

Internal Curing – Lessons Learned and Inspiration from Walt Disney

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Concrete Problems

Background
Exo/Endo
Proportioning
Volume
Spacing
Advanced
Aggregates
Experiences
Field Work
Cracks
Patches
Agg Testing
Freezing
ASR
Sustainability
Dream it Do it

- American's spend 4.2 billion hours a year stuck in traffic
- Bridges (>25%) are structurally deficient or functionally obsolete
- Highways (>33%) are in poor or mediocre condition
- Cracked and spalling concrete
- Corroding steel reinforcement

DRINKING WATER

Poor infrastructure fails America, civil engineers report

January 28, 2009

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America's civil engineers think the nation's aging and rusty infrastructure is just not making the grade.

The American Society of Civil Engineers issued an infrastructure report card Wednesday giving a bleak cumulative ranking of D.

"We've been talking about this for many many years," Patrick Natale, the group's executive director, told CNN.

"We really haven't had the leadership or will to take action on it. The bottom line is that a failing infrastructure cannot support a thriving economy."

The civil engineers said the nation's D- roads cost motorists $67 billion a year in repairs and operating costs.

The ranking -- which grades the condition of 15 infrastructure entities such as roads, bridges and dams -- is the same as the the last time such a report was issued, in 2005. In 2001, the grade was D+, slightly better but still poor.

Curing

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- When concrete is placed it is sensitive and can be easily damaged if not treated properly
- We want to maintain appropriate temperature and moisture during the first few weeks
- Proper curing enables concrete to hydrate (chemically react) developing potential strength and durability
- Proper curing reduce stress and cracking potential due to drying or temperature changes

DiBella et al. 2011

- Important but frequently overlooked step

Concrete Curing
Exoskeleton vs. Endoskeleton

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- ACI–308: Action taken to maintain moisture and temperature conditions in a freshly placed cementitious mixture to allow hydraulic-cement hydration and, if applicable, pozzolanic reactions to occur

http://science.howstuffworks.com/environmental/earth/geology/dinosaur-bone-age.htm

External Curing

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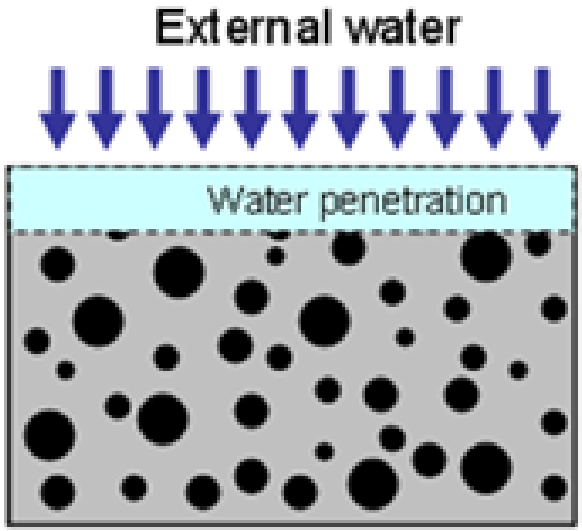
- Conventional concrete is done to the outside of the concrete



- Can think of this a little like a crab/lobster exoskeleton

http://express.howstuffworks.com/exp-exoskeleton.htm

Most Common Types of External Curing

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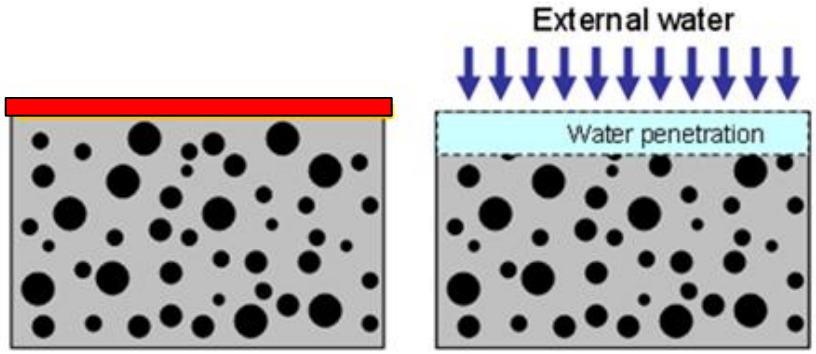
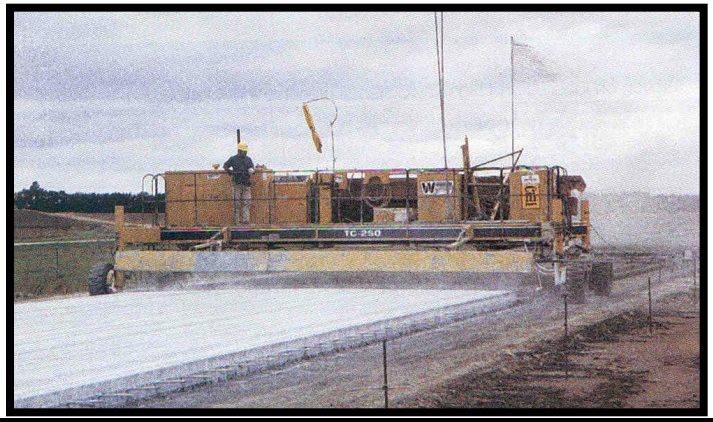
- Water Ponding, Sprinkling, Burlap: Supply Additional Water
- Curing Membranes: Only Reduce Loss of Water to the Environment





Internal Curing (IC)

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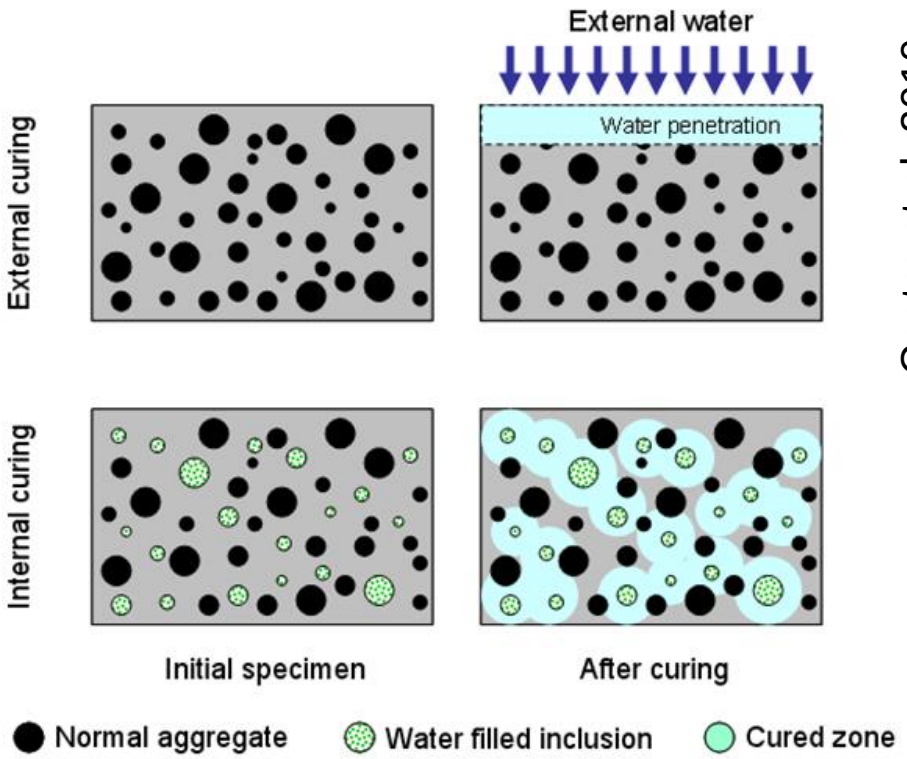
- IC works from the inside of concrete
- IC uses reservoirs of water that hide water before set to get a dense structure and make the water available after set for hydration



Castro et al. 2010

Proportioning Principles

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- How much LWA/water is needed – The majority of uses are performed based on replacing chemical shrinkage of the hydrating paste

- Aggregate Spacing – the LWA need to be well-spaced to allow water to reach all the paste
- Properties of the Aggregate – The aggregate needs to be able to absorb and release the water

Chemical Shrinkage

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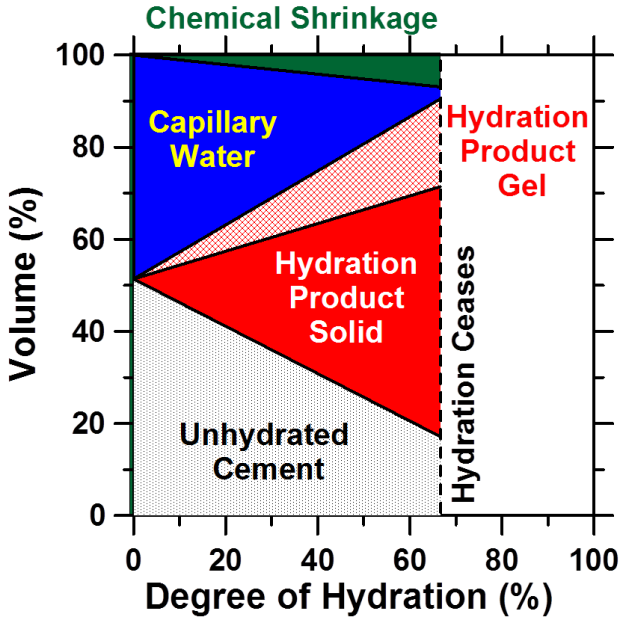
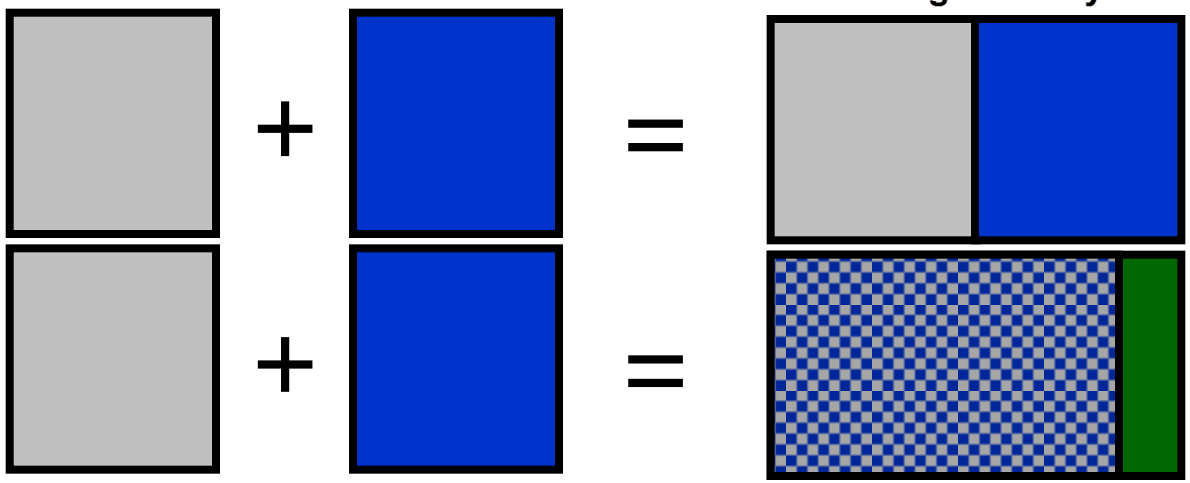
- Le Chatelier
- 1850-1936
- Volume of reactants larger than volume of the products
- Chemical Shrinkage





How Does Internal Curing Work?

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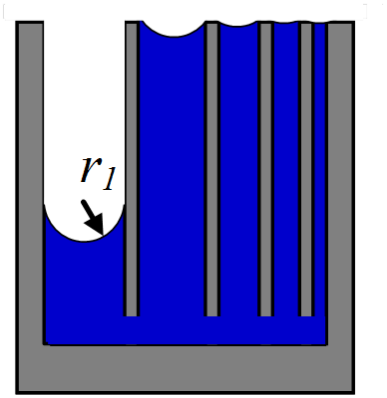
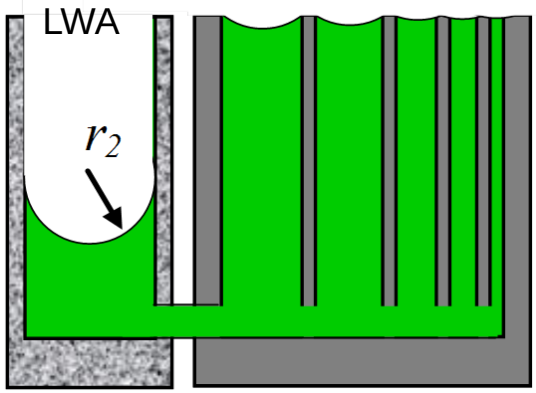
- Porous lightweight aggregate is 'prewetted' before mixing
- Water moves from the 'pores' in LWA to the paste on demand as needed
- This movement is due to fact that smaller pores want to remain 'water filled'



Conventional Concrete

Conceptual Model of Pores In Concrete



Internally Cured Concrete

Radlinska et al. 2007

Self Desiccation and Setting

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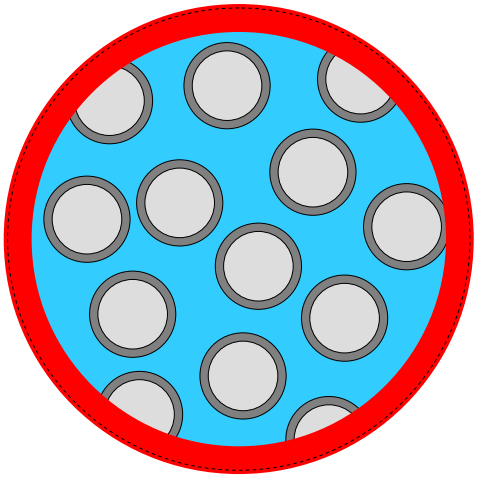

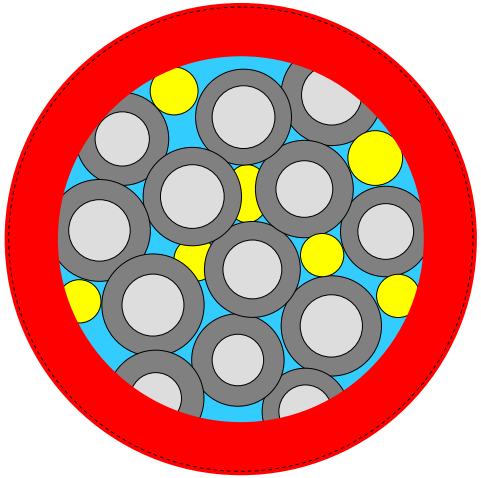

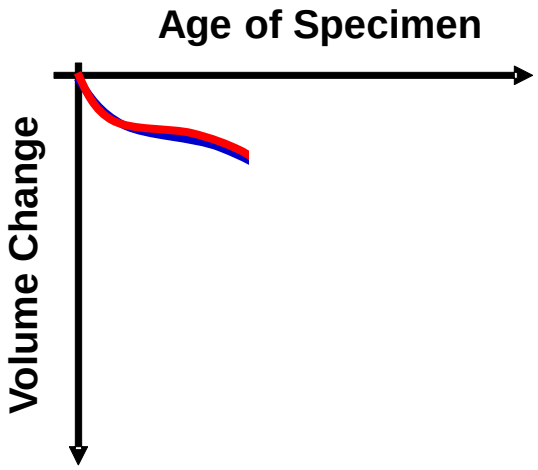

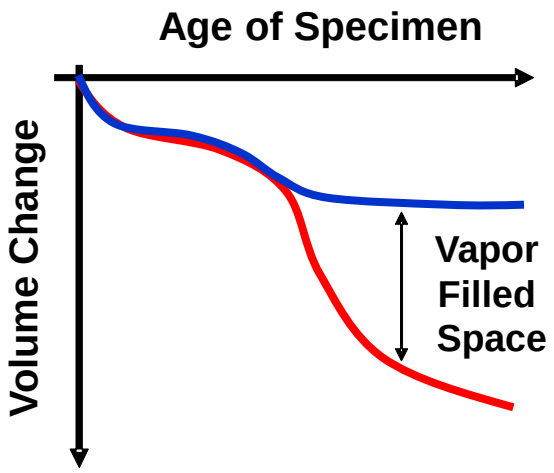

Sant et al.; Crouch et al. 2006

Chemical Shrinkage

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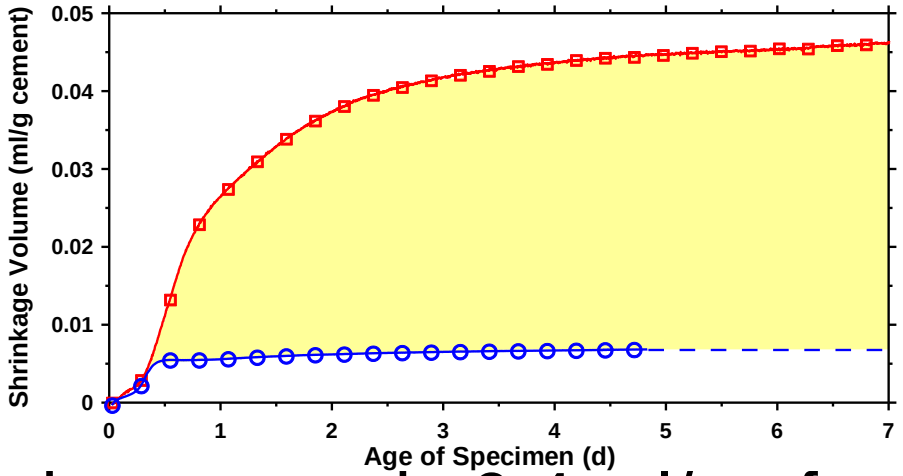
- Occurs in all cements
- Strictly speaking only the difference between the external and internal change needs to be used however it is practical to just use the entire CS



