

Internal Curing

Using Prewetted Lightweight Aggregates

“The Best Thing Since Water-Cement Ratio”

Presented to: Minnesota Concrete Council
May 17, 2018

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Internal Curing

The screenshot shows a web page from Concrete Construction. The navigation bar includes links for PRODUCTS, PROJECTS, BUSINESS, HOW TO, CONCRETE SURFACES, and RESOURCE CENTER. The main content area features a post by Bill Palmer titled "THE BEST THING SINCE WATER-CEMENT RATIO". The post is dated October 30, 2017, and has 11 likes, 37 comments, and 48 shares. A blue arrow points from the date "October 30, 2017" to "October 31, 2017".

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MATERIALS

Home > How To > Materials > The Best Thing Since Water-Cement Ratio

Posted on October 30, 2017 0 Likes 11 37 48

BILL'S BLOG

THE BEST THING SINCE WATER-CEMENT RATIO

Internal curing using lightweight aggregate has been known about for more than 20 years, so why isn't it used more?

By Bill Palmer

INTERNAL CURING USING PREWETTED LIGHTWEIGHT AGGREGATE

What is the biggest complaint about concrete?



INTERNAL CURING USING PREWETTED LIGHTWEIGHT AGGREGATE

Curing is one of seven essential procedures
“that make concrete capable of providing
decades of service with little or no
maintenance.”

[ACI 201 2R-08, Guide to Durable Concrete]

INTERNAL CURING USING PREWETTED LIGHTWEIGHT AGGREGATE

The diagram illustrates the curing process in two rows: External curing and Internal curing. Each row shows the state of the concrete specimen at two points: 'Initial specimen' and 'After curing'.

- External curing:** In the 'Initial specimen', there are black circles representing normal aggregate. In the 'After curing' stage, blue arrows labeled 'External water' point down at the surface. A blue layer at the top indicates 'Water penetration', with a double-headed arrow showing the depth of penetration.
- Internal curing:** In the 'Initial specimen', there are black circles (normal aggregate) and blue circles with dots (prewetted lightweight aggregate). In the 'After curing' stage, the blue circles have expanded and are now filled with water, labeled as 'Water filled intrusion'. The surrounding concrete matrix is shaded blue, labeled as 'Cured zone'.

● Normal aggregate ● Water filled intrusion ● Cured zone

- Use fine aggregate to distribute water
- Help satisfy increased water demand from SCM's
- Works even at moderate 0.40 – 0.48 w/cm

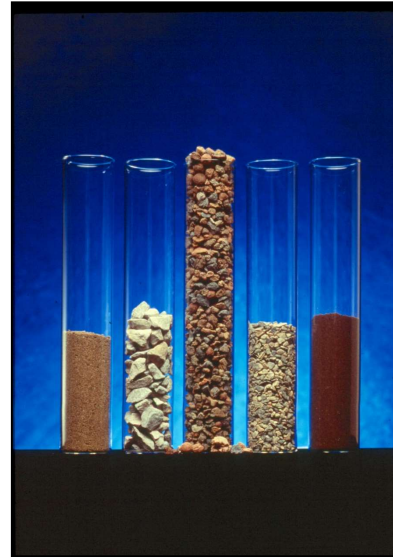
INTERNAL CURING USING PREWETTED LIGHTWEIGHT AGGREGATE


ACI CT-13 Definition: Internal Curing: *“process by which the hydration of cement continues because of the availability of internal water that is not part of the mixing water”*

INTERNAL CURING USING PREWETTED LIGHTWEIGHT AGGREGATE

What is LWA?

- Expanded shale, clay and slate (ESCS)
- Structural, ceramic aggregate produced in a rotary kiln
- Less than half the unit weight of ordinary aggregate
- Complies with ASTM C330 and C331





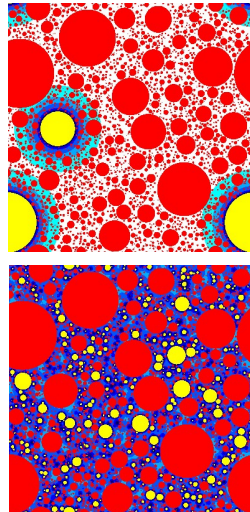
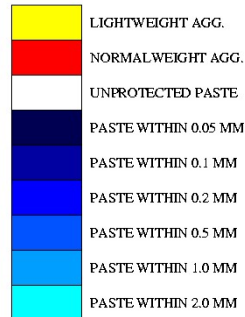
Expanded at
2000° F

INTERNAL CURING USING PREWETTED LIGHTWEIGHT AGGREGATE



INTERNAL CURING USING PREWETTED LIGHTWEIGHT AGGREGATE

It's All About the Distribution



Henkensiefken (2008)

