Internal Curing and Its Potential for Concrete Pavement

Jason Weiss, wjweiss@purdue.edu, Purdue University
Jack and Kay Hockema Professor, Director of the Pankow Materials Laboratory
Internal Curing – The Benefit

- Reduce the potential for unwanted cracking
- Reduce transport (permeability) corrosion
- Improve construction robustness (plastic, drying autogenous, thermal cracking etc…)
- When rapid opening prevents proper curing
- Improve sustainability (better use of cement, use less cement for same results)
- Reducing curling and warping
What is Concrete Curing

• When concrete is placed it is sensitive and can be easily damaged if not treated properly
• We want to maintain appropriate temperature and moisture during the first few weeks
• Proper curing enables concrete to hydrate (chemically react) developing potential strength and durability
• Proper curing reduce stress and cracking potential due to drying or temperature changes
• Important but frequently overlooked step
• ACI–308: Action taken to maintain moisture and temperature conditions in a freshly placed cementitious mixture to allow hydraulic-cement hydration and, if applicable, pozzolanic reactions to occur.

http://science.howstuffworks.com/environmental/earth/geology/dinosaur-bone-age.htm
External Curing

- Conventional concrete is done to the outside of the concrete

- Can think of this a little like a crab/lobster exoskeleton

http://express.howstuffworks.com/exp-exoskeleton.htm
Internal Curing (IC)

- IC works from the inside of concrete
- IC uses reservoirs of water that hide water before set to get a dense structure and make the water available after set for hydration

Castro et al. 2010
We are Familiar with the Steps in High Quality Concrete Paving
Today we will talk about curing
When we talk about curing pavements is this a picture that comes to mind?
Top is from 1969 the bottom is a recent photo
What’s changed over time?
Proper curing of concrete is essential for durable, maintenance free pavement.

Why is curing necessary?
- To assure proper hydration of the cement

How is curing achieved?
- By maintaining freshly placed concrete under controlled conditions for a given period of time.

For how long should pavement undergo the curing process?
- It depends, Generally longer is better.

So maybe nothing has changed
What are the main characteristics of the different methods of water preservation?

- Ponding building a "dike" around perimeter of pavement that will confine water within

- Sprinkling method continuously spray water to produce a constant, fine spray.

- Wet covers (earth, sand, or hay) stopped due to high cost of materials and labor.

- Wet covers (cotton or other textile).

- Waterproof paper, plastic sheets, compounds - advantage of eliminating the need to add water.

Maybe something has changed a little
Are Water Curing and Membrane Curing the Same Thing

- Water Ponding, Sprinkling, Burlap: Supply Additional Water
- Curing Membranes: Reduces the Loss of Water to the Environment
An Area of Great Confusion

- Many people discuss terms like chemical shrinkage and self-desiccation
- We will try to get to the heart of what these terms mean
- More importantly we will describe the influences of these terms
- Discuss the role IC plays especially when thinking about a concrete pavement
Lets Start with Chemical Shrinkage

- Fundamental but difficult concept
- Le Chatelier 1850-1936
- Volume of the reactants larger than the volume of the products
- Chemical Shrinkage
- Leads to Self Desiccation

\[ \text{Reactants} + \text{Products} = \text{Result} \]
Chemical Shrinkage (blue) Versus External (Autogenous) Shrinkage

Introduction

Internal vs External

Membrane vs Water Curing

Chemical Shrinkage

Self-Desiccation

Impacts

Proportioning

Field Batching

Benefits of IC

Examples

In a sealed system the empty space is vapor filled in water curing water is absorbed
How is Chemical Shrinkage Related to Self-Desiccation

- Concrete has pores of different sizes (Air – Big, Capillary Med., Gel – Small)
- Science says that big pores empty first (lower energy)
- If we have two different water to cement ratios we will have a similar amount of cement reacting
- Therefore we will have similar chemical shrinkage
- However the implications can be very different
How is Chemical Shrinkage Related to Self-Desiccation

- W/c influences pore sizes
- Chem. shr. - same volume
- RH is related to size
- RH is lower for HPC

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Internal vs External
Membrane vs Water Curing
Chemical Shrinkage
Self-Desiccation
Impacts
Proportioning
Field Batching
Benefits of IC
Examples
Self-Desiccation and the Decrease in Relative Humidity

• So what if the Humidity Decreases
  – Hydration will slow down and we will not use the cement or SCM as it will be unreacted
  – This limits strength development and limits the reduction in transport (permeability)
  – Shrinkage will start even in perfectly sealed concrete

![Graph showing the relationship between relative vapor pressure and amount of water](image)
Basic Idea with Internal Curing

