# 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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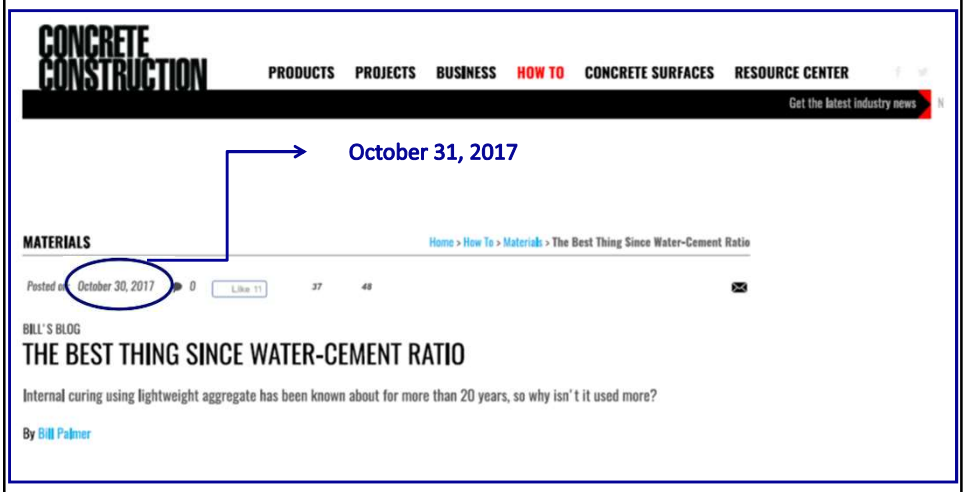
G.M. Marketing & Technical Sales
Trinity Lightweight

# Internal Curing



## INTERNAL CURING USING PREWETTED LIGHTWEIGHT AGGREGATE

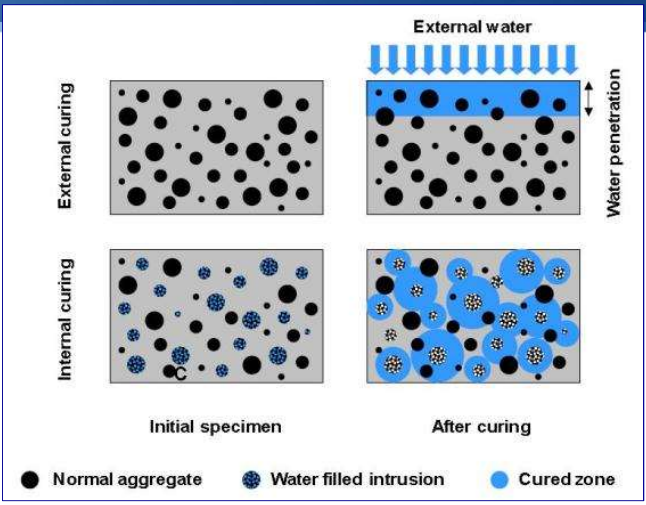
What is the biggest complaint about concrete?