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Benefits of Internal Curing

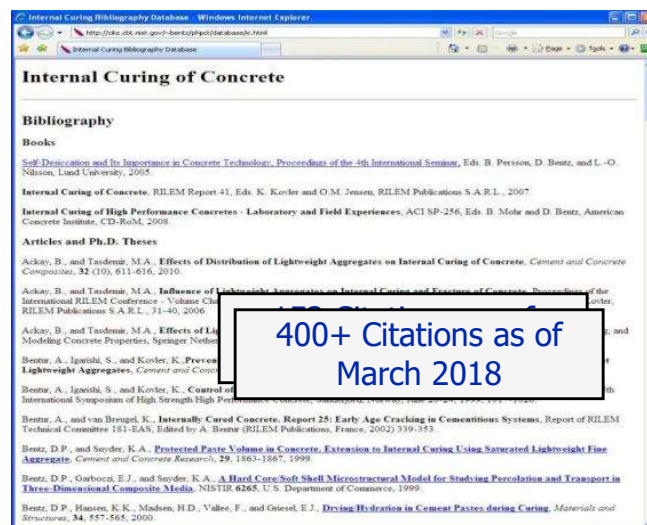
- Reduces shrinkage, delays cracking
- Improves fluid transport properties
 - lower water absorption
 - lower chloride permeability & penetration
- More cement hydration & SCM reaction
 - More efficient use
 - Less cement or more strength

INTERNAL CURING USING PREWETTED LIGHTWEIGHT AGGREGATE

Results

- More durable structures achieving extended service life
- Improved economics
- Increased sustainability

INTERNAL CURING USING PREWETTED LIGHTWEIGHT AGGREGATE

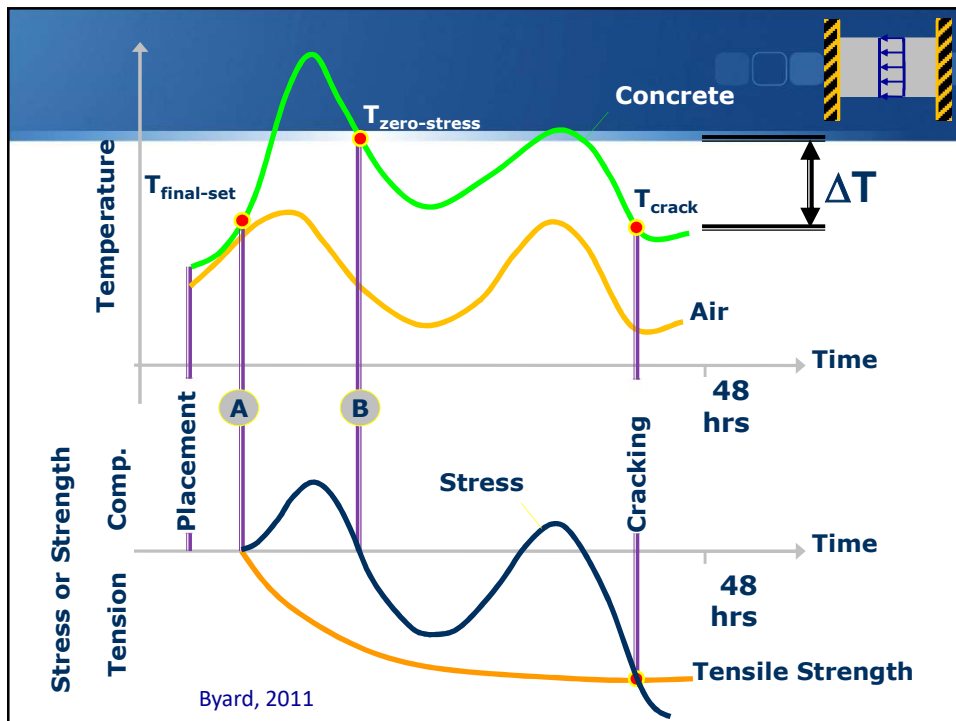


INTERNAL CURING USING PREWETTED LIGHTWEIGHT AGGREGATE
 Stress Development Mechanisms

Why Does Concrete Crack?



Restraint + Volume Change = Stress
Cracking Occurs When Tensile Stress Exceeds
 Tensile Capacity



INTERNAL CURING USING PREWETTED LIGHTWEIGHT AGGREGATE

Stress Development Mechanisms

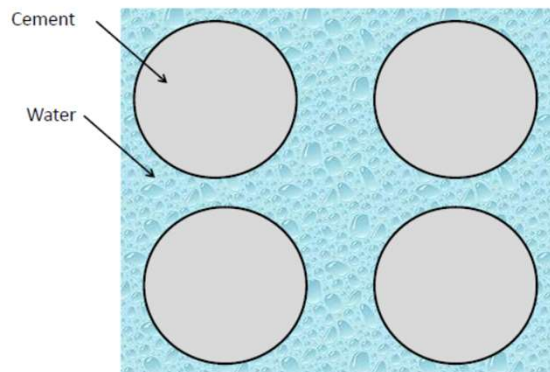
● Early-Age Volume Change Occurs Because of

- Chemical shrinkage
- Thermal effects
- Temperature changes due to hydration
- Coefficient of thermal expansion
- Decrease of internal relative humidity
- Drying due to atmospheric conditions
- Self-desiccation (autogenous shrinkage)

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Chemical Shrinkage and Self-Desiccation