- A good first number to use is 6.4 ml/g of cement (cementitious material) and while this varies depending on chemistry (6.4 to 7 ml/g is a good place to start)

Mixture Proportioning for IC

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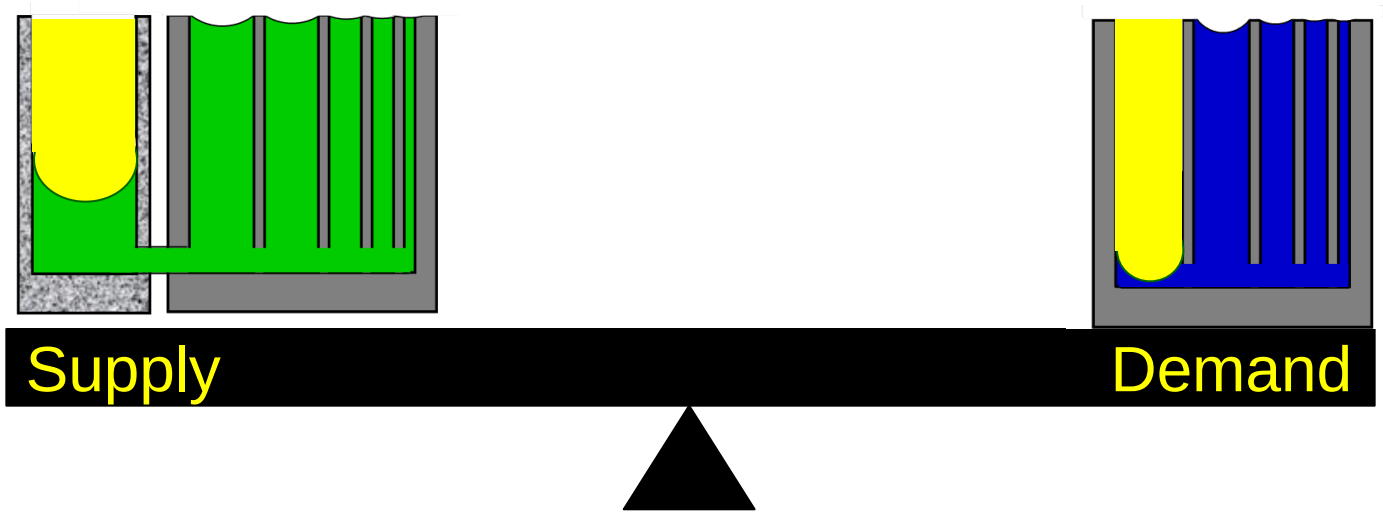
- Concept of proportioning mixtures for internal curing is simple



- Demand – Space created by chemical shrinkage (or other loss)
- Supply – Water stored in the LWA

Why is this an Issue in Lower w/c

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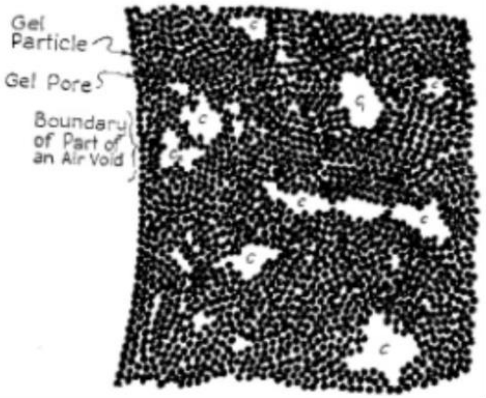
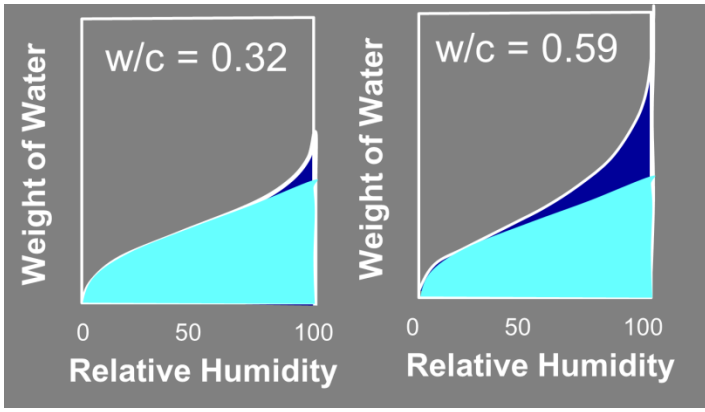
- Chemical Shrinkage (CS) is not very sensitive to w/c at early ages
- AS should decrease as w/c increases…..
- Do higher w/c have less self-desiccation ??
- Size of the voids:
  a) Capillary vs Gel
  b) Few/big voids
  c) Lower pressures



$$\sigma = \frac{2\gamma \cos\theta}{r}$$



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- How much LWA should we use ?
- Three Basic Methods
  - Rule of Thumb
    7 lbs per 100 lbs cementitious

  - Simple Calculation: Supply vs Demand

$$Supply = Demand$$

$$M_{Lwa}\ \emptyset\ S = C_f\ CS\ \alpha_{Max}$$

  - More Complicated Features
    - time dependent absorption
    - desorption (water release)
    - Features other than CS

$$M_{LWA} = \frac{C_f \times CS \times \alpha_{\max}}{t^A \times \phi_{LWA\,24h} \times \psi}$$

As Simple as Replacing a Volume of the Fine Aggregate Volume Proportions

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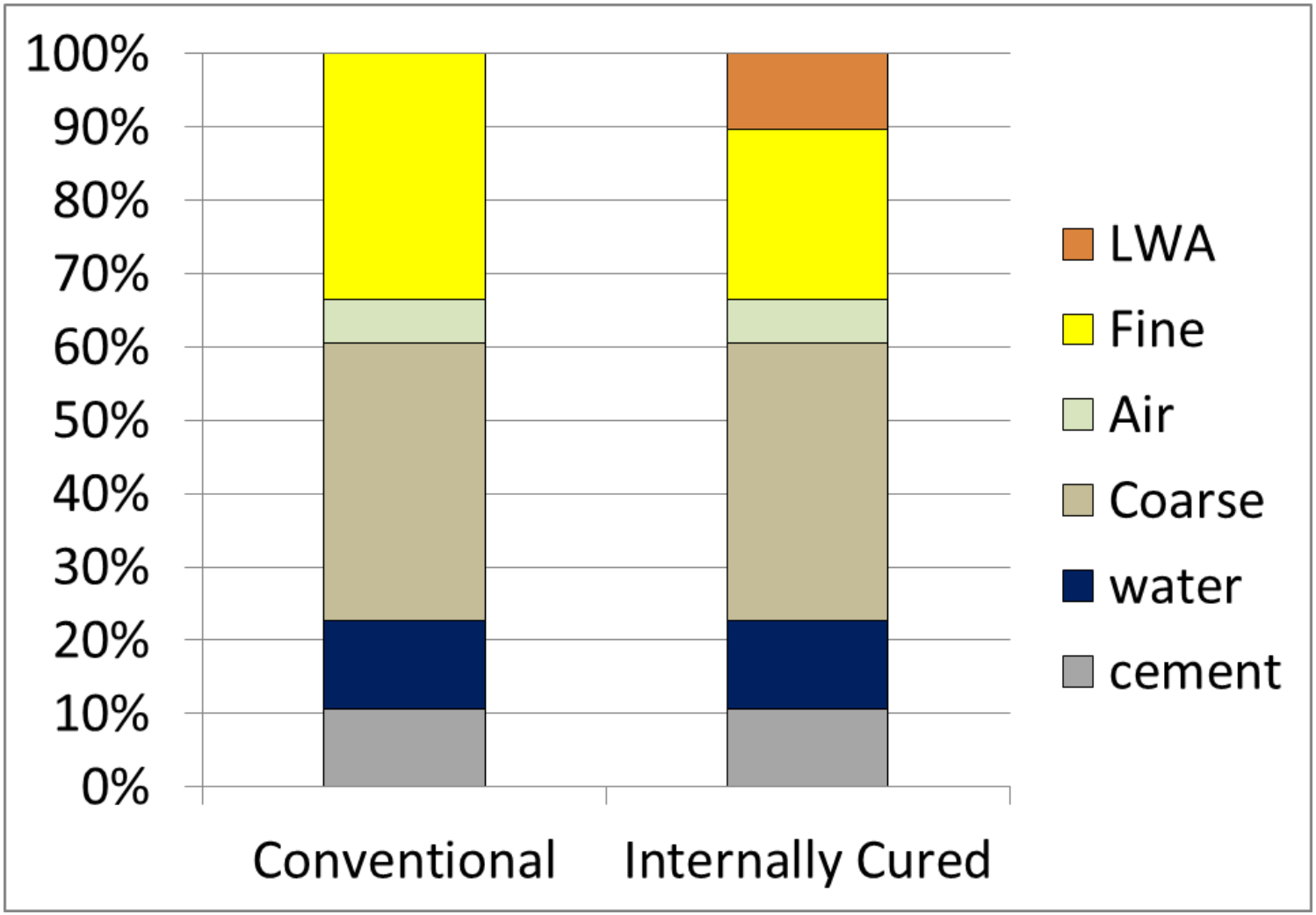

Aggregate Spacing
Internal Curing Water Distribution

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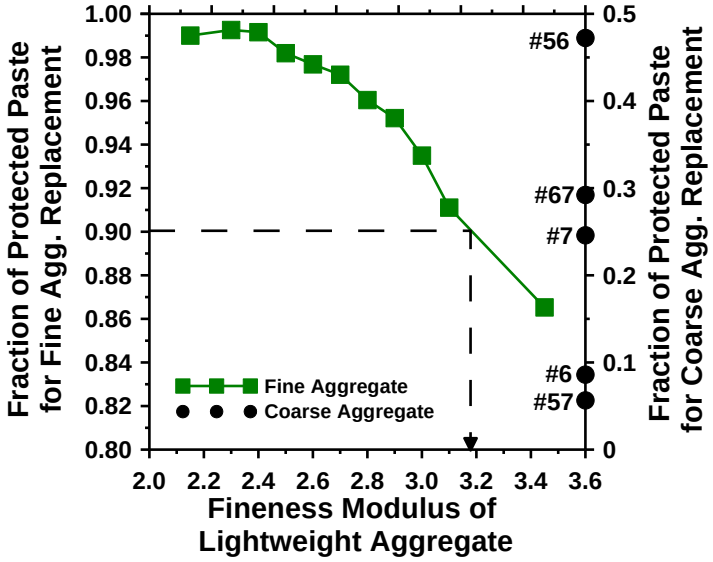
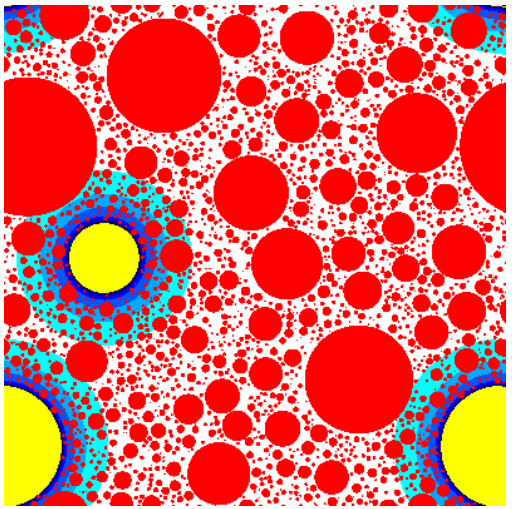
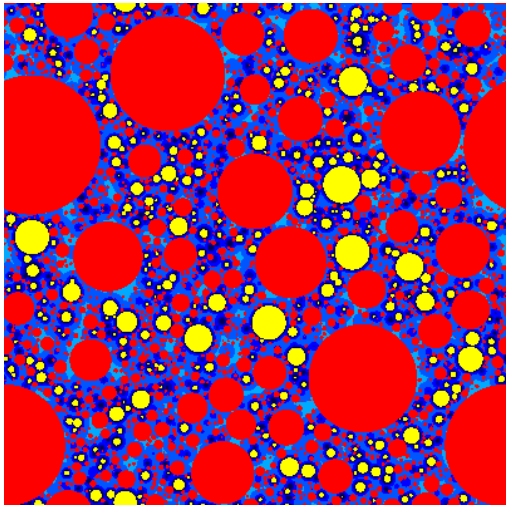
- Need paste to be within close proximity to LWA
- Fine aggregate protects more of the paste than the coarse LWA



Henkensiefken et al. 2009





Bentz

Lightweight Aggregate Structure

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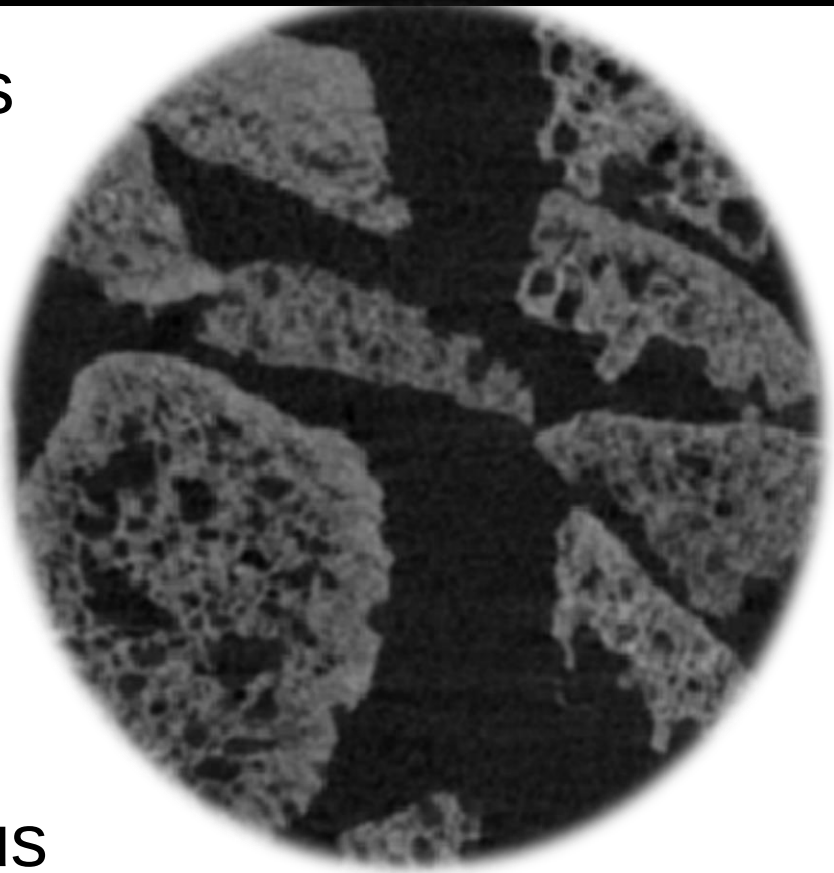
- #8 agg images from x-ray tomography
- A large volume of pores can be seen
- These pores come in various sizes and connectivity
- Pore size related to RH at water release