## 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




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

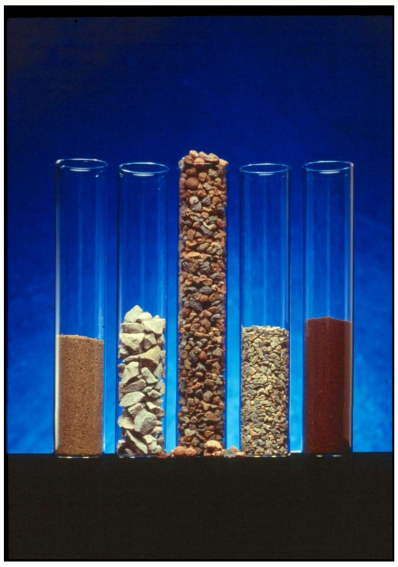
## INTERNAL CURING USING PREWETTED LIGHTWEIGHT AGGREGATE

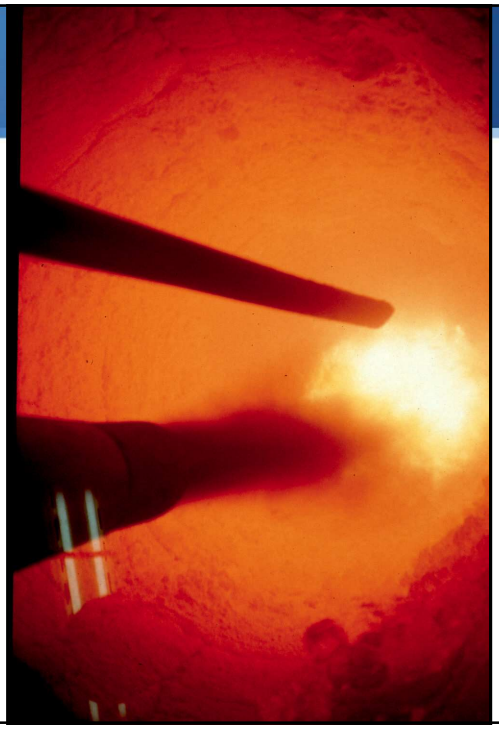
**ACI CT-13 Definition:** Internal Curing: *"process by which the hydration of cement continues because of the availability of internal water that is not part of the mixing water"*

## 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



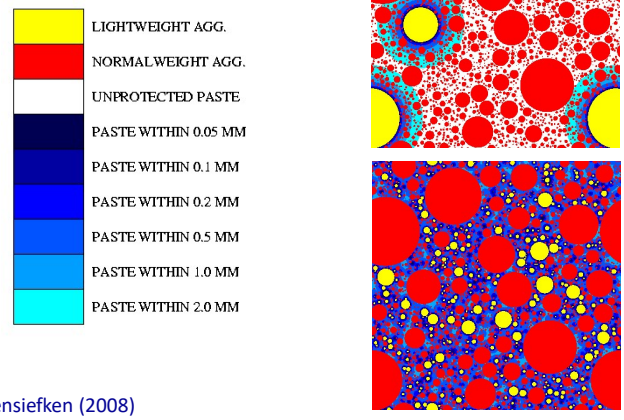


Expanded at 2000° F

## INTERNAL CURING USING PREWETTED LIGHTWEIGHT AGGREGATE

## INTERNAL CURING USING PREWETTED LIGHTWEIGHT AGGREGATE

### It's All About the Distribution




Henkensiefken (2008)

## INTERNAL CURING USING PREWETTED LIGHTWEIGHT AGGREGATE

### Benefits of Internal Curing

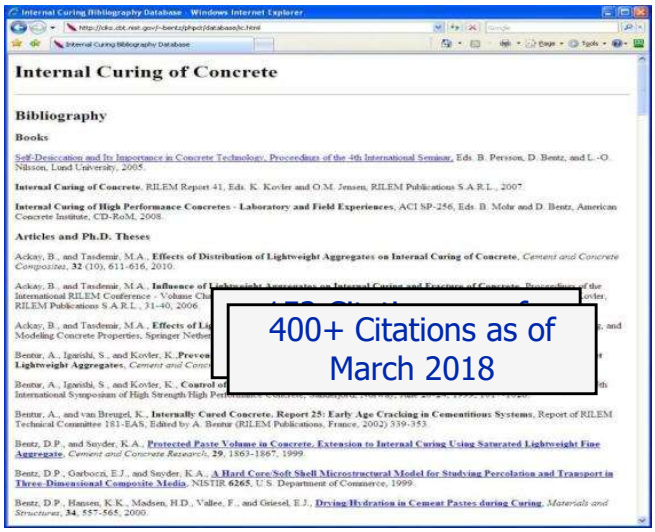
- Reduces shrinkage, delays cracking
- Improves fluid transport properties
  - lower water absorption
  - lower chloride permeability & penetration
- More cement hydration & SCM reaction
  - More efficient use
  - Less cement or more strength

