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The Economics, Performance, and Sustainability of Internally Cured Concrete, Part 1

ACI Fall 2012 Convention
October 21 – 24, Toronto, ON

ACI WEB SESSIONS

Jason Weiss is a Professor of Civil Engineering and Director of the Pankow Materials Laboratory at Purdue University. He earned a B.A.E. from the Pennsylvania State University and a MS and PhD from Northwestern University in 1999. He is actively involved in research on cement and concrete materials specifically focused on early age property development, cracking, transport in concrete, and concrete durability. Dr. Weiss has taught courses in civil engineering materials, concrete materials, service life, repair and non-destructive testing. His primary research interests are in the area of early age shrinkage cracking and mitigation as well as service life sensing and prediction. Dr. Weiss is a member of the American Concrete Institute (Past Chair of ACI 123), American Society of Civil Engineers, RILEM (Bureau Member, Past TAC member, TC CCD chair), Transportation Research Board (AFN 040 Chair), and American Society for Testing and Materials. He is editor in chief of the RILEM Materials and Structures Journal in 2012 and is an associate editor of the ASCE journal of Civil Engineering Materials and is a member of the editorial board of cement and concrete research. Dr. Weiss has authored over 200 publications with over 95 peer-reviewed journal articles. He is recipient of the NSF Career Award, the RILEM L'Hermite Medal, the ACI W. P. Moore, ACI Young Member, and ACI Wason Awards, the ESCSI Erskine Award, the TRB Burgraff and Mather Awards for outstanding research and publications, and the ASCE Huber Award. He is a fellow of ACI and is also the recipient of the Wansik, Munson, Buck, and Burke awards for outstanding teaching/advising in the school of civil engineering, has received the Potter award for outstanding teaching in the college of engineering, and has been inducted into the Purdue Teaching Academy.

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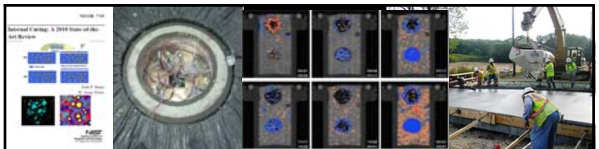

Internal Curing: Observations and Opportunities

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Professor & Director of the Pankow Materials Laboratory

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Objectives

- To understand the differences between conventional (external) and internal curing (IC)
- To understand why chemical shrinkage and self-desiccation play a key role in IC
- To quantify simple concepts behind mixture proportioning – Supply and Demand
- To understand how internal curing benefits are related to fundamental concepts
- To discuss how what we know is implemented
- To discuss emerging concepts which will no doubt continue to push the technology further

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Objectives

- Curing - External and Internal
- What is Self-Desiccation?
- Proportioning Concepts
- Benefits of Internal Curing
  - Increased Cement Hydration
  - Reduced Shrinkage and Restrained Shrinkage Cracking
  - Reduced Fluid Transport (Deicing Salts)
- Visions for the Future

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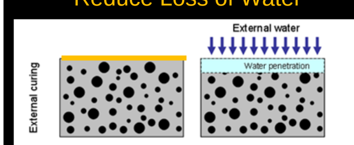
External Curing

- Typically we cure concrete from the outside
  - Water Ponding: Supply of Additional Water
  - Curing Membranes: Reduce Loss of Water



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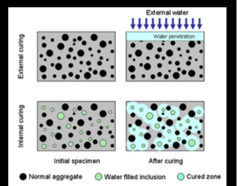
Why's & How's of Internal Curing

- HPC 'dense' and disconnects large pores
- Good for durability; bad for curing water mvmt.
- Self-Desiccation increases in low w/c and with SCM
- 'drying' from the inside without water loss
- Internal curing works from inside concrete using 'water reservoirs' that hide water till set



Outline

- Curing - External and Internal
- What is Self-Desiccation?
- Proportioning Concepts
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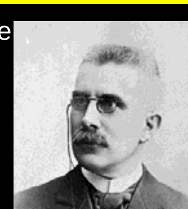
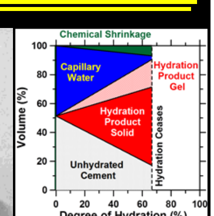
What is Self-Desiccation

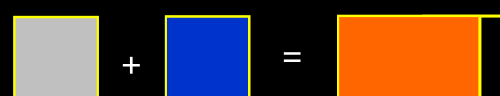
- The reduction in the internal relative humidity (RH) of a sealed system when empty pores are generated.
- What causes the pores top empty?
- Does the size of the pore that empties matter?

