Controlling Microcracking in Low Embodied Energy Concrete

Antoine Morandeau, Jeff P. Fitts, Satish Myneni and Claire E. White*

*Assistant Professor

Department of Civil and Environmental Engineering, and Andlinger Center for Energy and the Environment

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SOME FACTS ABOUT CEMENT

Portland Cement Production

Clinker: $3CaO{\cdot}SiO_2$

~1400°C

Fuel

$CaCO_3$, SiO_2

CO_2 sources:

- Chemistry ~ 55%

  $CaCO_3 \rightarrow CaO + CO_2$

- Fuel ~ 45%

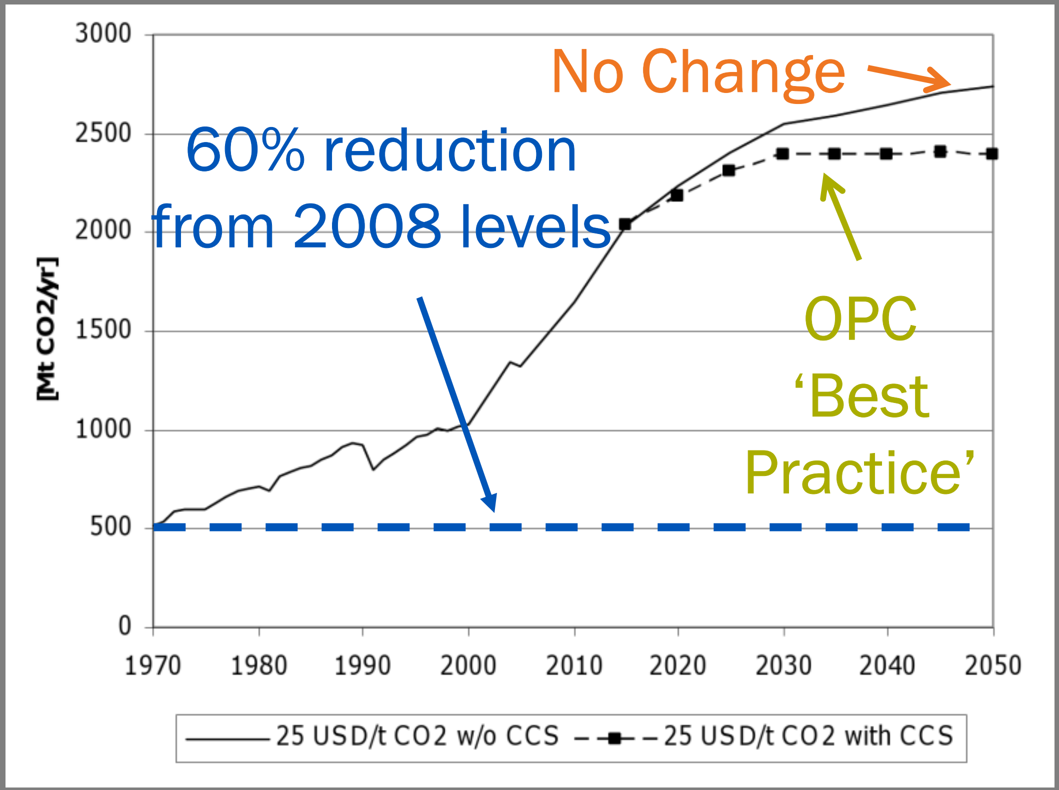
Total ~0.8 t / t clinker

SOME FACTS ABOUT CEMENT

THE HIDDEN DETAILS

- Cement manufacture makes up 5-8% of all CO_2
- Second most used material next to WATER
- ~ 0.8-0.9 ton of CO_2 per 1 ton of cement
- Market to double by 2050

Global Cement Production 1970 - 2050



Alternatives to ordinary Portland cement (OPC) are required to meet the VAST MAJORITY of cement in concrete.

ALKALI-ACTIVATED CONCRETE (GEOPOLYMERS)

Metallurgical Slags

Fly Ash

Natural Pozzolans

Cementitious Components

+

Alkaline Activator

Binder for Concrete

COMMERCIALIZATION OF ALKALI-ACTIVATED CONCRETE

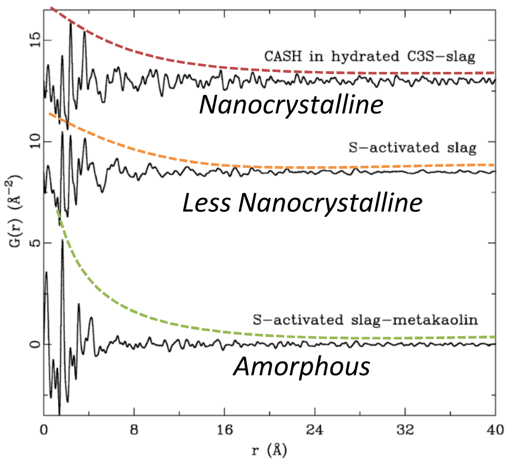
- Late 1950s - Glukhovsky in Kiev developed alkali activated binders, followed by Krivenko, who constructed slag AAC structures and a high rise building in Russia in the 1960s.
- Davidovits coined term **geopolymer** in the 1970s.
- Today many universities research alkali-activated concrete (geopolymers), but still little commercial activity.
    - Specific research-related road blocks

