability under pressure
- Cracks controlled through freeze-thaw cycling

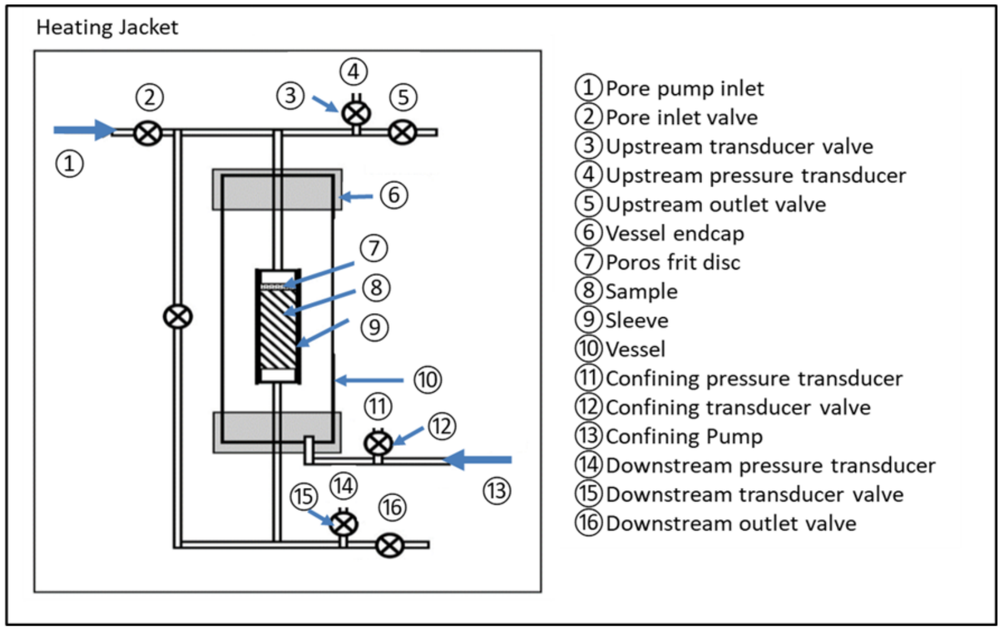
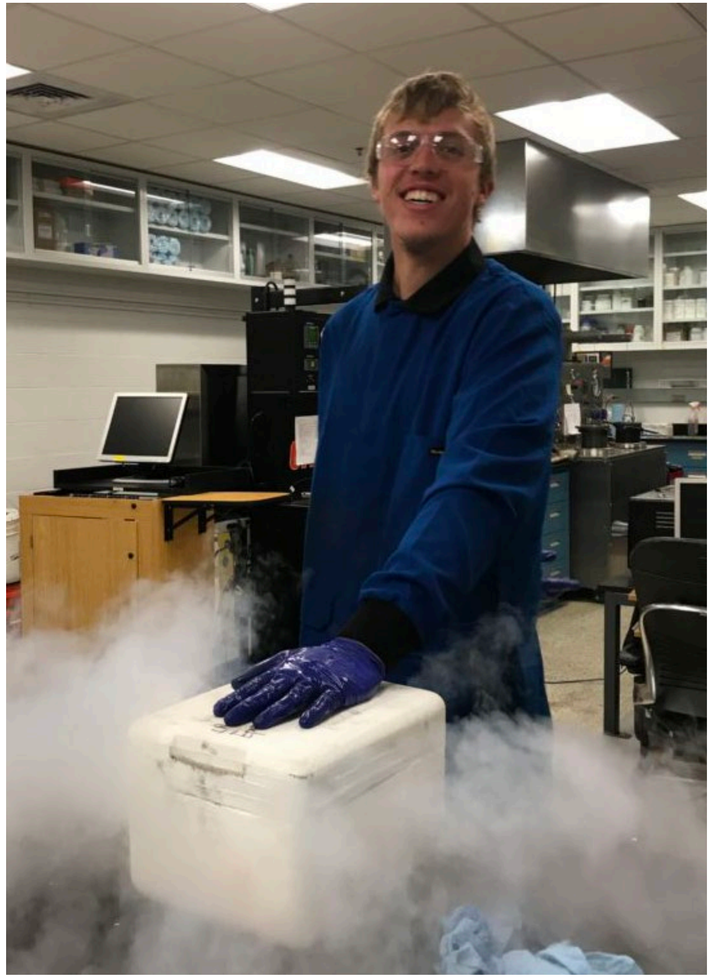
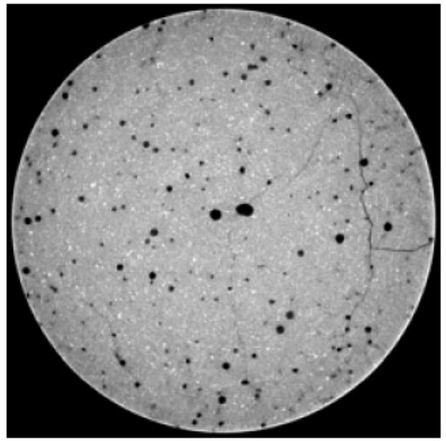


