The Economics, Performance, and Sustainability of Internally Cured Concrete, Part 2

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

SP 290-2
History and Evolution of Internal Curing of Concrete

12 Case Studies using 9 Different Absorbent Aggregates from Texas and Oklahoma to Eastern Canada

Self-Curing Concrete, Why Not?

IC to Mitigate Cracking and Improve Corrosion Performance
Raoufi, K., and Weiss J.

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The Genesis, Evolution and Accelerated Use of Internal Curing
How it Provides Improved Life Cycles at Reduced Cost

- Abstract
- First noticed by T.C. Powers et al in 1948, and then described by Baker, Geyer and Menniger in 1956 in benefit for hydration by supplying water internally, construction users in 1962 have grasped how the process is working. This paper will present the possibilities of accelerated curing along with the effects on durability and the potential cost saving. The cost of a building project is largely determined by the time factor. In the United States, the annual cost of a 10foot cube structure is only one-third of the cost of a 20-year-old structure. The reduction in overall costs may be significant. Concrete cured under the most adverse conditions of concrete can be highly economical with only small or no loss of quality. The cost of a building project is largely determined by the time factor. In the United States, the annual cost of a 10foot cube structure is only one-third of the cost of a 20-year-old structure. The reduction in overall costs may be significant. Concrete cured under the most adverse conditions of concrete can be highly economical with only small or no loss of quality.
Internal Curing Evolution

- Reduce or Eliminate Chemical and Autogenous Shrinkage and Cracking
- Improved Hydration of Cement and Cementitious Materials
  - Greater Early Age and Later Compressive Strength
  - Greater Early Age and Later Flexural Strength
  - Reduced Permeability
  - Reduced Warping
  - Improved Density of Interfacial Transition Zone (ITZ)
  - Reduced Carbonation
  - Less Reinforcement Corrosion
  - Provision of Longer Life
  - Lower Life Cycle Cost

Chesapeake Bay Bridge
Under Construction - 1952

Largest Continuous Over Water Steel Bridge (4 miles)
3500 PSI Mix with 105 Density
2nd Bridge built in 1973 and the 2” Asphalt Layer was removed from the Deck and the LW Deck was found to be in Excellent Condition.
The approaches with normal weight concrete had to be replaced.

The LW aggregate in the concrete in 1952 was batched at SSD

Limestone with absorption greater than 1% as Internal Curing

Absorbent Limestone Bridge
“No sign of Cracking” in 12/2011

Type K Cement with IC

15% Moisture in IC @ 100 lbs/yd3 = 15 lb water

CLEVELAND BRIDGE DECK Using IC
Compressive Strength 20% Greater
No cracking 12/2011

Main Avenue Bridge Deck, Cleveland, Ohio
Type K Cement and IC to Improve Curing
No cracking 12/2011

Chesapeake Bay Bridge
60 Years Later - January 2012

No cracking 12/2011

40% Moisture in IC @ 100 lbs/yd3 = 15 lb water

CLEVELAND BRIDGE DECK Using IC
Compressive Strength 40% Greater
No cracking 12/2011
IC to Mitigate Cracking and Improve Corrosion Performance

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ACI Fall 2012 Convention October 23rd 2012 Page 3 of 9

Lightweight Aggregate Infiltration Base Prior to Placement of Pads 1-4

Placement

PERVIOUS PAVEMENT

Control Texture
Addition of 100# of LWAS Texture

PERVIOUS PAVEMENT TEST PADS

Pad 4 Internal Curing No Poly
Pad 3 Internal Curing No Poly
Pad 2 Internal Curing No Poly
Pad 1 Reference/Control Poly Sheeting 14 Days

PERVIOUS PAVEMENT MIXTURE DESIGNS

TABLE 1

<table>
<thead>
<tr>
<th>DESIGN</th>
<th>50#</th>
<th>100#</th>
<th>150#</th>
</tr>
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<tbody>
<tr>
<td>IC 100</td>
<td>206 (360)</td>
<td>206 (360)</td>
<td>206 (360)</td>
</tr>
<tr>
<td>IC 150</td>
<td>206 (360)</td>
<td>206 (360)</td>
<td>206 (360)</td>
</tr>
<tr>
<td>IC 200</td>
<td>206 (360)</td>
<td>206 (360)</td>
<td>206 (360)</td>
</tr>
<tr>
<td>LWAS</td>
<td>50 (90)</td>
<td>50 (90)</td>
<td>50 (90)</td>
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PERVIOUS PAVEMENT MIXTURE DESIGNS