Regional Rail Link Project, Melbourne

Zeobond

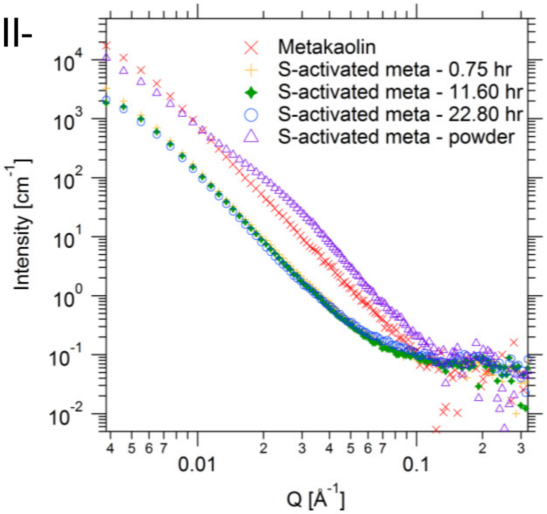
RESEARCH ON ALKALI-ACTIVATED MATERIALS

Nanostructural Ordering: Synchrotron Diffraction

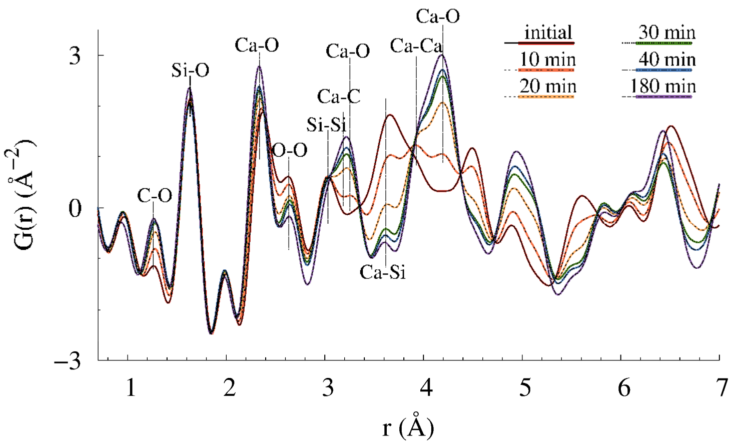


White et al., Cement and Concrete Research, 2015.

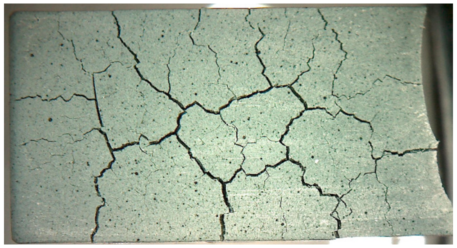
Gel Pores: Neutron Small-Angle Scattering



In situ Carbonation: Synchrotron Diffraction

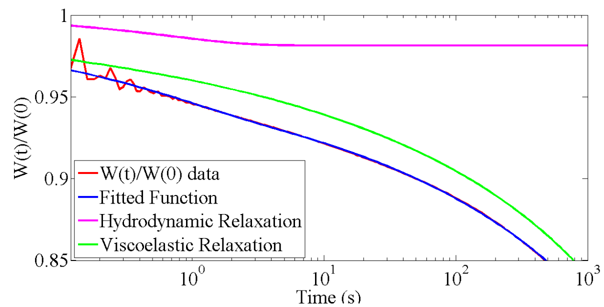


Microcracking: Image Analysis



2cm

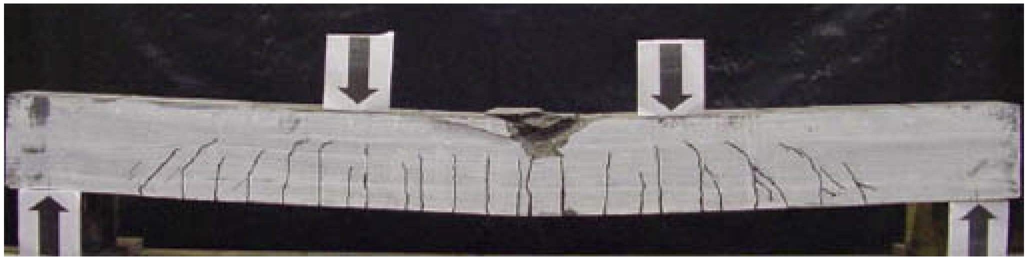
Permeability: Beam-Bending Technique



SUSCEPTABILITY TO MICROCRACKING

- Certain mix designs of alkali-activated pastes are prone to crack
  - Known as *microcracking*
  - Different form of cracking compared to cracks induced due to loading (tension in reinforced concrete)
  - Microcracking increases susceptibility to chemical degradation

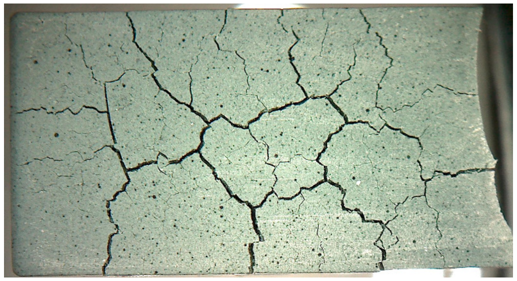
Cracking in reinforced concrete due to bending



