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Assessing the Freeze-Thaw Performance of CSA Systems

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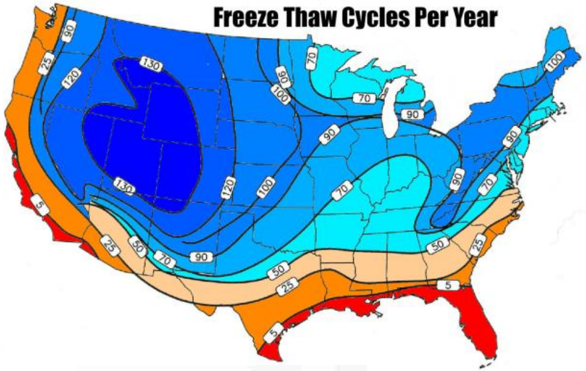
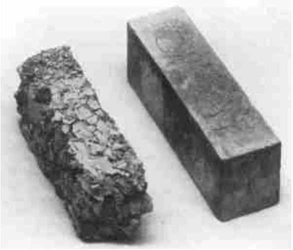
Motivation

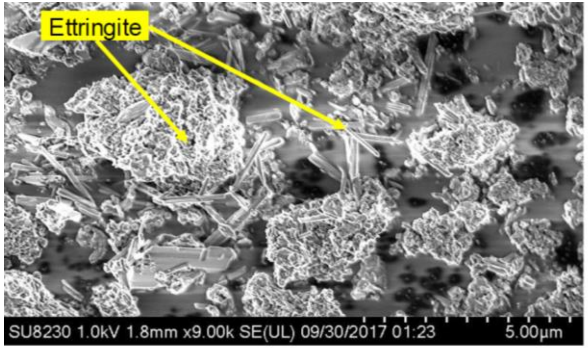
- Alternative cementitious materials (ACMs) such as calcium sulfoaluminate cements (CSA) receiving increasing attention worldwide due to their significantly lower embodied energy and numerous attractive properties
- However, there is a lack of knowledge regarding the durability of these materials in harsh, especially cold environments
- Liability due to freeze-thaw (FT) damage to the concrete infrastructure is potentially trillions of dollars





CSA Cements

- Composed of anhydrite, ye’elimite, and belite as main mineral phase.
- The primary hydration products of CSA cements are ettringite, aluminum hydroxide, and monosulfate.
- CSA cements can be designed to exhibit limited shrinkage.



P. Alapati, 2020

Freeze-Thaw Damage in OPC Systems

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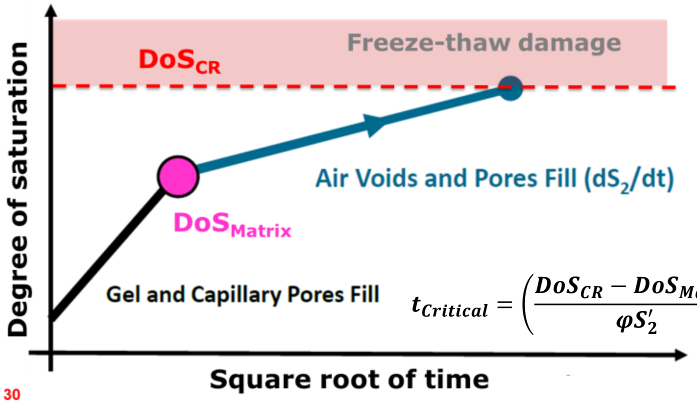
Important factors

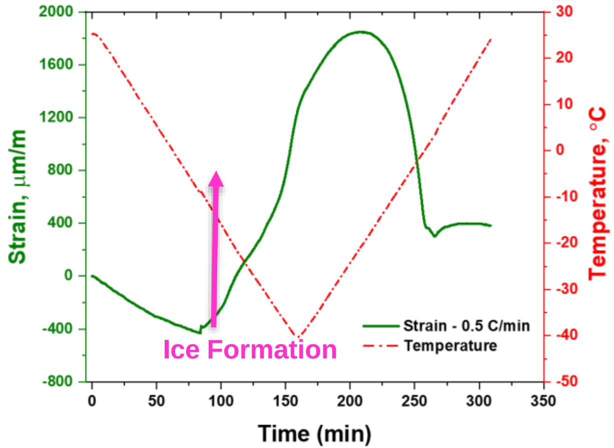
(a) Permeability of materials

(b) Distance to an escape boundary (i.e., spacing factor & air content)

(c) Degree of saturation



$$t_{Critical} = \left(\frac{DoS_{CR} - DoS_{Matrix}}{\varphi S'_2}\right)^2$$



How About CSA Systems?