FLEXURAL AND COMpressive STRENGTHS

<table>
<thead>
<tr>
<th>Pad 1</th>
<th>0.28 (1.4)</th>
<th>1155 (8.0)</th>
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</thead>
<tbody>
<tr>
<td>Pad 2</td>
<td>0.35 (2.2)</td>
<td>1225 (8.5)</td>
</tr>
<tr>
<td>Pad 3</td>
<td>0.40 (2.4)</td>
<td>1395 (9.4)</td>
</tr>
<tr>
<td>Pad 4</td>
<td>0.45 (2.6)</td>
<td>1590 (10.3)</td>
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</table>
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**COMPRESSIVE STRENGTH vs TIME**

**for TEST PADS 1 THROUGH 4**

- 100 lb IC
- 50 lb IC
- 10 lb IC

**DENVER WATER IC SLAB PLACEMENT**

10 Million Gallon Water Storage Tank with 285 lb IC + 43 lb/yd (5 gal)

**DENVER WATER Monolithic Pour**

Contractor also used IC walls & columns - No shrinkage cracks

**DIFFERENT AGGREGATES USED FOR DIFFERENT INTERNAL CURING APPLICATIONS**

<table>
<thead>
<tr>
<th>Concrete Density</th>
<th>Type of Aggregates</th>
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<tbody>
<tr>
<td>105</td>
<td>lightweight coarse and normal weight fine aggregate</td>
</tr>
<tr>
<td>115</td>
<td>lightweight coarse and normal weight fine aggregate</td>
</tr>
<tr>
<td>Inverted</td>
<td>normal weight coarse and lightweight fine aggregate</td>
</tr>
<tr>
<td>123-128</td>
<td>lightweight and normal weight coarse, normal weight fine and/or lightweight fine aggregate</td>
</tr>
</tbody>
</table>

**Three Story Building in Tulsa Oklahoma**

**Physical Properties and Compressive Strengths**

<table>
<thead>
<tr>
<th>Date</th>
<th>Air Content %</th>
<th>Slump</th>
<th>Concrete Temperature</th>
<th>7 Day Compressive Strength</th>
<th>28 Day Compressive Strength</th>
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</thead>
<tbody>
<tr>
<td>7/27/11</td>
<td>2.8</td>
<td>5.0&quot;</td>
<td>83° F</td>
<td>5136 psi</td>
<td>7064 psi</td>
</tr>
<tr>
<td>7/27/11</td>
<td>4.0</td>
<td>7.5&quot;</td>
<td>78° F</td>
<td>4190 psi</td>
<td>6440 psi</td>
</tr>
<tr>
<td>7/30/11</td>
<td>4.6</td>
<td>7.0&quot;</td>
<td>83° F</td>
<td>3550 psi</td>
<td>4911 psi</td>
</tr>
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Summary and Conclusions

Sixty years of concrete in service has brought the industry the basic knowledge that enables concrete to be perceived as the material of choice for many types of construction in the 21st Century. When cured properly and throughout the mass, it is able to make its contribution to sustainability.

The case studies represent those applications where Internal Curing (IC) can be justified based on life cycle cost analysis and frequently on first cost. They include bridges (long, short, and medium span), buildings (even 3-story ones), highways and parking lots (even porous pavements), and utilities (such as water tanks).

Geographically, they encompass the United States and Canada from Denver and Tulsa to New York City, from Florida to the St. Lawrence.

Recommendations

Starting with an optimum normal weight concrete mix design for a project, choose one or more characteristics that needs improvement.

Make comparative tests substituting different amounts of preconditioned absorbent lightweight aggregate sand (LWAS) for an equal volume of the normal weight sand.

Simultaneously, run 3, 7, 28, and 90 day compressive strength tests to make structural design decisions.

When the optimum replacement is established, apply the benefits to a life cycle cost analysis to ascertain the degree of sustainability enhancement.

REFERENCES

REFERENCES (cont’d)

27. Wei, Y., and Hansen, W., Presoaked Lightweight Fine Aggregates as Additives for Internal Curing in Concrete, ACI Puerto Rico, 1P-316-3, 2007.