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The Economics, Performance, and Sustainability of Internally Cured Concrete, Part 3

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

ACI WEB SESSIONS

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Purdue University
School of Civil Engineering

Chloride Transport Measurements for a Plain and Internally Cured Concrete Mixture

Developed for ACI Fall 2012 Convention by:
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October 23rd, 2012

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- Introduction
- Internal curing background
- Research significance
- Testing methods and results
  - Rapid chloride penetration test – RCPT
  - Surface resistivity
  - Rapid chloride migration
  - Migration cell
  - Chloride ponding and profiling
- Conclusions

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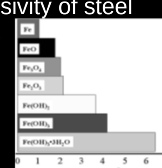
Introduction

Durable and long lasting concrete is a primary concern for many transportation agencies.

The durability of the concrete is largely governed by the fluid transport properties

Chloride ions reduce the natural passivity of steel reinforcement. Corrosion products exert tensile forces on the concrete cover.

As a result chloride ions weakens the concrete durability and reduce its service life.



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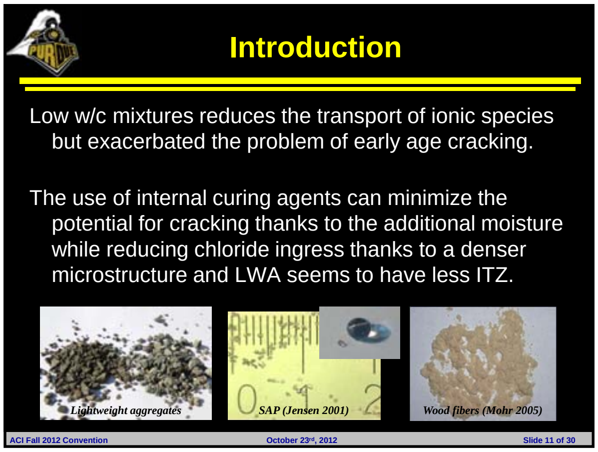

Introduction
Low w/c mixtures reduces the transport of ionic species but exacerbated the problem of early age cracking.
The use of internal curing agents can minimize the potential for cracking thanks to the additional moisture while reducing chloride ingress thanks to a denser microstructure and LWA seems to have less ITZ.
Lightweight aggregates
SAP (Jensen 2001)
Wood fibers (Mohr 2005)
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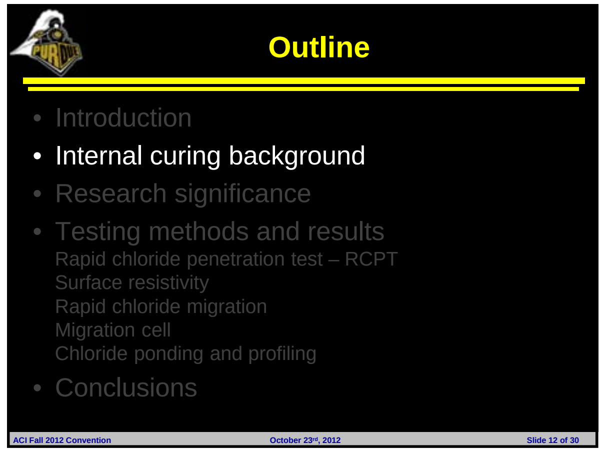

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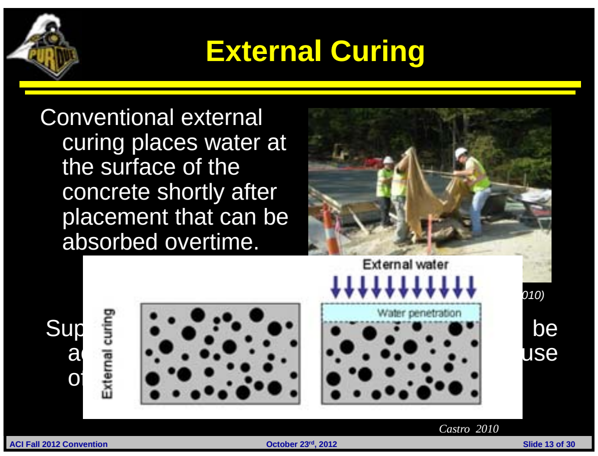