Chemical Shrinkage

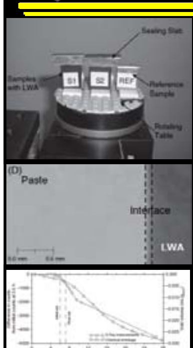
- Volume of the reactants larger than the products
- Le Chatelier
- Powers

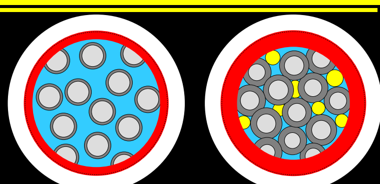


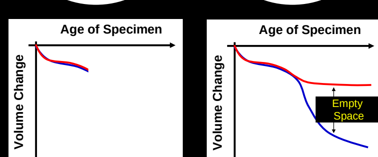




Self Desiccation and Setting

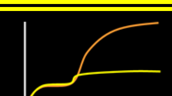


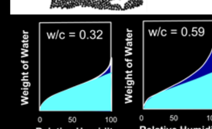


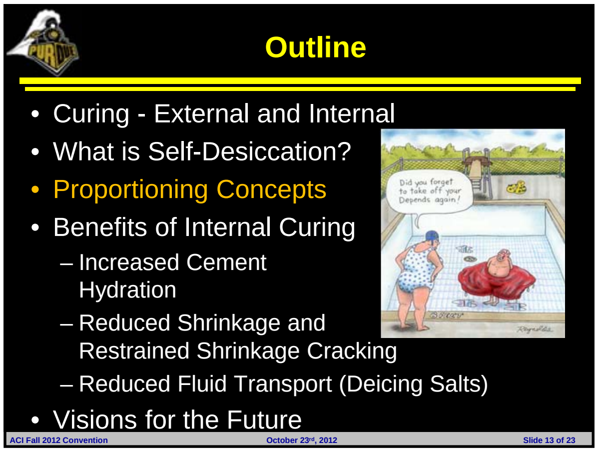


Why is this an Issue in Lower w/c

- CS is not very sensitive to w/c at early ages
- AS should decrease as w/c increases…..
- Do higher w/c have less self desiccation ??
- The size of the voids:
  a) Capillary vs Gel
  b) Fewer/bigger voids
  c) Lower pressures



