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

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

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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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Purdue University
School of Civil Engineering

Using Internal Curing to Mitigate Early Age Cracking and Improve Corrosion Performance

Developed for ACI Fall 2012 Convention by:
Kambiz Raoufi and Jason Weiss

October 23rd, 2012

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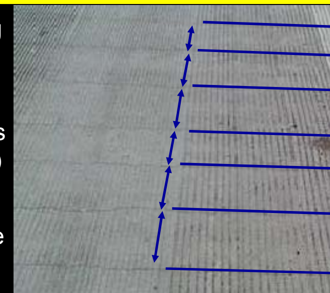
Early Age Cracking Frequently Observed in Low W/C High Cement Content Concrete

- Transverse cracking in 100,000+ bridges
- 62% of DOT's consider cracking as a problem (NCHRP)
- Cracks shorten service life, increase maintenance cost, and accelerate corrosion



Here we see cracks spaced at 2.5 ft On the approaches to a bridge

Photo http://www.aggregateresearch.com/caf/file/newdeckcracking.pdf

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Objectives

- To understand why low w/c, high cement content mixtures are susceptible to cracking
- To understand how internal curing reduces autogenous shrinkage & increases capacity
- To understand how internal curing improves transport properties
- To quantify the combined effect of reducing cracking and reducing fluid transport with internal curing

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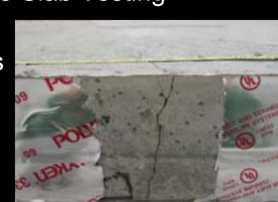
Outline

- Shrinkage and Stress Development
- Benefits for Thermal Shrinkage
- Restrained Shrinkage Slab Testing
- Corrosion Testing in Restrained Elements
- Chloride Ingress
- Comparison with Field Case
- Summary