3m

Sumajouw and Rangan, 2006

Microcracking in alkali-activated slag paste



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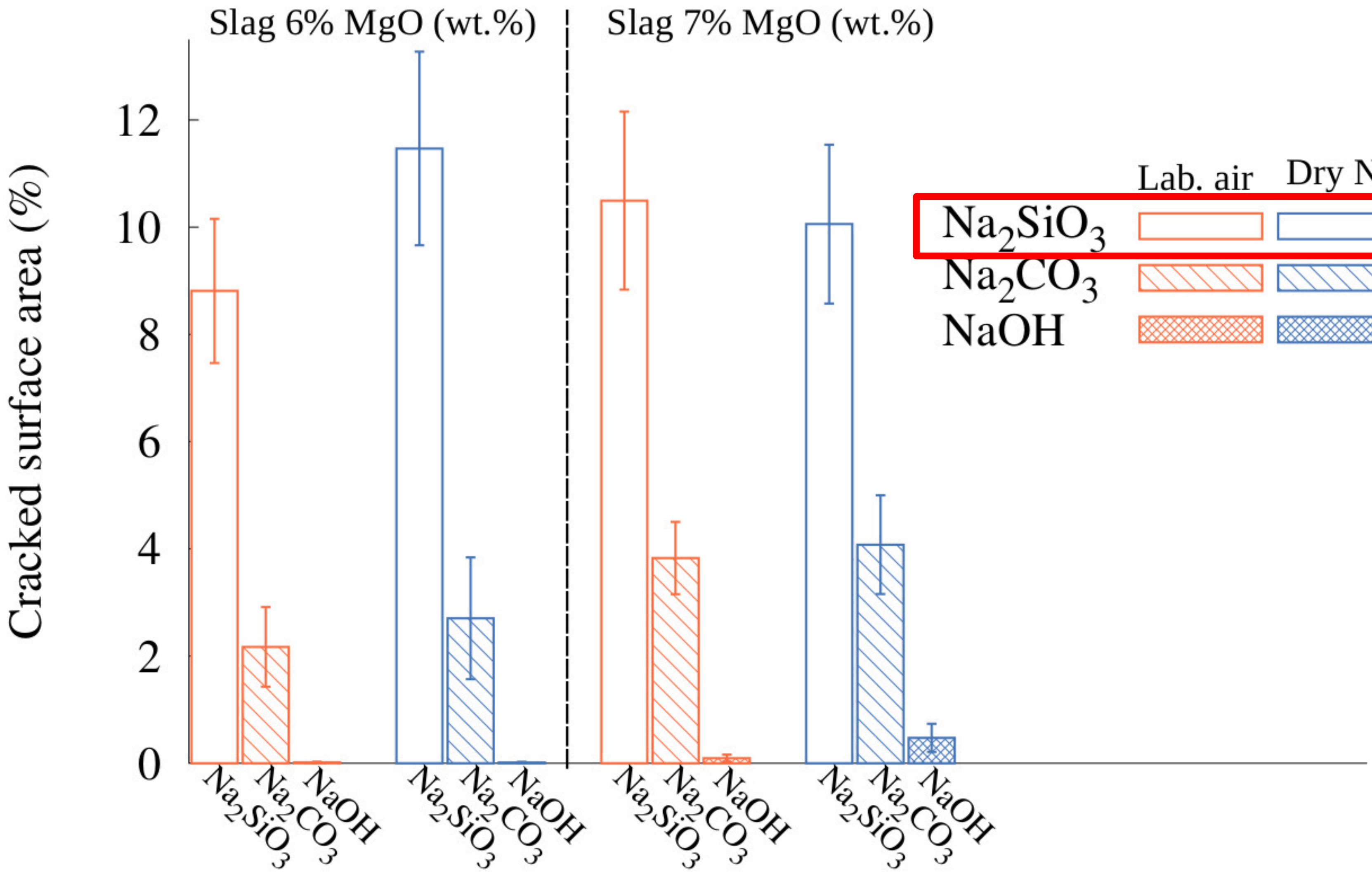
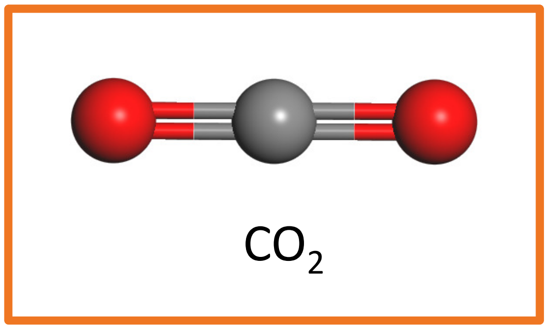
MICROCRACKING IN ALKALI-ACTIVATED SLAG PASTES

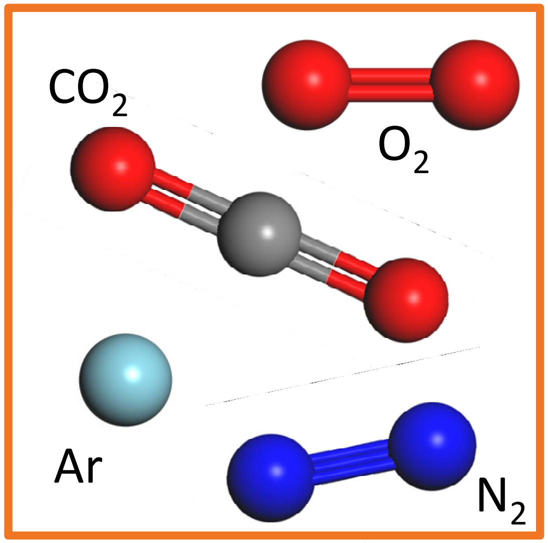


CAUSE(S) OF MICROCRACKING

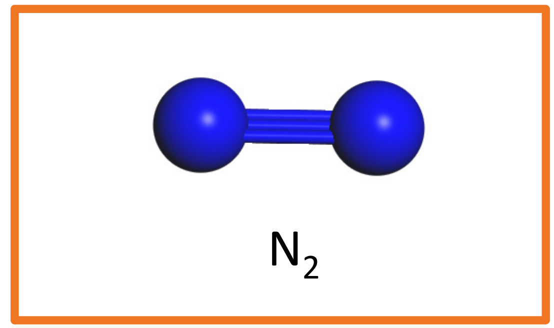
- Microcracking is induced by non-uniform shrinkage of the paste
- Possible causes of shrinkage include:
  - Autogenous (water in pores consumed by reaction)
  - Plastic (evaporation of water prior to setting)
  - Drying (evaporation of water at any stage)
  - Carbonation (dissolution/precipitation of phases due to reaction with CO_2)