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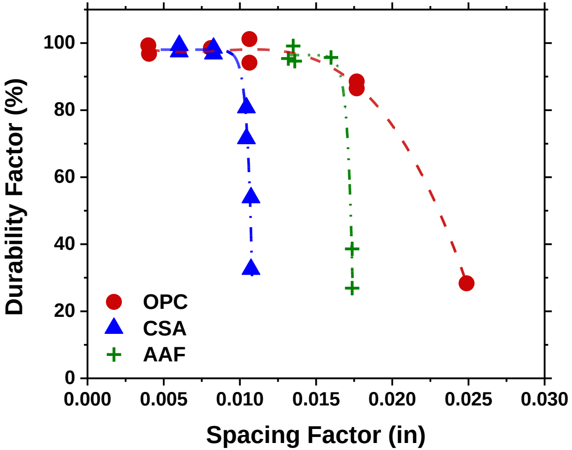
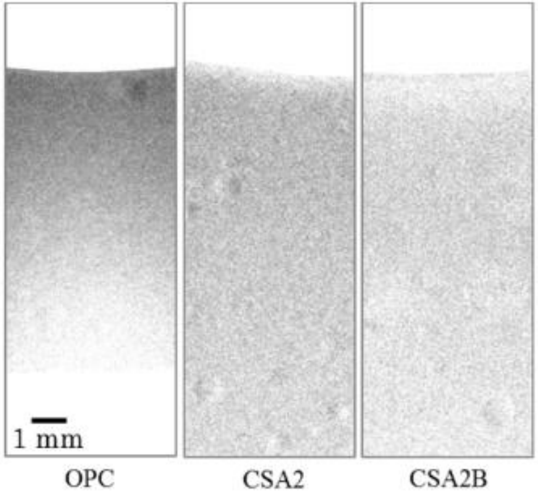
Preliminary studies have shown that CSA systems perform differently in FT environment and against salt intrusion

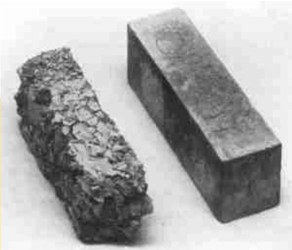


After Perry, 2017

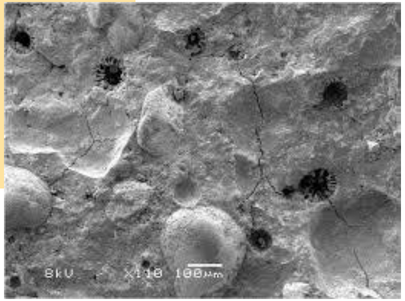


Khanzadeh et al. 2016

Project Objectives



- Compare the FT performance of CSA systems to that of OPC mixtures.
- Relate the CSA microstructure and transport properties to the FT performance



Research Approach

- Pore distribution in CSA and OPC systems
- Mass transport properties
- Freeze-thaw performance

Experimental Program

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- **Mixtures**
  - Cement paste and mortar samples with three different w/b were prepared (w/b= 0.40, 0.45, and 0.50).
  - A belitic calcium sulfoaluminate (BCSA) cement was used.
  - Volume of fine aggregate in mortar samples: 55%
  - Citric acid was used as a retarder in CSA mixtures.
  - Samples were sealed cured for 28 days.

Pore Size Distribution from Nitrogen Sorption Test

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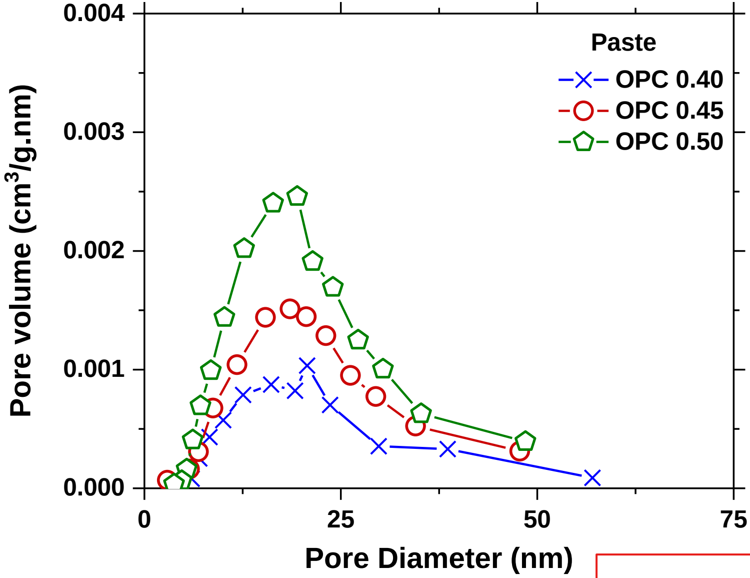
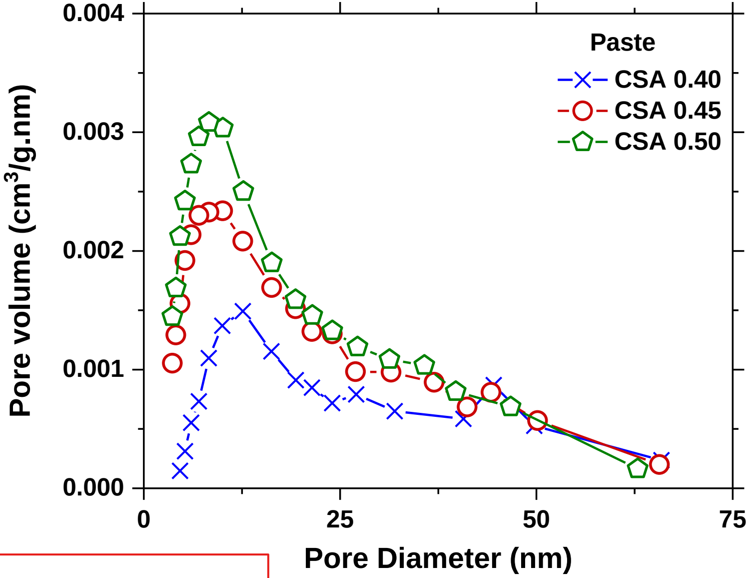
- In CSA systems, volume of smaller mesopores (<10 nm) is higher.