Titrk, Muench, Lura and Weiss 2009

Mixture Proportion Equation

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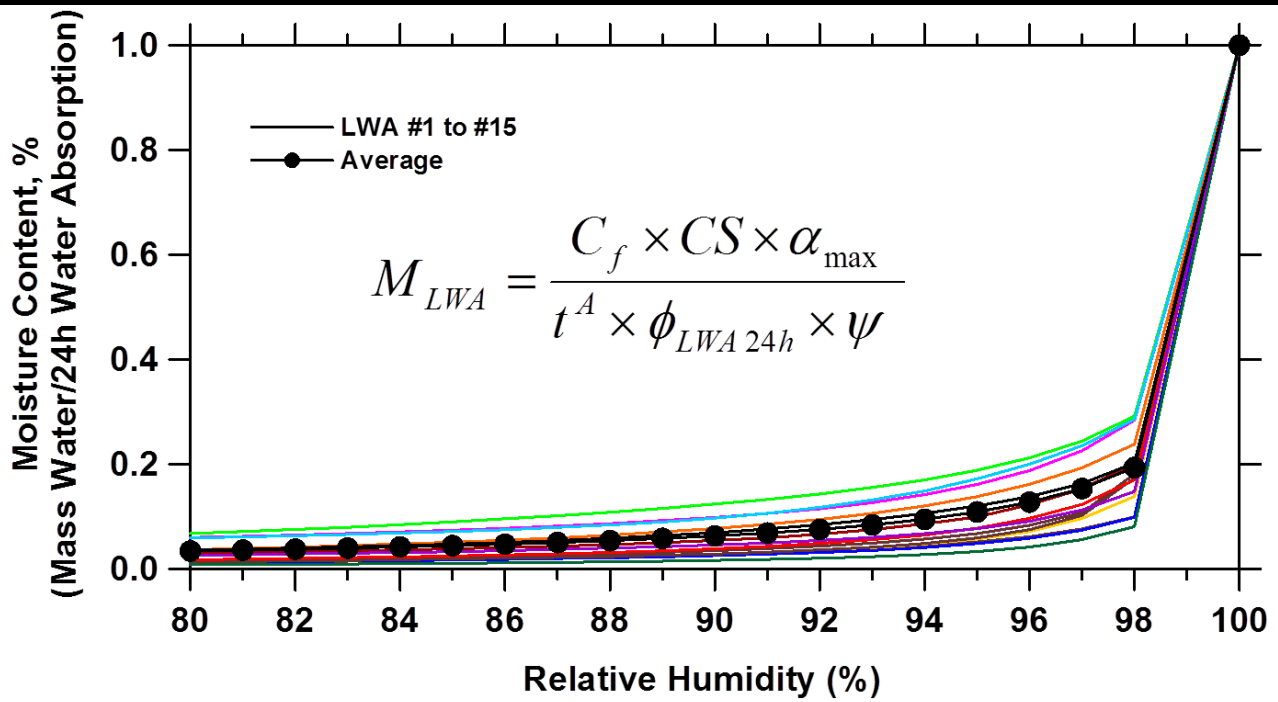

- Prewetted surface dry aggregate over salt solution
- KNO_3 - salt at 94% RH for a saturated salt solution
- Weigh the sample originally, weigh the sample till it comes to near equilibrium (mass changes are small), then oven dry the sample

Summary So Far

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- Internal Curing is Just Doing What We Should Be Doing Water Curing Concrete
- Proportion Based on Two Main Concepts
  - Provide water to replace chemical shrinkage volume (7 lb per 100 lbs cementitous)
  - Aggregate needs to be well spaced – Accomplished with the use fine aggregate
- Aggregate needs to desorb (i.e., release water when needed) occurs at high RH, ‘large pores’ and can simply be measured by mass with salt

Field Experiences (Monroe Co 2010)

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Plain and IC Bridge Decks (Monroe Co, Indiana 2010)

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Plain concrete bridge deck was pumped

IC concrete bridge deck was placed by means of a bucket

	Cement Content (kg/m^3)	W/C	Fine Agg. (kg/m^3)	Fine LWA (kg/m^3)	Coarse Agg (kg/m^3)	Mixture Water (kg/m^3)	Water in LWA (kg/m^3)	WR (%)[A]	AE (%)[A]
Plain	**390**	**0.39**	**726**	**-**	**1046**	**152**	**-**	**0.22**	**0.08**
Int. Cured	**390**	**0.39**	**313**	**270**	**1046**	**152**	**25**	**0.22**	**0.08**

[A] percentage referred to the cement weight

Internal Curing Applications

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- NYDOT using internal curing in bridge decks (map showing bridges as of 2012)
- General experience is positive
- Reduced cracking with no problems to contractor or supplier

Streeter et al. 2012

Strength Results

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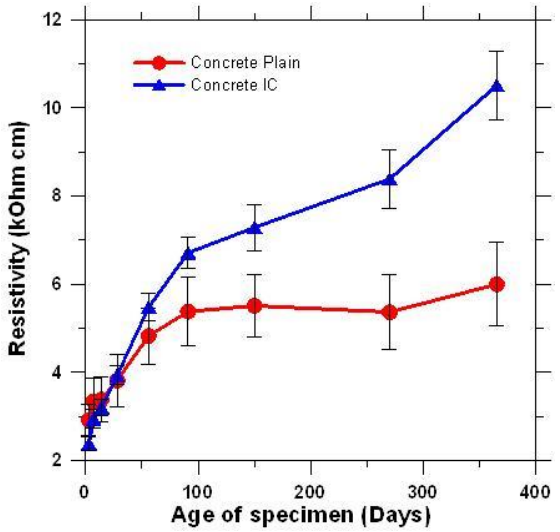
- Similar or slightly higher compressive strength results in Bloomington IN (DiBella et al. 2011)
- Similar Strength and Fresh Properties in Tonowanda and Lisle (not Shown) NY (Wolfe et al 2012)



	Class HP	Class HP-IC
Comp. Str. 7 day	3,040 psi	3,500 psi
Comp. Str. 28 day	4,677 psi	4,683 psi
Comp. Str. 56 day	5,343 psi	5,417 psi
Concrete Density	140.2 pcf	135.2 pcf
Air Content	5.5 %	6.0 %
Slump	5.0”	4.5”

Rapid Chloride Penetration Test

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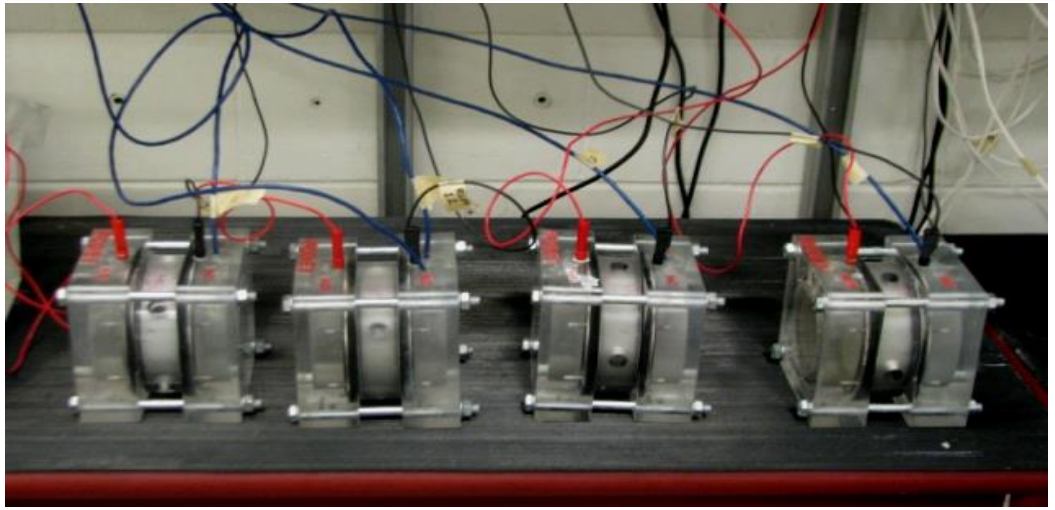

	NY Lisle		NY Tonawanda		Monroe Co	
Time [day]	Charge passing [Coulombs]		Charge passing [Coulombs]		Charge passing [Coulombs]	
	Plain Concrete	IC Concrete	Plain Concrete	IC Concrete	Plain Concrete	IC Concrete
28	535	423	572	570	4252	3822
56	373	406	342	313	2863	2458
91	357	392	308	301	3174	2065

Service Life Prediction
INDOT Class C; NYDOT IC HPC

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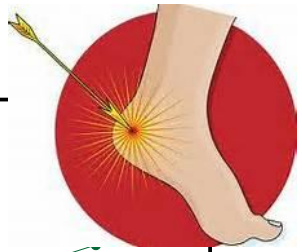
- Here we see the predicted service life model results for the decks cast in 2010
- Class C concrete 20 yrs, ICHPC 55-90 yr
- Model assumes no cracks



Visual Inspection of the Plain Bridge Decks after 20 Months

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- Plain bridge deck several cracks

- Internally cured deck no cracks 20 mos later
- Monroe county is very happy

Internally cured bridge deck

Main Take Always – Cracking/Corrosion

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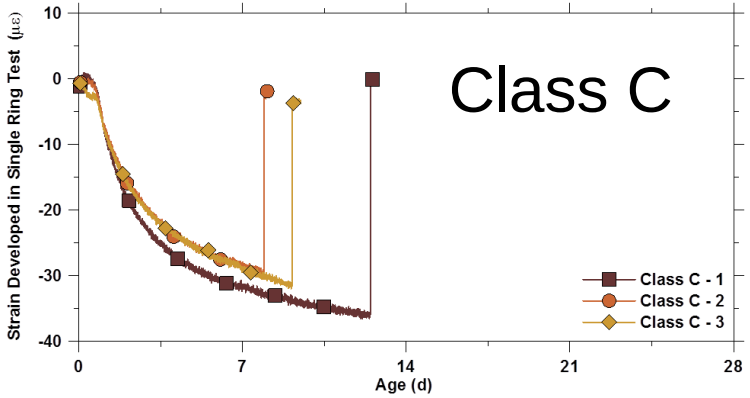

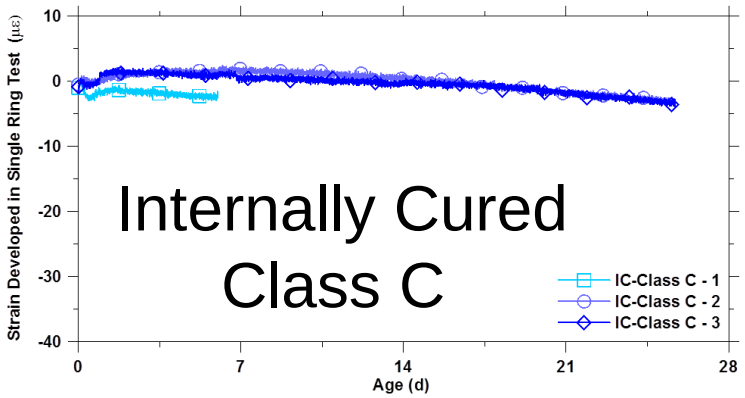

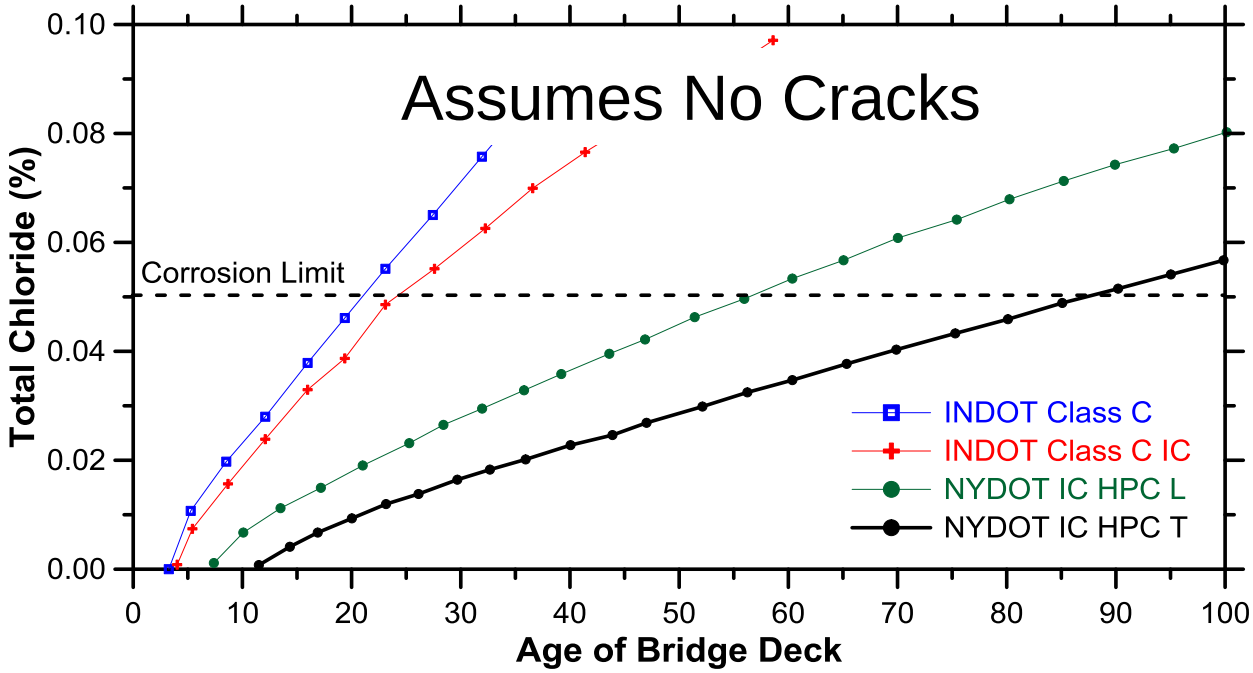

INDOT 2013 – 4 ICHPC Bridge Decks

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Special Thanks

Tommy Nantung

Tony Zander
and the team

Ron Walker

Contractors

Ready Mix
Producers

Tim Barrett and Albert Miller

Some Concepts from 2013

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- Maximum paste volume of 25%
- Cement content >390lbs/cyd
- Fly ash at 20-25% by mass
  (or ggbfs at 15-20% by mass)
- Silica fume at 3-7% by mass
- w/cm of 0.36 – 0.43
- Air content of 6.5%
- Slump from 2.5 - 5.5”
- Comp. strength at 28 days >5000psi
- Charge passed in RCPT <1500C

Bridge #1 Fort Wayne
I-69 over Little Black Creek

Background

Exo/Endo

Proportioning
Volume
Spacing
Advanced

Aggregates

Experiences
Field Work
Cracks
Patches

Agg Testing

Freezing

ASR

Sustainability

Dream it Do it

- IC posed no real issues
- Some honeycombing on harsh/ wrong mixture
- Conveyed not pumped
- Paste ‘too low’ IMHO