$t=0$, water meets cement



Auburn University

Byard, 2011

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Chemical Shrinkage and Self-Desiccation

t =initial set, hydration products form skeleton

Decrease in volume due to chemical shrinkage

Cement
Hydration Products

Byard, 2011

INTERNAL CURING USING PREWETTED LIGHTWEIGHT AGGREGATE

Chemical Shrinkage and Self-Desiccation

t =after set, hydration continues and cement consumes capillary pore water and induce capillary stresses

Additional decrease in absolute volume due to capillary stresses

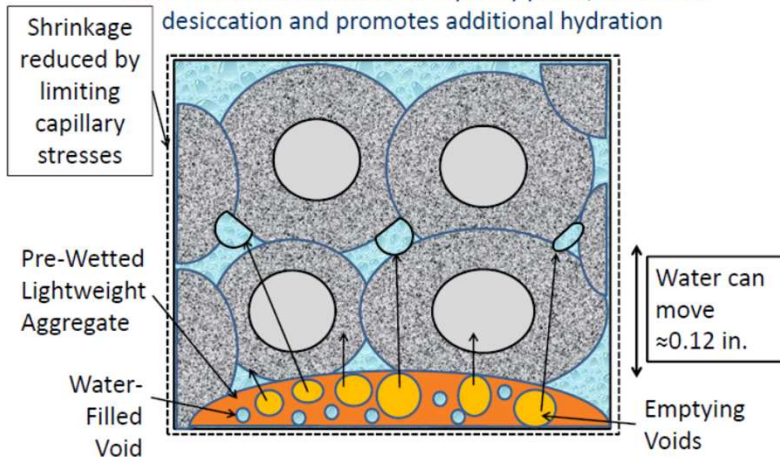
Desiccating capillary pores

Byard, 2011

INTERNAL CURING USING PREWETTED LIGHTWEIGHT AGGREGATE

Chemical Shrinkage and Self-Desiccation

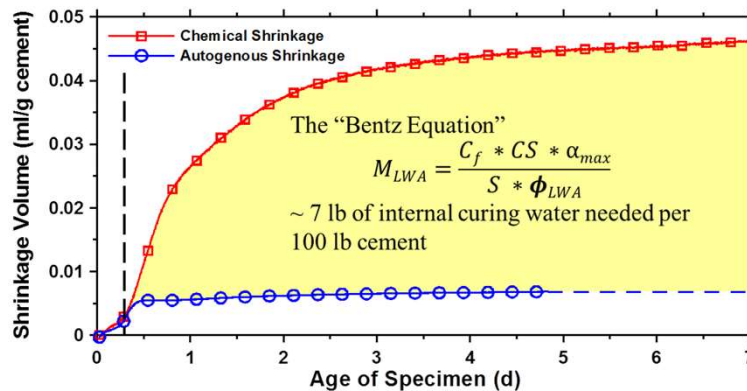
Water moves from LWA in to capillary pores, minimizes desiccation and promotes additional hydration



Byard, 2011

INTERNAL CURING USING PREWETTED LIGHTWEIGHT AGGREGATE

- How much vapor space would be created, estimated from chemical shrinkage
- Vapor space develops after set



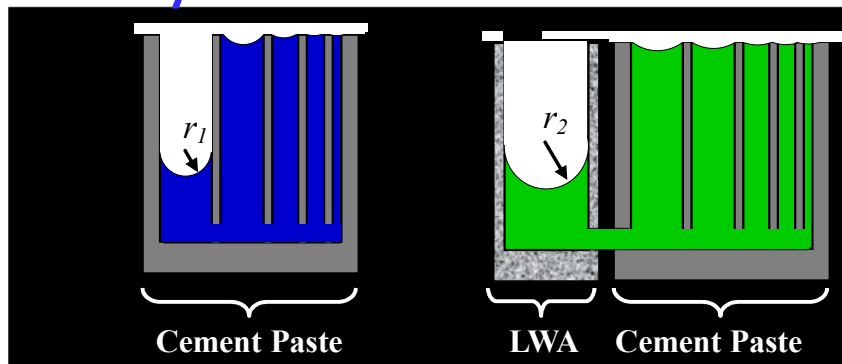
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For Internal Curing Replace a Portion of Natural Sand With Lightweight Aggregate Sand (LWAS)



INTERNAL CURING USING PREWETTED LIGHTWEIGHT AGGREGATE

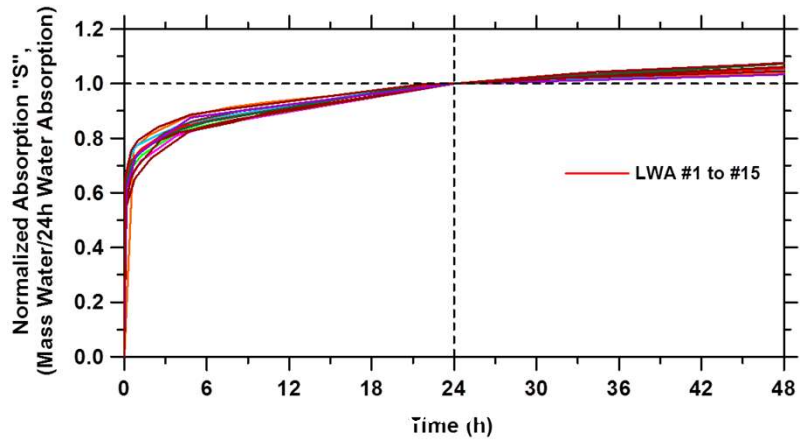
Why can LWA be used for IC?