## INTERNAL CURING USING PREWETTED LIGHTWEIGHT AGGREGATE

**Results**

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

## INTERNAL CURING USING PREWETTED LIGHTWEIGHT AGGREGATE



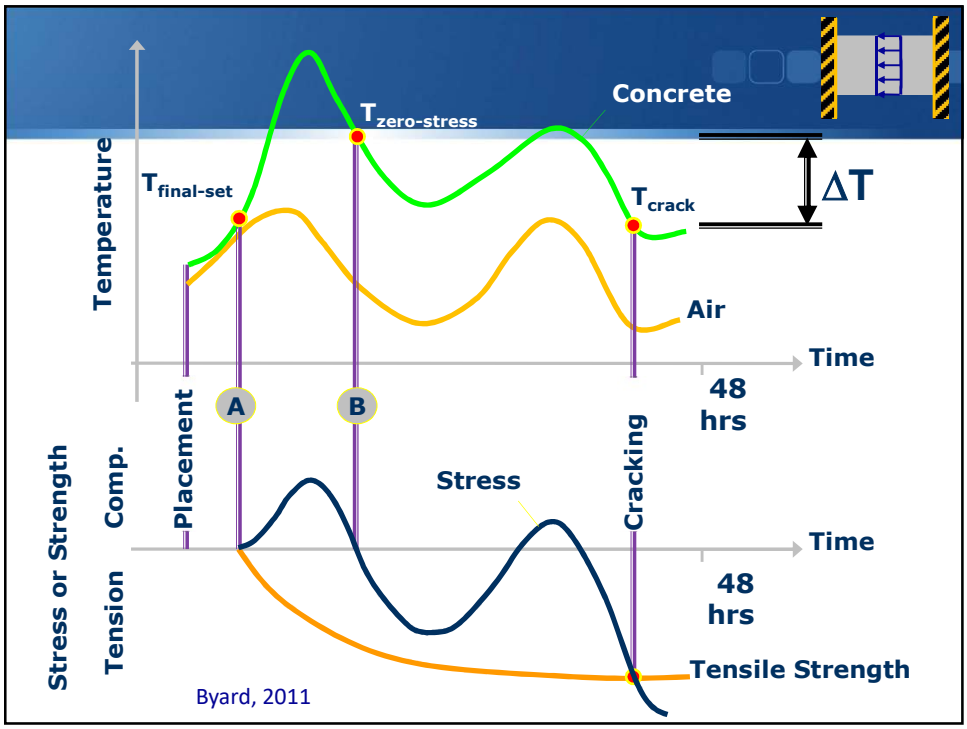
**INTERNAL CURING** USING PREWETTED LIGHTWEIGHT AGGREGATE

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

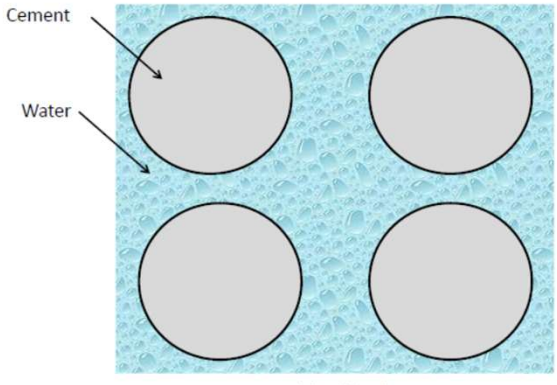
### Stress Development Mechanisms

- 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)

