ACPA 51st Annual Convention

Internally Cured Pavement Update

John Ries PE, FACI
Expanded Shale, Clay and Slate Institute
In your opinion, what is the biggest problem the concrete industry and/or the public have with concrete pavements?
Internally Cured Concrete (ICC)

1. Curing...important
2. What do we know
3. Why use IC
4. IC mixture
5. Case studies
6. Wrap up
1. Conventional Curing

- Curing membranes reduces the loss of water
- External water...not often
Internal Curing...Inside Out

- Use prewetted fine LWA to distribute water
- Help satisfy increased water demand from SCM’s
- Works even at moderate 0.40 – 0.50+ w/cm

Castro et al. 2010
2. What Do We Know

- Internal curing works
- 2000yr - Romans
- 1914 - ESCS LWA invented
- 1952 - First report on IC - LWC more forgiving
- 40yr - Just thinking...and thinking
- 1992 - 2014: research NIST, Europe, Purdue, others--- IC proven with new lab technology
- 2014 - ACPA Innovations & applications???
What Do We Know

- NIST has 150 citations on IC on their website http://ciks.cbt.nist.gov/lwagg.html

- IC is used successfully in
  - bridge decks... 30
  - water tanks
  - offshore oil platforms
  - pervious concrete
  - more
ACI & ASTM DOCUMENTS

- **ACI 213-14**, Guide for Str. LWA Concrete, Section 7.5 Enhanced performance due to internal curing
- **ACI (308/213)-13**, Report on Internally Cured Concrete Using Prewetted Absorptive LWA
Webinars

- **TRB, 5/1/14, Internal Curing – A Technology to Improve the Performance of Concrete**, Dale Bentz, Jason Weiss, Don Streeter. 495 attendees, 45 states
- **ACPA, 10/15/14, ICC Pavements, 2.5 hrs**, Jason Weiss & Mike Darter, 60 attendees
More Info on IC

- ESCSI video series by Jason Weiss (4 hrs)
  - Module 1 Overview
  - Module 2 Proportioning
  - Module 3 Shrinkage
  - Module 4 Transport
  - Module 5 Sustainability

- Tools, mix design, quality control, work sheet
  www.escsi.org
IC Sustainability

- Better curing
- Better concrete...more robust
- Longer life pavements
- Reduce maintenance and traffic delays
- Cost, based on LCCA...not first cost

Not Snake Oil
3 Why use Internal Curing?

- Better hydration...efficient use cement, SCM
- Reduces shrinkage (less & tighter cracks)
- Improves durability (more robust)
- Helps offset poor curing improves good curing
- Reduces curling – warping
- Modulus is lower (flexable)
$M_{LWA} = \frac{C_f \times CS \times \alpha_{max}}{S \times \phi_{LWA}}$

where

$M_{LWA}$ = mass of (dry) LWA needed per unit volume of concrete (kg/m³ or lb/yd³);

$C_f$ = cement factor (content) for concrete mixture (kg/m³ or lb/yd³);

$CS$ = chemical shrinkage of cement (mass of water/mass of cement);

$\alpha_{max}$ = maximum expected degree of hydration of cement (0 to 1);

For ordinary Portland cement, the maximum expected degree of hydration of cement can be assumed to be 1 for $w/c \geq 0.36$ and to be given by $[(w/c)/0.36]$ for $w/c < 0.36$.

$S$ = degree of saturation of aggregate (0 to 1);

$\phi_{LWA}$ = desorption of lightweight aggregate from saturation down to 93 % RH (mass water/mass dry LWA).

Source: Bentz, NIST
IC Mixture Design - Simple

- Need 7 lbs of IC water per 100 lbs cementitious
- Mix design
  - 540 lbs cementitious = 38 lbs of IC water
  - Assume 18% LWA absorption in the field
  - Assume prewetted LWA at 55 lbs/cf
  - 55 x 0.18 = 9.9 lb/cf water at 90% desorption 8.9
  - Need 38 lbs IC water / 8.9 = 4.2 cf of fine LWA
  - 4.2 cf x 55 lb/cf = 231 lbs fine LWA aggregate
- Material & handling $5/cy pavement (bridges charge $10/cy)
5. Case Studies

Evaluation of ICC for Paving Applications
Chetana Rao, Ph.D.,
Michael Darter, Ph.D., P.E.
September 2013
108 pages

Available on
ESCSI Web Site
www.escsi.org
Structural Advantages of ICC

- Small Changes In Key ICC Inputs:
  - + Strength
  - - Modulus Elasticity
  - - Thermal Expansion
  - - Unit Weight
  - - Shrinkage
  - - Curling/Warping
EXISTING ICC FIELD PROJECTS

SR 121 Dallas

Fort Worth, TX

UP Intermodal

Fort Worth, TX
SH 121 DALLAS, TX 2006

Conventional CRCP 13"

ICC CRCP 13"

Mike Darter
CRACK WIDTH
(% OF TOTAL AT 10 MONTHS OLD)
FRIGGLE AND REEVES

2015 crack width study approved
ME Design Guide Results SR 121

- Slab thickness
  - Conventional 11-in.
  - ICC 10-in.