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Curing - External and Internal
What is Self-Desiccation?
Proportioning Concepts
Benefits of Internal Curing
– Increased Cement Hydration
– Reduced Shrinkage and Restrained Shrinkage Cracking
– Reduced Fluid Transport (Deicing Salts)
Visions for the Future
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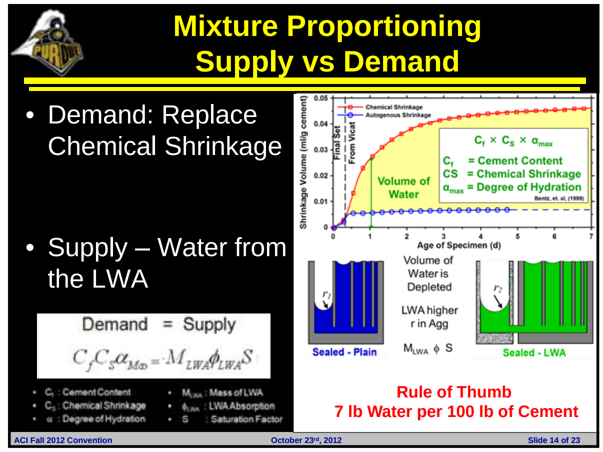
Mixture Proportioning Supply vs Demand
Demand: Replace Chemical Shrinkage
Supply – Water from the LWA
Demand = Supply
$C_f C_S \alpha_{Max} = M_{LWA} \phi_{LWA} S$
Chemical Shrinkage
Autogenous Shrinkage
Volume of Water
Age of Specimen (d)
Volume of Water is Depleted
LWA higher r in Agg
Sealed - Plain
Sealed - LWA
Rule of Thumb
7 lb Water per 100 lb of Cement
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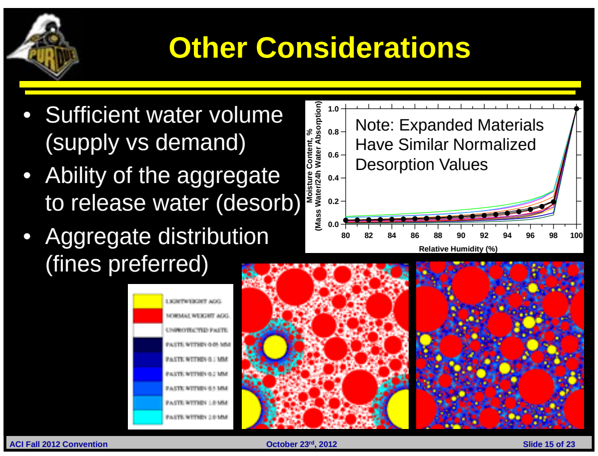
Other Considerations
Sufficient water volume (supply vs demand)
Ability of the aggregate to release water (desorb)
Aggregate distribution (fines preferred)
Note: Expanded Materials Have Similar Normalized Desorption Values
Relative Humidity (%)
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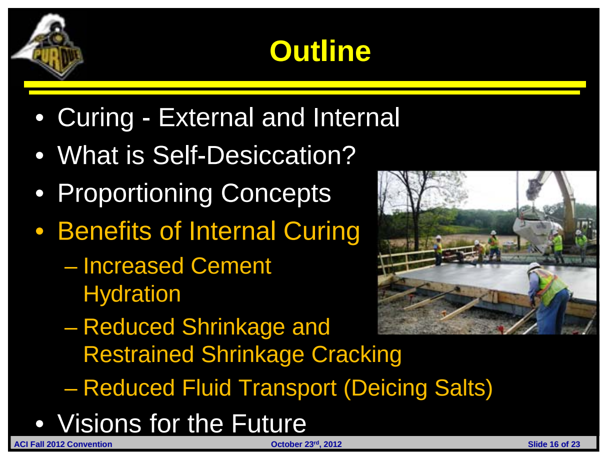
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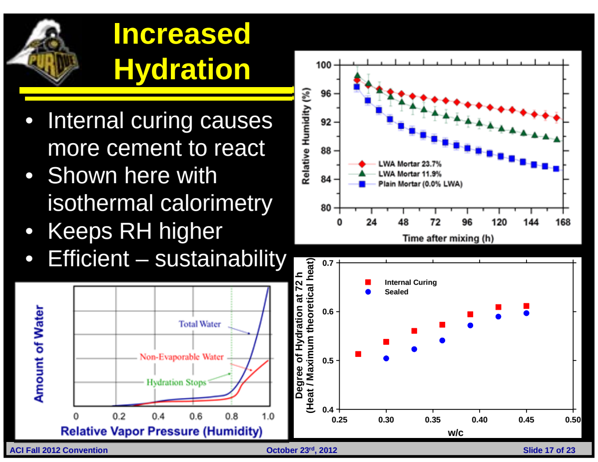
Increased Hydration
Internal curing causes more cement to react
Shown here with isothermal calorimetry
Keeps RH higher
Efficient – sustainability
Relative Humidity (%)
Time after mixing (h)
Amount of Water
Total Water
Non-Evaporable Water
Hydration Stops
Relative Vapor Pressure (Humidity)
Internal Curing
Sealed
w/c
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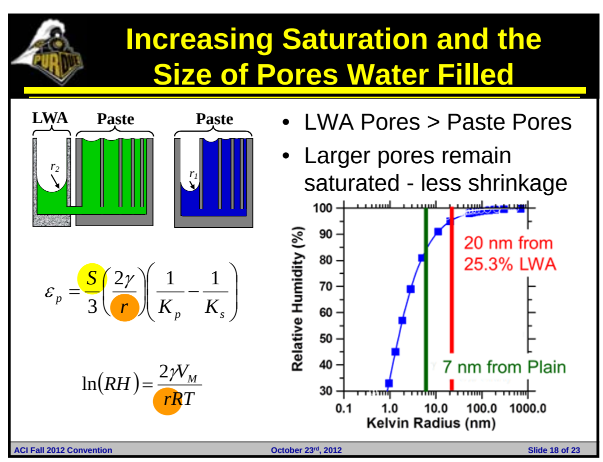
Increasing Saturation and the Size of Pores Water Filled
LWA
Paste
Paste
LWA Pores > Paste Pores
Larger pores remain saturated - less shrinkage
$\varepsilon_p = \frac{S}{3}\left(\frac{2\gamma}{r}\right)\left(\frac{1}{K_p} - \frac{1}{K_s}\right)$
$\ln(RH) = \frac{2\gamma V_M}{rRT}$
Relative Humidity (%)
20 nm from 25.3% LWA
7 nm from Plain
Kelvin Radius (nm)
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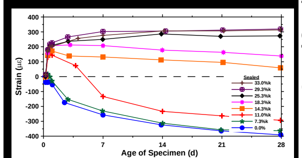
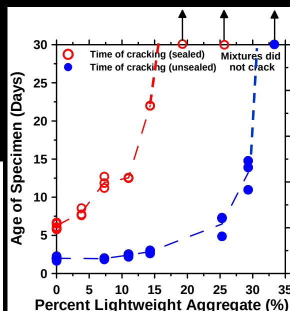
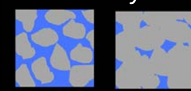
Reduced Shrinkage and Restrained Shrinkage Cracking

