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Advancing concrete knowledge

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

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John Ries PE, FACI has been in design, construction and lightweight aggregate industry for 45 years. He is a Montana State University graduate and serves on several ACI, ASTM, NCMA committees and is active in several concrete related organizations. John has authored/coauthored several publications and a reference manual on lightweight aggregate and concrete. He has spoke to several national organizations on how lightweight aggregate and concrete weight affect sustainability. Prior to ESCSI he was a consultant on all types of civil engineering and construction projects. Was the 2007 recipient of ACI Cedric Willson Award for his contributions to the technology of lightweight concrete.

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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?
  - <u>Performance – longevity of concrete</u>
  - 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

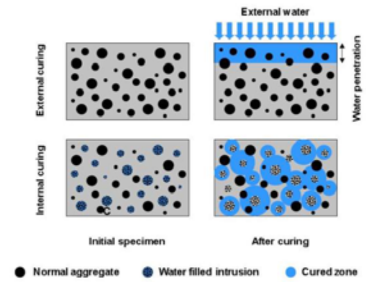
Our Title is Wrong

Optimizing the ~~Sustainability~~ <u>Performance</u> 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



Internal curing

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

Bentz & Weiss (2011)

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

1C + 1W = 1.8 HC

Purdue, Univ.

The Solution - How Internal Curing Works

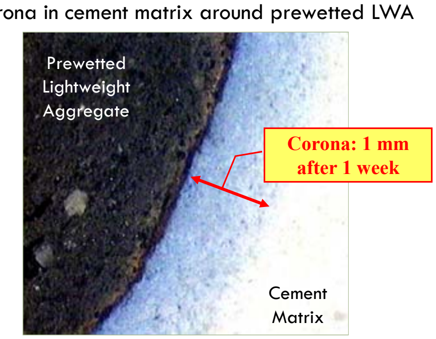
- It's simple…just say no to cracks…
- Add absorbent materials that releases water
  - Maintains a high moisture levels
  - Release over 85% of absorbed water at RH 94%
- Absorbent materials
  - LWA, SAP (diapers), RC-Aggregate, wood chips, etc.
- North America almost all have been ESCS-LWA

Visualization of Water Transport

Blue-ink corona in cement matrix around prewetted LWA

w/c = 0.37

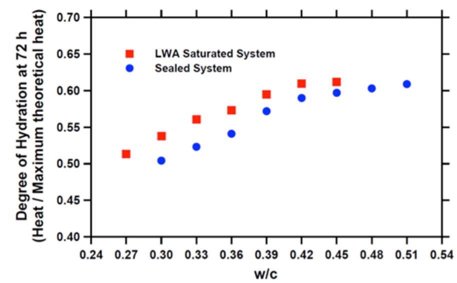
Higher w/c the larger the corona 2-4+ mm



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

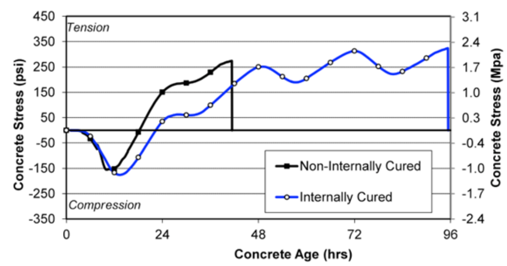


Degree of hydration of sealed specimen (Castro 2011)

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.



Stress development of bridge deck concrete

Byard

During Construction

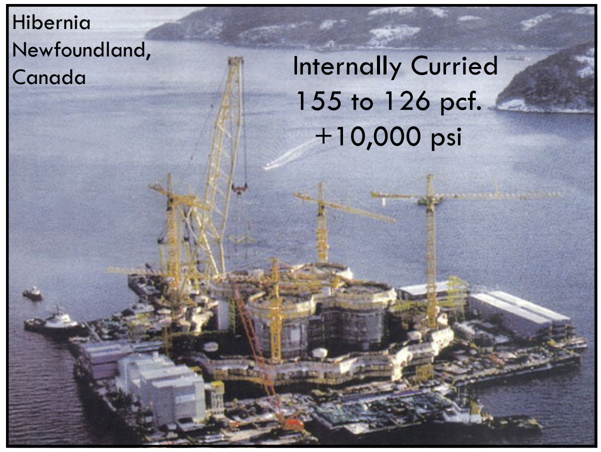
- Early-age robustness with respect to temperature changes
  - Reduced thermal stresses
- Reduced plastic and drying shrinkage cracking
- Improved workability and finishability
  - less stickiness with SCM, (silica fume etc.)
- Internal curing starts as soon as the hydration demands more moisture…time 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

