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

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Internal Curing Overview and Objectives

Objectives

• To understand the differences between conventional (external) and internal curing (IC)
• To understand why chemical shrinkage and self-desiccation play a key role in IC
• To quantify simple concepts behind mixture proportioning – Supply and Demand
• To understand how internal curing benefits are related to fundamental concepts
• To discuss how what we know is implemented
• To discuss emerging concepts which will no doubt continue to push the technology further

External Curing

• Typically we cure concrete from the outside
  – Water Ponding: Supply of Additional Water
  – Curing Membranes: Reduce Loss of Water

Objectives

• Curing - External and Internal
• What is Self-Desiccation?
• Proportioning Concepts
• Benefits of Internal Curing
  – Increased Cement Hydration
  – Reduced Shrinkage and Restrainted Shrinkage Cracking
  – Reduced Fluid Transport (Deicing Salts)
• Visions for the Future

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**Why’s & How’s of Internal Curing**

- HPC ‘dense’ and disconnects large pores
- Good for durability; bad for curing water mvt.
- Self-Desiccation increases in low w/c and with SCM
- ‘drying’ from the inside without water loss
- Internal curing works from inside concrete using ‘water reservoirs’ that hide water till set

**Outline**

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**What is Self-Desiccation**

- The reduction in the internal relative humidity (RH) of a sealed system when empty pores are generated.
- What causes the pores to empty?
- Does the size of the pore that empties matter?

**Chemical Shrinkage**

- Volume of the reactants larger than the products
- Le Chatelier
- Powers

**Self Desiccation and Setting**

**Why is this an Issue in Lower w/c**

- CS is not very sensitive to w/c at early ages
- AS should decrease as w/c increases…..
- Do higher w/c have less self desiccation ??
- The size of the voids:
  a) Capillary vs Gel
  b) Fewer/bigger voids
  c) Lower pressures
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Mixture Proportioning
Supply vs Demand

- Demand: Replace Chemical Shrinkage
- Supply – Water from the LWA

\[ \text{Demand} = \text{Supply} \]

\[ C_{f} = M_{f} \times \left( P_{f} \right) \]

7 lb Water per 100 lb of Cement

Rule of Thumb

Other Considerations

- Sufficient water volume (supply vs demand)
- Ability of the aggregate to release water (desorb)
- Aggregate distribution (fines preferred)

Increased Hydration

- Internal curing causes more cement to react
- Shown here with isothermal calorimetry
- Keeps RH higher
- Efficient – sustainability

Increasing Saturation and the Size of Pores Water Filled

- LWA Pores > Paste Pores
- Larger pores remain saturated - less shrinkage

\[ \epsilon_p = \frac{1}{3} \left( 2 \gamma + \frac{1}{K_p} - \frac{1}{K_v} \right) \]

\[ \ln(RH) = \frac{2 \gamma}{RT} \]

LWA Paste

<table>
<thead>
<tr>
<th>Relative Humidity (%)</th>
<th>Kelvin Radius (nm)</th>
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<tbody>
<tr>
<td>20 from 25.3% LWA</td>
<td>7 nm from Plain</td>
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Reduced Shrinkage and Restrained Shrinkage Cracking

- Reduced porosity - increased hydration
- Reduced ITZ and connectivity

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The Future of Internal Curing

- Practices and specifications being developed
  - Pavements in Texas
  - Bridge deck Ohio, Indiana, New York, Utah
  - Water tanks in Colorado

Ready to Implement, But Need More Information?

- RILEM IC 196 Report
- ACI SP 218; SP from this session
- ACI 231, 308 docs
- NIST Report
- REACCT Short Course Videos
  - https://sites.google.com/site/afn40concretematerials/internal-curing-workshop

The Future of Internal Curing

- Opportunities
  - Sustainability: More Efficient Use of Cement which implies reductions and greater substitutions
  - Sustainability: Works well with SCM’s that have higher chemical shrinkage
  - Sustainability: Longer Lasting Concrete
  - Use of waste materials as porous inclusions
  - Hide fluids other than water (SRA, Lithium, Cl)
  - Applications in new systems (e.g. LW grid decks)
  - New models for performance
Summary

- Internal Curing – Uses Water Reservoirs
- What is Self-Desiccation? ‘Drying’ due to Chemical and Shrinkage Pore Size
- Proportioning Concepts – Supply and Demand
- Benefits of Internal Curing – Increased Cement Hydration – Reduced Shrinkage Restrained Cracking – Reduced Fluid Transport (Deicing Salts)
- Technology that’s ready to implement and grow