Fig. 1. Schematics of the PTT device, adapted from van Oort (1994)



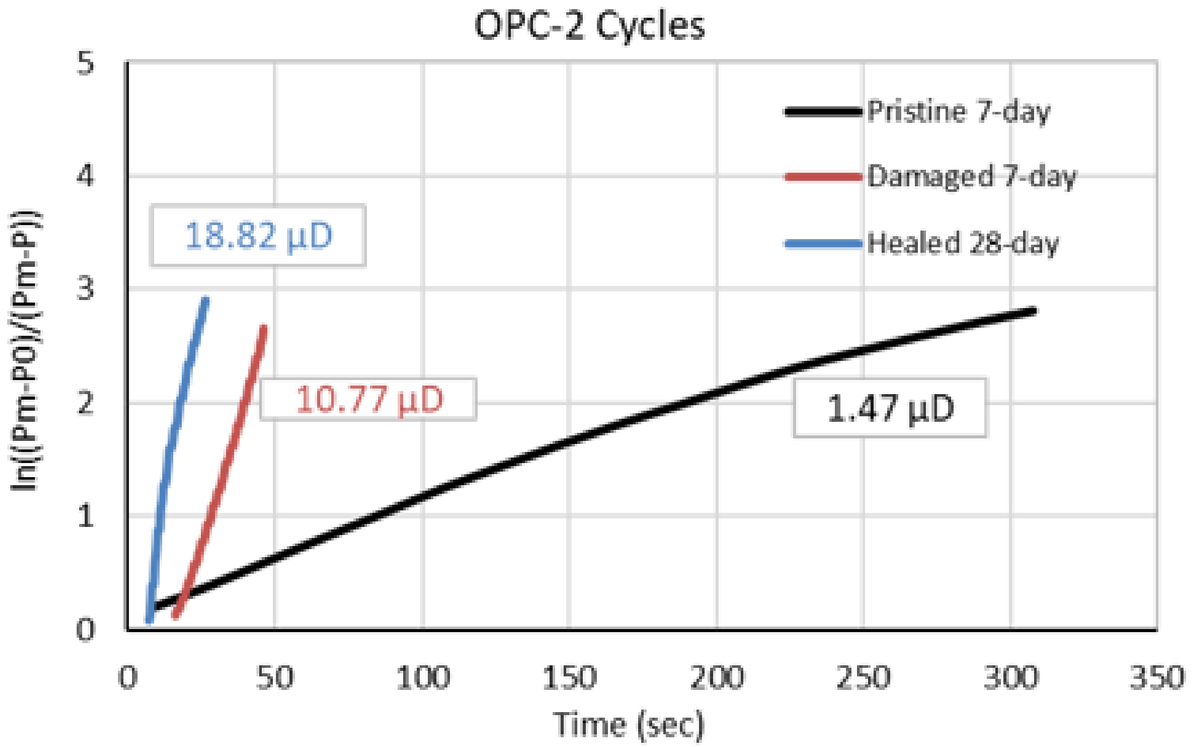


µCT Results – 1 in. Diam.