External Curing
Conventional external curing places water at the surface of the concrete shortly after placement that can be absorbed overtime.
External water
Water penetration
External curing
Castro 2010
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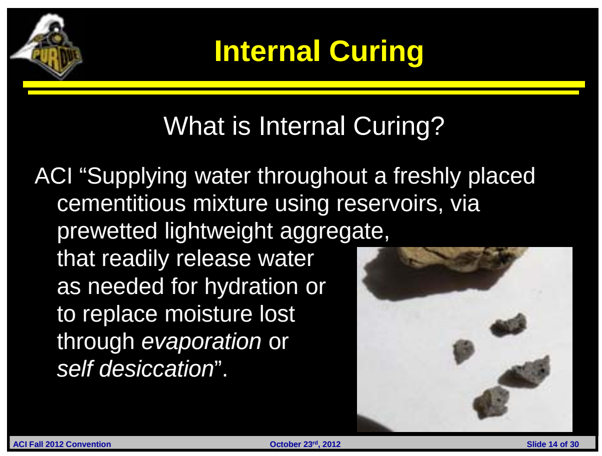

Internal Curing
What is Internal Curing?
ACI "Supplying water throughout a freshly placed cementitious mixture using reservoirs, via prewetted lightweight aggregate, that readily release water as needed for hydration or to replace moisture lost through evaporation or self desiccation".
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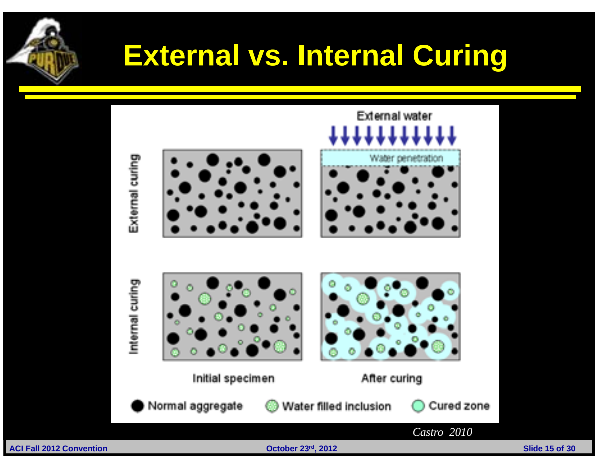

External vs. Internal Curing
External water
Water penetration
External curing
Internal curing
Initial specimen
After curing
Normal aggregate
Water filled inclusion
Cured zone
Castro 2010
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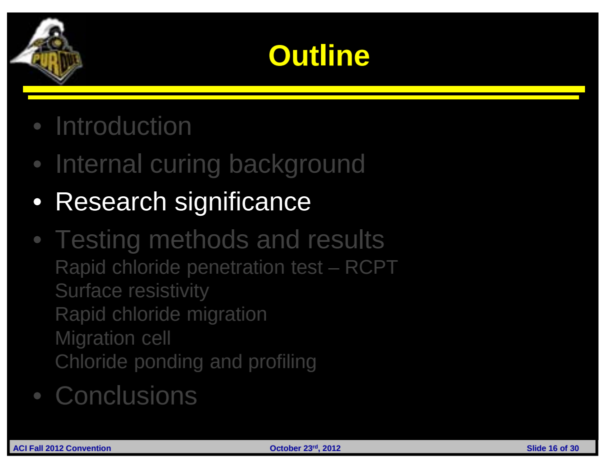

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Research Significance

Relatively little research has documented the effect of internal curing on reducing ionic ingress and fluid transport.

Evaluation of the chloride transport performance of plain and internally cured concrete bridge deck mixture.

- Two bridge decks were cast in September 2010: one plain and one internally cured were cast in the state of Indiana (Monroe Co.).
- Two high strength internally cured bridge decks were cast in the state of New York (cities of Lisle and Tonawanda).

Plain and Internally Cured Bridge Decks: Monroe Co.

Two Bridges Near One Another

Similar Exposure/Traffic, materials and same construction crew.

Plain concrete bridge deck was pumped

IC concrete bridge deck was placed by means of a bucket

Constituent Materials

In order to perform additional tests similar materials employed for the casting were acquired.

	Cement Content (kg/m³)	W/C	Fine Aggregate (kg/m³)	Fine LWA (kg/m³)	Coarse Aggregate (kg/m³)	Mixture Water (kg/m³)	Water in LWA (kg/m³)	WR (%)[A]	AE (%)[A]
Plain Concrete	390	0.39	726	-	1046	152	-	0.22	0.08
Internally Cured Concrete	390	0.39	313	270	1046	152	25	0.22	0.08

[A] percentage referred to the cement weight

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Rapid Chloride Penetration Test

One surface of the sample is exposed to NaCl solution and the other surface to NaOH solution.