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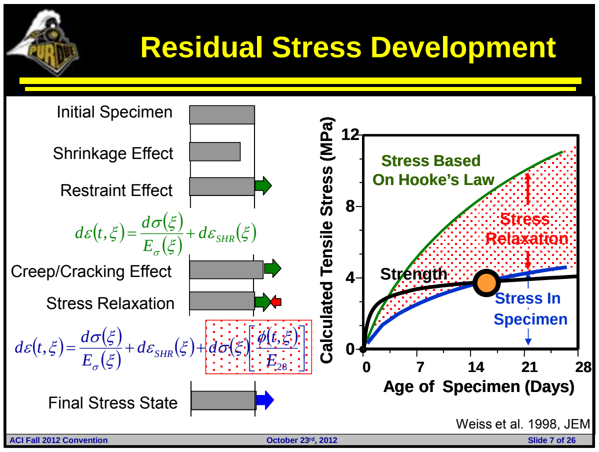
Residual Stress Development
Initial Specimen
Shrinkage Effect
Restraint Effect
Creep/Cracking Effect
Stress Relaxation
Final Stress State
Stress Based On Hooke's Law
Stress Relaxation
Strength
Stress In Specimen
Calculated Tensile Stress (MPa)
Age of Specimen (Days)
Weiss et al. 1998, JEM
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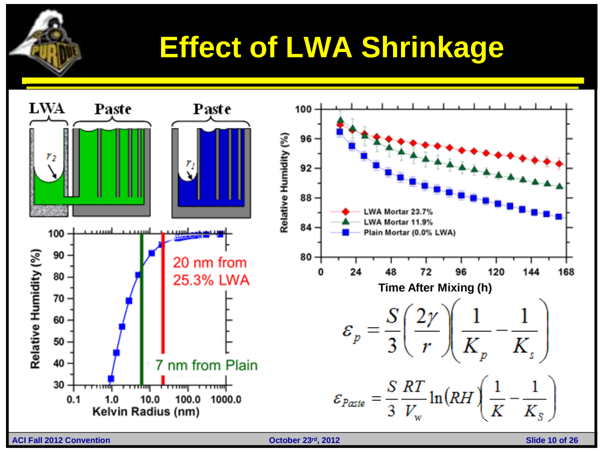
Effect of LWA Shrinkage
LWA
Paste
Paste
Relative Humidity (%)
Kelvin Radius (nm)
20 nm from 25.3% LWA
7 nm from Plain
LWA Mortar 23.7%
LWA Mortar 11.9%
Plain Mortar (0.0% LWA)
Time After Mixing (h)
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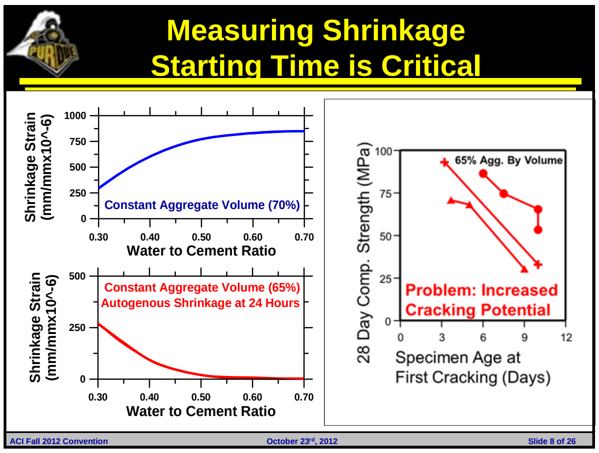
Measuring Shrinkage Starting Time is Critical
Shrinkage Strain (mm/mmx10^-6)
Constant Aggregate Volume (70%)
Water to Cement Ratio
Constant Aggregate Volume (65%)
Autogenous Shrinkage at 24 Hours
28 Day Comp. Strength (MPa)
65% Agg. By Volume
Problem: Increased Cracking Potential
Specimen Age at First Cracking (Days)
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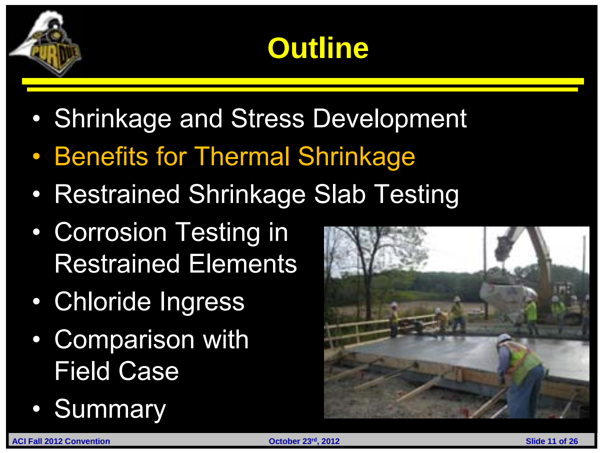
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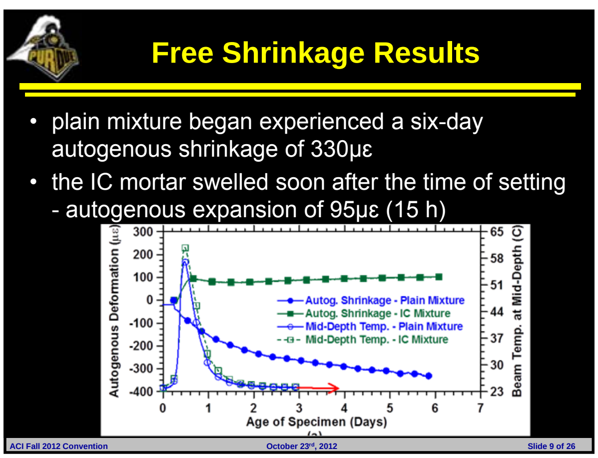
Free Shrinkage Results
plain mixture began experienced a six-day autogenous shrinkage of 330με
the IC mortar swelled soon after the time of setting - autogenous expansion of 95με (15 h)
Autogenous Deformation (με)
Autog. Shrinkage - Plain Mixture
Autog. Shrinkage - IC Mixture
Mid-Depth Temp. - Plain Mixture
Mid-Depth Temp. - IC Mixture
Beam Temp. at Mid-Depth (C)
Age of Specimen (Days)
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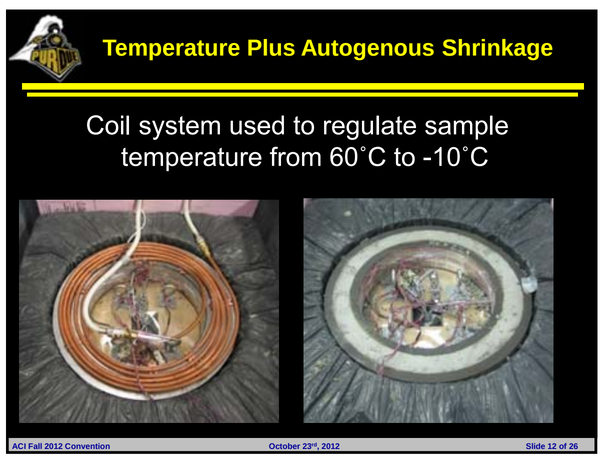
Temperature Plus Autogenous Shrinkage
Coil system used to regulate sample temperature from 60˚C to -10˚C
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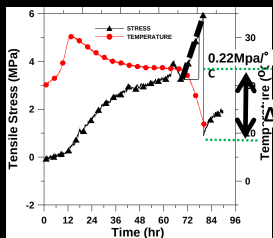
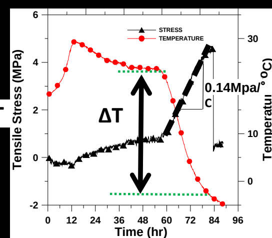
Effect of Internal Curing on Thermal Stress Development

