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

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ACI – Toronto, Canada

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

March 23, 2011  Anton Schindler, Jason Weiss, Jiri Grygar

This Presentation is About

Optimizing the Sustainability of Concrete Through Internal Curing

Benjamin E. Byard PhD, University of Tennessee
John Ries PE, FACI, Expanded Shale, Clay and Slate Institute

Sustainability

- What is it?
  - Performance – longevity of concrete
  - Planning… build the right project
  - Good design and engineering
  - Balancing social, economical and environmental issues
- Paradigm shift in the way
  - We live and think
  - We see each other and our future

Our Title is Wrong

Optimizing the Sustainability Performance of Concrete Through Internal Curing
Brief Overview of Internal Curing

- Curing concrete from the inside out
- It’s not new
  - Occurs naturally when using LWA or absorptive material
- What is new?
  - Better understanding of the IC process

External Curing and Internal Curing

- Use fine LWA to distribute water
- Works even at moderate w/cm 0.40 – 0.50

The Problem

- Chemical shrinkage
- Autogenous shrinkage
  - Hydration consumes the free water
  - Capillary tensile stresses
- Shrinkage causes CRACKS - problem
- FHWA bridge survey
  - Early-age deck cracking
  - Corrosion

Chemical Shrinkage

- Le Chatelier
- 1850-1936
- Chemical Shrinkage

The Solution - How Internal Curing Works

- It’s simple...just say no to cracks...
- Add absorbent materials that releases water
  - Maintains a high moisture levels
  - Release over 85% of absorbed water at RH 94%
- Absorbent materials
  - LWA, SAP (diapers), RC-Aggregate, wood chips, etc.
- North America almost all have been ESCS-LWA

Visualization of Water Transport

Blue-ink corona in cement matrix around prewetted LWA

w/c = 0.37

Prewetted Lightweight Aggregate

Corona: 1 mm after 1 week

Higher w/c the larger the corona 2-4+ mm

Cement Matrix
Durability and Performance
That's Why Internal Curing is Used

- Increased cement hydration
- Improves SCM reaction because
  - Higher and longer water demand
  - Increased chemical and autogenous shrinkage
- Reduce self-desiccation and shrinkage
- Improved interfacial transition zone (ITZ)
  - Greatly reduces the transport properties

Degree of Hydration

Reduced Stress Development
Another Reason Internal Curing is Used

- Less crack potential
  - Minimize the internal autogenous stresses
  - Reduce modulus of elasticity
  - Reduce coefficient of thermal expansion (CTE)
- In the Field
  - Fewer cracks
  - Increased crack spacing
  - Decreased crack widths

Stress Development Bridge Deck Conc.

During Construction

- Early-age robustness with respect to temperature changes
  - Reduced thermal stresses
- Reduced plastic and drying shrinkage cracking
- Improved workability and finishability
  - Less stickiness with SCM, (silica fume etc.)
- Internal curing starts as soon as the hydration demands more moisture…time of set
IC does not Replace Conventional Surface Curing!!

- However it can help compensate for:
  - higher temperatures
  - low relative humidity
  - poor conventional curing
- Enhances good conventional curing

A Little History

- Internal curing dates back to 3000 B.C.
  - Sumerians used LWA concrete to build Babylon.
  - LWA concrete used extensively Romans period
- 1950’s - 60’s Klieger, Cambell, Tobin & others
  - “LWA concrete was more forgiving”…IC
- Early 1990’s LWA used on Hibernia Offshore Platform to improve buoyancy
  - Replaced 50% of coarse NWA with wetted ESCS LWA

Hibernia
Newfoundland, Canada
Internally Curried
155 to 126 pcf.
+10,000 psi

Hibernia
Hibernia at the North Sea
IC Documents

- NIST has over 120 citations on IC on their website
- New ASTM C1761
  - Standard Specification for Lightweight Aggregate for Internal Curing of Concrete