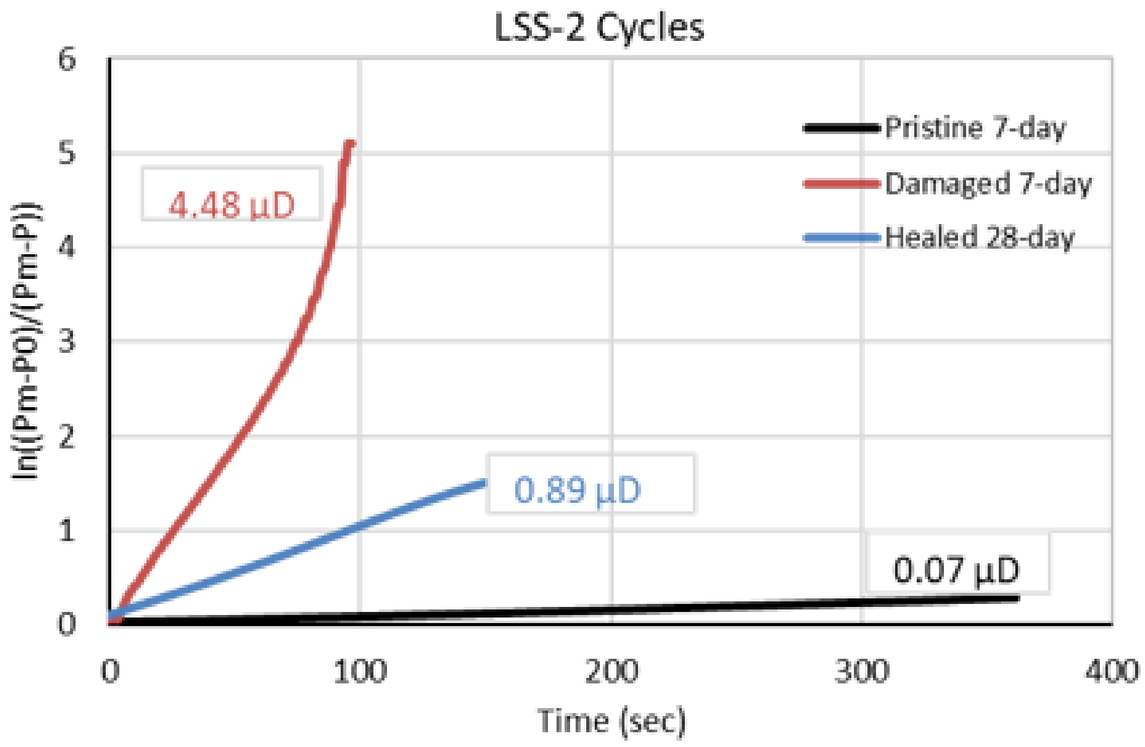
J.H. Ross et al.

Cement 10 (2022) 100048

Geopolymers: Self-healing



LSS = activated by liquid sodium silicate

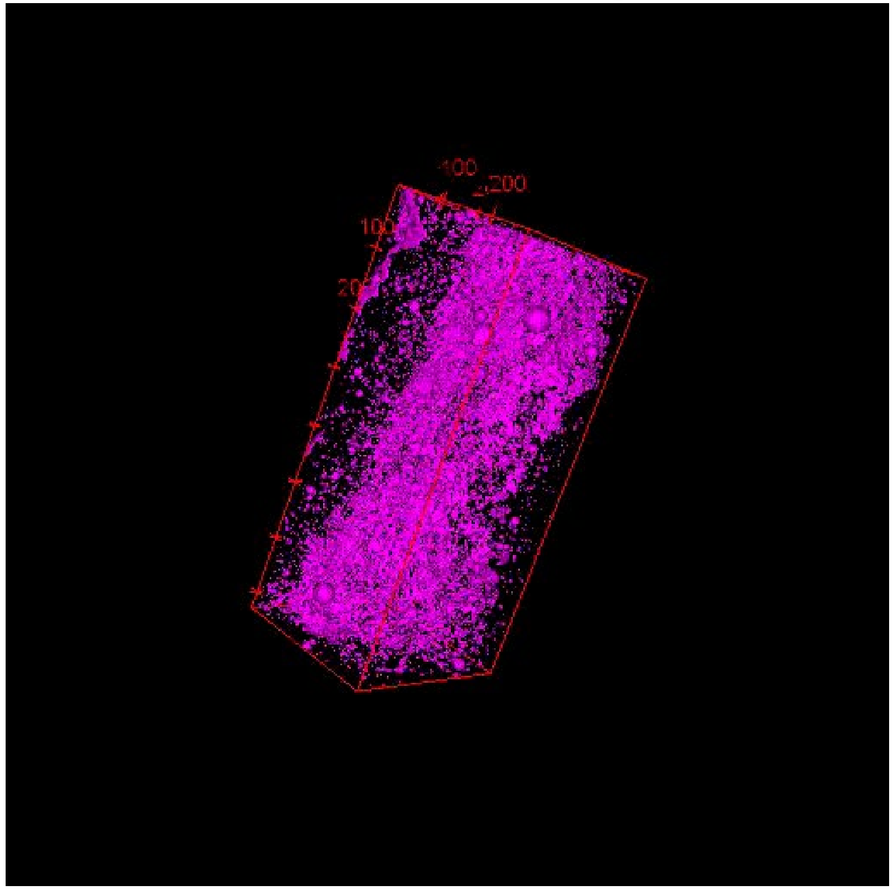


- Permeability of OPC increases after wet curing post cracking.
- Permeability of fly-ash based geopolymers decreases after wet curing post cracking.