OPC Systems



CSA Systems



$$\ln(p/p^0) = -2\gamma V_m / RT(r_p - t_c)$$

Pore Size Distribution from Nitrogen Sorption Test

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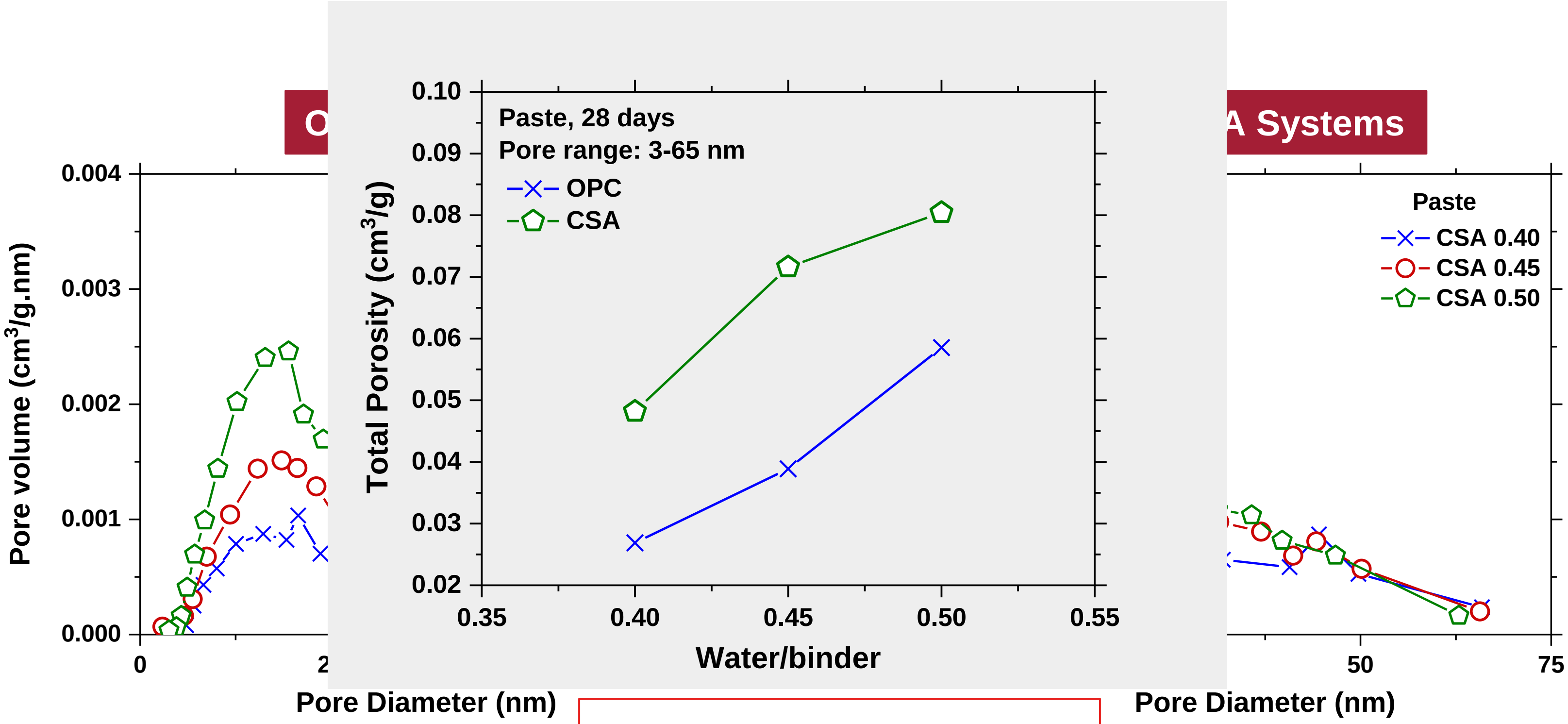

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Porosity using Gravimetric Method

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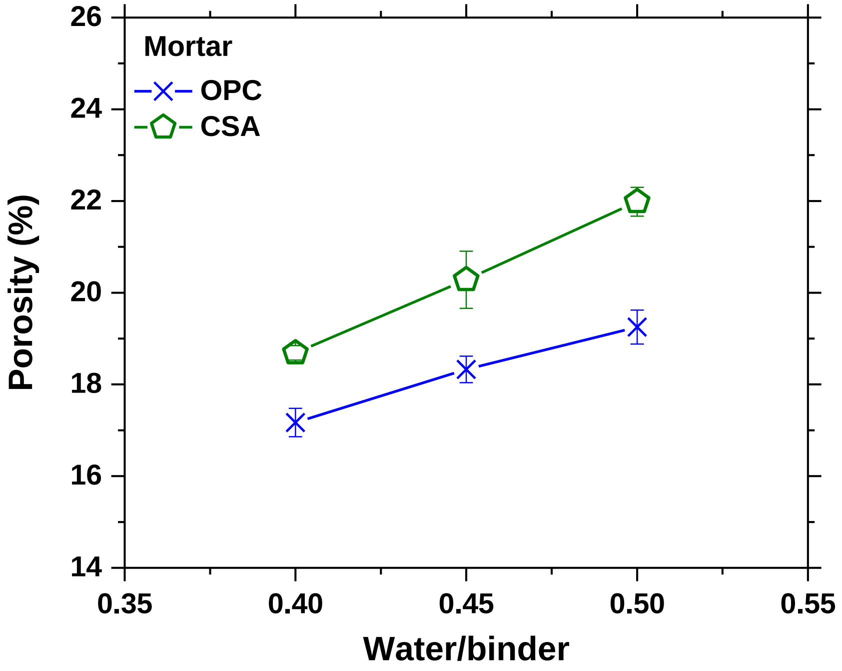
- CSA mortar samples show higher porosity compared to OPC samples.
- The difference is higher at w/b of 0.50.



