Zeolite Concrete Research at the UW: An Overview

Brandon Lou, Eleftheria Roumeli, Dwayne Arola
Department of Materials Science and Engineering
12/18/2023
Introduction

- **Brandon Lou**
  - B.S., M.S. Materials Science and Engineering
  - University of Washington, Class of ‘22, ’23
  - Department of Materials Science and Engineering
  - Previous research in biological alternatives for cement in structural materials
  - Academic advisement from Professors Arola and Roumeli

- **Zeolite Composites, LLC**
  - Founded in March 2022
  - Co-founder Dan Uhm
  - Focusing on utilization of zeolite for environmental benefits
  - Exclusive access and rights to natural zeolite mine
Introduction - Cement

- Ordinary Portland Cement (OPC)
  - 7-15 wt% concrete
  - 1 kg cement emits ~1 kg CO₂ [1]
  - Hydration reactions cause strength development

- Pozzolanic reaction:
  \[ \text{Ca(OH)}_2 + \text{H}_2\text{O} + \text{pozzolan} \rightarrow \text{C-S-H} + \text{C-(A-)S-H} \]
  - Densification/strengthening
  - Reduction of CO₂ emissions associated with cement production

- Cement replacement with pozzolans
  - Blast furnace slag, fly ash, silica fume, calcined clay, limestone
  - Reactivity classified by relative amounts of silica and alumina

Introduction - Cement

- Ordinary Portland Cement (OPC)
  - 7-15 wt% concrete
  - 1 kg cement emits ~1 kg CO\(_2\) [1]
  - Hydration reactions cause strength development

- Pozzolanic reaction:
  \[ \text{Ca(OH)}_2 + \text{H}_2\text{O} + \text{pozzolan} \rightarrow \text{C-S-H} + \text{C-(A-)S-H} \]
  - Densification/strengthening
  - Reduction of CO\(_2\) emissions associated with cement production

- Cement replacement with pozzolans
  - Blast furnace slag, fly ash, silica fume, calcined clay, limestone
  - Reactivity classified by relative amounts of silica and alumina

Global CO\(_2\) Emissions [1]

Introduction - Zeolite

- What is zeolite?
  - Minerals composed of crystalline aluminosilicates
  - Zéō ("boiling") + líthos ("stone")
  - Used as detox agent, drying agent, water/air purifier, ingredient in detergents
  - Natural and synthetic options available

- Zeolite as a cement replacement
  - Pozzolanic -> viable supplementary cementitious material (SCM)
  - Clinoptilolite highly reactive due to high (>4) Si:Al
  - Microporous structure -> ability to capture molecules
  - Non-intensive processing reduces upfront carbon emissions

---

<table>
<thead>
<tr>
<th>Material</th>
<th>Effectiveness in concrete</th>
<th>Environmental footprint</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cement</td>
<td>Very Good</td>
<td>Very Bad</td>
</tr>
<tr>
<td>Slag</td>
<td>Good</td>
<td>Very Bad</td>
</tr>
<tr>
<td>Silica fume</td>
<td>Very Good</td>
<td>Good</td>
</tr>
<tr>
<td>Zeolite</td>
<td>Very Good</td>
<td>Very Good</td>
</tr>
</tbody>
</table>
Goal: Understand zeolite potential in concrete to reduce CO\textsubscript{2} emissions associated with cement production.

- Achieving this goal takes time and understanding:
  - Need to understand how zeolite effects the chemical reactions that take place in concrete
  - Does zeolite change the durability of concrete over time? In different environments?
  - Are there other ways that zeolite reduces carbon emissions?

Recent collaboration with Western Interlock to understand zeolite effect on pavers:
- Creating sample pavers with their materials, scientific lens for industrial work
Experimentation

- Making samples
  - 2 in. x 2 in. x 2 in. cubic samples
  - Varying amounts of zeolite content
Experimentation

- Making samples
  - 2 in. x 2 in. x 2 in. cubic samples
  - Varying amounts of zeolite content

- Breaking samples
  - Compressive testing after specified times of curing (3, 7, 14, 28d)
  - Maximum load recorded, compared between samples

\[ \sigma_{\text{max}} \]

Stress (\(\sigma\))

Strain (\(\varepsilon\))

Stressed by Brandon Lou
Experimentation

- Making samples
  - 2 in. x 2 in. x 2 in. cubic samples
  - Varying amounts of zeolite content

- Breaking samples
  - Compressive testing after specified times of curing (3, 7, 14, 28d)
  - Maximum load recorded, compared between samples

- Characterizing samples
  - Thermal degradation
  - Porosity
  - Elemental analysis
  - Microstructure observation
Mechanical results

Data Collected by UW Civil Engineering Department

- UW Control
- Mix 1
- Mix 2
- Mix 3
- Mix 4
- Mix 5
- Mix 6

WI Paver Mechanical Results

- Day 1
- Day 7
- Day 14

Compressive Strength [MPa]

- ASTM C595 - Blended cements 28d
- IBC 1905.1.1 - Structural
- ASTM C90 - Masonry
Ca(OH)$_2$ growth

Recall the image from earlier!

Mortar sample with zeolite powder added to composite
Future Work

- Post-cure carbon capture
  - How will carbon capture work?
  - Expose samples to CO$_2$ rich environments for predetermined time intervals
  - Measure resultant change in properties and CO$_2$ captured

- Environmental exposure
  - Ex: seawater, humid, high temperature

- Long-term durability
  - Currently characterized to 28d, need to see effect over longer periods of time
Industrial Efforts

- **11/17/23 C-Crete collaboration**
  - 100% OPC-free zeolite-based concrete mix
  - Poured at Commercial Project in Seattle

- **12/04/23 Western Interlock partnership**
  - 1<sup>st</sup> low carbon zeolite paver production run
  - Manufacture and Distribute Low Carbon Hardscape Products (Retail Distribution and Big Box Retailers) in 2024

- **Carbon credit recognition**
  - 12/12/23 approved and registered with Climate Action Reserve
  - Zeolite Composites one of 12 global companies participating with VERRA protocol development for low carbon concrete

- **January 2024**
  - Mutual Materials collaboration for zeolite pavers
  - Alquist 3D, COBOD collaboration for low carbon concrete for 3D printing of concrete
Acknowledgement

Zeolite Composites LLC