Plain Mortar (w/c =0.30) Not Internally Cured



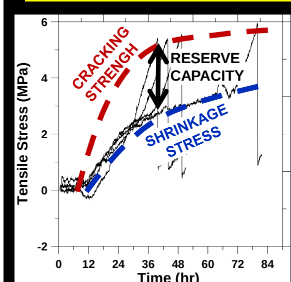
ΔT crack = 10.3°C

Internally Cured Mortar (w/c = 0.30)

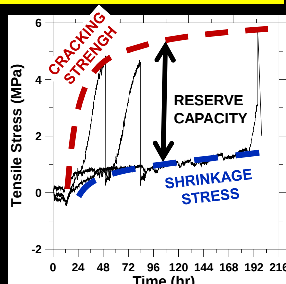


ΔT crack = 27.1°C

Effect of Internal Curing On Reserve Capacity Curve



Plain Mortar (w/c =0.30) Not Internally Cured



Internally Cured Mortar (w/c = 0.30)

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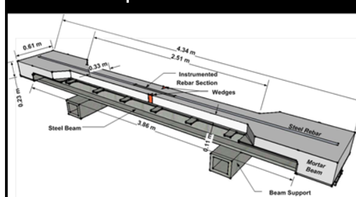
Simultaneous Shrinkage/Corrosion

- IC is effective in reducing shrinkage, shrinkage cracking and transport properties
- This research uses a full-scale slab geometry and instrumented rebar to study in-situ corrosion behavior of steel reinforced concrete with internal curing.
- The results of this investigation are aimed at understanding the impact that IC concrete may have on improving the service life of steel reinforced concrete structures.

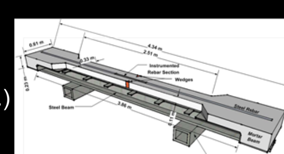
Restrained Shrinkage

- Plain and IC in a 5 m restrained slab (14 days section cut and exposed to NaCl)
- Instrumented steel rebar was embedded in each specimen was monitored for corrosion