IC Mix Design - The Science

where

\[ M_{LWA} = \text{mass of (dry) LWA needed per unit volume of concrete (kg/m}^3 \text{ or lb/yd}^3) \]
\[ C_f = \text{cement factor (content) for concrete mixture (kg/m}^3 \text{ or lb/yd}^3) \]
\[ CS = \text{chemical shrinkage of cement (mass of water/mass of cement)} \]
\[ \alpha_{\text{max}} = \text{maximum expected degree of hydration of cement (0 to 1)} \]

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 \( w/c < 0.36 \).

\[ S = \text{degree of saturation of aggregate (0 to 1)} \]
\[ \Phi = \text{desorption of lightweight aggregate from saturation down to 93% RH (mass water/mass dry LWA)} \]

Source: Bentz, NIST

IC Mix Design – Making it Simple

- Need to know
  - How much IC water is needed
  - LWA absorption
  - LWA rate of desorption
  - Total aggregate grading (fines or intermediate)
- Mix Results
  - About 300-350 lbs pre-wetted FLWA per cubic yard
  - Replace about 30% of NW sand with FLWA

How Much IC Water - In General

7 Pounds Water for IC

100 Pounds

Maybe higher to accommodate evaporation, or to satisfy the higher SCMs water demand

Water Distribution from Prewetted LWA
**IC Protected Paste – Aggregate Size Matters**

Paste must be within close proximity to wetted LWA

![Coarse LWA aggregate](image1.png)

![Fine LWA aggregate](image2.png)

**Prewetting Aggregate With Sprinklers**

Done by sprinkling, soaking, vacuum saturation or thermal quenching

**The LWA is Pre-wetted**

**Bentz**

**Purdue, Univ.**

**Sustainability and Cost**

Who benefits from better concrete performance?

- Society from longer service life
- Economy from lower life cycle cost
- Environment from
  - more efficient use of cementing material
  - potential lower carbon footprint

**Benefits of internal curing on service life and life-cycle cost of high-performance concrete bridge decks**


Used analytical models to predict the times to corrosion onset of damage failure of bridge decks

Increased service life with IC is a result of
- reduced early-age shrinkage cracking
- reduced chloride diffusion

**Life Cycle Cost Analysis bridge decks**

**Service Life Predictions**

- **NC**: 23 years
- **HPC**: 40 years
- **HPC-IC**: 63 years

Cusson (2010)
**Life Cycle Cost Analysis**

Initial Cost vs Life Cycle Costs

- **Base cost** +25% +29%
- **23yr 40yr 63yr**

**Mixture Design Cost Assumptions**

- **Fine LWA cost**
  - $50/ton or 2.5 cents/lb (fob LWA plant)
  - Handling (freight, watering, batching) $20/ton or 1 cents/lb
  - Total Fine LWA cost = 3.5 cents/lb (.035)

- **Fine NWA $7-18/ton, used 0.65 cents/lb (.0065)**

**HPC Mixture Design (w/cm 0.42)**

Bridge decks in Syracuse, NY

<table>
<thead>
<tr>
<th>Batch weights in pounds</th>
<th>Spencer St Standard Mix</th>
<th>$/cy</th>
<th>Court St IC mix</th>
<th>$/cy</th>
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</thead>
<tbody>
<tr>
<td>Cement</td>
<td>500</td>
<td>500</td>
<td>500</td>
<td></td>
</tr>
<tr>
<td>Fly Ash</td>
<td>135</td>
<td>135</td>
<td>135</td>
<td></td>
</tr>
<tr>
<td>Microsilica</td>
<td>40</td>
<td>40</td>
<td>40</td>
<td></td>
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<tr>
<td>Fine LWA $.035/#</td>
<td>0</td>
<td>0</td>
<td>196</td>
<td></td>
</tr>
<tr>
<td>Fine Agg $.0065/#</td>
<td>1130</td>
<td>7.34</td>
<td>782</td>
<td></td>
</tr>
<tr>
<td>Coarse Agg</td>
<td>1720</td>
<td>1720</td>
<td>1720</td>
<td></td>
</tr>
<tr>
<td>Water</td>
<td>270</td>
<td>270</td>
<td>270</td>
<td></td>
</tr>
<tr>
<td>Total (fob R-M Plant)</td>
<td>7.34</td>
<td>11.94</td>
<td>(+4.60)</td>
<td></td>
</tr>
</tbody>
</table>