National Institute of Science and Technology (NIST)

Around 2000 NIST started an extensive investigation into Internal Curing

Dale Bentz
and many others involved

IC Documents

- NIST has over120 citations on IC on their website
  - http://ciks.cbt.nist.gov/lwagg.html
- *"Internal Curing: A 2010 State-of-the-Art Review,"* by Bentz and Weiss
- New ASTM C1761
  - *Standard Specification for Lightweight Aggregate for Internal Curing of Concrete*

IC Mix Design - The Science

where
M_{LWA} = mass of (dry) LWA needed per unit volume of concrete (kg/m^3 or lb/yd^3);
C_f = cement factor (content) for concrete mixture (kg/m^3 or lb/yd^3);
CS = chemical shrinkage of cement (mass of water/mass of cement);
α_{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);
Φ_{LWA} = 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

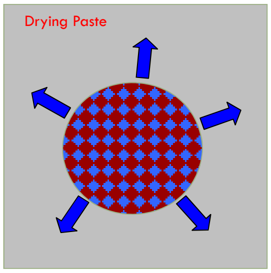
7 Pounds
Water for IC

100 Pounds

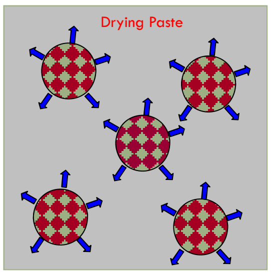
Maybe higher to accommodate evaporation, or to satisfy the higher SCMs water demand

Water Distribution from Prewetted LWA

Coarse aggregate

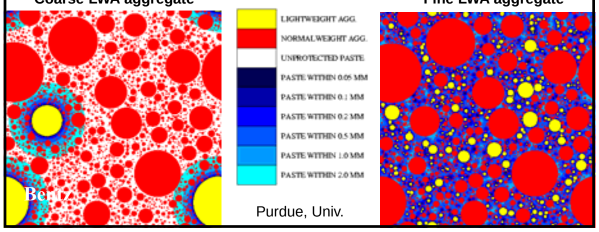


Fine aggregate



IC Protected Paste – Aggregate Size Matters

Paste must be within close proximity to wetted LWA



The LWA is Pre-wetted

Done by sprinkling, soaking, vacuum saturation or thermal quenching

Prewetting Aggregate With Sprinklers

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

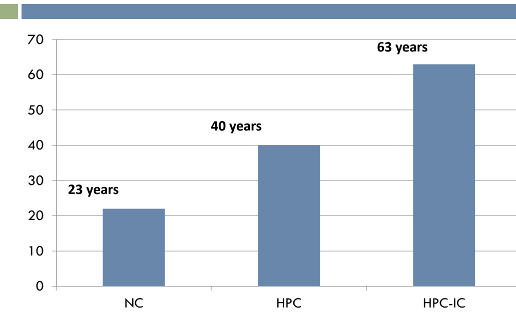
- Cusson, D., Z. Lounis, and L. Daigle, 2010. Case study for *National Research Council Canada*

Used analytical models
- 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

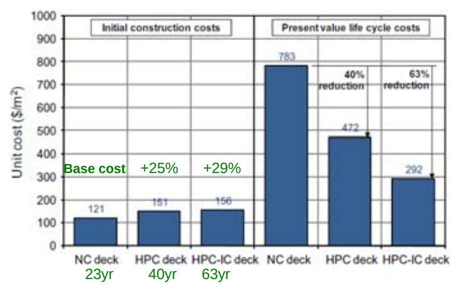
Service Life Predictions



Cusson (2010)

Life Cycle Cost Analysis

Initial Cost verse Life Cycle Costs



Cusson (2010)