## INTERNAL CURING USING PREWETTED LIGHTWEIGHT AGGREGATE

### Chemical Shrinkage and Self-Desiccation

t=0, water meets cement

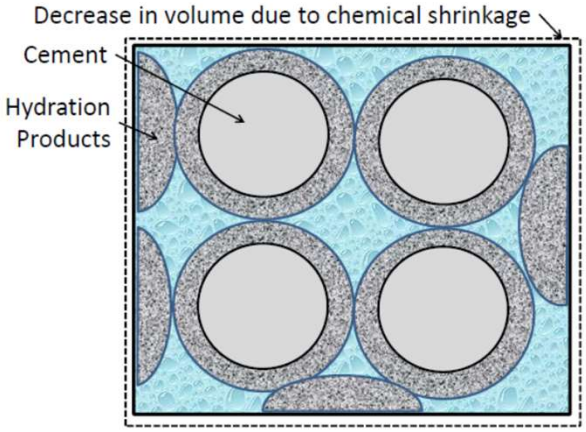



Byard, 2011

## INTERNAL CURING USING PREWETTED LIGHTWEIGHT AGGREGATE

### Chemical Shrinkage and Self-Desiccation

t=initial set, hydration products form skeleton

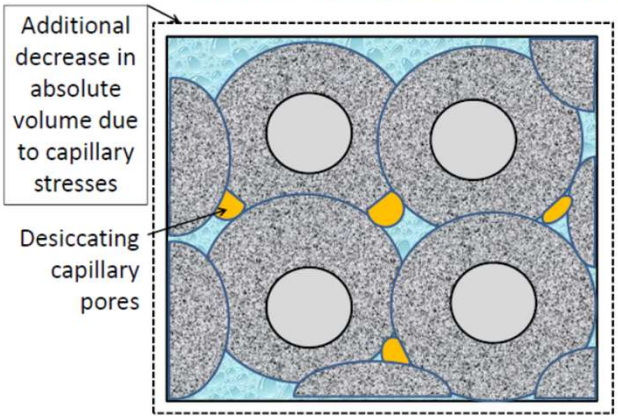



Byard, 2011

## 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




Byard, 2011

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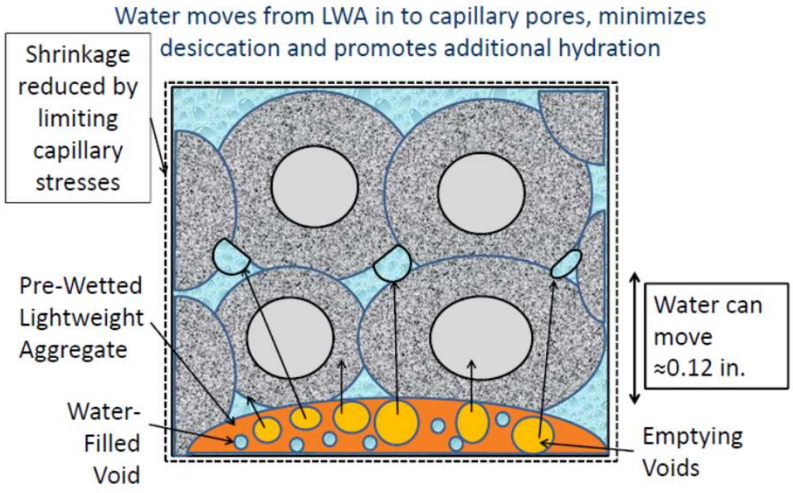
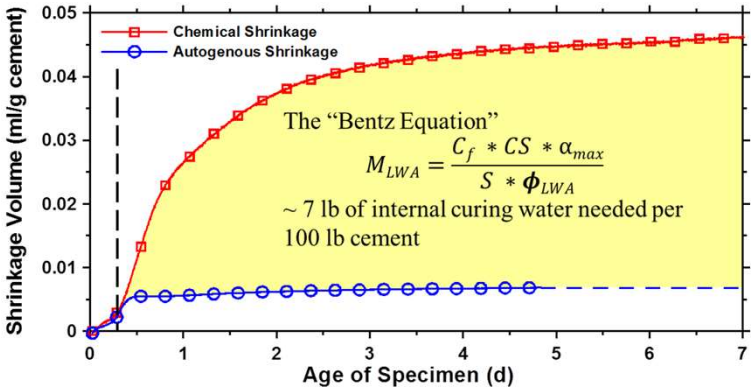
### Chemical Shrinkage and Self-Desiccation




Byard, 2011

## INTERNAL CURING USING PREWETTED LIGHTWEIGHT AGGREGATE

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



## INTERNAL CURING USING PREWETTED LIGHTWEIGHT AGGREGATE

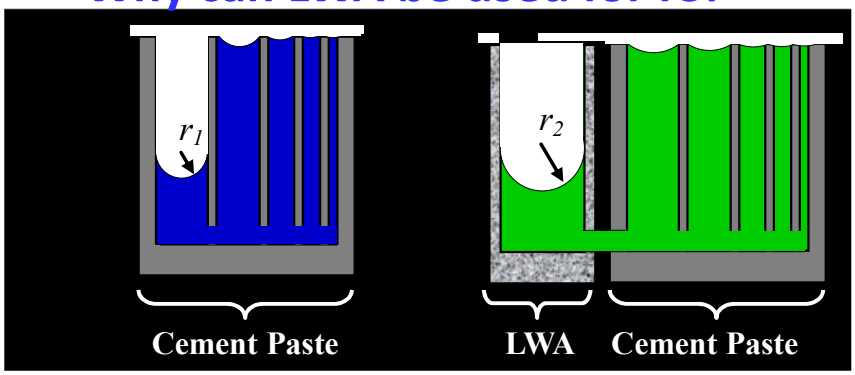
For Internal Curing Replace a Portion of Natural Sand With Lightweight Aggregate Sand (LWAS)