Water Absorption

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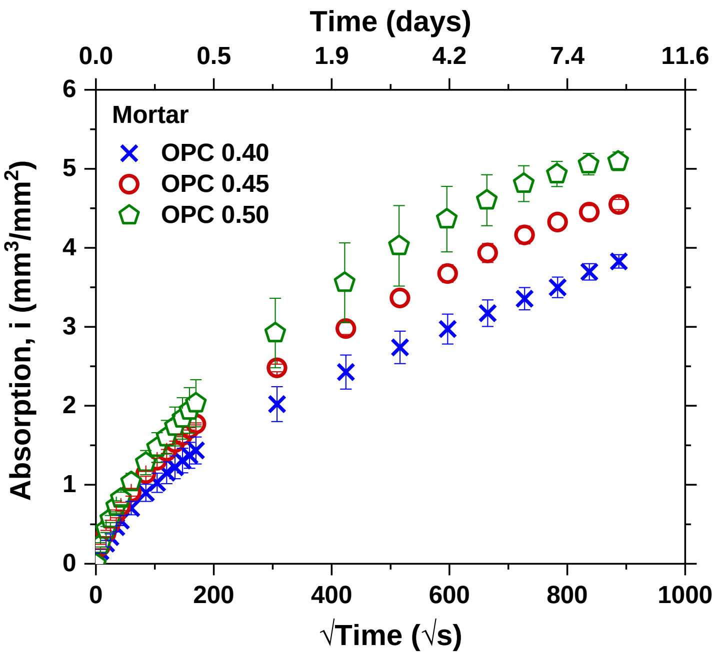
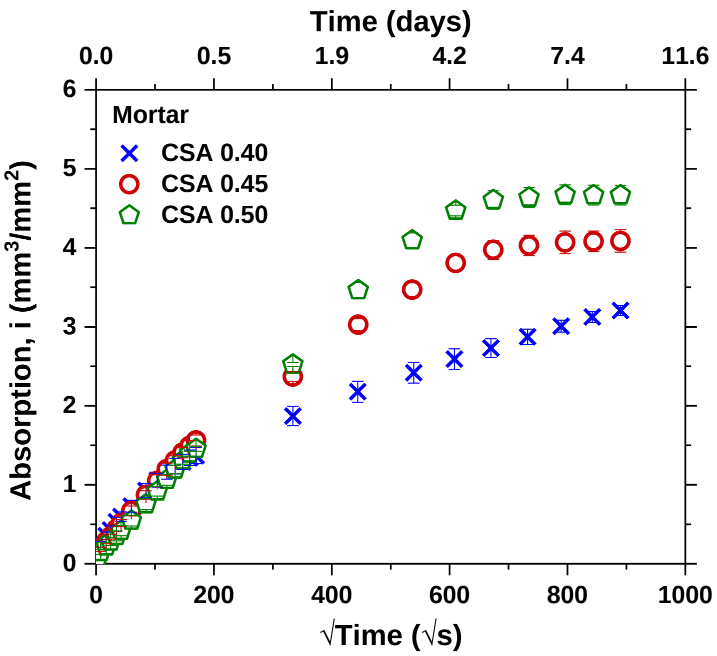
- CSA mortar samples (with w/b of 0.45 and 0.50) show higher secondary slope.