Carbon Dioxide



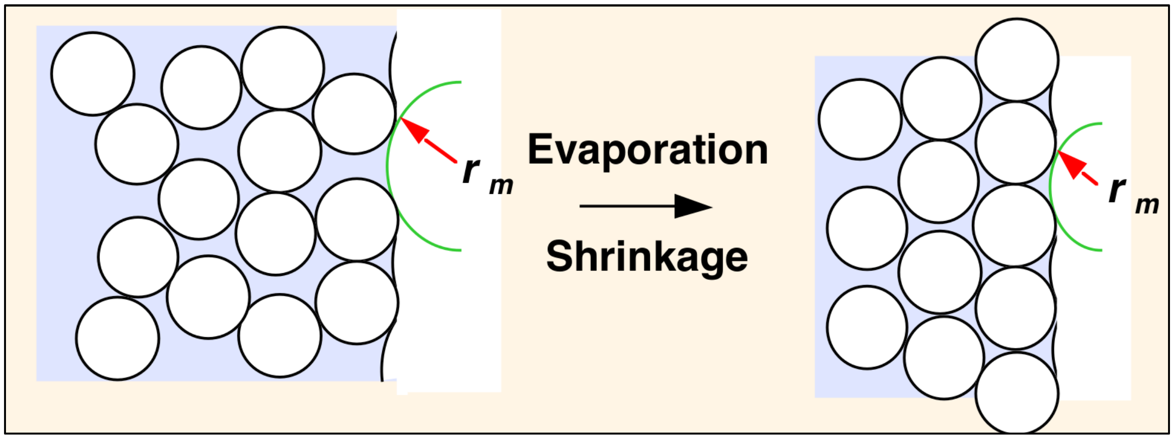
Air (in laboratory)



Nitrogen

THEORY OF CRACKING DUE TO DRYING

- Evaporation of water from pores causes a build up in capillary pressure
- Initially the evaporation does not empty the capillary pores inside the paste
  - Overall paste dimensions can be reduced

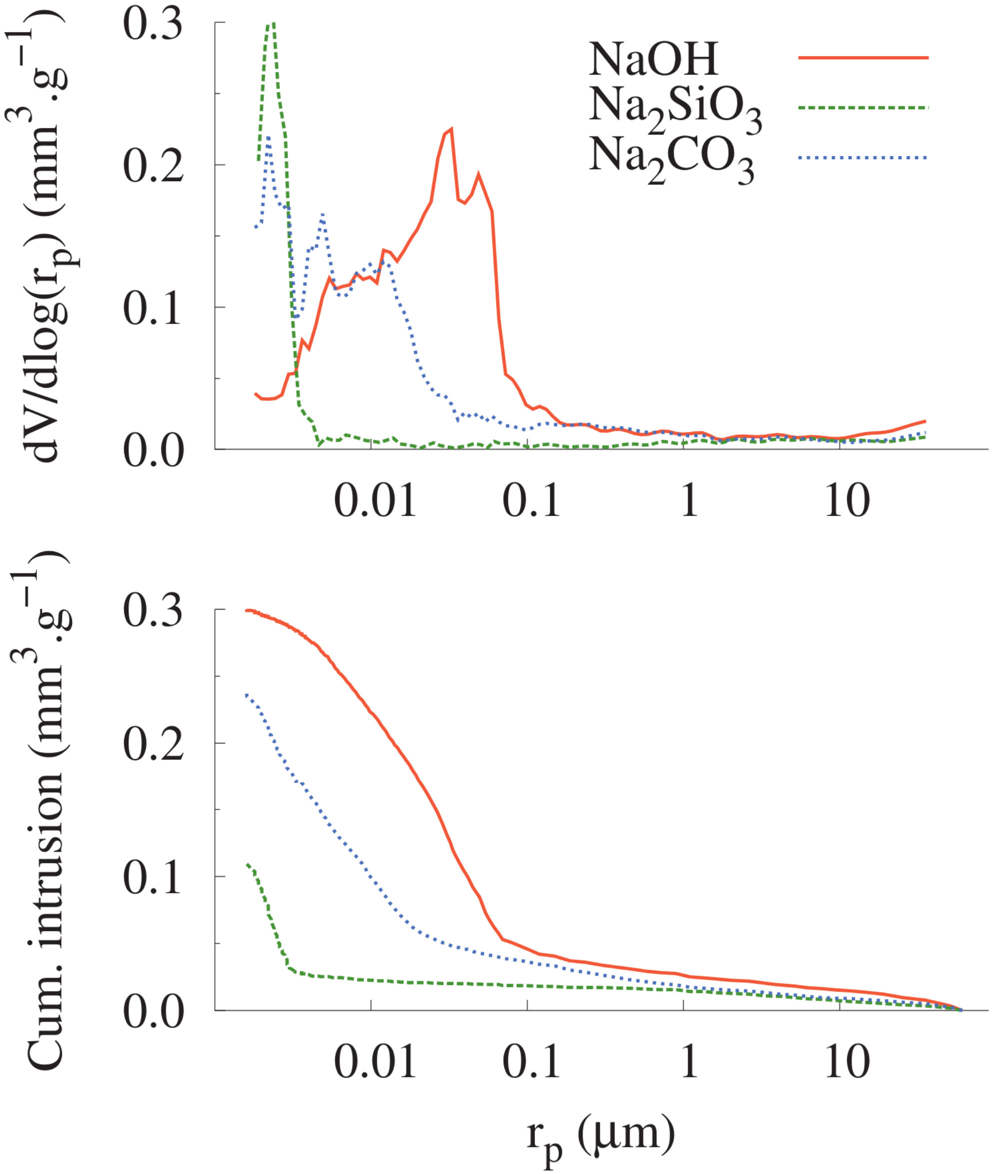


- Later stage involves menisci retreating into the body
  - Can reach high capillary pressure $\left(P_c = \frac{2\gamma_{LV}}{r_m}\right)$
  - Possible to induce microcracking