**In-Place Concrete Cost - $/cy**

<table>
<thead>
<tr>
<th></th>
<th>In the example IC mixture</th>
<th>$4.60/cy</th>
<th>$10/cy</th>
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</thead>
<tbody>
<tr>
<td>Bridges</td>
<td>$400-500/cy</td>
<td>1.1%</td>
<td>2.4%</td>
</tr>
<tr>
<td>Water tanks</td>
<td>$300-375/cy</td>
<td>1.3%</td>
<td>2.9%</td>
</tr>
<tr>
<td>Paving</td>
<td>$170-200/cy</td>
<td>2.5%</td>
<td>5.4%</td>
</tr>
</tbody>
</table>

If the entire structure is considered, IC is only about 1% more

**Embodied Energy Study - LWC In Steel Framed Buildings by Walter P Moore & Assoc 9/21/2012**

- A representative 5-story office building in Moderate-seismicity, Charlotte, North Carolina
- Overall the study found
  - Reduction in material quantities (less weight)
  - Offset the energy to produce the ESCS LWA
  - Lowered total embodied energy by 1 to 3%

**Internal Curing Projects**

- Since 2003, over 2 million yd$^3$ of IC Normalweight concrete have been placed
  - Includes 1.3 million yd$^3$ of low slump pavements
  - City streets and parking areas Dallas-FW area
Union Pacific Intermodal Facility
Hutchins, Texas January of 2005

250,000 yd³ project with low slump IC pavement
Visual inspections at 6 yrs minuscule plastic or drying shrinkage cracks

Low Slump IC Mixtures

Enhanced workability
Better consolidation
Flexural strengths of 650 - 750 psi at 28d

Texas State Highway SH 121

- SH -121, Dallas, Texas, 2006
- 1300 cubic yards, 5 miles
- Continuously Re-enforced Concrete Pavement (CRCP)
- Class P (3500 psi or 570 psi flex at 7d)

Sieve Analysis

Aggregates Grading
SR-121

Only 300 lbs (5 ft³/yd³)
Intermediate LWA

Paving Mixture with Internal Curing

SR-121 TX
4000psi at 4d
6000+ at 28d

SR-121 Crack Spacing of IC section

500 ft section CRCP no joints
Survey: 10m old, Number of cracks, IC 21 vs. 52 control
Crack Width (% of total at 10 months old)

New York State
- Has done about 20 bridges using Internally cured concrete

Court Street Overpass I-81
Syracuse, NY
- September 2009

Bartell Road Overpass I-81
Cicero, NY
- May 2010

The State of Indiana
Five miles northeast of Bloomington
- Two bridges replacement about ¼ mile apart
  - Pre-stressed concrete box beams
  - Composite reinforced concrete deck
  - 8” thick centerline and 4 1/2” thick edge
SUMMARY—The Goal of Internal Curing

- Reduce or eliminate cracking
- Provide additional internal curing water
- Keep the hydrating cementitious paste saturated and autogenous stress free
Summary – Internal Curing Helps

- Concrete achieve its maximum potential
- Extend the service life of concrete
- Improve the economical, environmental, and social aspects of the concrete industry
- That supports the sustainability of concrete

My First Job!

And One Great Truth Is

All Great Truth Begin as Blasphemy

Concrete Performs Better with Internal Curing

Thank You

Carbon Foot Print of Mix Design

- In general
  - 100 # of ESCS generates about 18 lbs of CO₂
  - 18 # of cement generate about 18 lbs of CO₂
- Evaluating carbon footprint of a concrete mixture
  - ESCS CO₂
  - Potentially less cement CO₂ from better hydration
  - Increased SCM use