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

Batch weights in pounds	Spencer St Standard Mix	$/cy NWC	Court St IC mix	$/cy IC
Cement	500		500	
Fly Ash	135		135	
Microsilica	40		40	
Fine LWA $.035/#	0	0	196	6.86
Fine Agg $.0065/#	1130	7.34	782	5.08
Coarse Agg	1720		1720	
Water	270		262	
Total (fob R-M Plant)		7.34		11.94 (+4.60)

In-Place Concrete Cost - $/cy

In the example IC mixture		$4.60/cy	$10/cy
Bridges	$400-500/cy	1.1%	2.4%
Water tanks	$300-375/cy	1.3%	2.9%
Paving	$170-200/cy	2.5%	5.4%

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 Modereate-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 yd^3 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 Pavment (CRCP)
- Class P (3500 psi or 570 psi flex at 7d)

Sieve Analysis

Aggregate Grading SR-121

Only 300 lbs (5 ft^3/yd^3) Intermediate LWA

			% Passing			
Sieve Size	Coarse agg. 1	Coarse agg. 2	*Lightweight agg.*	Fine agg.	Combined	*Combined % Retained*
2"	100				100	*0*
1 1/2"	99.3	100			99.8	*0.2*
1"	80	99.3			95.2	*4.6*
3/4"	51.8	85.8			84.3	*10.9*
1/2"	34	48.3	*100*		67.6	*16.7*
3/8"	12.1	19.8	*99.8*	100	52.9	*14.6*
no. 4	1.3	4.2	*58.9*	97.7	38	*14.9*
no. 8	0	1.4	*15.5*	87.9	27.1	*10.9*
no. 16		0	*4.1*	75.6	21.4	*5.7*
no. 30			*0*	58.9	16.2	*5.2*
no. 50				22.4	6.2	*10*
no. 100				2.6	0.7	*5.4*
no. 200				0.3	0.1	*0.6*
pan						*0.1*

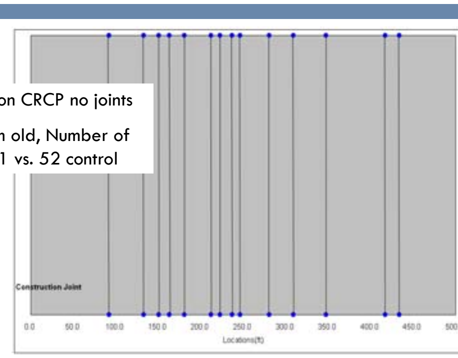
Paving Mixture with Internal Curing

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

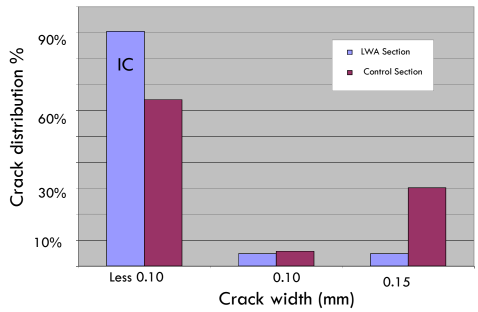
SR-121 Crack Spacing of IC section

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

Bartell Road Overpass I-81

Cicero, NY

The State of Indiana

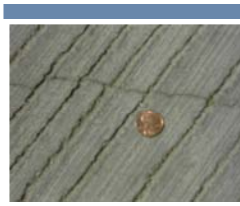
Five miles northeast of Bloomington

- 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

Standard External Curing (pre-wetted burlap) Used on Both Bridges

Plain Concrete Deck at One Year Old

Plain Concrete Deck at One Year Old



Longitudinal and Transverse crack

IC Deck at One Year Old

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!

All Great Truth Begin as Blasphemy

And One Great Truth Is

Concrete Performs Better with Internal Curing

Thank You

Carbon Foot Print of Mix Design

- In general
  - 100 # of ESCS generates about 18 lbs of CO_2
  - 18 # of cement generate about 18 lbs of CO_2
- Evaluating carbon footprint of a concrete mixture
  - ESCS CO_2
  - Potentially less cement CO_2 from better hydration
  - Increased SCM use