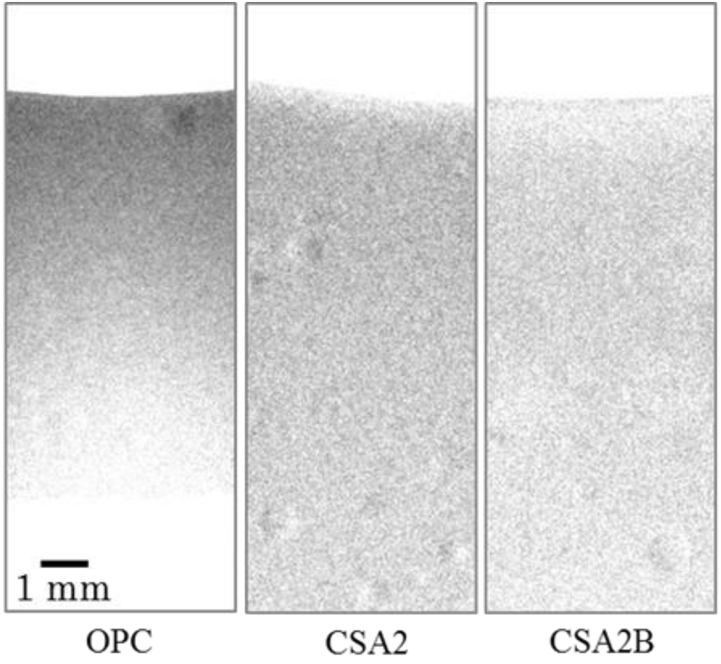
OPC Systems

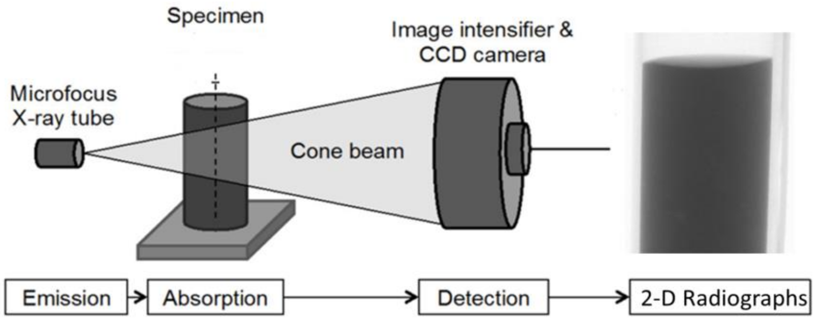


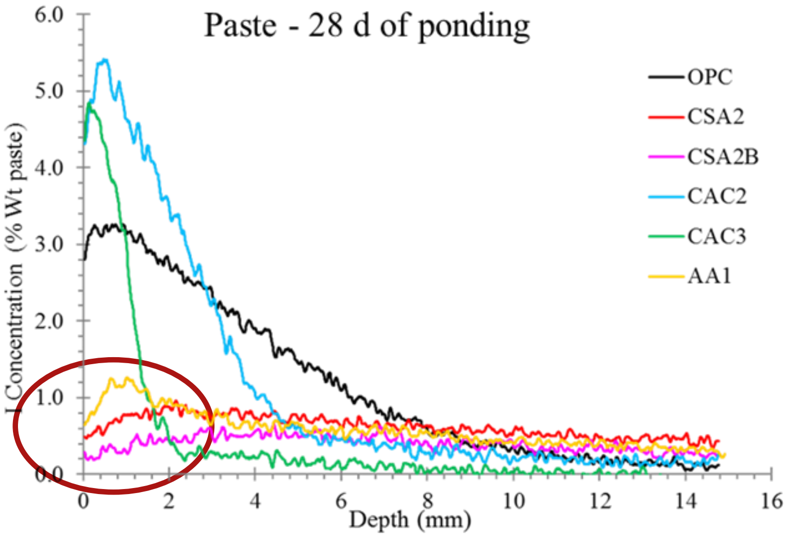
CSA Systems

Diffusion from mCT

Paste, 28-day diffusion







Khanzadeh et al. CBM, 2016

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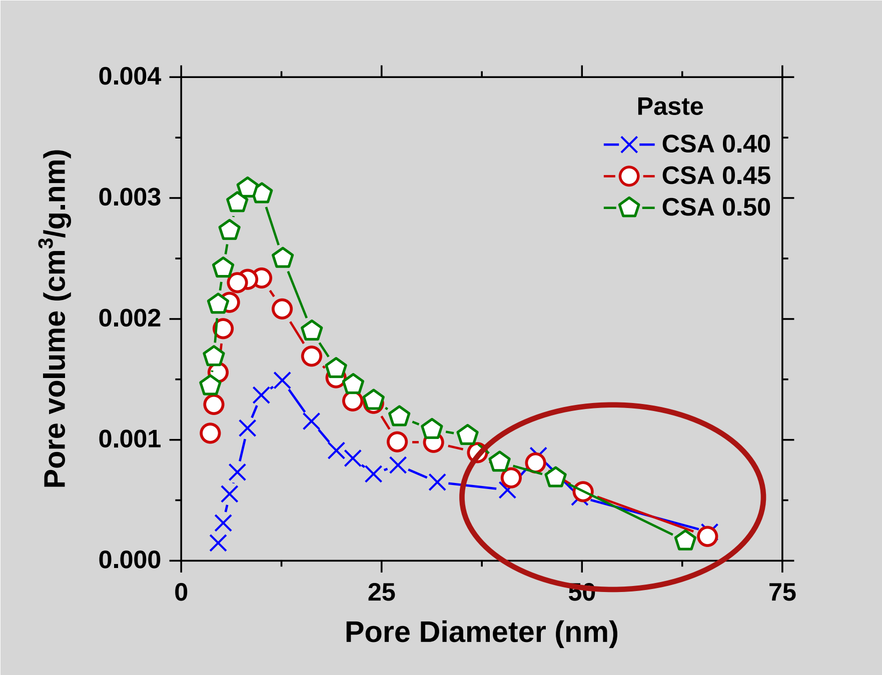
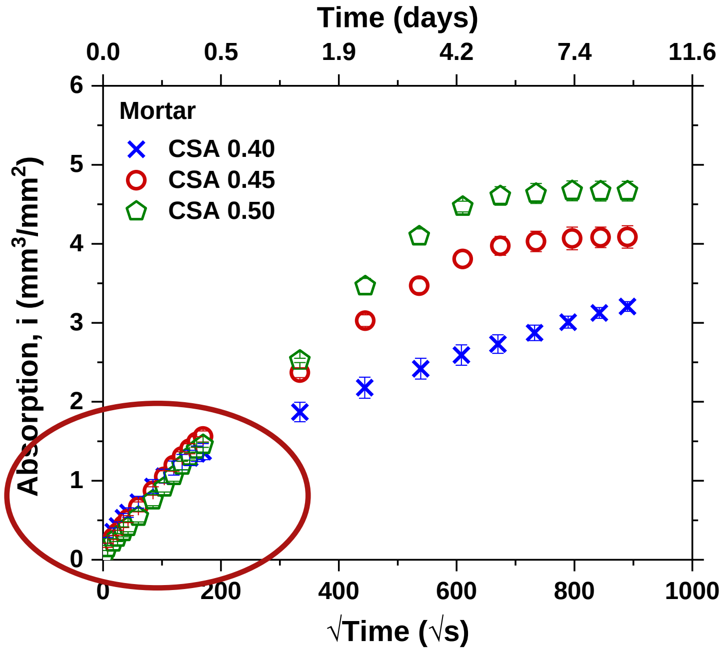
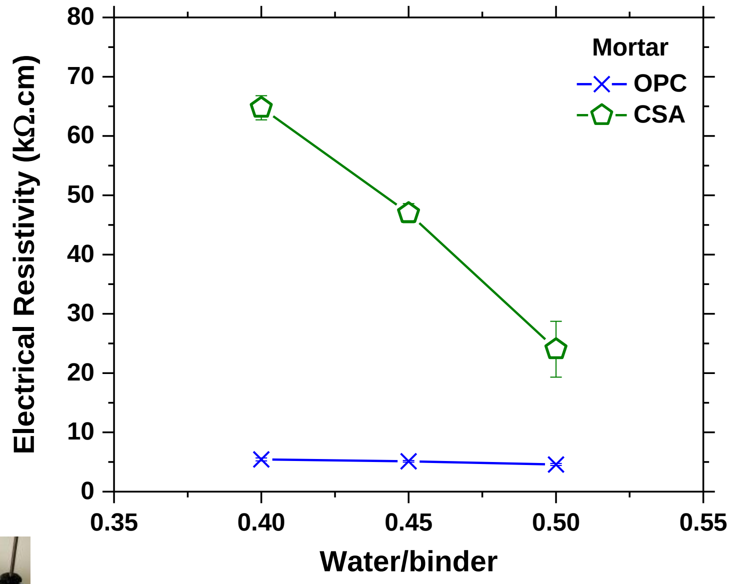




CSA Systems

Bulk Electrical Resistivity Measurements

- CSA samples show much higher resistivity.