Introduction
Internal vs External
Membrane vs Water Curing
Chemical Shrinkage
Self-Desiccation
Impacts
Proportioning
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Benefits of IC
Examples
Concept – LWA Supplies Water

- Water stays in LWA until the time that this under pressure develops
- At that point water would be drawn out of bigger pores in LWA in a perfect world
Self-Desiccation with Internal Curing

• Water is pulled out of the LWA during the reaction
  – Reacts more of the cement/SCM
  – Dramatically reduces shrinkage
So How do I Internally Cure

- Assume we want to use internal curing
- How would we go about proportioning concrete to do this
- First we need a source of LWA (fines are better due to distribution) expanded clay, slate, slag, and shale all seem to work
- Desorption key ASTM C1761
Example Proportions

- Consider a mixture like the one shown
- The cost of IC is related to swapping sand with fine LWA
- This is approximately 10% of the material cost (3 to 10 dollars per cubic yard)

<table>
<thead>
<tr>
<th>Materials</th>
<th>Conventional</th>
<th>Internally Cured</th>
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</thead>
<tbody>
<tr>
<td>Cement</td>
<td>480</td>
<td>480</td>
</tr>
<tr>
<td>GGBFS</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Fly Ash</td>
<td>120</td>
<td>120</td>
</tr>
<tr>
<td>Silica Fume</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Sand</td>
<td>1458</td>
<td>1005</td>
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<tr>
<td>Lightweight Aggregate</td>
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<tr>
<td>Water</td>
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<tr>
<td>Air</td>
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<tr>
<td><strong>Σ</strong></td>
<td><strong>3948</strong></td>
<td><strong>3792</strong></td>
</tr>
</tbody>
</table>
As Simple as Replacing a Volume of the Fine Aggregate Volume Proportions

Introduction

Internal vs External

Membrane vs Water Curing

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Examples
How Does Internal Curing Work

- LWA (typically) supplies water to the hydrating cement paste after setting (i.e., after the structure forms)
- The LWA need to be well-spaced to allow water to reach all the paste
  - Generally accomplished automatically with the use of fine light weight aggregate
- The aggregate needs to be able to absorb and release the water
  - Properties of all North American aggregates are well known and easily measured
How Do We Design IC Mixtures

- A certain amount of shrinkage occurs when cement reacts with water (~7 ml/g)
- This reaction is known as chemical shrinkage (known since the 1880s)
- We can use a variety of concepts however this is as simple as including 7 lb of IC water/100 lb of cementitious material
- Additional benefits come from using this with supplementary cementitious materials due to higher chemical shrinkage (FA 2x, SF 4x)
Converting a Concrete Mixture to an Internally Cured Mixture

- The majority of the time I believe that you will be asked to convert an existing mixture to an internally cured mixture.
- This for example can be a paving mixture or a bridge deck mixture.
- There is no reason to reinvent the wheel.
Simple Approach for Design (1)

- **Begin with a mixture design you like**

<table>
<thead>
<tr>
<th>Plain Mixture Design</th>
<th>Legend</th>
</tr>
</thead>
<tbody>
<tr>
<td>Target Air, %</td>
<td>6.0%</td>
</tr>
<tr>
<td>w/c</td>
<td>0.400</td>
</tr>
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</table>

<table>
<thead>
<tr>
<th>Materials</th>
<th>Weight</th>
<th>SG (SSD)</th>
<th>Volume, ft³</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cement</td>
<td>480</td>
<td>3.15</td>
<td>2.442</td>
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<tr>
<td>GGBFS</td>
<td>0</td>
<td>2.99</td>
<td>0.000</td>
</tr>
<tr>
<td>Fly Ash</td>
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<td>2.64</td>
<td>0.728</td>
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<tr>
<td>Silica Fume</td>
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<td>2.75</td>
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<tr>
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<td>Coarse Aggregate 2</td>
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<tr>
<td>Water</td>
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<td>3.846</td>
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<tr>
<td>Air</td>
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<td>0</td>
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<tr>
<td><strong>Σ</strong></td>
<td>3948</td>
<td>-</td>
<td>27.000</td>
</tr>
</tbody>
</table>

- **Enter the values in the orange cells**
Simple Approach for Design (2)

- Enter properties for the LWA you will use

<table>
<thead>
<tr>
<th>Internal Curing Properties</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>LWA Absorption:</td>
<td>20.0%</td>
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<tr>
<td>LWA Desorption:</td>
<td>85.0%</td>
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<tr>
<td>LWA Specific Gravity</td>
<td>1.800</td>
</tr>
<tr>
<td>Cement Factor</td>
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<tr>
<td>Chemical Shrinkage</td>
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<tr>
<td>Degree of Hydration</td>
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<td>SSD LWA Replacement</td>
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</tr>
<tr>
<td>SSD Sand Replaced</td>
<td>453</td>
</tr>
</tbody>
</table>