Bridge #1 Fort Wayne
I-69 over Little Black Creek

Background

Exo/Endo

Proportioning
Volume
Spacing
Advanced

Aggregates

Experiences
Field Work
Cracks
Patches

Agg Testing

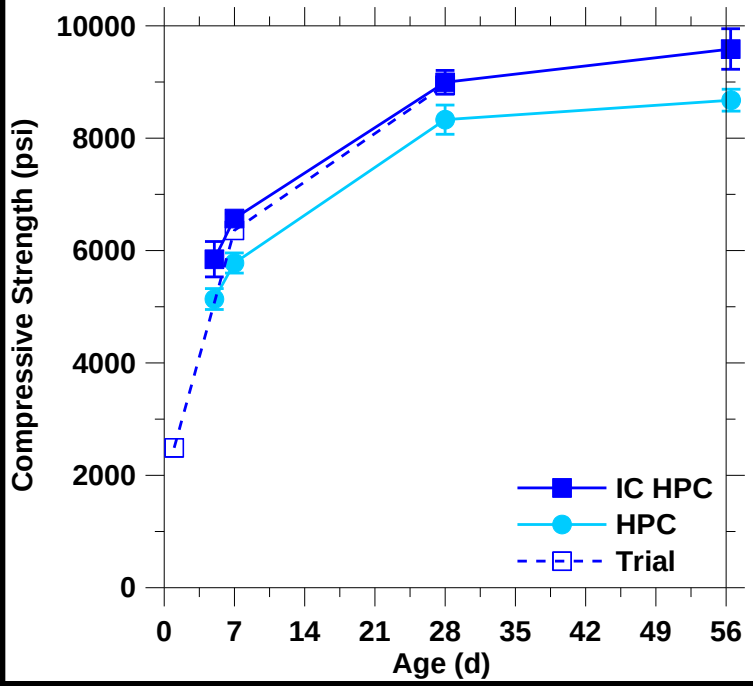
Freezing

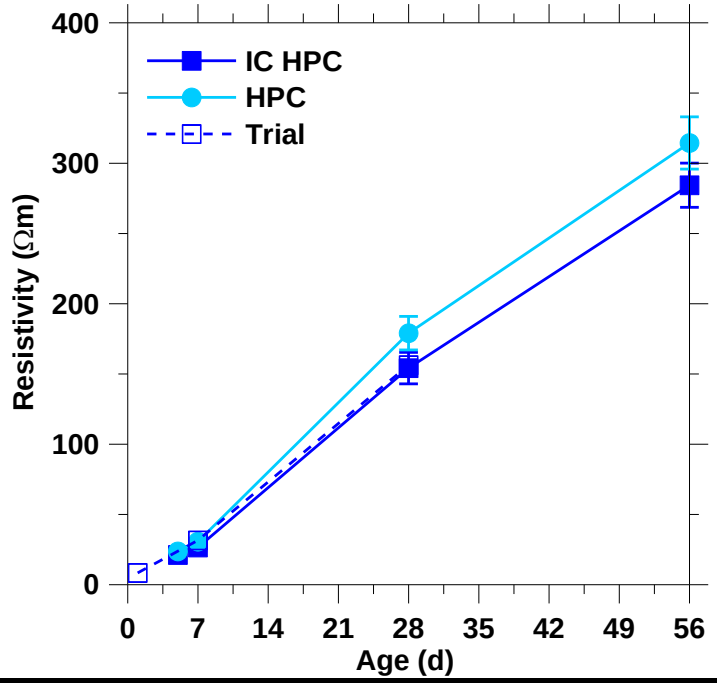
ASR

Sustainability

Dream it Do it

- Low variability from trial to cast
- Note: The first half of the deck was made with this mixture





Bridge #2 Paoli
US 150 over Lost River

Background
Exo/Endo
Proportioning
Volume
Spacing
Advanced
Aggregates
Experiences
Field Work
Cracks
Patches
Agg Testing
Freezing
ASR
Sustainability
Dream it Do it

- IC Comments: Contractor had to refill LWA bins during day
- Workability harder midway (we detected moisture change in the aggregate)
- Long haul with slow traffic on a hot day
- Mixture was hard to pump, was losing air and was sticky

Bridge #2 Paoli
US 150 over Lost River

Background

Exo/Endo

Proportioning
Volume
Spacing
Advanced

Aggregates

Experiences
Field Work
Cracks
Patches

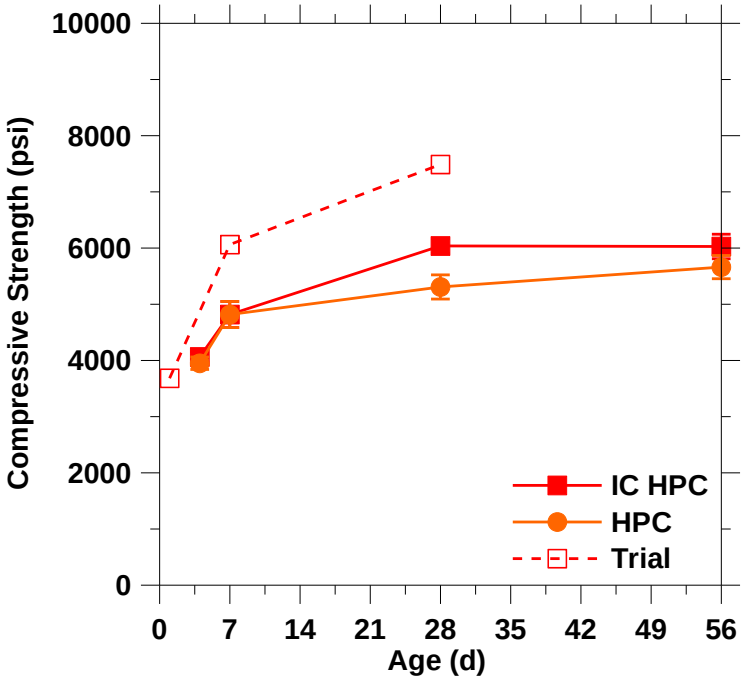
Agg Testing

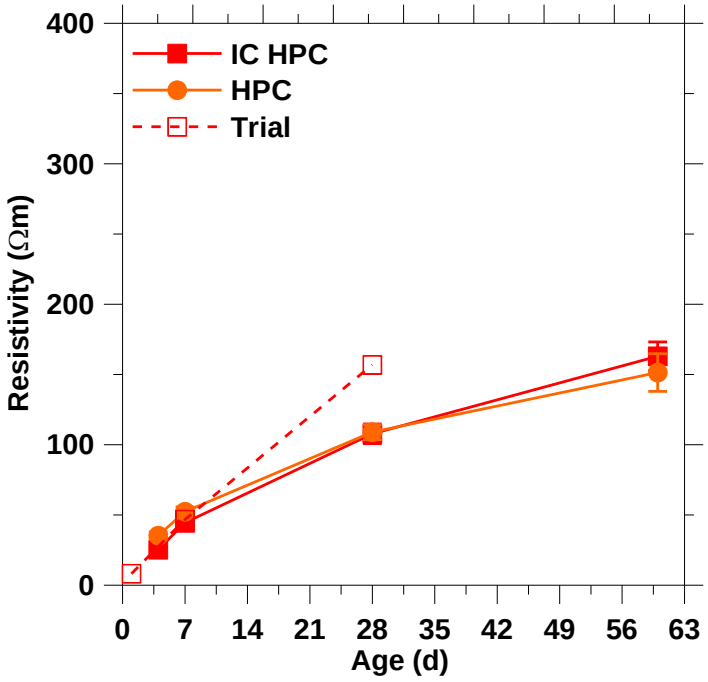
Freezing

ASR

Sustainability

Dream it Do it





Bridge #3
US 31 over Hutto Creek

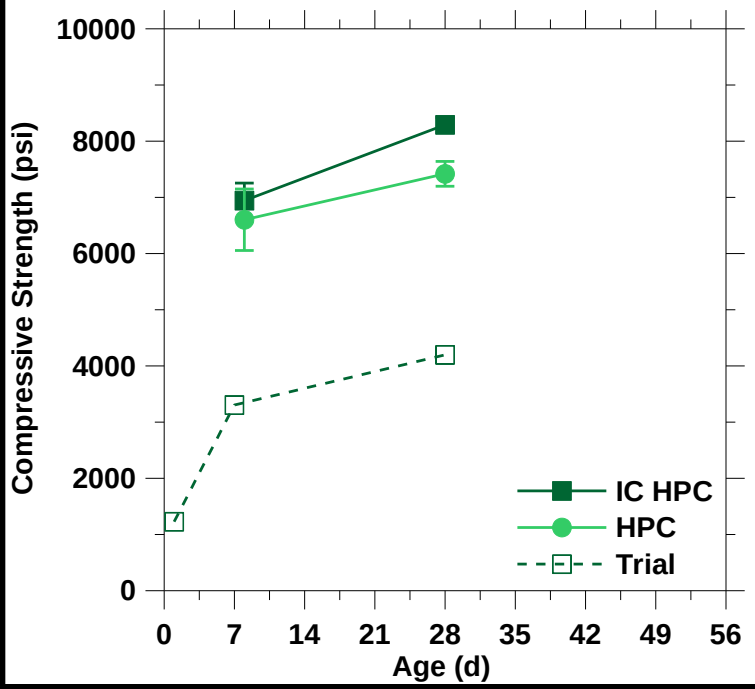
Background
Exo/Endo
Proportioning
Volume
Spacing
Advanced
Aggregates
Experiences
Field Work
Cracks
Patches
Agg Testing
Freezing
ASR
Sustainability
Dream it Do it

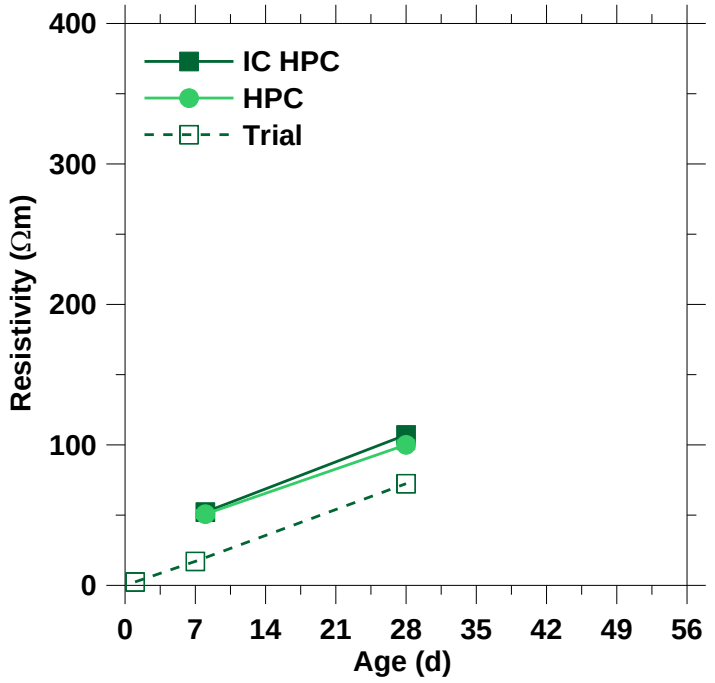
- Contractor liked the mixture
- Did not know that it was an internally cured mixture until informed mid-cast
- Did not have continuous supply of concrete (Likely truck scheduling)
  - Wait time exceeded 20 minutes between trucks (7 trucks)
  - Pump re-cycled twice

Bridge #3
US 31 over Hutto Creek

Background
Exo/Endo
Proportioning
Volume
Spacing
Advanced
Aggregates
Experiences
Field Work
Cracks
Patches
Agg Testing
Freezing
ASR
Sustainability
Dream it Do it

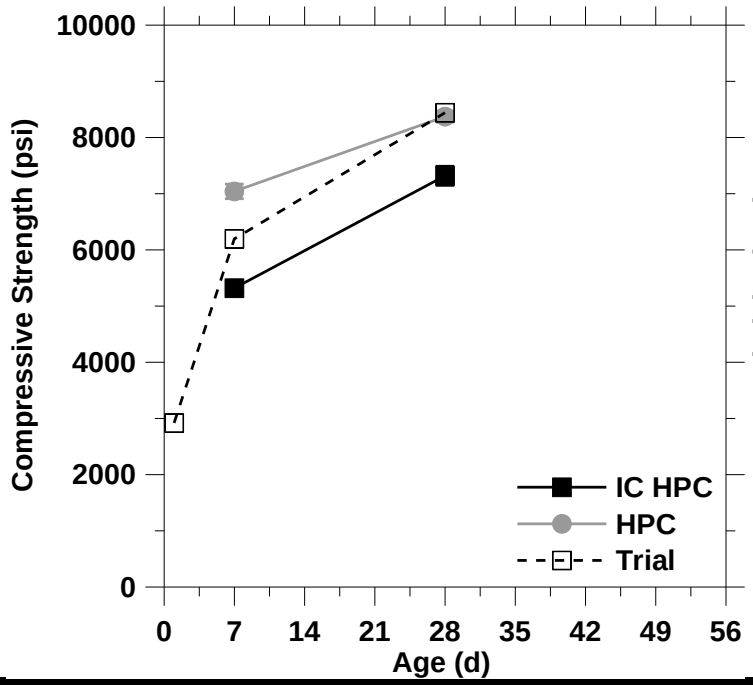
- Some variations in the mixture design between trial and actual batching

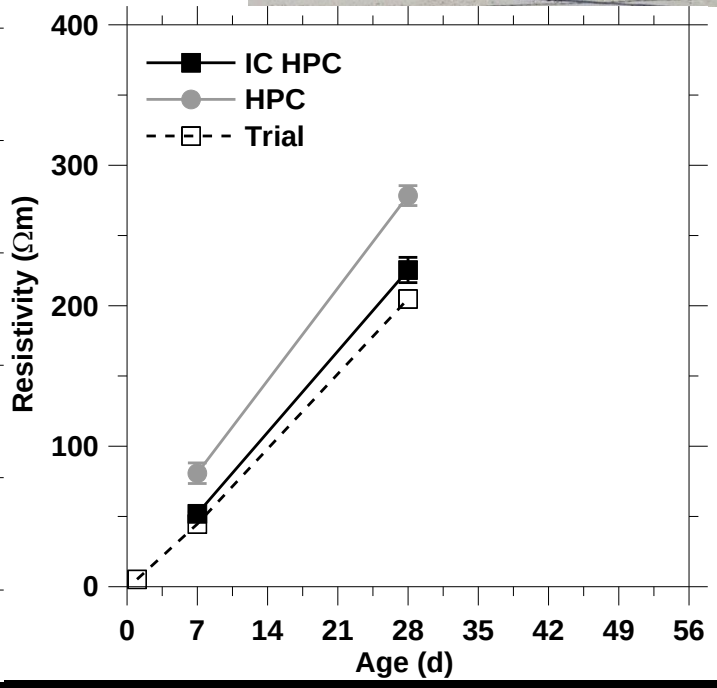




Bridge #4 South Bend SR 933 Baugo Creek

- High levels of HRWRA
- Tallest LWA pile (variability from pile)





Background
Exo/Endo
Proportioning
Volume
Spacing
Advanced
Aggregates
Experiences
Field Work
Cracks
Patches
Agg Testing
Freezing
ASR
Sustainability
Dream it Do it

Summary of Main Findings from the Summer of 2013 (Documented All)

Background

Exo/Endo

Proportioning
Volume
Spacing
Advanced

Aggregates

Experiences
Field Work
Cracks
Patches

Agg Testing

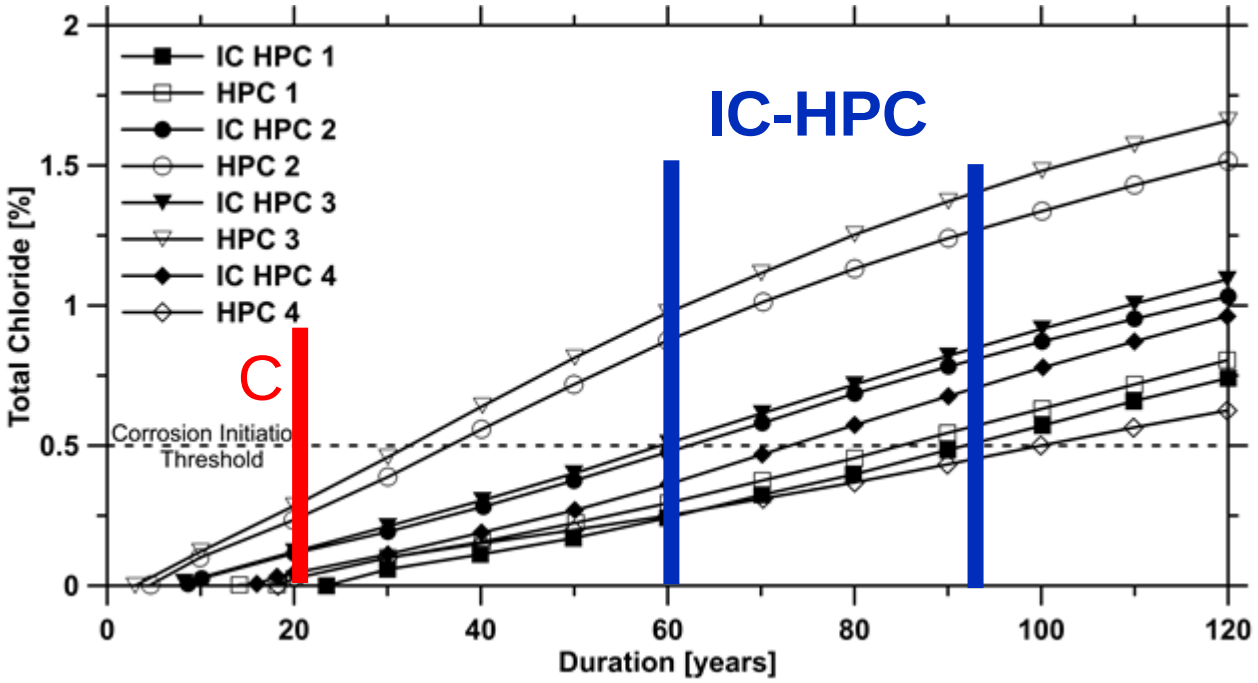
Freezing

ASR

Sustainability

Dream it Do it

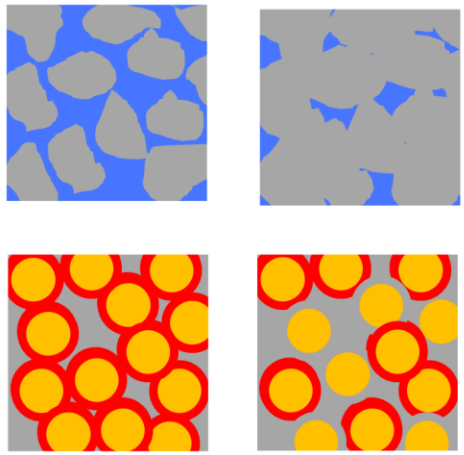
- IC has minimal impact on construction IC HPC outperforms Class C mixtures
- Quality control is crucial
- Minimize variation btw trial and field cast