15-30% LWAS 70-85% Natural Sand

**Mixture Proportions of the Fine Aggregate In a Yard of Concrete**

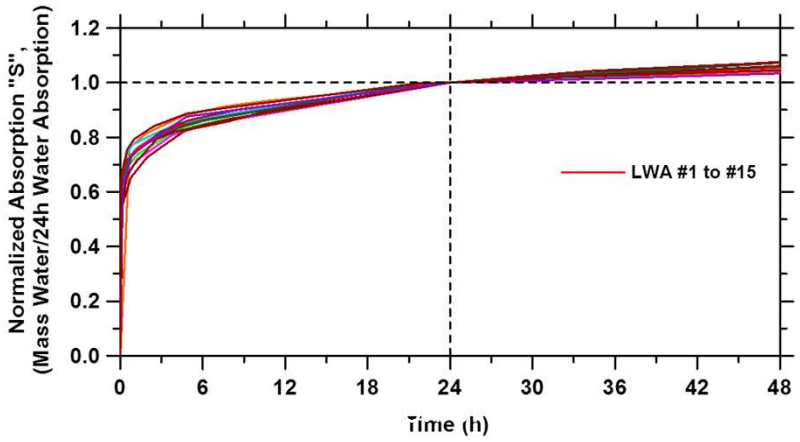
## INTERNAL CURING USING PREWETTED LIGHTWEIGHT AGGREGATE

### 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

## Why can LWA be used for IC?




INTERNAL CURING USING PREWETTED LIGHTWEIGHT AGGREGATE

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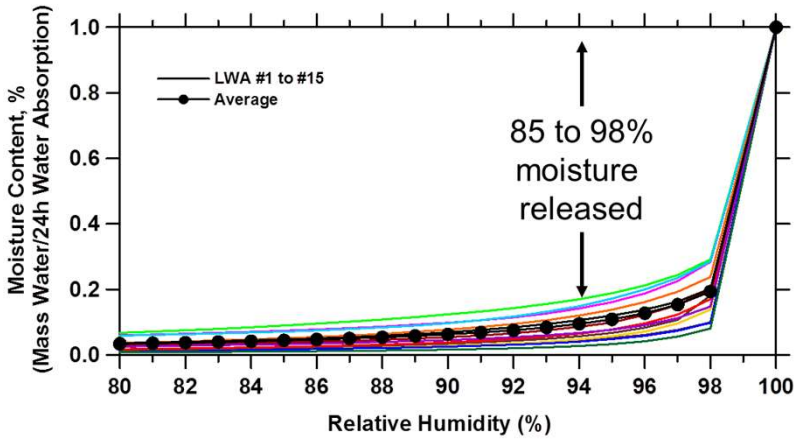
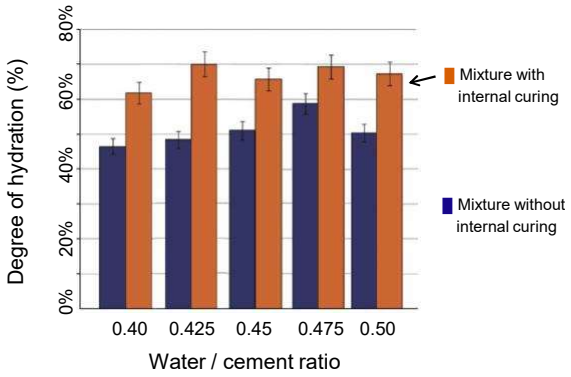



Desorption of LWA

## INTERNAL CURING USING PREWETTED LIGHTWEIGHT AGGREGATE

### More Hydration




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

## INTERNAL CURING USING PREWETTED LIGHTWEIGHT AGGREGATE

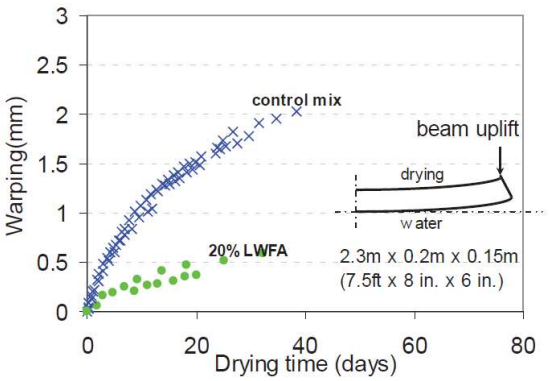
### Less Shrinkage; Less Cracking

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

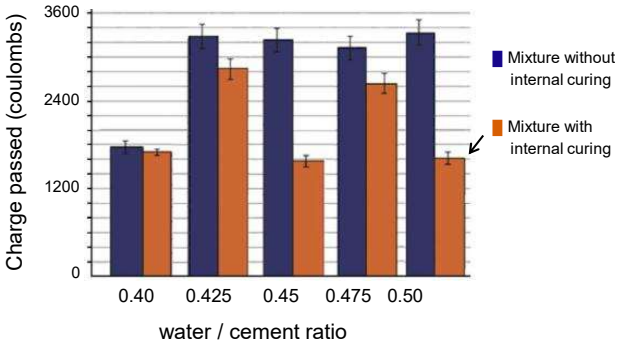



Wet base, 7 day cure then 73°F @ 50% RH on slab surface

Wei (2008)