Image courtesy of George Scherer

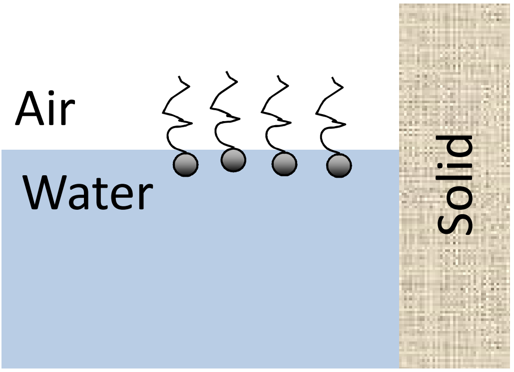
LINK WITH PORE SIZE DISTRIBUTION

Mercury Intrusion Porosimetry



POTENTIAL SOLUTIONS TO MICROCRACKING

- Shrinkage reducing admixtures
  - Reduces the surface tension between air/water
  - Do not work for alkali-activated materials, unless at extremely high concentrations



- Crack bridging using reinforcement
  - e.g., Fibers

- Extended curing conditions

http://www.fhwa.dot.gov/pavement/pccp/pubs/06003/

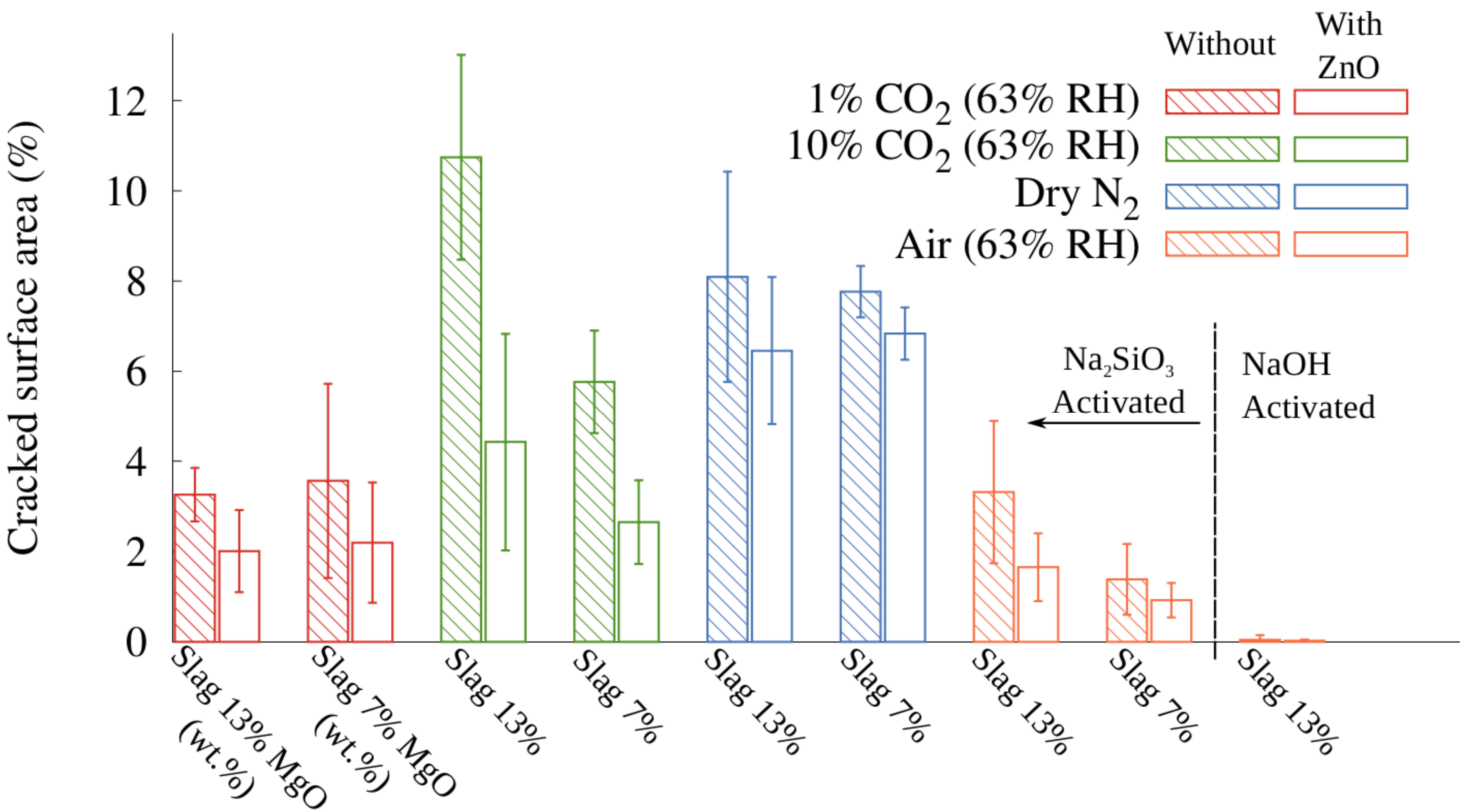
MITIGATING CRACKING WITH NANOPARTICLES?