- Properties in green should come from the LWA producer
- Easy to perform (take 24 to 72 hours)
Simple Approach for Design (3)

- Calculation in spreadsheet to provide you with the proportions for a typical IC mixture

Note Spreadsheet basic calcs, will explain to those interested, most just want the answer
Simple Approach for Design (4)

- Your mixture is automatically adjusted

<table>
<thead>
<tr>
<th>IC Mixture Design</th>
<th>Materials</th>
<th>Weight</th>
<th>SG (SSD)</th>
<th>Volume, ft³</th>
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<tr>
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<tr>
<td></td>
<td>Sand</td>
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<td>2.75</td>
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<td>Lightweight Aggregate</td>
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<td>1.800</td>
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<td>-</td>
<td>27.000</td>
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</table>
Simple Design Approach In Review

- This is the entire spreadsheet I just discussed I am glad to send it to you
- Orange comes from an existing mixture
- Green comes from the LWA producer
- Many make this more complex however
- 600 lb cem., 42 lb water

### Plain Mixture Design

<table>
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<td></td>
<td><strong>27.000</strong></td>
</tr>
</tbody>
</table>

### Internal Curing Properties

- LWA Absorption: 20.0% ←This is 24 hour design absorption
- LWA Desorption: 85.0% ←If unknown, use 85%
- LWA Specific Gravity: 1.800 ←This is 24 hour pre-wetted surface-dry specific gravity
- Cement Factor: 600
- Chemical Shrinkage: 0.07
- Degree of Hydration: 1
- SSD LWA Replacement: 296
- SSD Sand Replaced: 453

### IC Mixture Design

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<td>Air</td>
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<td>0</td>
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<tr>
<td><strong>Σ</strong></td>
<td>3792</td>
<td></td>
<td><strong>27.000</strong></td>
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</tbody>
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# Lightweight Aggregate Properties

<table>
<thead>
<tr>
<th>LWA name</th>
<th>24 h centrifuge absorption, %</th>
<th>24 h centrifuge desorption, %</th>
<th>24 h PSD Relative Density (SG)</th>
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</thead>
<tbody>
<tr>
<td>Gravelite (Riverlite LA)</td>
<td>16.4</td>
<td>92.4</td>
<td>1.502</td>
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<tr>
<td>Livlite (Riverlite AL)</td>
<td>30.0</td>
<td>97.5</td>
<td>1.430</td>
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<tr>
<td>TXI (Trinity) Frazier Park</td>
<td>17.5</td>
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<td>1.633</td>
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<tr>
<td>Buildex Marquette</td>
<td>18.8</td>
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<td>Buildex New Market</td>
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<td>Stalite</td>
<td>9.1</td>
<td>97.5</td>
<td>1.647</td>
</tr>
</tbody>
</table>

- Data from the open literature in papers by Castro et al & Miller et al
- Can vary due to production but this is a reasonable start
- All ESCSI materials work as well as expanded slag
Quality Control and Water

- Absorbed water
  - varies with LWA material, soaking time, storage, and mixing time
  - Does not change volumetrics
  - Does not change the w/c

- Free water
  - Controls the slump
  - Is related to changes in w/c and strength

- Centrifuge test – 3 minute answers
### Batching Internally Cured Concrete

(Daily change in SG, surface moisture)

#### Materials Design SSD Weight based on 24h PWSD, lbs/cy

<table>
<thead>
<tr>
<th>Materials</th>
<th>Design SSD Weight based on 24h PWSD, lbs/cy</th>
<th>Design SSD Weight to be Input Day of Batching, lbs/cy</th>
<th>Tested Aggregate Surface Moisture, %</th>
<th>Target Batch Weight, lbs/cy</th>
<th>Target Batch Weight, lbs</th>
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</thead>
<tbody>
<tr>
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<td>564</td>
<td>564</td>
<td>-</td>
<td>564</td>
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<td>-</td>
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<tr>
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<td>591</td>
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<td>608</td>
<td>5472</td>
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<tr>
<td>LWA</td>
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<td>472</td>
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<td>258</td>
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<td>-</td>
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<td>3666</td>
<td>3725</td>
<td>-</td>
<td>3725</td>
<td>33526</td>
</tr>
</tbody>
</table>

| Batch Size, cy | 9 | ←This accounts for changes in specific gravity if 24 hour design absorption is exceeded |
| LWA Specific Gravity Day of Batching | 2.000 |

- **Adjusted mixture design day of batching accounts for the aggregate in the pile absorbing more water than considered in design**
- **Accounting for surface moisture (fast test centrifuge)**