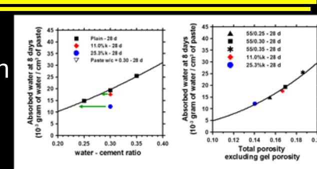




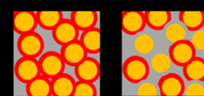
Reducing Transport

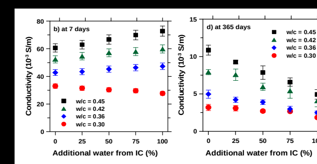
- Reduced porosity - increased hydration





- Reduced ITZ and connectivity





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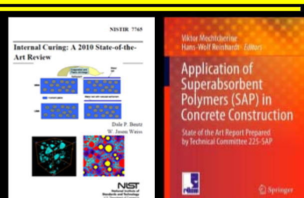
The Future of Internal Curing

- Practices and specifications being developed
  - Pavements in Texas
  - Bridge deck Ohio, Indiana, New York, Utah
  - Water tanks in Colorado

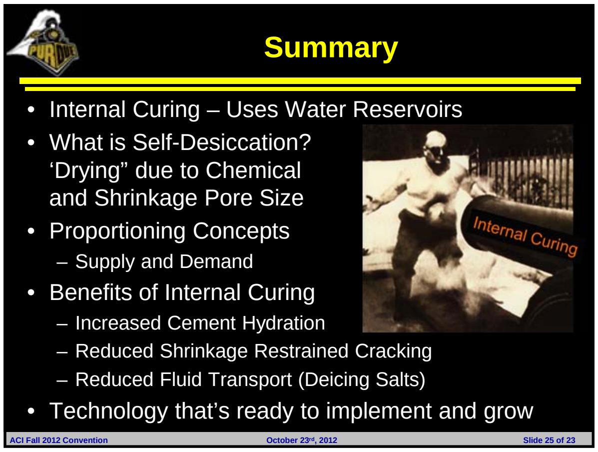
Ready to Implement, But Need More Information?

- RILEM IC 196 Report
- ACI SP 218; SP from this session
- ACI 231, 308 docs
- NIST Report
- REACCT Short Course Videos
- https://sites.google.com/site/afn40concretematerials/internal-curing-workshop
- http://ciks.cbt.nist.gov/bentz/phpct/database/ic.html



The Future of Internal Curing

- Opportunities
  - Sustainability: More Efficient Use of Cement which implies reductions and greater substitutions
  - Sustainability: Works well with SCM's that have higher chemical shrinkage
  - Sustainability: Longer Lasting Concrete
  - Use of waste materials as porous inclusions
  - Hide fluids other than water (SRA, Lithium, CI)
  - Applications in new systems (e.g. LW grid decks)
  - New models for performance


Summary
• Internal Curing – Uses Water Reservoirs
• What is Self-Desiccation? 'Drying" due to Chemical and Shrinkage Pore Size
• Proportioning Concepts
– Supply and Demand
• Benefits of Internal Curing
– Increased Cement Hydration
– Reduced Shrinkage Restrained Cracking
– Reduced Fluid Transport (Deicing Salts)
• Technology that's ready to implement and grow
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