- Largest pores will empty first
- The saturated LWA provides water to the paste and keeps a large pore full

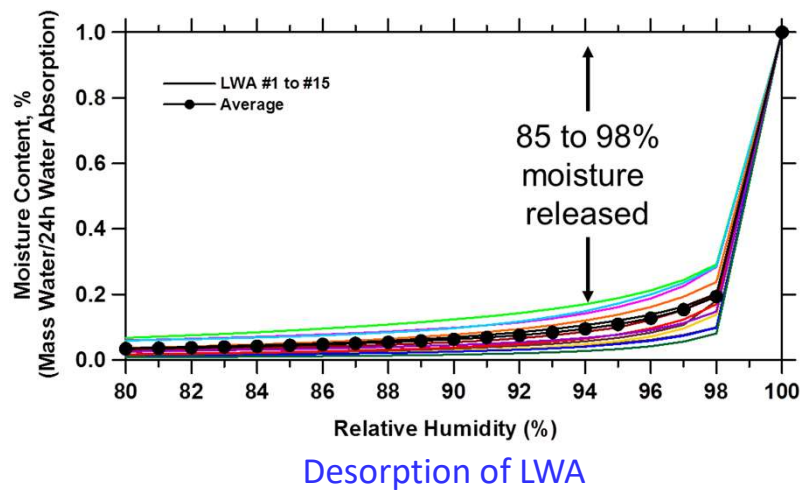
INTERNAL CURING USING PREWETTED LIGHTWEIGHT AGGREGATE

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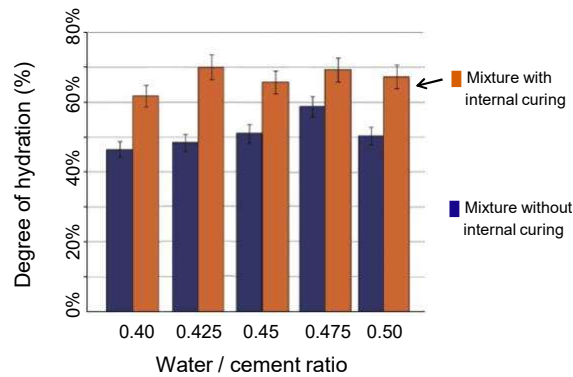
INTERNAL CURING USING PREWETTED LIGHTWEIGHT AGGREGATE

Why can LWA be used for IC?



INTERNAL CURING USING PREWETTED LIGHTWEIGHT AGGREGATE

More Hydration



Degree of hydration of cement @ 90 days, cured @ 50% RH

INTERNAL CURING USING PREWETTED LIGHTWEIGHT AGGREGATE

Less Shrinkage; Less Cracking



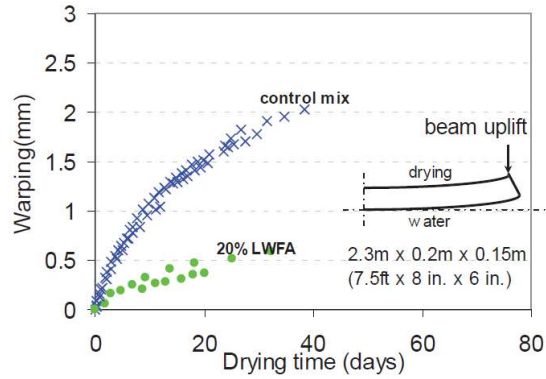
Plain 0.30 Concrete
0.6 mm wide crack
observed @ 12 days



IC 0.30 Concrete
0.4 mm wide crack
observed @ 43 days

INTERNAL CURING USING PREWETTED LIGHTWEIGHT AGGREGATE

Reduced Warping – 80% Reduction

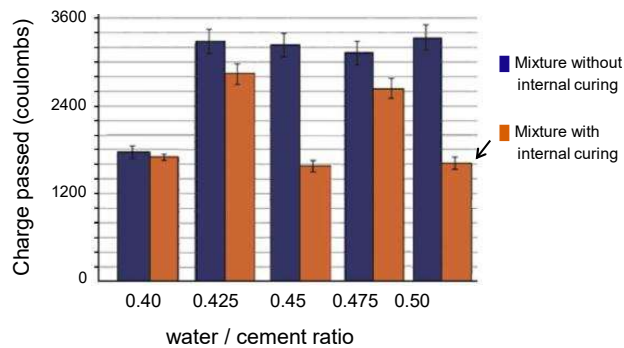


Wet base, 7 day cure then 73°F @ 50% RH on slab surface

Wei (2008)