**Introduction**

- Internal vs External
- Membrane vs Water Curing
- Chemical Shrinkage
- Self-Desiccation

**Impacts**

- Proportioning
- Field Batching
- Benefits of IC

**Examples**

ACPA Webinar Internal Curing

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Easy Ways to Measure Desorption

• Place approximately 5 grams of prewetted surface dry aggregate in the dish and record mass $M_{PSD}$
• Place in a chamber with a saturated salt solution of Potassium Nitrate (93-94%)
• Some salt should appear on the bottom of the container after mixing it in
• Measure Mass Over Time
Typical Findings with Internal Curing

- More cement hydrates (more SCM hydrates) as water stays available
- Strength is generally +/- 10%
- Modulus is lower (makes the material more extensible)
- Lower rate of shrinkage
- Lower autogenous shrinkage
- Reduced fluid transport (absorption)
Other Benefits

- Typical freeze thaw properties behavior is similar to plain concrete
- Where ASR occurs due to the fine aggregate fine LWA offers a solution due to dilution + space
- Improved performance with SCM using less clinker, lower CO₂ footprint
Impact on Thermal Stress Induced Cracking

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

Internally Cured Mortar (w/c = 0.30)

\[ \Delta T_{\text{crack}} = 10.3^\circ C \]

\[ \Delta T_{\text{crack}} = 27.1^\circ C \]

- Since thermal and autogenous stress is additive it reduces thermal cracking
Impact on Plastic Shrinkage Cracking

Initial System During Settlement
Constant Rate Period Falling Rate Period

Higher Capillary Stress Develops and Greater Settlement Occur in the Plain System As Water is Drawn Out by Drying

Plain System

System with LWA

Introduction
Internal vs External
Membrane vs Water Curing
Chemical Shrinkage
Self-Desiccation
Impacts
Proportioning
Field Batching
Benefits of IC
Examples
- IC reduces the width and likelihood of plastic shrinkage crack formation
- Can prevent cracking from occurring all together
- Note if the water in LWA is used up in the fresh state its gone
Example 1 - Patching

- Here we can see IC HES patching in West Lafayette, premature cracking was observed in many cases for plain HES.
- Performed using IC in the standard HES patching and the benefit is reduced cracking and curling and increased hydration of the cement/opening.
### Example 2 – Bridge Decks

Plain concrete bridge deck was pumped | IC concrete bridge deck was placed by means of a bucket

<table>
<thead>
<tr>
<th></th>
<th>Cement Content (kg/m³)</th>
<th>W/C (kg/m³)</th>
<th>Fine Agg. LWA (kg/m³)</th>
<th>Fine Coarse Agg (kg/m³)</th>
<th>Mixture Water (kg/m³)</th>
<th>Water in LWA (kg/m³)</th>
<th>WR %</th>
<th>AE %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plain</td>
<td>390</td>
<td>0.39</td>
<td>726</td>
<td>-</td>
<td>1046</td>
<td>152</td>
<td>-</td>
<td>0.22</td>
</tr>
<tr>
<td>Int. Cured</td>
<td>390</td>
<td>0.39</td>
<td>313</td>
<td>270</td>
<td>1046</td>
<td>152</td>
<td>25</td>
<td>0.22</td>
</tr>
</tbody>
</table>

^n^ percentage referred to the cement weight
Example 2b – Bridge Decks

- IC slightly stronger and less permeable
- Plain bridge deck several cracks
- Internally cured no cracks 20+ mos
- NY decks similar

Internally cured bridge deck
General Field Observations

• First, IC has minimal impact on batching and placing when done properly
• Second, the main thing to watch for is the aggregate moisture (surface/absorbed).
• Third, IC HPC is a great use of this as it provides dense concrete with a low potential for cracking
• Fourth, substantial reduction in plastic observed for water tank construction
• Fifth, there is a great potential to reduce shrinkage and curling stresses
Summary

- Concrete - sensitive to poor curing/durability
- IC – Curing with water supplied from LWA
- Water curing – supplies additional water
- Internal curing goes hand and in hand with good concrete practice and sustainability (less cement, hydrate SCM)
- Easy to proportion mixtures, batch
- Many benefits of internal curing
- Actively being used in practice
- Plethora of existing data and tools
Want Additional Information

- Please feel free to email any questions you may have
- Available resources
- Papers/reports (40+) with data
- ESCSI video series (Approximately 5 hrs)
  - Module 1 Overview
  - Module 2 Proportioning
  - Module 3 Shrinkage
  - Module 4 Transport
  - Module 5 Sustainability
- Worksheet tools, design, quality control