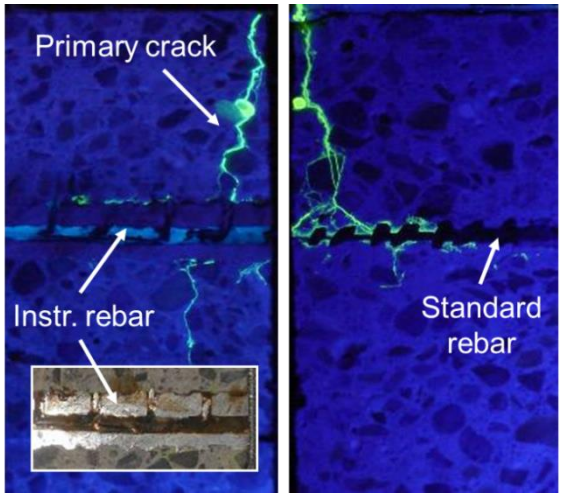
Discussion of Internal Curing, Cracking, and Corrosion

Background
Exo/Endo
Proportioning
Volume
Spacing
Advanced
Aggregates
Experiences
Field Work
Cracks
Patches
Agg Testing
Freezing
ASR
Sustainability
Dream it Do it

- IC increases hydration, reduces porosity,
- Reduces interfacial zones
- IC reduces absorption and reduces chloride diffusion



- Internal curing reduces the potential for cracking
  - Cracks accelerate fluid ingress and corrosion of reinforcing steel

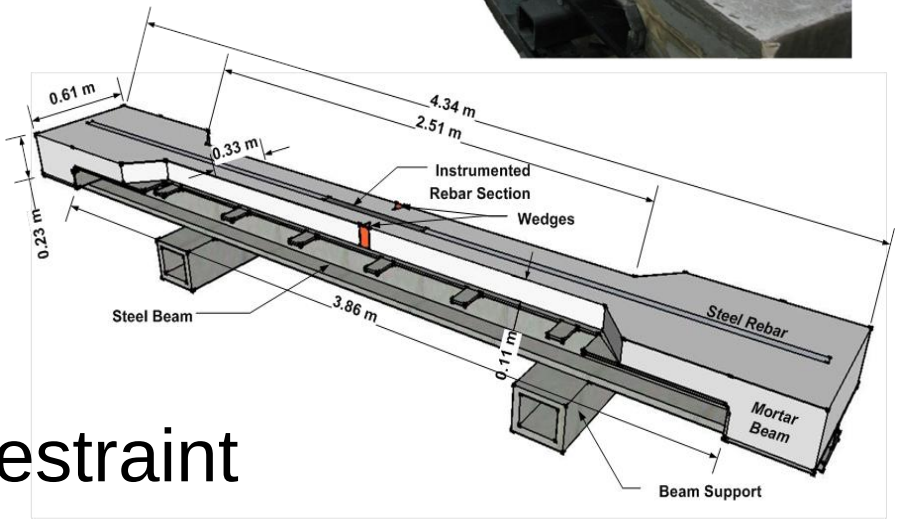


Pease et al. 2008

Restrained Shrinkage

Background
Exo/Endo
Proportioning
Volume
Spacing
Advanced
Aggregates
Experiences
Field Work
Cracks
Patches
Agg Testing
Freezing
ASR
Sustainability
Dream it Do it

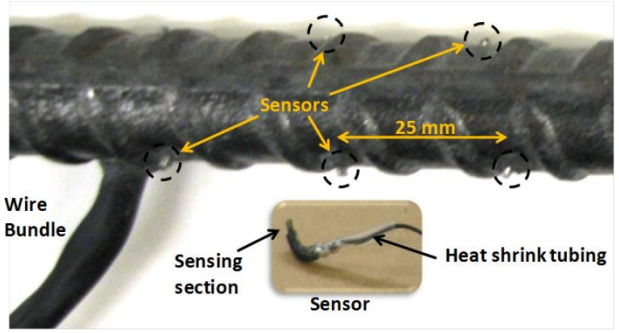
- Instrumented W12 × 210 beam – Widened steel beam restrains concrete from moving freely as the concrete shrinks.
- threaded rods used to anchor the specimen at ends
- wedges - 1.5mm (1/16in.) wide tip and widened to 10mm (3/8 in.)
- 15 ft long, 90% restraint



Cracking and Corrosion

Background
Exo/Endo
Proportioning
Volume
Spacing
Advanced
Aggregates
Experiences
Field Work
Cracks
Patches
Agg Testing
Freezing
ASR
Sustainability
Dream it Do it

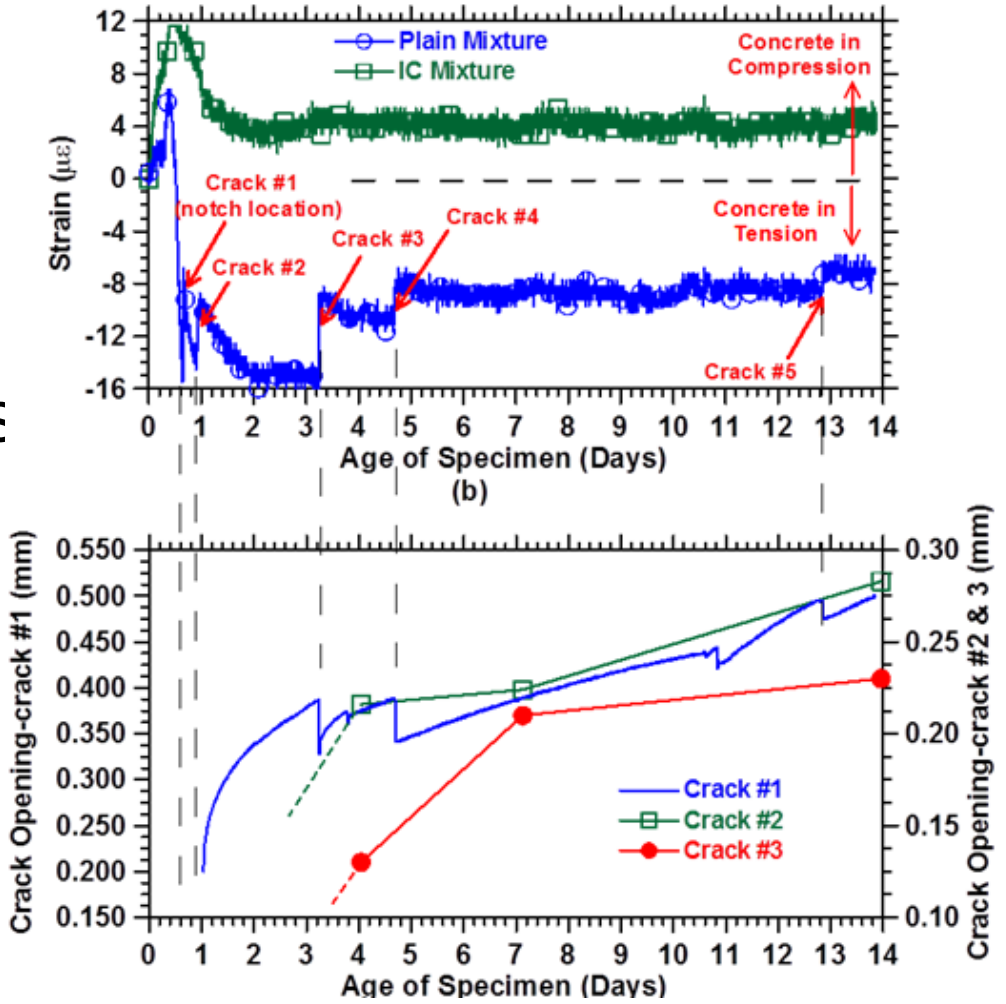
- 0.3 w/c - plain
- 0.3 w/c – internal curing
- No. 6 rebar (hollowed) 28 corrosion sensors
- Notch at mid-span to control the location of first crack
- Strain gages monitor stress development and cracking in concrete



Restrained Shrinkage Behavior

Background
Exo/Endo
Proportioning
Volume
Spacing
Advanced
Aggregates
Experiences
Field Work
Cracks
Patches
Agg Testing
Freezing
ASR
Sustainability
Dream it Do it

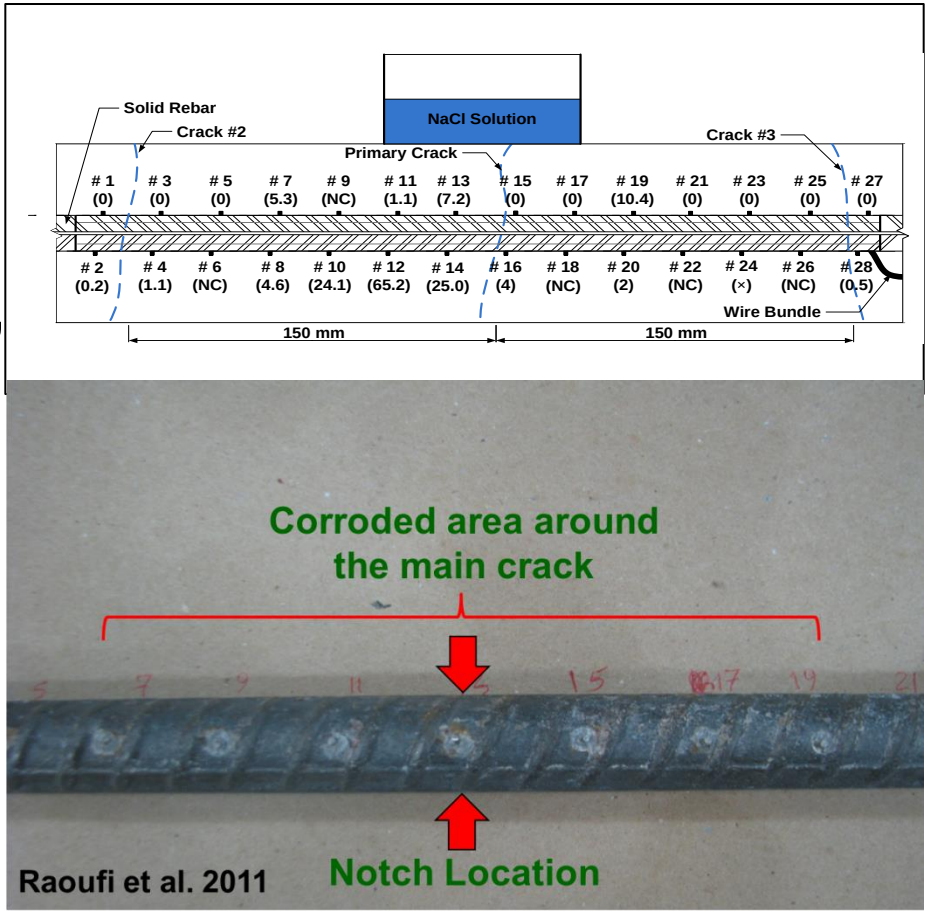
- Multiple cracks along the reinforcing bar
- Each crack caused others to close slightly
- Cracking resulted in substantial debonding



Corrosion/Transport Testing

Background
Exo/Endo
Proportioning
Volume
Spacing
Advanced
Aggregates
Experiences
Field Work
Cracks
Patches
Agg Testing
Freezing
ASR
Sustainability
Dream it Do it

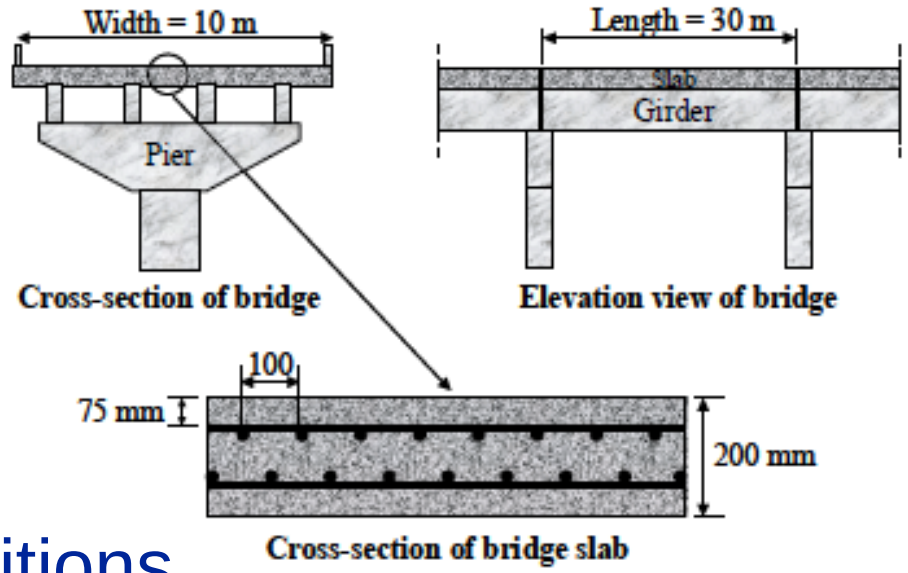
- corrosion potential was greatly influenced by crack proximity of the crack around at the steel-mortar interface.
- Sensors #1, 3, 5, 15, 17, 21, 25, and 27 on the top surface of the rebar and started to corrode immediately



Life Cycle Cost Analysis

Background
Exo/Endo
Proportioning
Volume
Spacing
Advanced
Aggregates
Experiences
Field Work
Cracks
Patches
Agg Testing
Freezing
ASR
Sustainability
Dream it Do it

- Cusson et al. 2010 reported results of a case study that compared a convention, high performance and high performance internally cured deck
- 200-mm (8 in) thick bridge deck
- 75 mm (3 in) cover
- Canadian exposure conditions