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Lower Chloride Permeability



INTERNAL CURING USING PREWETTED LIGHTWEIGHT AGGREGATE

Internal Curing vs. No Internal Curing



Courtesy Florida DOT Materials Lab

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Internal Curing vs. No Internal Curing

Denver Water Test Slabs – 92°F ambient, 20% RH



No conventional curing

INTERNAL CURING USING PREWETTED LIGHTWEIGHT AGGREGATE

Denver Water – 10 million gallon tank
Lone Tree – 1300 yard slab pour



INTERNAL CURING USING PREWETTED LIGHTWEIGHT AGGREGATE

Denver Water Lone Tree – 10 million gallon tank
– 1300 yard slab pour



INTERNAL CURING USING PREWETTED LIGHTWEIGHT AGGREGATE

Denver Water Lone Tree – 10 million gallon tank
– Contractor requested change order to use IC mix for ring girder, columns and walls



INTERNAL CURING USING PREWETTED LIGHTWEIGHT AGGREGATE

Denver Water Lone Tree – 10 million gallon tank



INTERNAL CURING USING PREWETTED LIGHTWEIGHT AGGREGATE

Denver Water Lone Tree – 10 million gallon tank
– 8" thick PT roof slab placed monolithically

**INTERNAL CURING** USING PREWETTED LIGHTWEIGHT AGGREGATE

- Using IC resulted in an 80% reduction in shrinkage cracks compared to similar size tanks built previously (squirts, spurts, and drips)
- Based on the Lonetree Basin project success, Denver Water has continued to use IC:
 - Highlands - 10 MG tank completed in 2015

INTERNAL CURING USING PREWETTED LIGHTWEIGHT AGGREGATE

Denver Water Highlands – 10 million gallon tank

**INTERNAL CURING** USING PREWETTED LIGHTWEIGHT AGGREGATE

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 - Ashland – Two 10 MG tanks will be completed this year

INTERNAL CURING USING PREWETTED LIGHTWEIGHT AGGREGATE

Denver Water Ashland – Two 10 million gallon tanks

**INTERNAL CURING** USING PREWETTED LIGHTWEIGHT AGGREGATE

- Using IC resulted in an 80% reduction in shrinkage cracks compared to similar size tanks built previously (squirts, spurts, and drips)
- Based on the Lonetree Basin project success, Denver Water has continued to use IC:
 - Highlands - 10 MG tank completed in 2015
 - Ashland – Two 10 MG tanks will be completed this year
 - Hill Crest – Three 15 MG tanks currently under construction, to be completed in 2018

INTERNAL CURING USING PREWETTED LIGHTWEIGHT AGGREGATE

Denver Water Hill Crest – Three 15 million gallon tanks



INTERNAL CURING USING PREWETTED LIGHTWEIGHT AGGREGATE

Denver Water Hill Crest – Three 15 million gallon tanks



INTERNAL CURING USING PREWETTED LIGHTWEIGHT AGGREGATE

Denver Water Hill Crest – Three 15 million gallon tanks



INTERNAL CURING USING PREWETTED LIGHTWEIGHT AGGREGATE



INTERNAL CURING USING PREWETTED LIGHTWEIGHT AGGREGATE

Illinois Tollway Bridge Decks

- 100 Year Design Life
- Stainless Steel Re-bar
- Jointless
- Load Limit Increased
 - 80,000 lbs to 120,000 lbs
- Performance Based Concrete Spec
 - Includes IC as an option

INTERNAL CURING USING PREWETTED LIGHTWEIGHT AGGREGATE

Success of Tollway Crack-Resistant HPC Mixes Developed through Research

31 of 77 HPC decks built last three years developed cracks

- Three classified as having isolated shrinkage cracks
- Four possibly having widespread shrinkage cracks

Of 49 mainline decks, only 17 developed cracks of any kind

- Seven having shrinkage cracks (extensive shrinkage cracking on four mainline bridges)



INTERNAL CURING USING PREWETTED LIGHTWEIGHT AGGREGATE

Summary of Cracking

- 44 of 77 decks built with SRA mixes
- 21 of 77 decks built with saturated lightweights
- 12 of 77 decks built with SRA and lightweights both
 - 17 of 31 decks that cracked were constructed with SRA-only HPC mixes
 - 8 of 31 decks that cracked were constructed with saturated lightweight fines only in the HPC mixes
 - 6 of 31 decks that cracked were constructed with combination of both in the HPC mix