## INTERNAL CURING USING PREWETTED LIGHTWEIGHT AGGREGATE

### Lower Chloride Permeability



## INTERNAL CURING USING PREWETTED LIGHTWEIGHT AGGREGATE

### Internal Curing vs. No Internal Curing


Courtesy Florida DOT Materials Lab

INTERNAL CURING USING PREWETTED LIGHTWEIGHT AGGREGATE

### 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

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- 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

## 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)

Illinois Tollway

Presented by Steve Gillen on April 27, 2016 65

## INTERNAL CURING USING PREWETTED LIGHTWEIGHT AGGREGATE

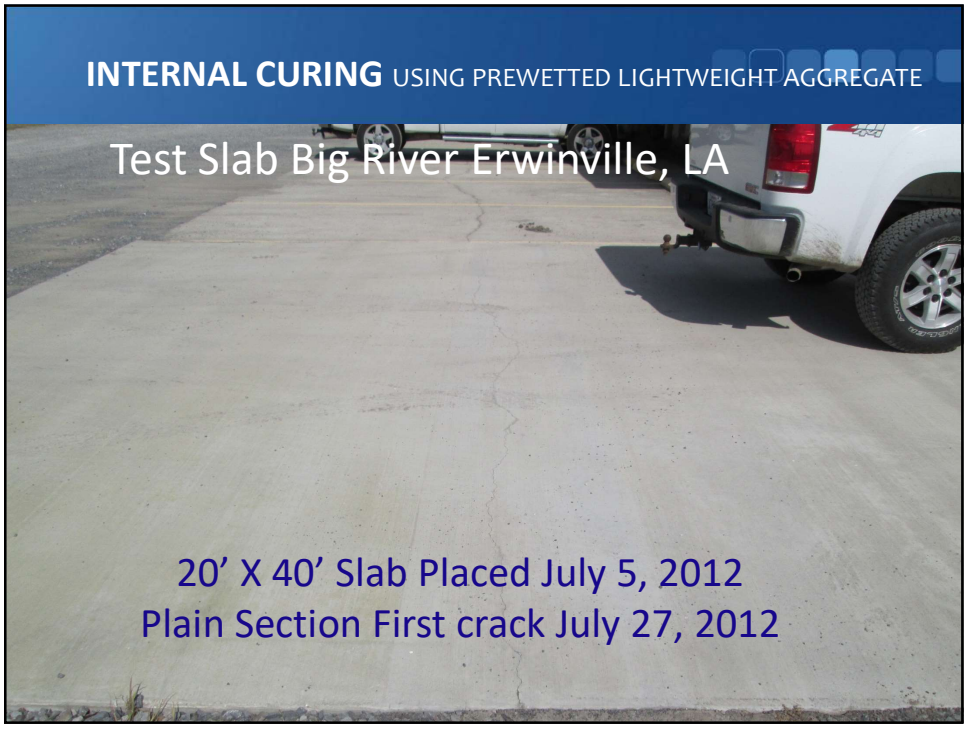
### Summary of Cracking

- 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