- Nanoparticles currently used in concrete to:
  - Increase the rate of hydration
  - Increase the early age compressive strength of paste/concrete
  - Photocatalytic properties (nano-TiO_2)
  - Bridge cracking (using carbon nanotubes)

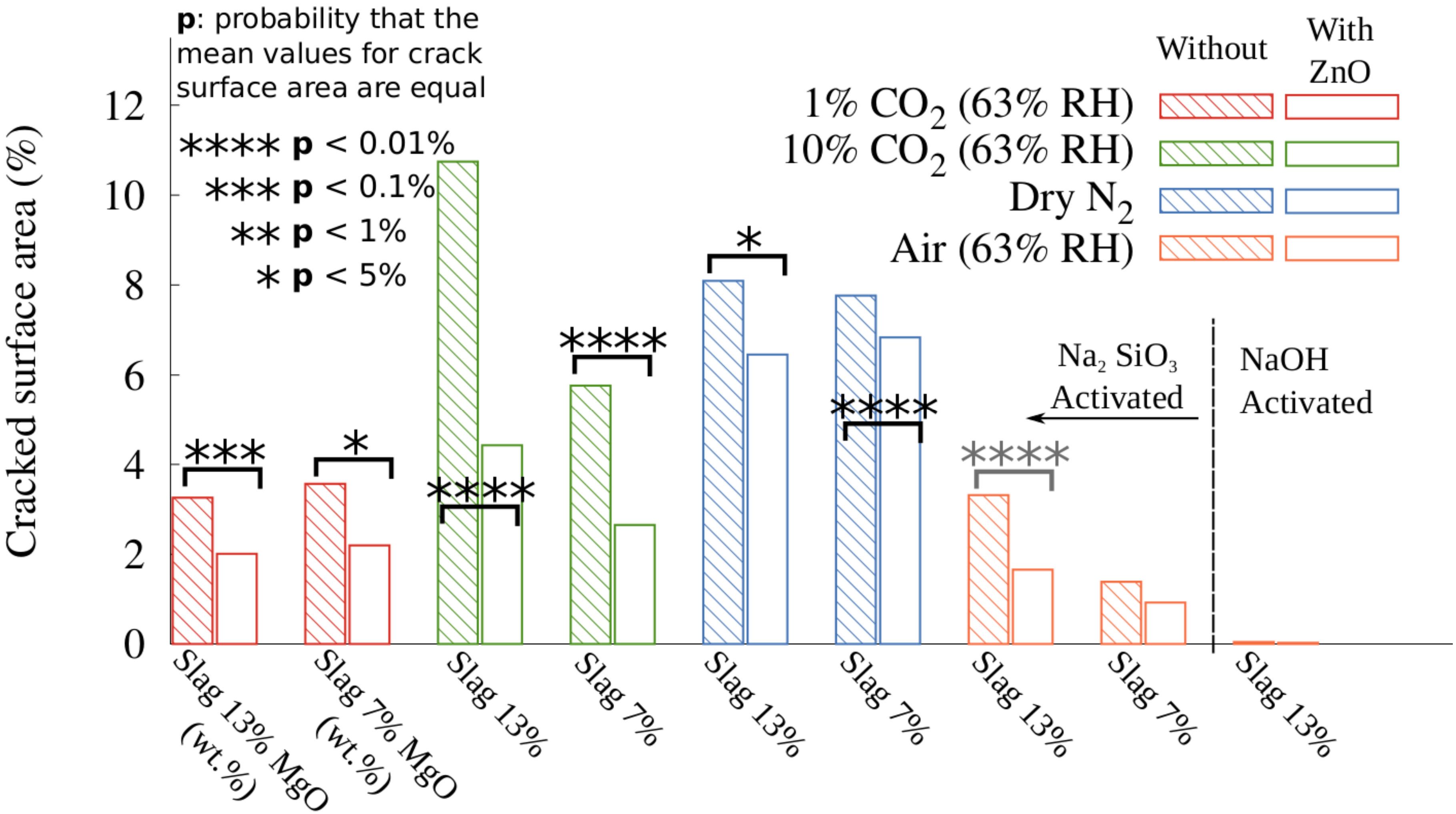
- Potential for nanoparticles to:
  - Alter the paste pore structure (reduce pore size so evaporation occurs only at extremely low RH)
  - Act as seeds to increase the nanostructural ordering of the paste (increase stiffness)

- In this study, we used ZnO nanoparticles (~ 35nm)
  - Stable in high pH solutions (compatible with alkaline activators)
  - Low cost (~ 1% increase in price of concrete)
  - Readily available (used in sunscreen and in solar cells)