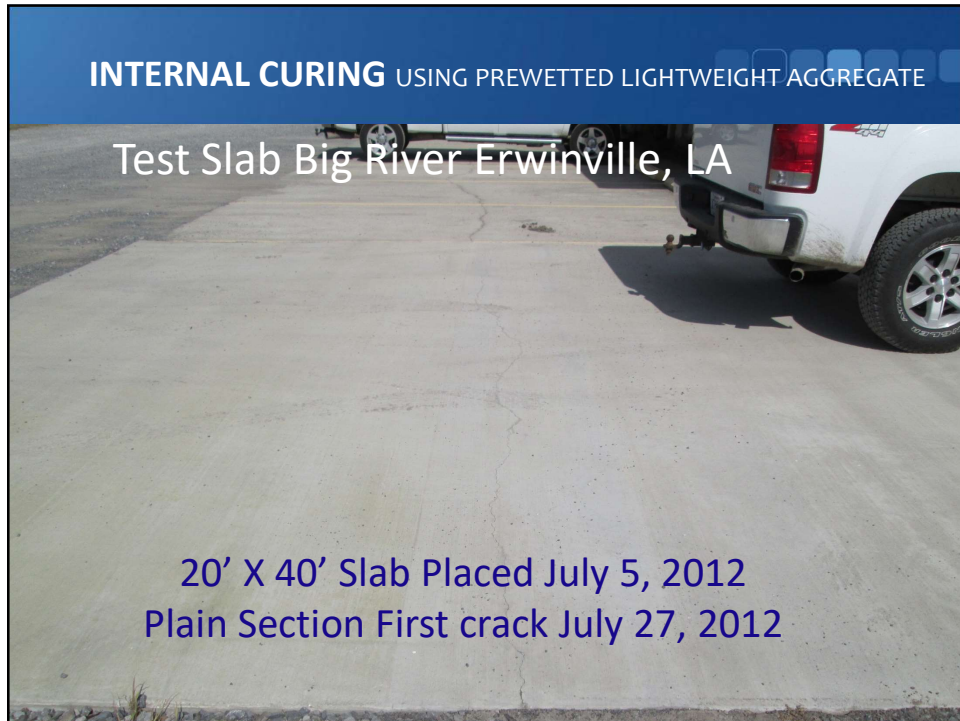


Presented by Steve Gillen on April 27, 2016

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INTERNAL CURING USING PREWETTED LIGHTWEIGHT AGGREGATE
New Standards

ACI (308-213)R-13

**Report on Internally Cured
Concrete Using Prewetted
Absorptive Lightweight Aggregate**

Reported by ACI Committee 308
and ACI Committee 213

Committee 308
has begun the
process of
converting the
**Report to a
Guide**

 American Concrete Institute®

INTERNAL CURING USING PREWETTED LIGHTWEIGHT AGGREGATE

NISTIR 7765

Internal Curing: A 2010 State-of-the-Art Review

Dale P. Bentz
W. Jason Weiss

2010!!

NIST
National Institute of
Standards and Technology
U.S. Department of Commerce

INTERNAL CURING USING PREWETTED LIGHTWEIGHT AGGREGATE

Using Internal Curing

- NW concrete with IC is still normal weight concrete
 - Air content can still be determined using pressure meter
- Density is reduced by 3-5 lb / cu ft
- Design using ACI 318 for NWC
- No strength modifiers required

INTERNAL CURING USING PREWETTED LIGHTWEIGHT AGGREGATE

Using Internal Curing

- Absorbed water does not affect w/cm
 - But, need to determine the surface moisture
 - Easiest way: centrifuge
- Adjust batch water for surface moisture
- Absorbed water can be used to calculate how much LWA to use for IC

INTERNAL CURING USING PREWETTED LIGHTWEIGHT AGGREGATE

Centrifuge test

Moisture Property Calculations			
A	Mass of empty centrifuge bowl:	2174.2	Surface Moisture (%) = $\frac{B - D}{D}$
B	Mass of pre-wetted lightweight aggregate added to centrifuge bowl (800 ± 5 g):	2776.1	
C	Mass of centrifuge bowl and pre-wetted surface-dry aggregate after spinning:	2748.3	Absorption (%) = $\frac{D - C}{C}$
D	Subtract line A from line C, (D = C - A):		Total Moisture (%) = $\frac{B - C}{C}$
E	Mass of empty pan used for oven drying aggregate:	545.3	
F	Mass of pan and oven-dry aggregate:		
G	Subtract line E from line F, (G = F - E):		
Note: Total Moisture - Absorption = Surface Moisture			
Specific Gravity Calculations			
H	Mass of pycnometer filled with water to calibration mark:		$SG_{ova\ dry} = \frac{L}{J + H - K}$

INTERNAL CURING USING PREWETTED LIGHTWEIGHT AGGREGATE

Specifying Internal Curing

- Bentz Equation

The "Bentz Equation"

$$M_{LWA} = \frac{C_f * CS * \alpha_{max}}{S * \phi_{LWA}}$$

~ 7 lb of internal curing water needed per
100 lb cement

- ESCSI calculator at ESCSI.org
- Excel spreadsheet form
- DOT Methods

INTERNAL CURING USING PREWETTED LIGHTWEIGHT AGGREGATE

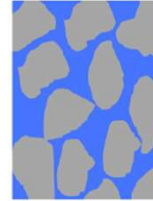
Specifying Internal Curing

- DOT Methods
 - NY DOT: 30% replacement of sand by volume
 - IL DOT 30% replacement of sand by volume
 - IN DOT: Bentz equation but in no case less than 30% replacement of sand by volume
 - LA DOTD: 225 lb to 275 lb pre-wetted LWFA per CY of concrete; reduce sand by the volume of LWFA
- Don't over-complicate it