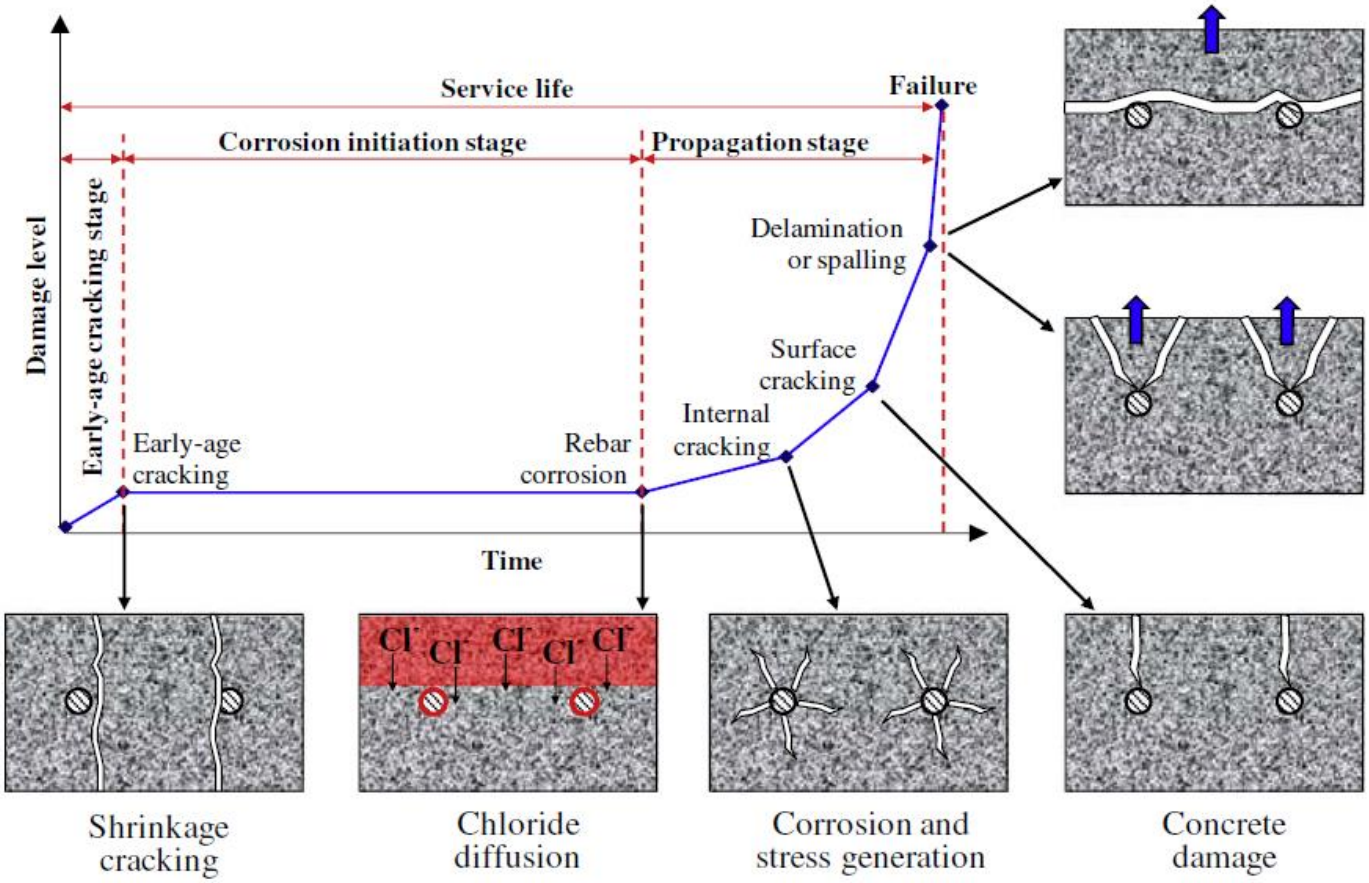


Cusson (2010)

Cusson et al. 2010 Service Life Model

Background
Exo/Endo
Proportioning
Volume
Spacing
Advanced
Aggregates
Experiences
Field Work
Cracks
Patches
Agg Testing
Freezing
ASR
Sustainability
Dream it Do it

- Schematic of life cycle model used



Cusson et al. 2010 Service Life Model

Background
Exo/Endo
Proportioning
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Advanced
Aggregates
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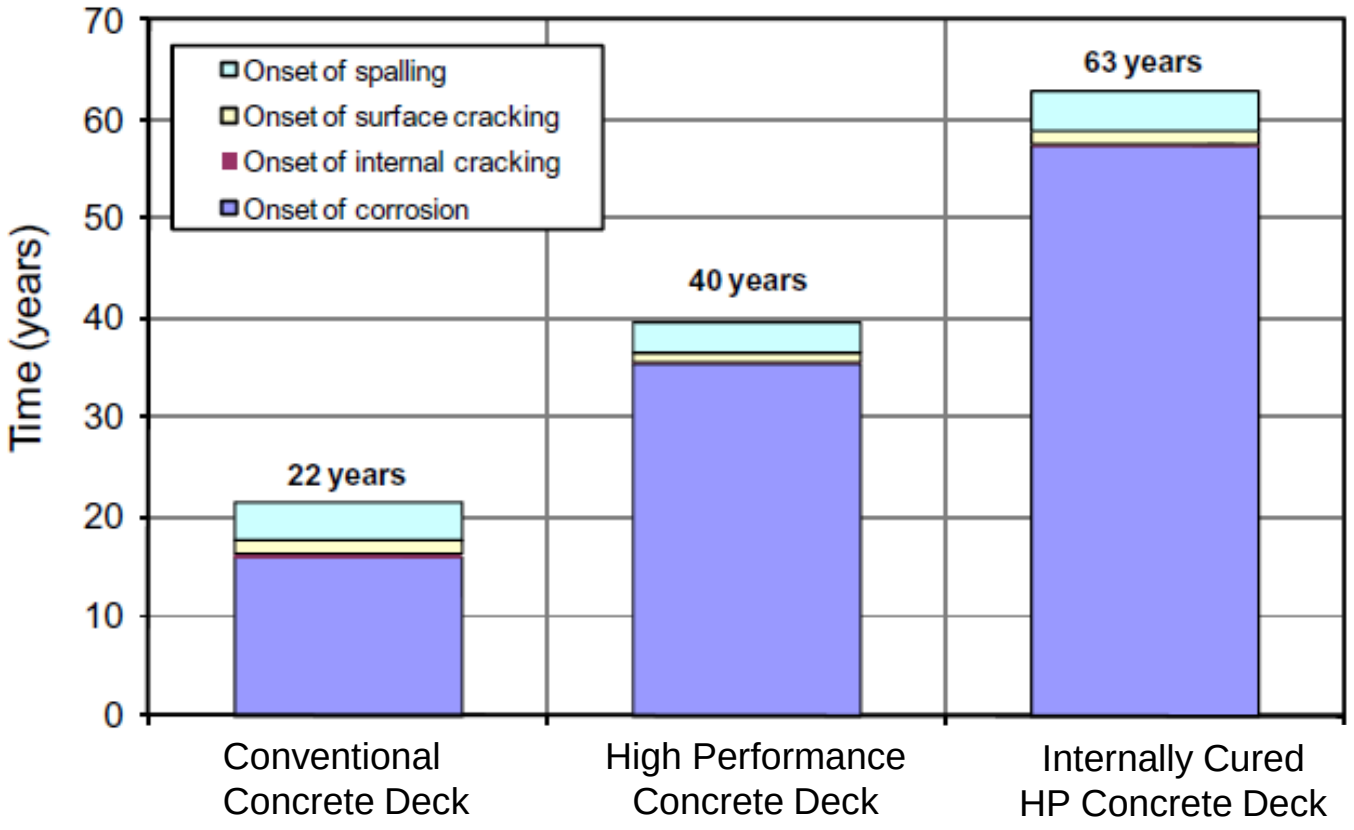
Cracks
Patches
Agg Testing
Freezing
ASR
Sustainability
Dream it Do it

- Internal curing improved service life
- 38% lower life cycle cost (5 year recovery)

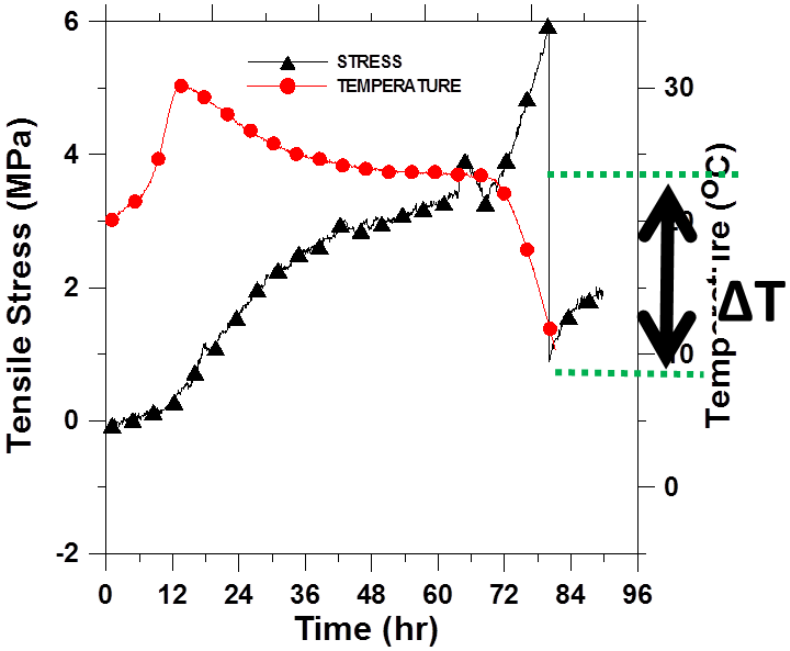


Temperature Required to Crack

Background
Exo/Endo
Proportioning
Volume
Spacing
Advanced
Aggregates
Experiences
Field Work
Cracks
Patches
Agg Testing
Freezing
ASR
Sustainability
Dream it Do it

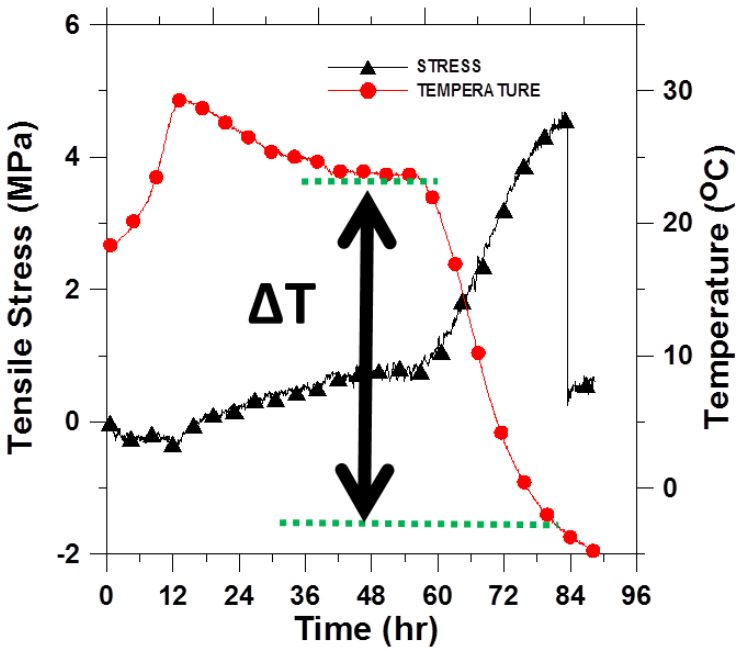
- Internally cured systems are more robust

Plain Mortar (w/c =0.30)
Not Internally Cured



ΔT crack = 10.3° C

Internally Cured Mortar
(w/c = 0.30)



ΔT crack = 27.1° C

Schlitter et al. 2010

Pavement Patching (HES)

Background
Exo/Endo
Proportioning
Volume
Spacing
Advanced
Aggregates
Experiences
Field Work
Cracks
Patches
Agg Testing
Freezing
ASR
Sustainability
Dream it Do it

- Here we can see IC HES patching in West Lafayette, premature cracking was observed in many cases for plain HES
- Performed using IC in the standard HES patching and the benefit is reduced cracking and curling and increased hydration of the cement/opening

Barrett et al. 2014

Summary of Field Aspects and Cracking Aspects So Far

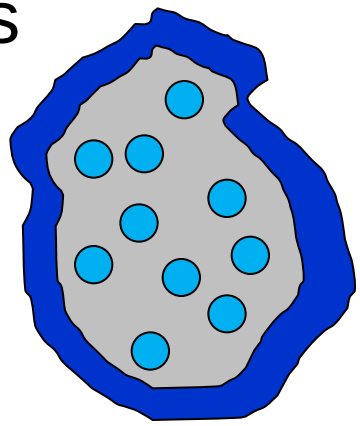
Background
Exo/Endo
Proportioning
Volume
Spacing
Advanced
Aggregates
Experiences
Field Work
Cracks
Patches
Agg Testing
Freezing
ASR
Sustainability
Dream it Do it

- First, IC has minimal impact on practice when done properly
- Second, the main thing to watch for is the aggregate moisture (surface/absorbed)
- Third, IC HPC is a great use of this as it provides dense concrete with a low potential for cracking (improvement to C)
- Fourth, cracks occur not only at the surface but along the bar which can be problematic as a large section corrodes
- NY – Only issue is researchers asking Q's

Discussion of Quality Control Two Components of Water

Background
Exo/Endo
Proportioning
Volume
Spacing
Advanced
Aggregates
Experiences
Field Work
Cracks
Patches
Agg Testing
Freezing
ASR
Sustainability
Dream it Do it

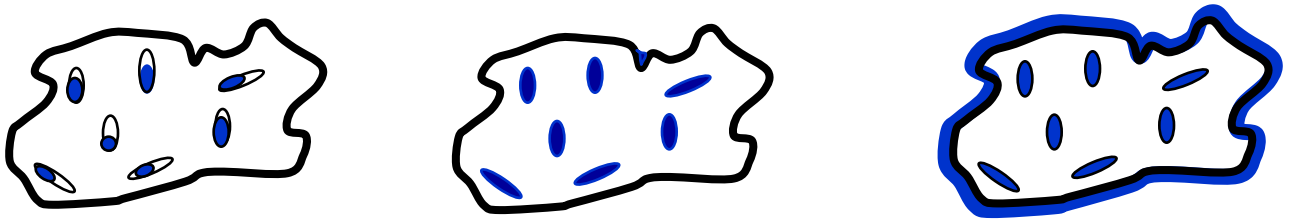
- Absorbed water
  - varies with LWA material, soaking time, storage, and mixing time
  - Does not change volumetrics
  - Does not change the w/c
- Free water
  - Controls the slump
  - Is related to changes in w/c and strength



SSD and the Fallacy

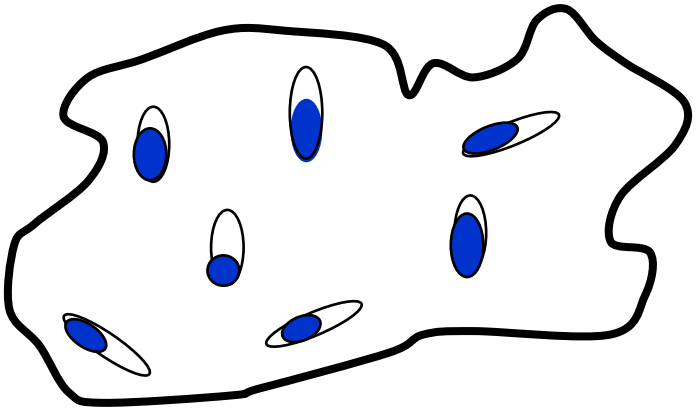
Background
Exo/Endo
Proportioning
Volume
Spacing
Advanced
Aggregates
Experiences
Field Work
Cracks
Patches
Agg Testing
Freezing
ASR
Sustainability
Dream it Do it

- SSD – Saturated Surface Dry



Air-Dry | Saturated Surface Dry (SSD) | Wet

- In Reality – Not Really Saturated
- Better to say pre-wetted and surface dry



Determining Absorption

Background
Exo/Endo
Proportioning
Volume
Spacing
Advanced
Aggregates
Experiences
Field Work
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Patches
Agg Testing
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ASR
Sustainability
Dream it Do it

- Generally soak the aggregate for 24 hours (or 72 hours if you follow ASTM C 1761) then do one of the following methods to get the aggregate in prewetted surface dry condition
  - ASTM C 128 (Sand Castle Method)
  - Cobalt Chloride
  - Paper Towel Method

How to Prepare the Aggregate

Background
Exo/Endo
Proportioning
Volume
Spacing
Advanced
Aggregates
Experiences
Field Work
Cracks
Patches
Agg Testing
Freezing
ASR
Sustainability
Dream it Do it

- Drying a bit at a time – test each stage

- Centrifuge method

"give it a whirl"