- The ER change as a function of w/b is more steeper in CSA systems.



Bulk Electrical Resistivity Measurements

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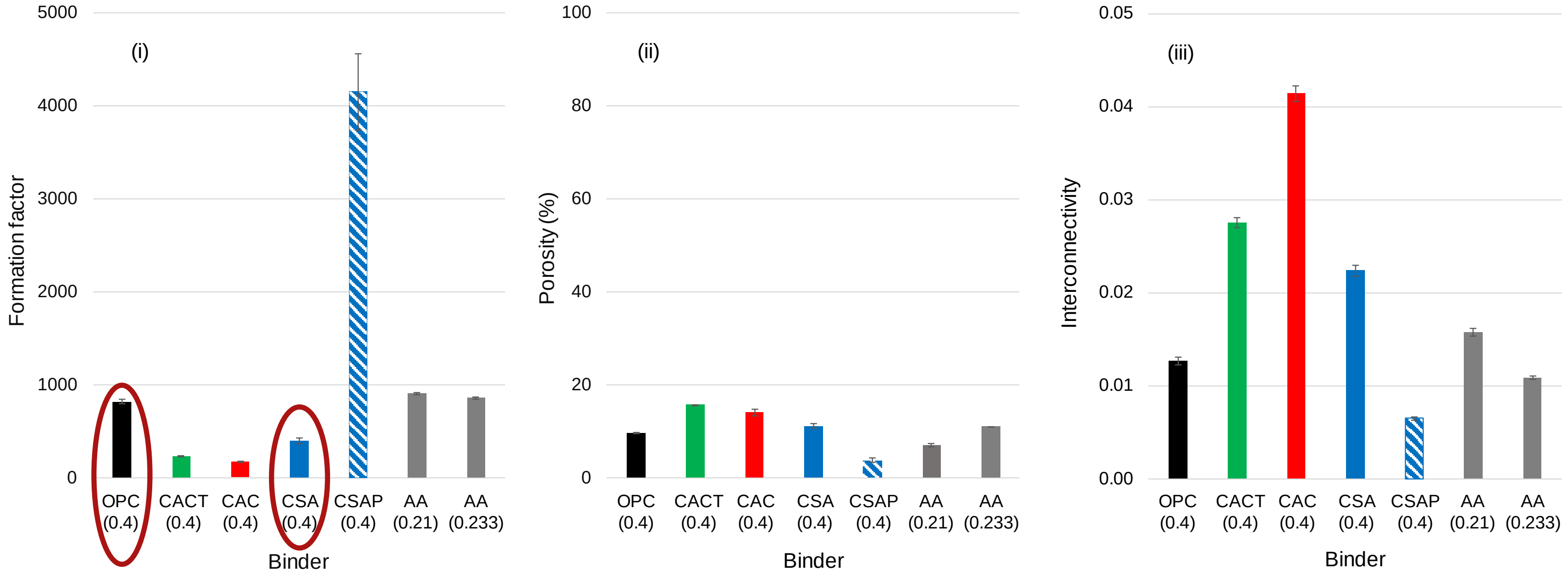
- Formation factor values are comparable
- CSA systems show higher pore interconnectivity

$$F = \frac{\rho_T}{\rho_0} \cong \frac{1}{\beta . \varphi}$$



Alapati et al., Designing Corrosion Resistant Systems with Alternative Cementitious Materials, *Cement*, 2022