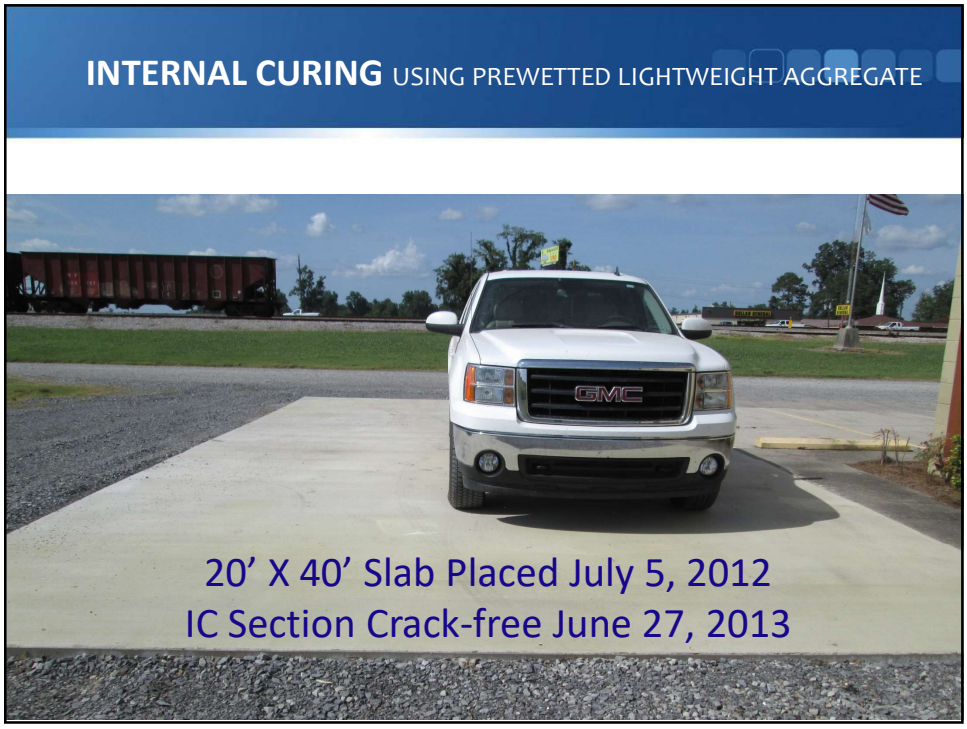


## INTERNAL CURING USING PREWETTED LIGHTWEIGHT AGGREGATE

## **INTERNAL CURING** USING PREWETTED LIGHTWEIGHT AGGREGATE



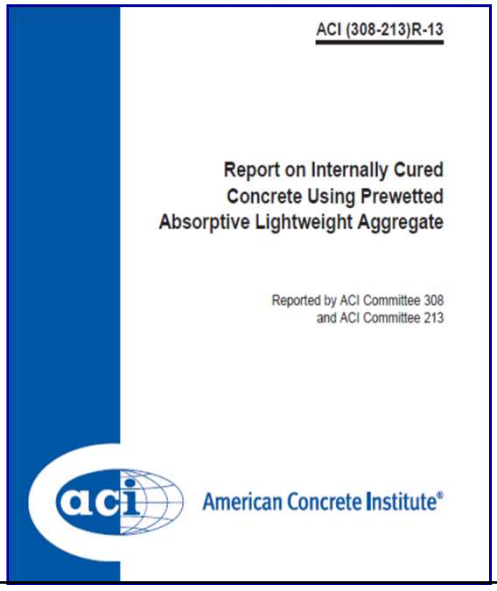

## **INTERNAL CURING** USING PREWETTED LIGHTWEIGHT AGGREGATE



20’ X 40’ Slab Placed July 5, 2012
IC Section First Crack July 16, 2013

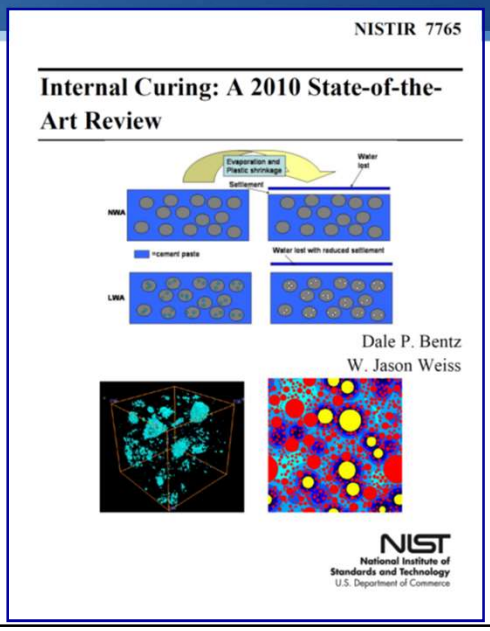
## INTERNAL CURING USING PREWETTED LIGHTWEIGHT AGGREGATE

New Standards




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

## INTERNAL CURING USING PREWETTED LIGHTWEIGHT AGGREGATE


NISTIR 7765

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

Dale P. Bentz
W. Jason Weiss

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

2010!!