EFFECT OF NANOPARTICLES ON MICROCRACKING

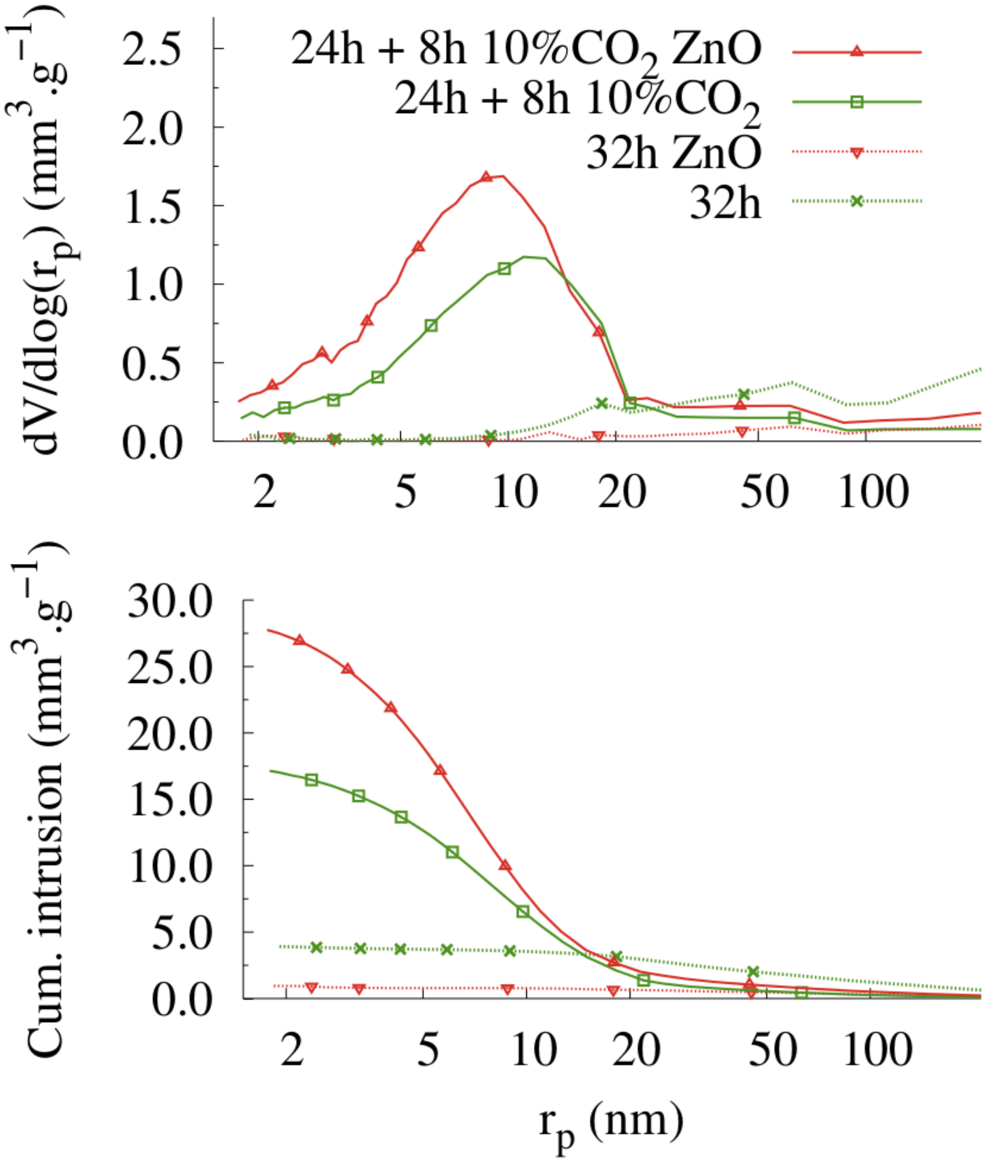


EFFECT OF NANOPARTICLES ON MICROCRACKING

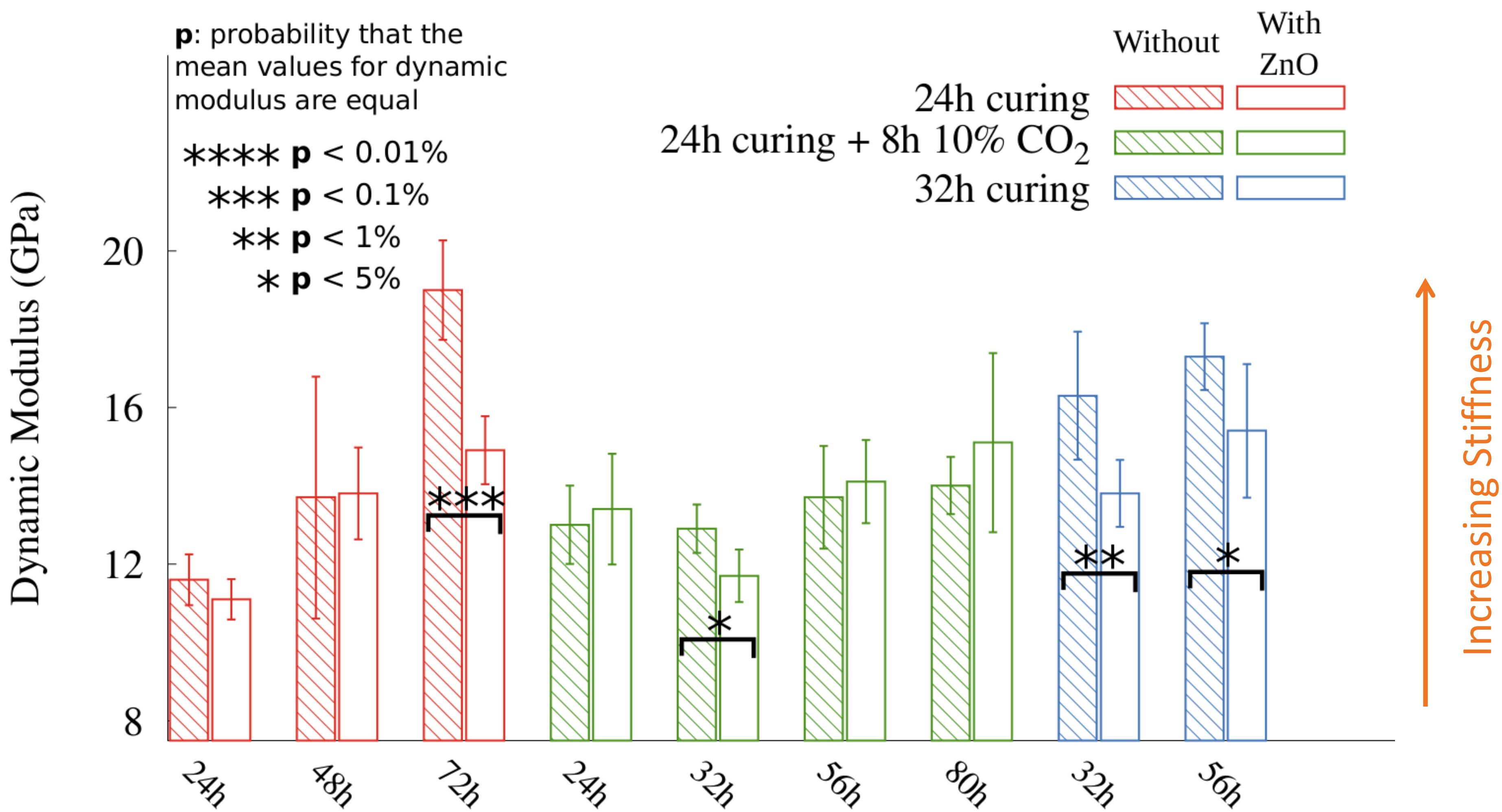


IMPACT OF NANOPARTICLES ON PORE SIZE

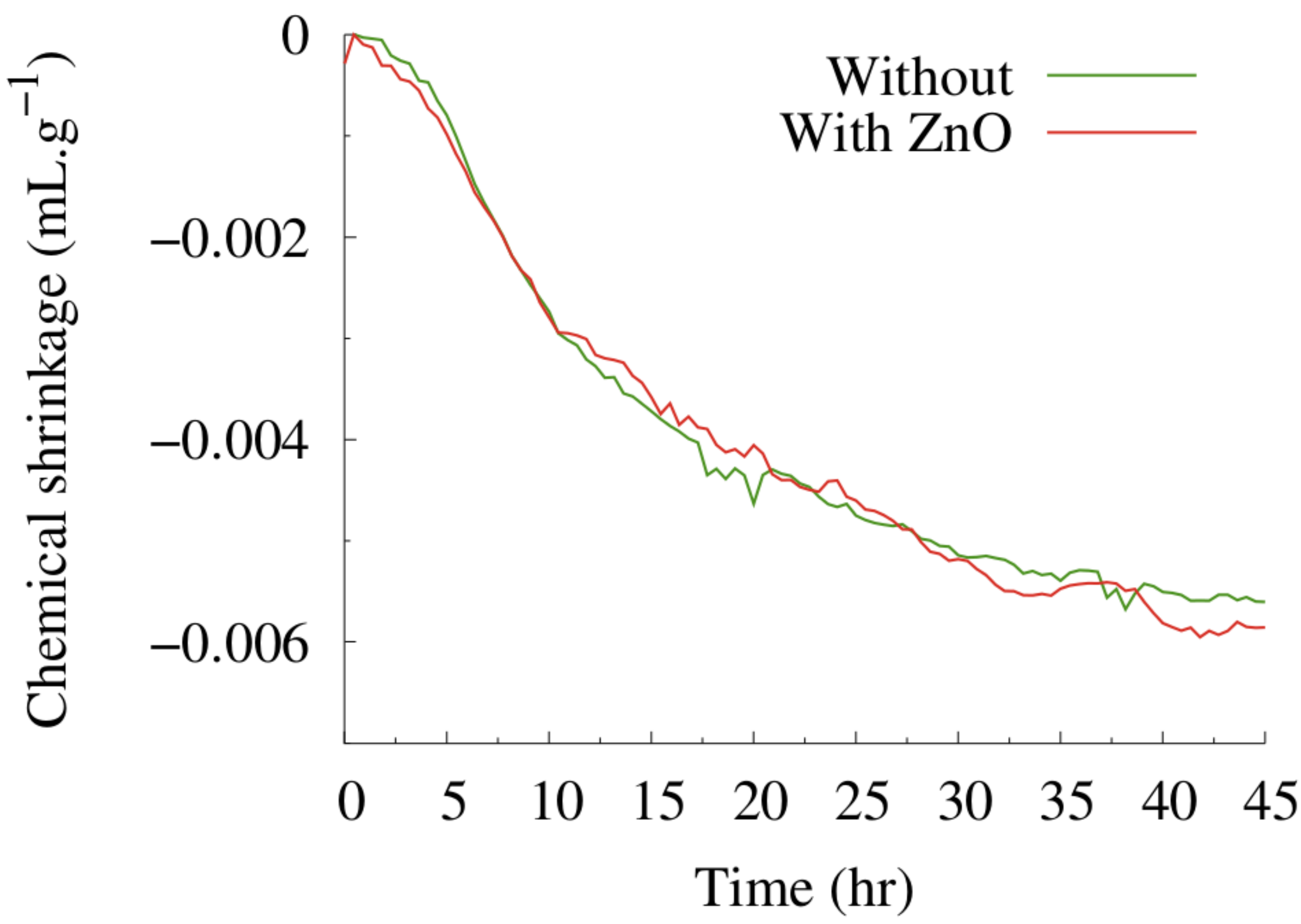
Nitrogen Sorption



EFFECT ON PASTE STIFFNESS



EFFECT ON RATE OF HYDRATION



CONCLUSIONS

- Silicate-activated slag paste is prone to extensive microcracking
  - Issue for commercialization, since silicate-activated pastes have advantageous early strength properties
- Conventional approaches to mitigating microcracking in concrete do not work for alkali-activated systems
- 0.1% wt. of nanoparticles (nano-ZnO) are seen to decrease the extent of surface microcracking
  - Does not appear to correlate with the pore size, paste stiffness or rate of hydration (strength development)

FUTURE WORK

- Use imaging (electron microscopy) to see if the pore walls are affected by the nanoparticles
  - Possible that the nanoparticles increase pore wall roughness, and prevent the evaporation of water within the pores (liquid evaporates at surface)
- Assess if nanoparticles are clogging pores at surface
  - Impact rate of evaporation
- Investigate the impact of dosage
  - Working with very small amounts (0.1% wt.) compared to conventional usage of nanoparticles in concrete (~ 5-10% wt.)

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