Paper Towel and Absorption

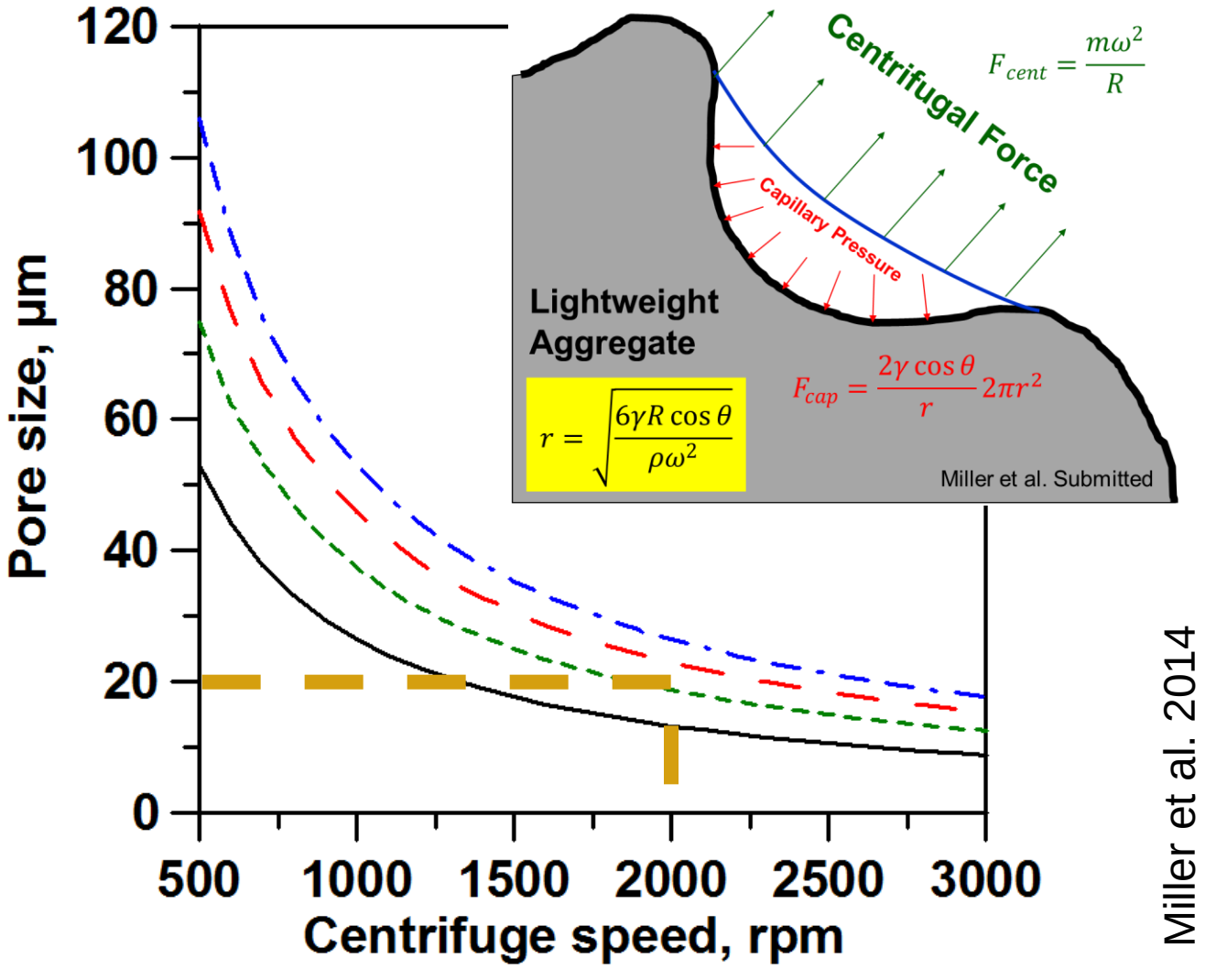
Background
Exo/Endo
Proportioning
Volume
Spacing
Advanced
Aggregates
Experiences
Field Work
Cracks
Patches
Agg Testing
Freezing
ASR
Sustainability
Dream it Do it

- Commercial grade, folded or roll paper towel
- Force is not specified
- commercial grade paper towels - a capillary radius from 25 µm to 30 µm (testing Purdue paper towels and in a Georgia Tech Thesis and 3rd Grade Canadian Science fair)

$$R_{cap} = \frac{2\gamma}{L_c \rho g}$$

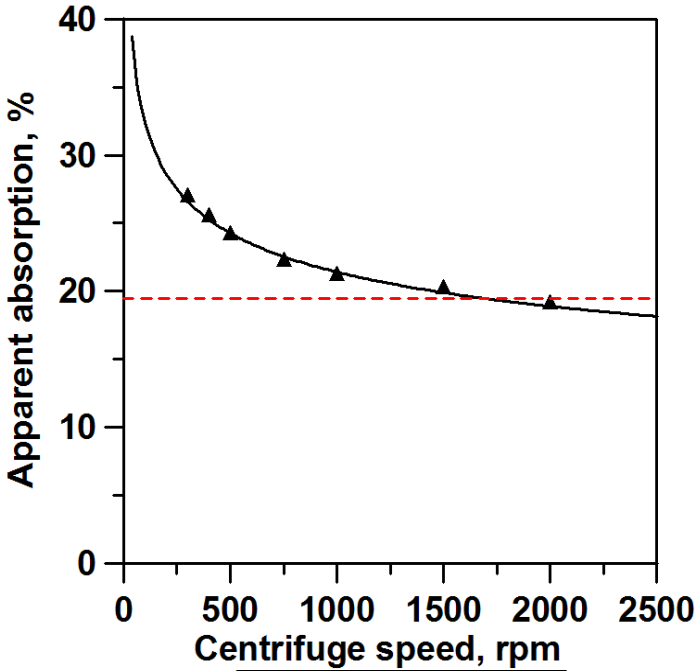
Effect of Sample Size and Speed

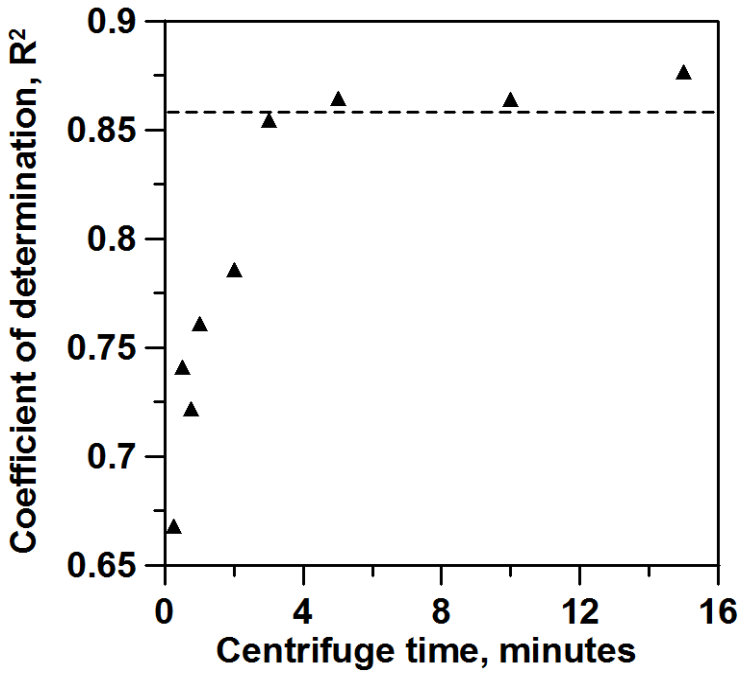
Background
Exo/Endo
Proportioning
Volume
Spacing
Advanced
Aggregates
Experiences
Field Work
Cracks
Patches
Agg Testing
Freezing
ASR
Sustainability
Dream it Do it

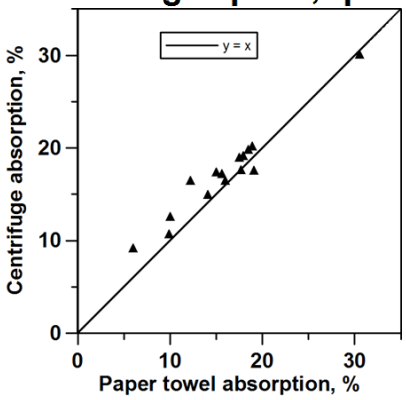


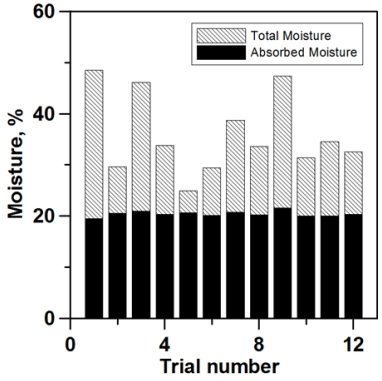
Effect Spinning Speed and Time

Background
Exo/Endo
Proportioning
Volume
Spacing
Advanced
Aggregates
Experiences
Field Work
Cracks
Patches
Agg Testing
Freezing
ASR
Sustainability
Dream it Do it









Miller et al. 2014

Freeze-Thaw Behavior

Background
Exo/Endo
Proportioning
Volume
Spacing
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Experiences
Field Work
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ASR
Sustainability
Dream it Do it

- Performance of lightweight bridge concrete bridge decks is atleast as good as normal density concrete (Brown et al. 1985)
- Experiments have shown that plain and internally cured concrete behave similarly if they are properly air entrained

- Want to be careful at early ages, and use a sufficiently low w/c where self-desiccation will pull water out of the LWA

Freeze-Thaw Behavior

Background
Exo/Endo
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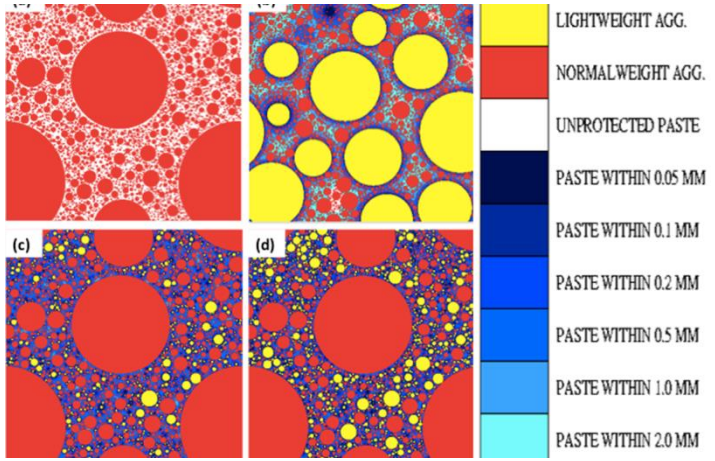
Dream it Do it

- Class H Concrete Colorado
  - 0.42 w/c
  - 74% Aggregate
  - 570 lb/yd^3 cement



Mix 1: Standard Class H
Mix 2: LWFA 1 x CS
Mix 3: LWFA 2 x CS
Mix 4: CLWA 1 x CS
Mix 5: 100% CLWA Replacement
Mix 6: IC Buildex
Mix 7: IC Utelite
Mix 8: Standard Class D
Mix 9: IC Class D

Standard Class H Mixture *Note: Agg in SSD Condition*		
	Amount (kg/m^3)	**Amount (lbs/yd^3)**
Cement	270	456
Fly Ash	68	114
Water	142	239
FA	885	1493
CA	1091	1840

Jones et al. 2013

Freeze-Thaw Behavior

Background
Exo/Endo
Proportioning
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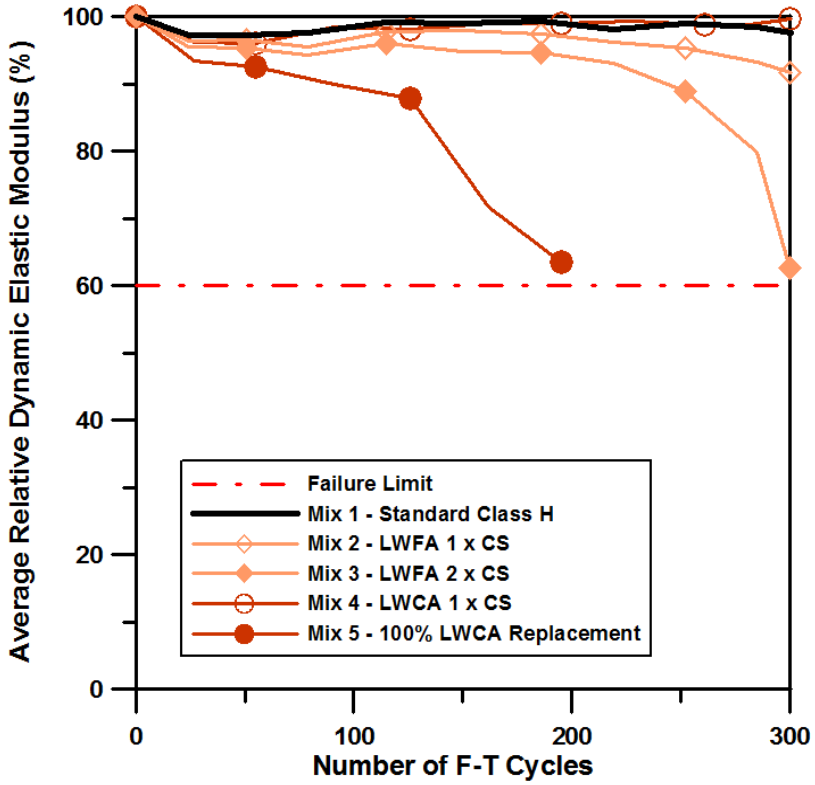
Sustainability
Dream it Do it

- Here we can see the ASTM C 666 data
- The conventional concrete is fine as is the LWA with the water in the LWA = CS (Mix 2, 4)
- The 2x CS will leave water in the LWA and the LWCA has excess water