## 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

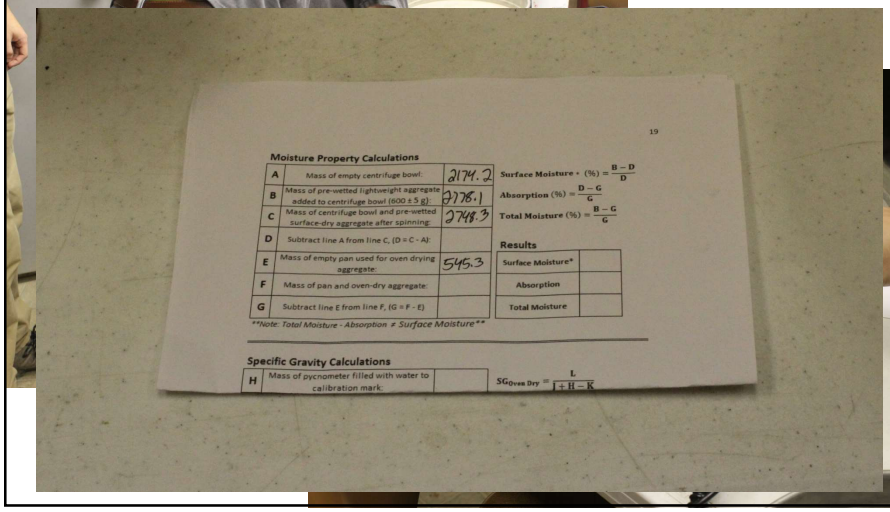
## INTERNAL CURING USING PREWETTED LIGHTWEIGHT AGGREGATE

### 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



## 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

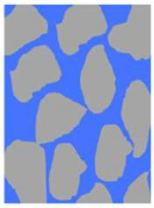
### Specifying Internal Curing

- 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

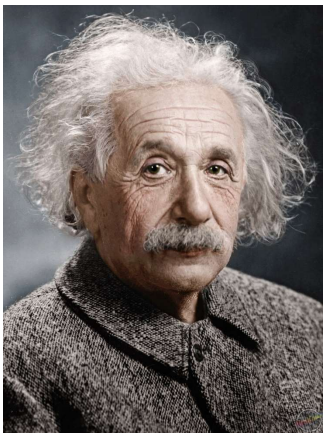
APPLE IPHONE AND APP STORE, 2007 AND 2008

- Example 2 – "New" Admixtures
  - 20 Years!

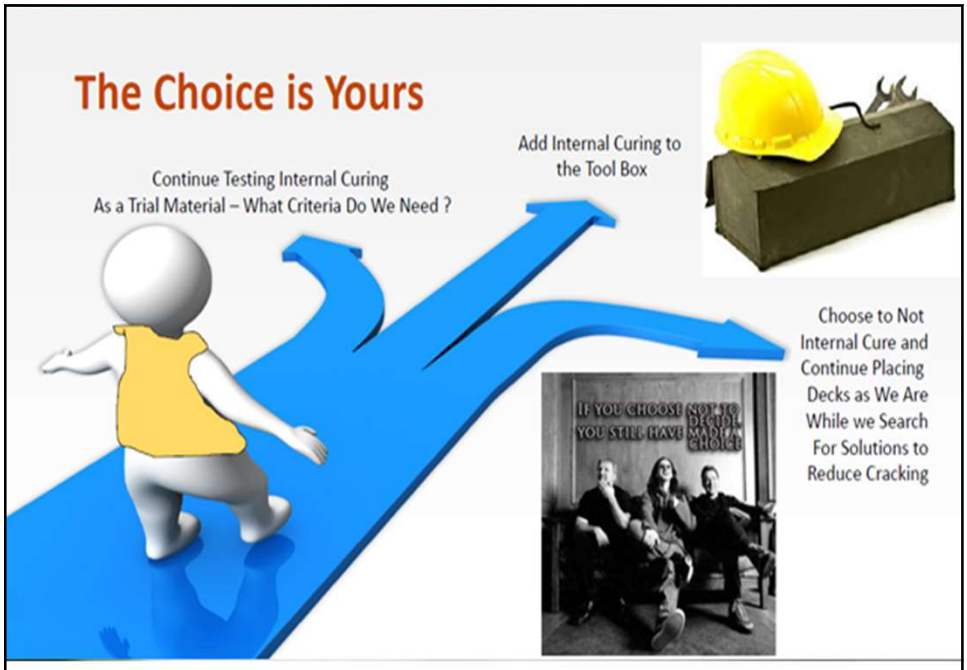
## INNOVATION?

- 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."




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

TCG TOURNEY CONSULTING GROUP

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**."

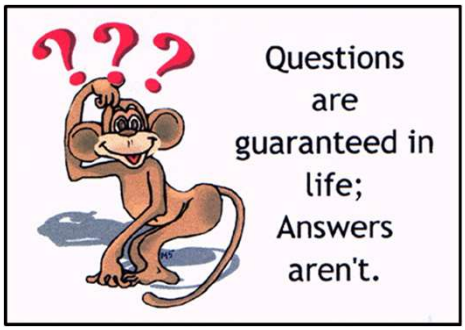
## INTERNAL CURING USING PREWETTED LIGHTWEIGHT AGGREGATE

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"




**INTERNAL CURING** USING PREWETTED LIGHTWEIGHT AGGREGATE

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