- Initial construction cost; ICC lower by 5%
  - reduction in CRCP thickness & reinforcement
  - increase in IC concrete cost by 7% ($10/cy)

- Maintenance & rehabilitation net present cost
  - ICC lower cost by 21% (due to reduced punchouts)
## Predicted Performance CRCP 50-Years

<table>
<thead>
<tr>
<th>AASHTO ME Performance</th>
<th>Conventional</th>
<th>ICC</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>IRI in/mile</td>
<td>141</td>
<td>110</td>
<td>ICC lower</td>
</tr>
<tr>
<td>Punchouts No./mile</td>
<td>22</td>
<td>5</td>
<td>ICC lower</td>
</tr>
<tr>
<td>Crack spacing inch</td>
<td>66</td>
<td>68</td>
<td>Same</td>
</tr>
<tr>
<td>Crack width</td>
<td>17*10^-3 in</td>
<td>12*10^-3 in</td>
<td>ICC tighter cracks</td>
</tr>
<tr>
<td>Crack LTE</td>
<td>60</td>
<td>99</td>
<td>ICC higher LTE</td>
</tr>
</tbody>
</table>
AASHTO ME Prediction Cracking

UP Intermodal - JPCP

Conventional Concrete

Same thickness

Internally Cured Concrete
Patching – Rapid Repair

- Using IC in standard HES patching, West Lafayette, IN
  - reduced cracking and curling
  - increased hydration
- Barrett et al. 2014
High Early Strength ICC to Avoid Cracks

I-635 Off Ramp, Dallas, TX

ICC High Early Strength

Conventional PCC
ICC benefits JPCP, CRCP (structurally)
LCCA...ICC had lower net present cost over 50-60 yr based only on structural consideration
Add Durability benefit...substantial cost reduction
What’s Needed

- More field project (monitored over time)
  - State of Kansas ICC test sections
  - CP Tech Center 2015-1016?
  - Others
- Answers...Is it cost effective in pavements?
  - New construction
  - Overlays
  - Thinner section
  - Extend service life...how much
US-54: Internal Curing on Pavement

Internal Curing with Lightweight Aggregate
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The information presented here is preliminary and is subject to change.

KDOT makes no warranties, guarantees, or representations for accuracy of this information and assumes no liability or responsibility for any errors or omissions.
WHAT ARE WE LOOKING FOR?

- Evaluate the effects on curling and warping
  - Both moisture and stain effects
- Determine benefits/effects on hardened properties
  - Specifically pavement design inputs: CTE, elastic modulus, comp strength, unit weight
  - Determine other benefits to permeability, tensile strength, Poisson's ratio, F/T durability, AVA
- Observe effects on paving operation
WHAT CAN WE MEASURE AND WHEN?

- Deflections
- Strain
- Moisture
- Temperature; internal and ambient
- Curling: high and low temps
  - mid-day and overnight
- Warping:
  - most moisture loss occurs in first 72-96 hrs
How?

- Deflections – Dipstick
  1’ walking profile

- Strain – 6” Vibrating Wire Strain Gauges

- Moisture – internal moisture sensor 3”x3”

- Temperature – VWSG and MS
ICC Placement 5/2/2014 -- Control Placed 7/24/14
- 9in thick PCCP
- 27’ wide placement; monitored outside 15’ lane
- Approximately 380’ of ICC (7700 ft³)
- 4” compacted granular base
- 15’ joints
- 540 lbs/yd³ total cementitious - 25% Class C Fly Ash
- 9% replacement of 3rd agg (¼ chip) with 3/8 x 0 LWA
- Measured 5 total panels, 2 panels contained instrumentation
Deflections Age: Day 2 Morning

Series 1

-0.400
-0.350
-0.300
-0.250
-0.200
-0.150
-0.100
-0.050
0.000
0.050
0.100
0.150
0.200
0.250
0.300
0.350
0.400

Series 9

1 4 7 10 13 16 19 22 25 28 31 34 37 40 43 46 49 52 55 58 61 64 67 70 73 76 79 82

-0.050-0.000
-0.000-0.050
-0.050-0.100
-0.100-0.150
-0.150-0.200
-0.200-0.250
-0.250-0.300
-0.300-0.350
-0.350-0.400

0.050-0.100
0.000-0.050
-0.050-0.000
-0.100-0.050
-0.150-0.100
-0.200-0.150
-0.250-0.200
-0.300-0.250
-0.350-0.300
Deflections Age: Day 3 Morning
Deflections Age: Day 5 Morning
Typical dowel rebar 1" from top

Typical Top gage/sensor at 2" from top

Typical middle gage/sensor at 4.5" from top

Typical dowel rebar 18" total length

Typical Bottom gage/sensor at 2" from bottom

Typical dowel rebar spaced 2"-3"

6' 4"

12' 2"
STRAIN GAGES AND MOISTURE SENSORS
TIME OF ZERO STRESS

Strain(2) vs Temp(2)
TIME OF ZERO STRESS

Strain(2) vs Temp(2)