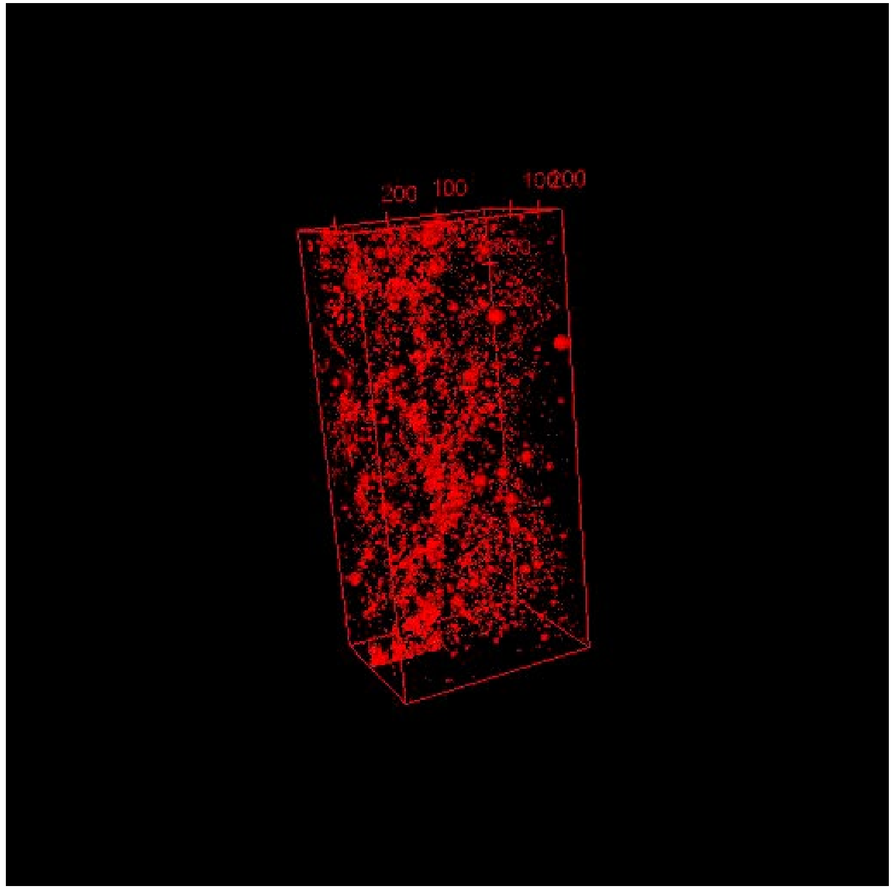
Danzhu Zheng, George Ulerio II, Veerabhadra S Denduluri, Maria Juenger, and Eric van Oort, Geoenergy Science & Engineering, 2024.

Geopolymers: Self-healing

After initial damage



After 28 days of healing



μCT scans and videos taken by Parth Panchmatia
[unpublished; confidential]

Summary and Conclusions

- There has been increasing interest in sustainable cements over the past 25 years – both in research and in commercialization.
- Alternative cements can have excellent or even enhanced performance compared to portland cement. Sustainability does not mean that you have to sacrifice performance.
- Scalability, cost, and durability of new or alternative cements will determine their impact on the concrete industry.

THANK YOU

Current and former students and postdocs :
- Veer Denduluri, Moneeb Genedy, Luca Montanari, Parth Panchmatia, Katey O'Quinn, John Ross, George Ulerio, Angie Zheng

Collaborators:
- Susan Bernal, Michelle Cooper, Yuvaraj Dhandapani, Eric van Oort

Funding:
- National Science Foundation, CODA/RAPID industrial affiliates program, FHWA Turner-Fairbank Highway Research Center
- American Concrete Institute