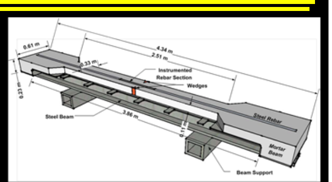
Restrained Shrinkage

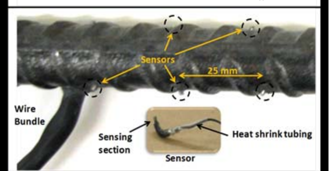
- 4.34m (14.25ft.) long, 0.330m (13in.) wide, and 114mm (4.5in.) thick
- Instrumented W12×210 beam – Widened at ends
- Steel beam restrains concrete from moving freely as the concrete shrinks.
- threaded rods were used to anchor the specimen at beam ends
- wedges - 1.5mm (1/16in.) wide tip and widened to 10mm (3/8 in.)



Instrumented Rebar

- #6 grade-60 rebar
- central section 380mm (15in.)
- Hollowed out
- rebar threaded to a solid section
- connections sealed using marine-epoxy
- minimum steel as specified by ACI318
- 28 sensors, 25 mm





Reference Electrode

- A reference electrode - 6mm (1/4in.) dia., 90mm (3.5in.) long, stainless steel (A316)
- Positioned midway between the rebar and the side face of the slab
- Separate tests performed to assess the stability of the stainless steel reference bar.
- Stainless steel remained stable for short testing period as compared with a standard saturated calomel electrode

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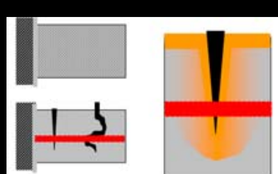
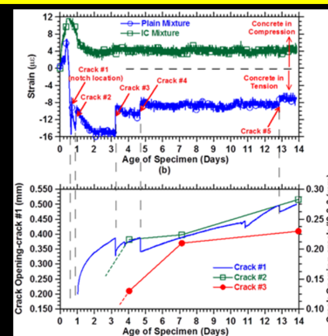


Restrained Shrinkage Behavior

- Multiple Cracks along the reinforcing bar
- Each crack caused others to close slightly
- Cracking resulted in debonding

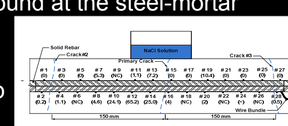


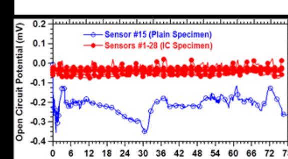
Corrosion/Transport Testing

- corrosion sensing using the instrumented rebar section, corrosion mapping using half-cell potential, and chloride ingress testing
- Open circuit potential (OCP) was monitored upon exposure of specimens to NaCl wrt SS
- different distances of corrosion sensors to the reference electrode, resulted in the OCP
- A OCP drop of 100 mV was used to signal the onset of corrosion activities for a sensor.

Corrosion/Transport Testing

- corrosion potential was greatly influenced by crack proximity of the crack around at the steel-mortar interface.
- Sensors #1, 3, 5, 15, 17, 21, 25, and 27 on the top surface of the rebar and started to corrode immediately
- ASTM C876 (-275 mV after 4 days)
  90% of the plain sample





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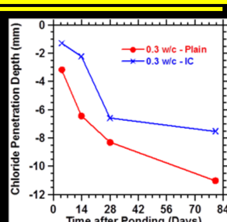
Chloride Ingress

- chloride ingress in mortar cylinders at 14 days
- 3% NaCl solution at the age of five weeks.
- 0.1-N silver nitrate solution ($AgNO_3$)
- IC shows less penetration due to dense cement paste microstructure and less porous/connected ITZ



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Visual Inspection of the Bridge Decks after 20 Months

Plain bridge – 3 cracks

IC bridge – no cracks

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Conclusions

- Low w/c, high paste mixtures are susceptible to cracking – autogenous, drying, thermal shrinkage
- Internal curing reduces autogenous shrinkage, increases capacity, reduces transport
- Large scale samples were prepared to simultaneously investigate cracking and transport
- instrumented rebar to determine the age of corrosion and distribution along the interface
- plain mixture - cracked at several locations and corroded quickly over a large debonded area
- IC mixture – did not crack

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