3 am
## Time of Set and Zero Stress

<table>
<thead>
<tr>
<th></th>
<th>Average Time of Set</th>
<th>Average Time of Set</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>ICC Section</td>
<td>Control Section</td>
</tr>
<tr>
<td>Cast</td>
<td>9:30 AM</td>
<td>10:30 AM</td>
</tr>
<tr>
<td>Initial Set</td>
<td>6:10 PM (8:40 hours)</td>
<td>4:30 PM (6:00 hours)</td>
</tr>
<tr>
<td>Final Set</td>
<td>10:20 PM (12:50 hours)</td>
<td>6:15 PM (7:45 hours)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Date /Time of TZ</th>
<th>Date /Time of TZ</th>
</tr>
</thead>
<tbody>
<tr>
<td>ICC Section</td>
<td>Control Section</td>
</tr>
<tr>
<td>5/3/2014 3:10 AM</td>
<td>7/24/2014 7:15 PM</td>
</tr>
<tr>
<td>(17:57 hours of age)</td>
<td>(9:17 hours of age)</td>
</tr>
</tbody>
</table>
Panel 2 Strain

Strain (ȝİ)

Date

Actual Strain(1)
Actual Strain(2)
Actual Strain(3)
SAW TIME AND CRACKING

Saw Time and Cracking

Date/Time

Strain (ȝİ)

-15.000
-10.000
-5.000
0.000
5.000
10.000
15.000

5/3/14 12:00 AM
5/3/14 2:24 AM
5/3/14 4:49 AM
5/3/14 7:12 AM
5/3/14 9:36 AM
5/3/14 12:00 PM
5/3/14 2:24 PM
5/3/14 4:49 PM

- Actual Strain(5)
- Actual Strain(4)
- Actual Strain(12)
- Actual Strain(13)
ICC PANEL 2 TOP STRAIN

P2 Top Strain

- Actual Strain(3)
- Strain ΔT 3
- Moisture Strain 3
## Hardened Concrete Results

<table>
<thead>
<tr>
<th>Test</th>
<th>ICC Result</th>
<th>Control</th>
</tr>
</thead>
<tbody>
<tr>
<td>28 Day Compressive Strength</td>
<td>4940 psi</td>
<td>5290 psi</td>
</tr>
<tr>
<td>28 Day Flexural Strength</td>
<td>740 psi</td>
<td>760 psi</td>
</tr>
<tr>
<td>28 Day Tensile Strength</td>
<td>490 psi</td>
<td>470 psi</td>
</tr>
<tr>
<td>28 Day Shrinkage</td>
<td>0.030%</td>
<td>0.035%</td>
</tr>
<tr>
<td>28 Day Elastic Modulus</td>
<td>3500 ksi</td>
<td>3630 ksi</td>
</tr>
<tr>
<td>28 Day Poisson’s Ratio</td>
<td>0.21</td>
<td>0.19</td>
</tr>
<tr>
<td>Coefficient of Thermal Expansion (CTE)</td>
<td>7.5 με/°C</td>
<td>7.5 με/°C</td>
</tr>
<tr>
<td>28 Day Volume Permeable Voids (Boil)</td>
<td>14.1%</td>
<td>13.9%</td>
</tr>
<tr>
<td>28 Day Surface Resistivity</td>
<td>6.0 kΩ-cm</td>
<td>7.4 kΩ-cm</td>
</tr>
<tr>
<td>56 Day Rapid Chloride Permeability (RCP)</td>
<td>2540 C</td>
<td>2440 C</td>
</tr>
</tbody>
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OBSERVATIONS FROM US-54 ICC

- Overall, project was successful.
- Verify moisture and absorption at start of day – adjust mix design if needed.
- Track moisture throughout.
CONSTRUCTION

- Need for 3rd aggregate bin at batch plant
  - May need to use Ready-Mix Supplier (test section)
- Need to watch moisture levels
  - Keep an eye on slump to avoid loss of pavement edge
- For this project, increased concrete cost 35%
  - Change order – was not bid with LWA
LOOKING AHEAD

- 6 month survey
- 1 year survey
- Evaluate effects on pavement design
- Construction Report – Fall/Winter 2014/15
- Full Report – Summer 2015
LOOKING AHEAD

- Evaluation of pavement design
  - Increased joint spacing
    - 15’ is KDOT standard

- KDOT plans to let project in 2015* with ICC and increased joint spacing
  - Likely 18’, 21’, 24’ joint spacing**
    *Project lets in 2015 with construction likely in 2016
    **Final lengths have not been chosen
PLACEMENT
Questions For KDOT?

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Wrap Up

- Just curing
- Simple, Not New
- Small rocks with holes
- 1914
The public and DOT’s will value concrete pavement to the same degree we value it.

True or False
THANK YOU
Basic Idea with Internal Curing

Sealed - Plain

Sealed - LWA

Paste

LWA Paste

Weiss, Purdue
1. IC has minimal impact on batching & placing (done properly)
2. Monitor aggregate moisture (surface/absorbed)
3. IC has great potential to reduce shrinkage and curling stresses
4. Concrete - sensitive to poor curing/durability (IC supplies additional water when needed)
5. Internal curing goes hand and in hand with good concrete practice and sustainability