The current passing through the sample is monitored for a 6 hour period.

Rapid chloride penetration (RCP) test cells – ASTM C1202-12

Rapid Chloride Penetration Test

IC Monroe Co. shows consistently lower charge.

After 180 days IC concrete shows 35% lower penetration than plain concrete.

	Monroe County Bridge Deck Concrete			
Time [days]	Charge Passed [Coulombs]			
	Plain Concrete	Standard Deviation	Internally Cured Concrete	Standard Deviation
28	4252	116	3822	159
56	2863	560	2458	55
91	3174	450	2065	113
180	2656	226	1239	251

Surface Resistivity

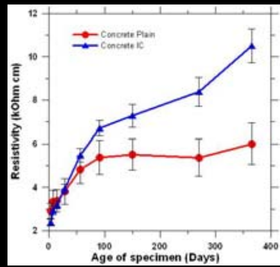
- A four point Wenner probe to measure the electrical resistivity.
- An alternating current is at the outer pins. The potential difference is measured in the two inner pins.

$$\rho_{bulk} = \rho_{surface} / K$$

Wenner probe – AASHTO TP 95-11

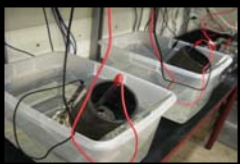
Surface Resistivity

- At 56 d the resistivity of the plain and IC concretes are similar, after 365 d the IC has higher resistivity - 45 %.
- Samples are cured in lime water and are permitted to absorb water.
- Do not represent curing in the field..



Rapid Chloride Migration

- To determine the non-steady state chloride migration coefficients according to NT Build 492.
- The voltage is applied for a 24 h period and after the sample is split and sprayed with 0.1 M $AgNO_3$.



Rapid chloride migration – NT Build 492

Split sample after testing and sprayed with silver nitrate

Rapid Chloride Penetration NT Build 492

- The internally cured mixture shows benefits of internal curing at each age.
- At 91 days IC shows lower diffusion coefficient (15 %) and at 180 days (up to 30 %).

	Monroe County Bridge Deck Concrete			
Time [day]	Diffusion coefficients (m^2/s)			
	Plain Concrete	Standard deviation	IC Concrete	Standard deviation
28	1.42E-11	9.89E-13	1.15E-11	5.65E-13
56	1.26E-11	4.24E-13	8.98E-12	2.83E-13
91	3.99E-12	4.24E-13	3.42E-12	1.91E-13
180	4.70E-12	3.46E-13	3.32E-12	1.98E-13

Migration Cell

- One surface of the sample is exposed to NaCl solution and the other surface to NaCl + NaOH solution.
- A constant DC potential of 20 V is maintained for 14 days.
- The data obtained along with the porosity measurements are entered in STADIUM Lab software.

Migration cell experimental set up

Migration Cell

- The modeled diffusion coefficients confirm the trend obtained with the NT Build 492.
- IC concretes have higher porosity and lower tortuosity.

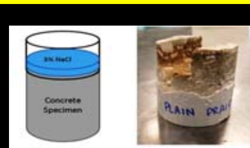
	Monroe County Bridge Deck Concrete	
Time [days]	Diffusion coefficients (m^2/s)	
	Plain Concrete	IC Concrete
28	8.56E-11	5.78E-11
91	7.67E-11	2.97E-11

	Monroe County Bridge Deck Concrete					
Time [days]	Porosity %				Tortuosity	
	Plain Concrete	STD	IC Concrete	STD	Plain Concrete	IC Concrete
28	12.6	0.49	13.0	0.49	0.0421	0.0284
91	13.3	0.35	14.5	0.83	0.0377	0.0146

Chloride Ponding and Profiling

A 3% NaCl solution is ponded on the surface of the specimen.

The powder collected at different depths is analyzed to determine the chloride content.



Sketch of a ponded sample and sample after profile grinding – ASTM C1543-10

Automated titration unit

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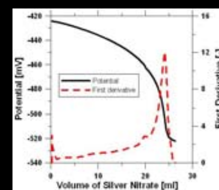
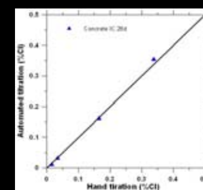
Chloride Ponding and Profiling

The titrator adds 0.01 N silver nitrate to the solution in 0.2 ml increments while simultaneously monitoring the electric potential of the solution.