Freeze-Thaw Performance from TMA

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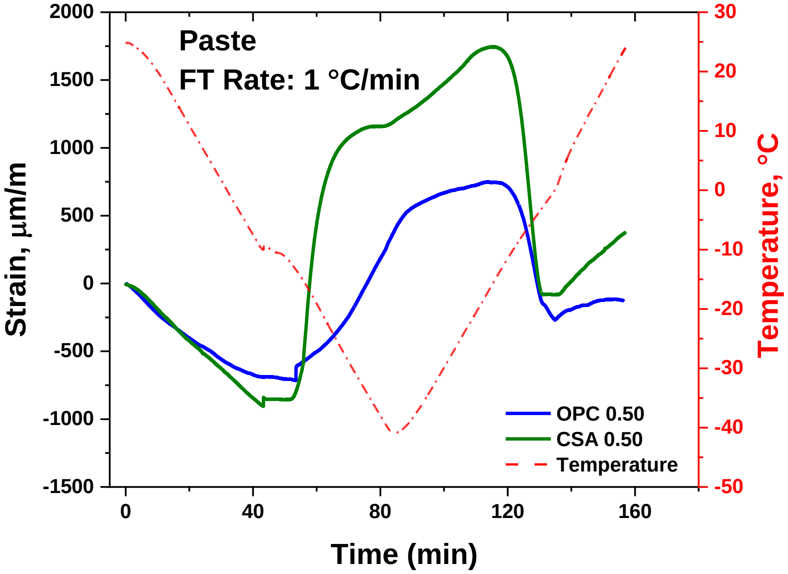
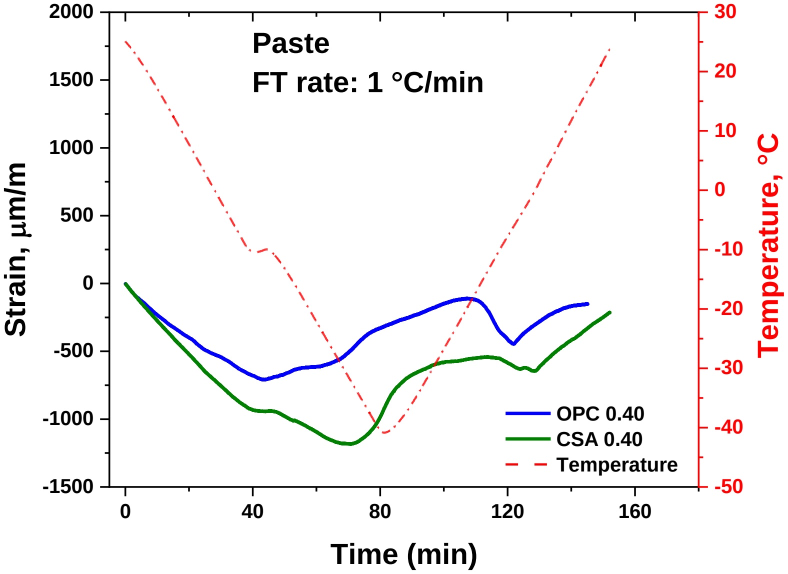
Paste samples