INTERNAL CURING USING PREWETTED LIGHTWEIGHT AGGREGATE

Summary:

- Less shrinkage, less cracking
- More hydration & SCM reaction
- Improved transport properties
 - Lower water absorption
 - Lower chloride permeability & penetration
 - Increased durability
 - Increased service life



INTERNAL CURING USING PREWETTED LIGHTWEIGHT AGGREGATE

- So...why isn't IC being more widely used?
- Despite all the success, documentation, and information, The Same FAQ's:
 - How do I know this really works? We need to wait 3, 5, 10, 30, etc. years to find out.
 - What's the slump of IC concrete?
 - Will it affect the strength?
 - This sounds like lab crete. How do I know it will work in the field?
 - How do I know if it will work in my state?

INTERNAL CURING USING PREWETTED LIGHTWEIGHT AGGREGATE

- Remember My Cousin Vinny?
- <https://youtu.be/OdCRRc9zlas?t=35>
-

There's a lesson there for all of us!

INTERNAL CURING USING PREWETTED LIGHTWEIGHT AGGREGATE**INNOVATION**

- Example 1 – iPhone

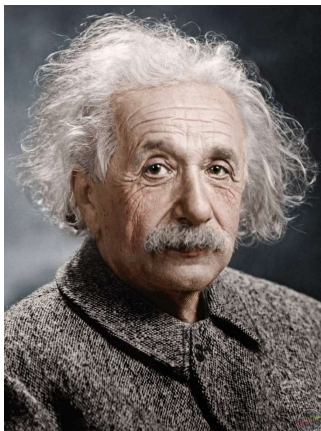


APPLE IPHONE AND APP STORE,
2007 AND 2008

- Example 2 – “New” Admixtures
 - 20 Years!

INTERNAL CURING USING PREWETTED LIGHTWEIGHT AGGREGATE**INNOVATION?**

- Excuses
 - I don't have enough aggregate bins
 - I'll have to prewet the LWA.
 - The wet LWA will make batching more difficult
 - I'll have to do more QC, monitor moisture content, buy a centrifuge, etc.,etc.
- If you're looking for an excuse, any excuse will do


INTERNAL CURING USING PREWETTED LIGHTWEIGHT AGGREGATE

- “We can't solve problems by using the same kind of thinking we used when we created them.”

The Choice is Yours

Continue Testing Internal Curing
As a Trial Material – What Criteria Do We Need ?

Add Internal Curing to
the Tool Box



Choose to Not
Internal Cure and
Continue Placing
Decks as We Are
While we Search
For Solutions to
Reduce Cracking

IF YOU CHOOSE NOT TO
DECIDE
YOU STILL HAVE
MADE
CHOICE

Weiss, 2017

INTERNAL CURING USING PREWETTED LIGHTWEIGHT AGGREGATE

- Bonus Material
 - TCG on Predicted Service Life
 - Schindler on LWA in Mass Concrete

INTERNAL CURING USING PREWETTED LIGHTWEIGHT AGGREGATE

● Service Life Modeling



Determination of Transport Properties of Lightweight Aggregate Concrete for Service Life Modeling

January 27, 2017

INTERNAL CURING USING PREWETTED LIGHTWEIGHT AGGREGATE

● Stadium[®] Service Life Analysis

Table 12 STADIUM Predictions of Service Life (6 years after corrosion initiation)

Concrete	LW1	LW2	ALW	C	IC	LWF
Service Life (years)	43	41	45	34	43	60
Increase over control	26%	21%	32%	--	26%	76%

INTERNAL CURING USING PREWETTED LIGHTWEIGHT AGGREGATE

● Life 365™ Service Life Analysis

Table 10 Life 365™ Predictions of Service Life (6 years after corrosion initiation)

Concrete	LW1	LW2	ALW	C	IC	LWF
Service Life (years)	37	47	89	30	41	73
Increase over control	23%	57%	197%	--	37%	143%

INTERNAL CURING USING PREWETTED LIGHTWEIGHT AGGREGATE

● Conclusions

- The addition of a small quantity of LW fines for internal curing was shown to reduce restrained shrinkage cracking and to increase compressive strength and the service life.
- Total replacement of NW fines with LW fines could increase the service life of the concrete up to a factor of 1.5 to 3.

Schindler on Mass Concrete

- “Although an increasing amount of LWA in the concrete will increase the maximum concrete temperature in mass concrete applications, the increasing use of LWA will **reduce the modulus of elasticity, reduce the coefficient of thermal expansion, and eliminate autogenous shrinkage** effects, which all contribute to **improve [sic] the resistance to early-age cracking.**”

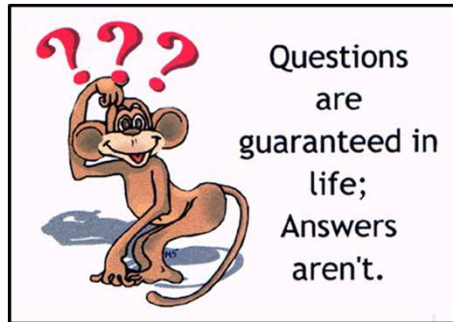
INTERNAL CURING USING PREWETTED LIGHTWEIGHT AGGREGATE

Summary:

- Significant increase in service life with IC
- Even more significant with increased volume of LWFA
- Enhances benefits of SCMs
- Significant life cycle cost reduction
- Increased sustainability

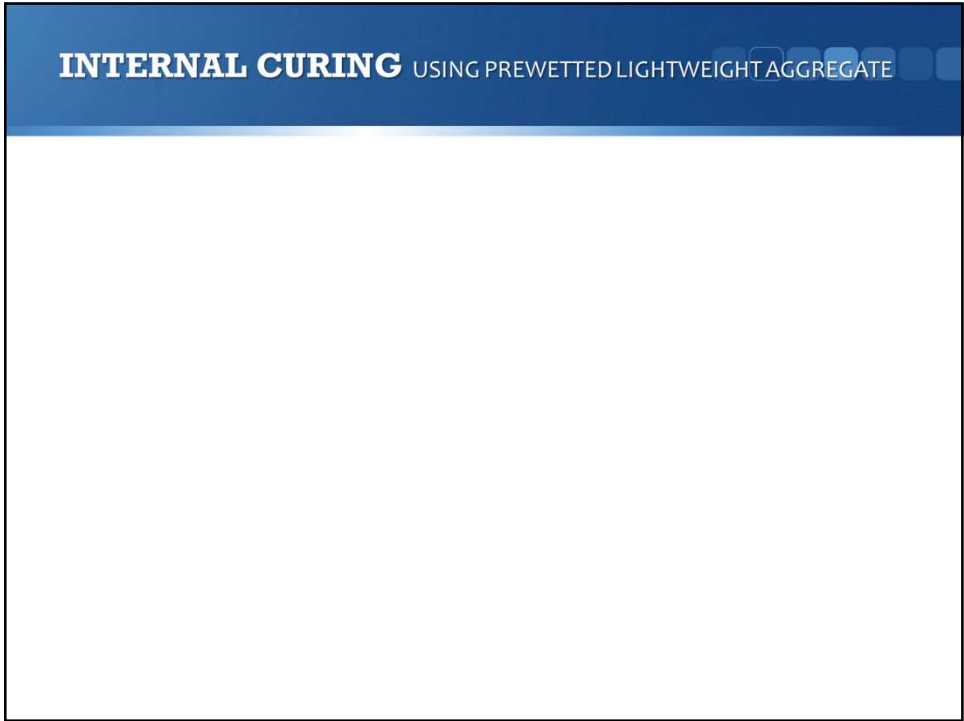
Parting Thoughts...

- And IC isn't new
- It's proven technology ready for implementing now
- "It's the best thing for concrete since w/cm ratio"

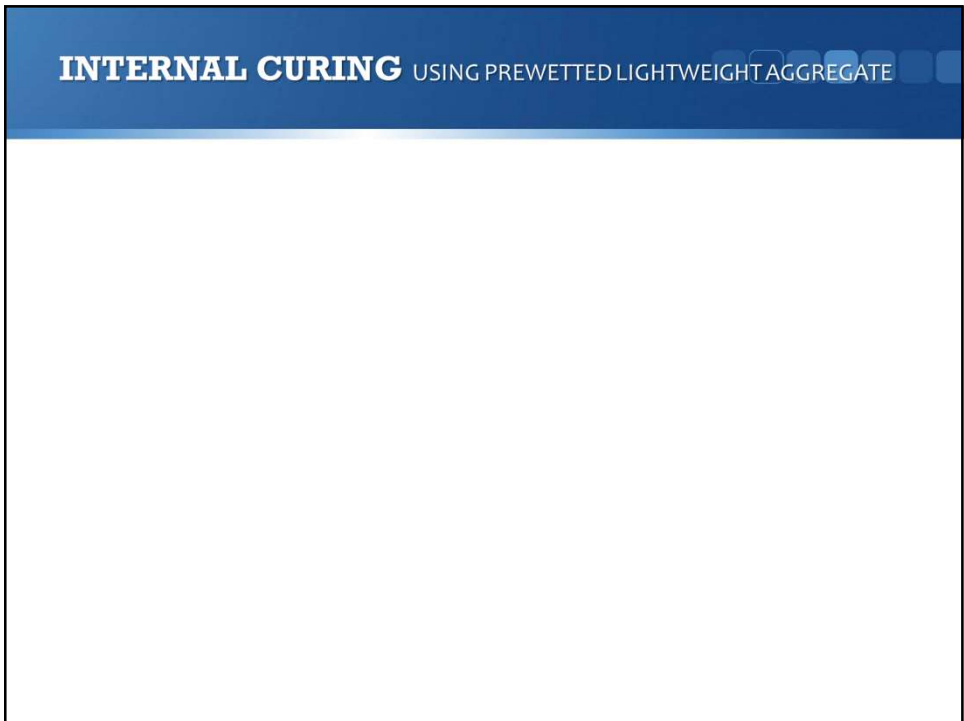


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