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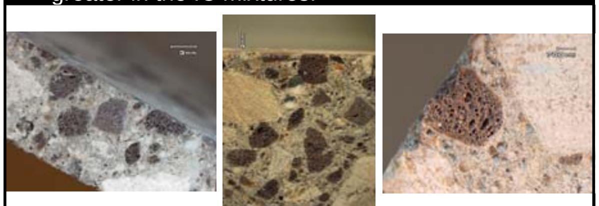
Chloride Ponding and Profiling

The acid-soluble chloride content after 28 and 91 days of ponding (28 days curing).

Within the first 8-10 mm the chloride concentration is greater in the IC mixtures.



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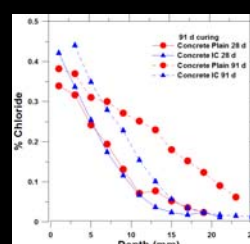
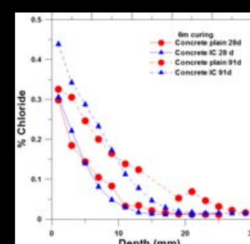
Chloride Ponding and Profiling

Longer curing (3 and 6 months) shows a reduction in the chloride content in the case of internally cured mixtures.





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Visual Inspection of the Bridge Decks after 20 Months

The plain bridge deck showed two long cracks: one longitudinal and the other one transverse

Transverse crack going through the concrete deck

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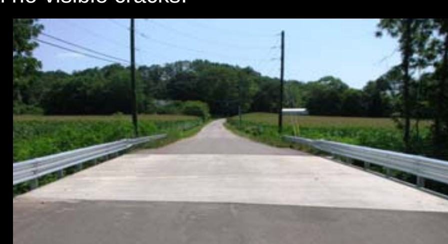
Visual Inspection of the Bridge Decks after 20 Months

The internally cured bridge deck mixture resulted in no visible cracks.



Internally cured bridge deck

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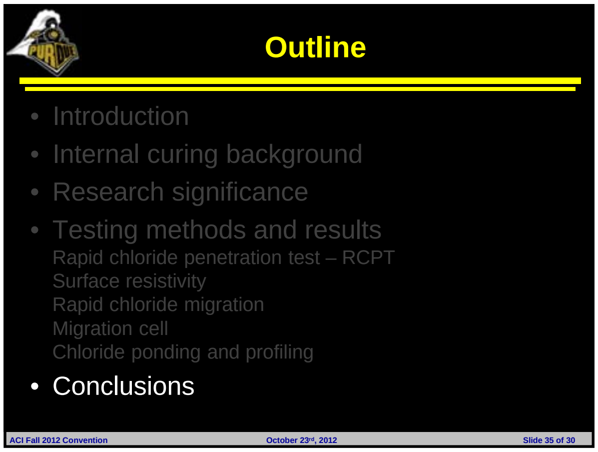
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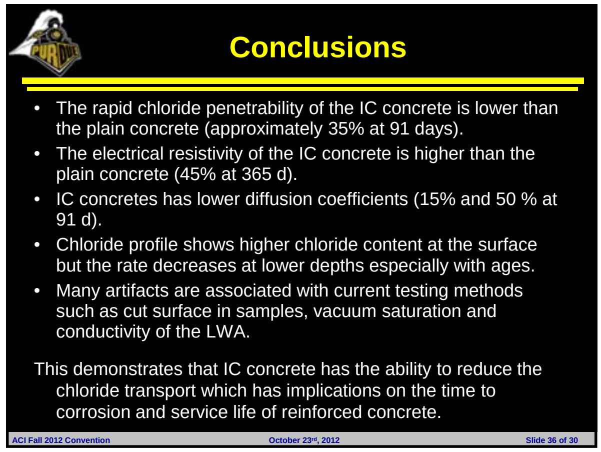
Conclusions
• The rapid chloride penetrability of the IC concrete is lower than the plain concrete (approximately 35% at 91 days).
• The electrical resistivity of the IC concrete is higher than the plain concrete (45% at 365 d).
• IC concretes has lower diffusion coefficients (15% and 50 % at 91 d).
• Chloride profile shows higher chloride content at the surface but the rate decreases at lower depths especially with ages.
• Many artifacts are associated with current testing methods such as cut surface in samples, vacuum saturation and conductivity of the LWA.
This demonstrates that IC concrete has the ability to reduce the chloride transport which has implications on the time to corrosion and service life of reinforced concrete.
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