- The impact from w/b is enormous



w/b = 0.50

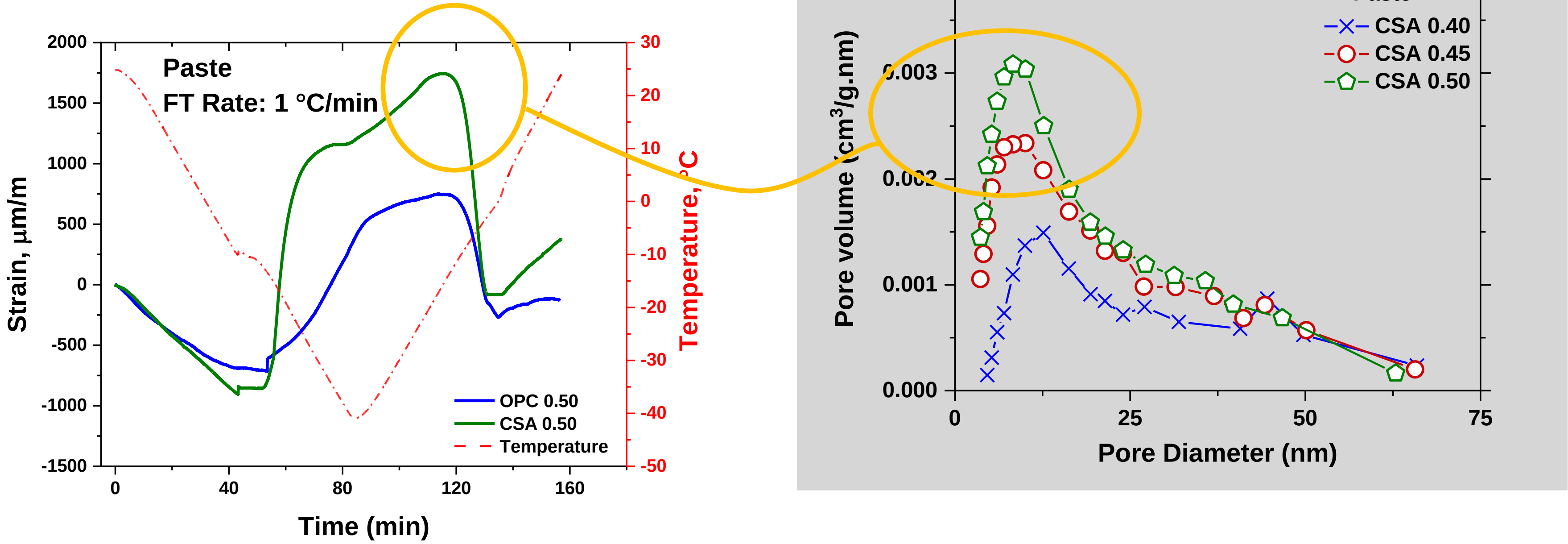


w/b = 0.40

Freeze-Thaw Performance from TMA

Paste samples

- The impact from w/b is enormous



w/b = 0.50

Freeze-Thaw Performance from TMA

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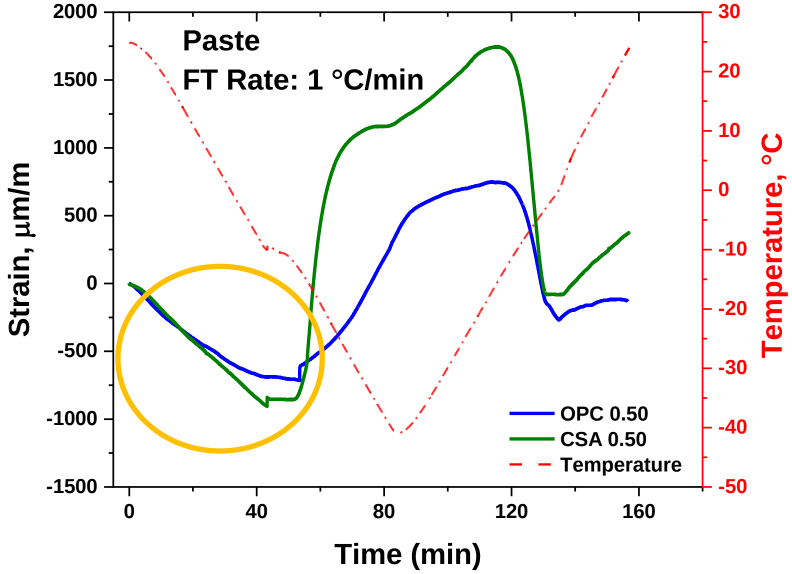
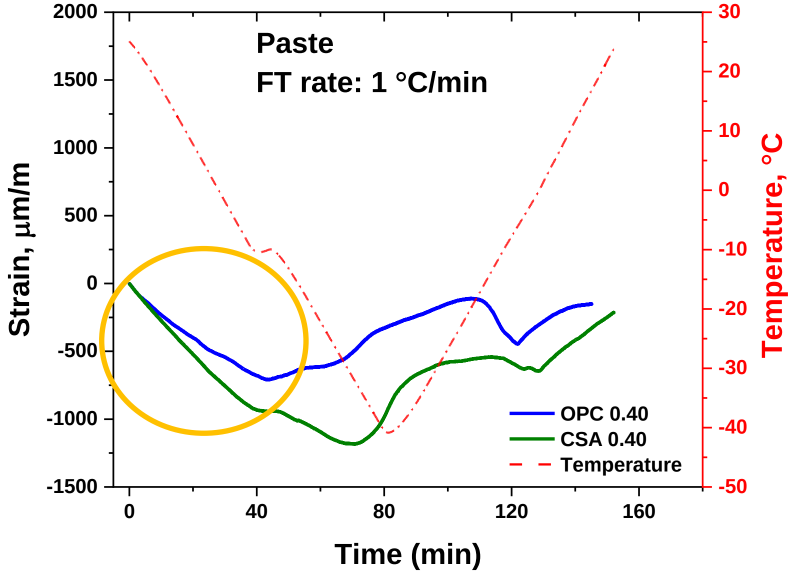
Paste samples

- The CTE values are higher for CSA samples



w/b = 0.50



w/b = 0.40

Conclusions

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- The total pore volume is higher in CSA samples. However, the CSA samples show higher volume of smaller mesopores (<10 nm).
- The CSA mortar samples (with w/b of 0.45 and 0.50) show a higher secondary sorption rate due to higher interconnectivity of mesopores.
- Formation factor is a better indicator of interconnectivity of pores
- The CSA samples with a low w/b show a comparable FT performance (to OPC samples). However, the amount of residual strain (i.e., damage) due to FT cycles is considerably higher in 0.50 CSA samples.
- The coefficient of thermal expansion (CTE) value is higher CSA systems.

Acknowledgements

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Thank You!

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