Jones et al. 2013

Freeze-Thaw Behavior

Background

Exo/Endo

Proportioning
Volume
Spacing
Advanced

Aggregates

Experiences
Field Work
Cracks
Patches

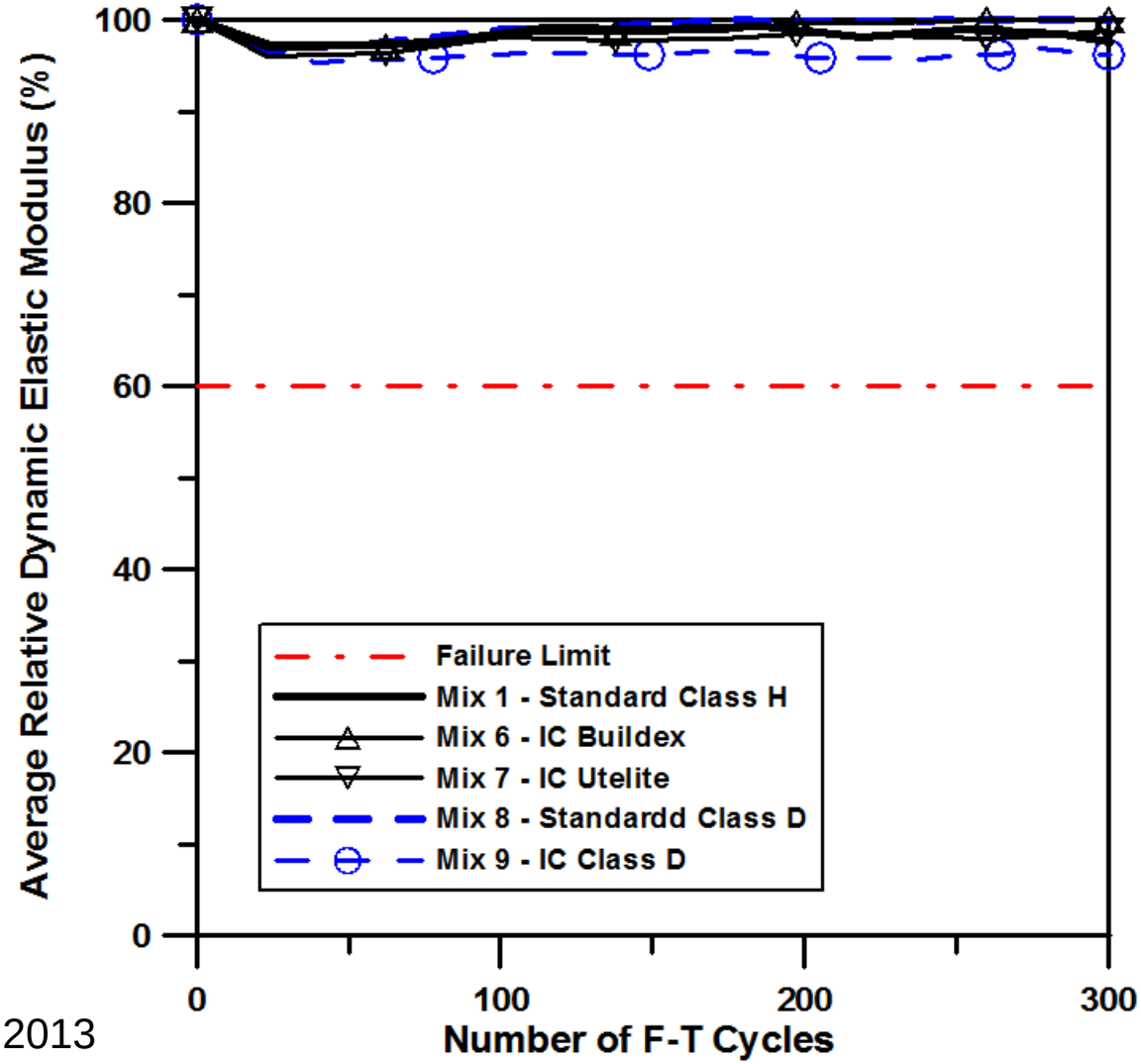
Agg Testing

Freezing

ASR

Sustainability

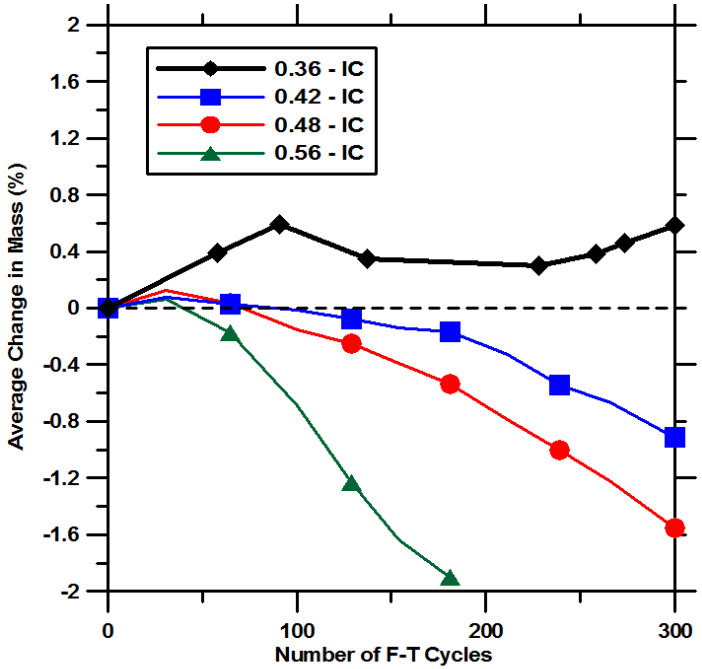
Dream it Do it

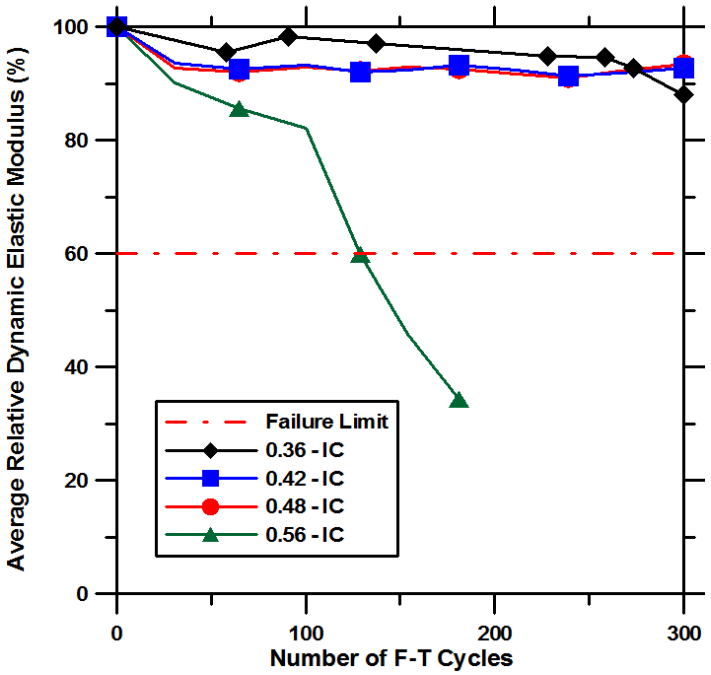


Jones et al. 2013

Influence of w/c

Background
Exo/Endo
Proportioning
Volume
Spacing
Advanced
Aggregates
Experiences
Field Work
Cracks
Patches
Agg Testing
Freezing
ASR
Sustainability
Dream it Do it





- High w/c will not draw water from the LWA as fast as low w/c since the suction is higher low w/c
- May be susceptible to damage at early ages

Jones et al. 2013

Alkali Silica Reaction

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- Shin et al. 2010 reported results for 5 systems (reactive, 15 & 28% reactive sand (m), 15 & 28% non reactive sand (N))
- Internal Curing Pros –
  - decreases porosity through hydration,
  - accommodation space allows gel without pressure,
  - dilution (replaces reactive aggregates)
- Internal Curing Cons –
  - Higher RH/moisture which would enable more ASR reaction to occur

Alkali Silica Reaction

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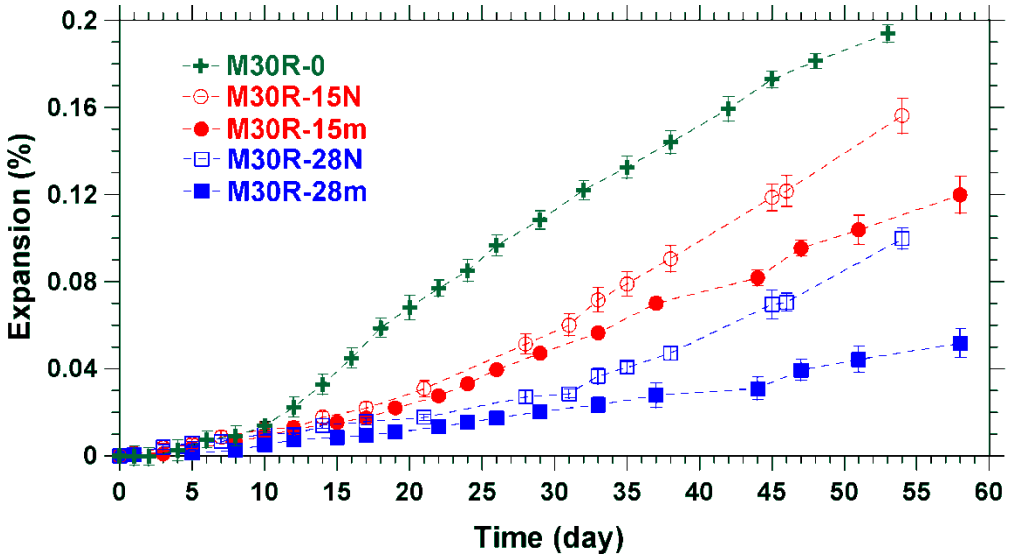
- Shin et al. 2010 reported about 5 systems
- Reactive (R) – Most reactive and expansive
- Non Reactive Aggregate Replacement at 15 & 28% (m) – Reduces expansion due to dilution
- Internal Curing – LWA Replacement at 15 & 28% % (N)) – more effective even than non reactive aggregate
  LWA provides space for expansive gel to form
- 15% replacement is CS volume



Potential Approach for Sustainability

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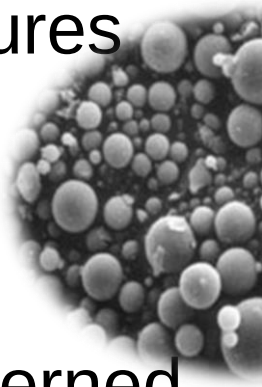
- Reduce the cement (clinker) content of concrete used in transportation structures
- Current limits of 20-25% fly ash
- Can higher volumes of ash be used?
  - Contractors and agencies are concerned with slow strength development
  - Other concerns:
    slow set time,
    admixture incompatibilities,
    scaling, freeze-thaw damage,
    extended times for moist curing



Project Thought Process

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- de la Varga et al. examined potential use of high volume fly ash mixtures (HVFA)
- Typical w/cm 0.42 concrete bridge deck mixture modified using HVFA to obtain similar early age strengths
- Similar paste volume
- Similar workability obtained with chemical admixtures

	0%	20%	40%	60%	80%
0.45	■	X	X	X	X
0.42	■	■	X	X	X
0.36	■	■	■	X	X
0.30	■	■	■	■	■

- Reference Mixture (INDOT – BASE CASE) >> 0.42
- Constant Paste Volume, Volume Replacements

Early Age Compressive Strength

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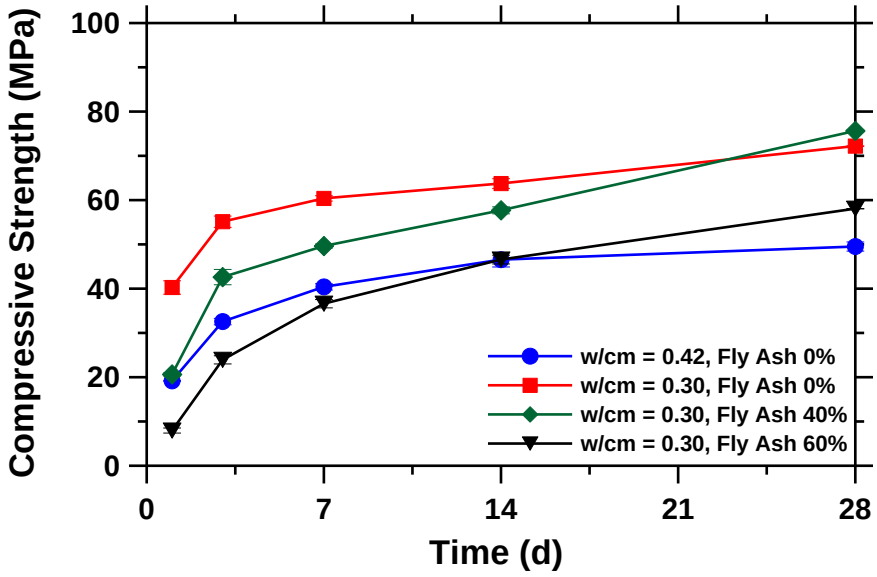
- As the w/c is reduced and the fly ash volume is increased similar strengths can be obtained at early ages
- Transport properties were also greatly improved
- However, as the w/c is reduced, the autogenous shrinkage and cracking potential can increase



HVFA with Internal Curing

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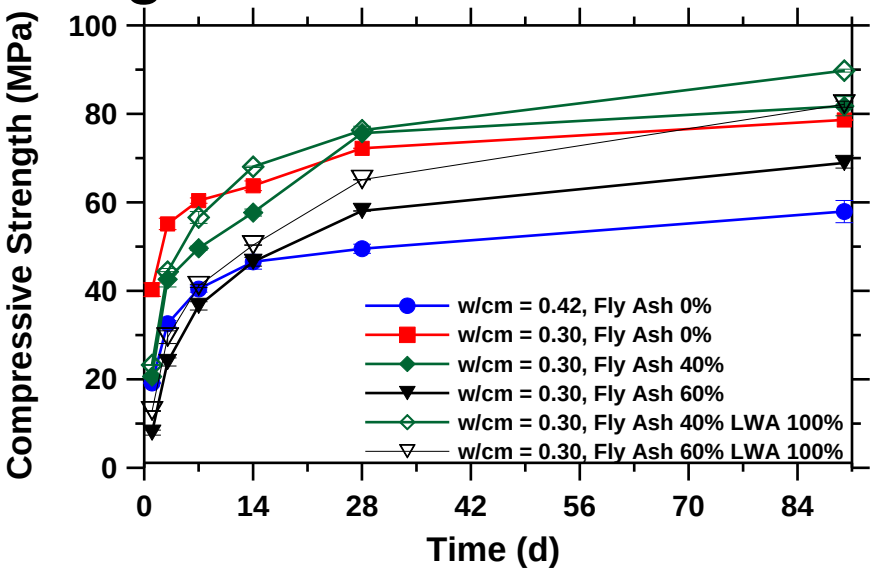
- Internal curing can improve the strength, especially at later ages due to enhanced hydration
- Internal curing has a residual stress that was much lower than the plain mixture, being similar or less than the 0.42 mixture with benefits of 60% less cement, improved strength, and transport



Water Absorption with HVFA

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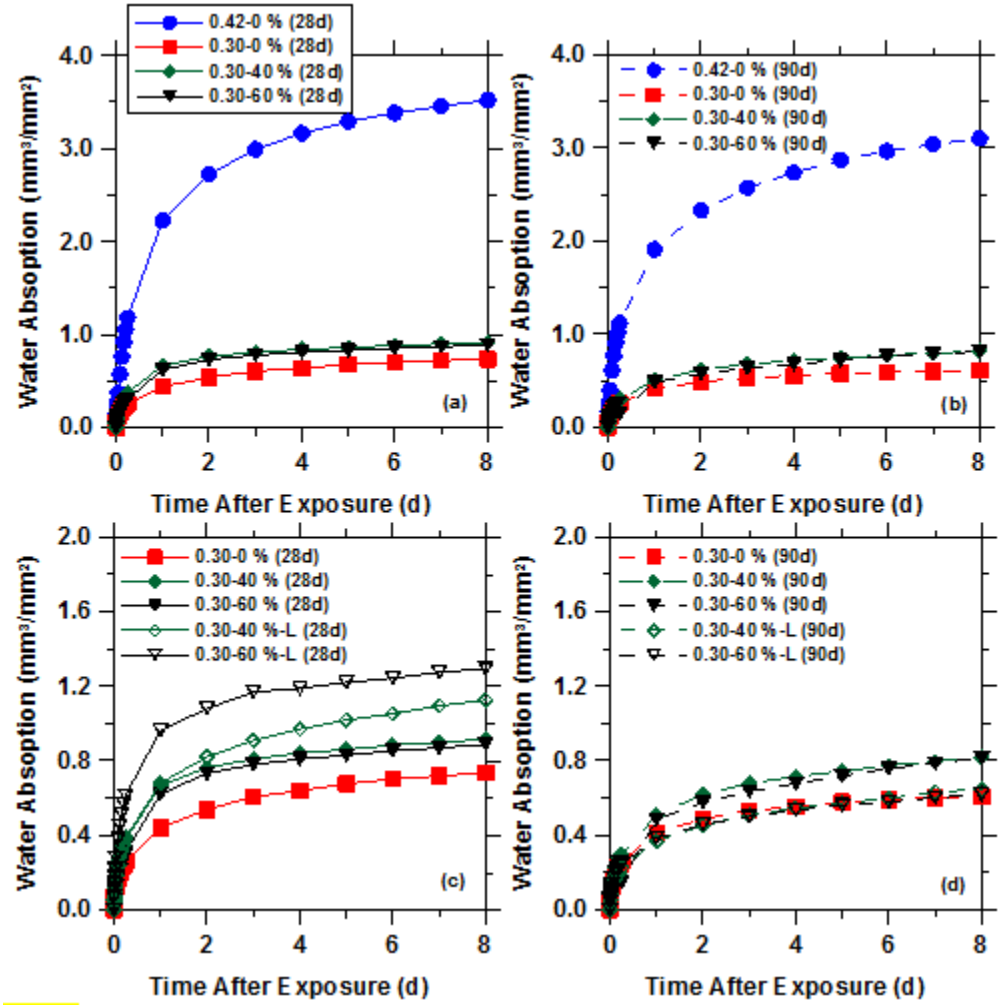
- Conventional mixture shown in blue
- Replacing 60% of the cement with fly ash and using a lower w/c reduces transport
- Internal curing beneficial



Electrical resistivity

Background

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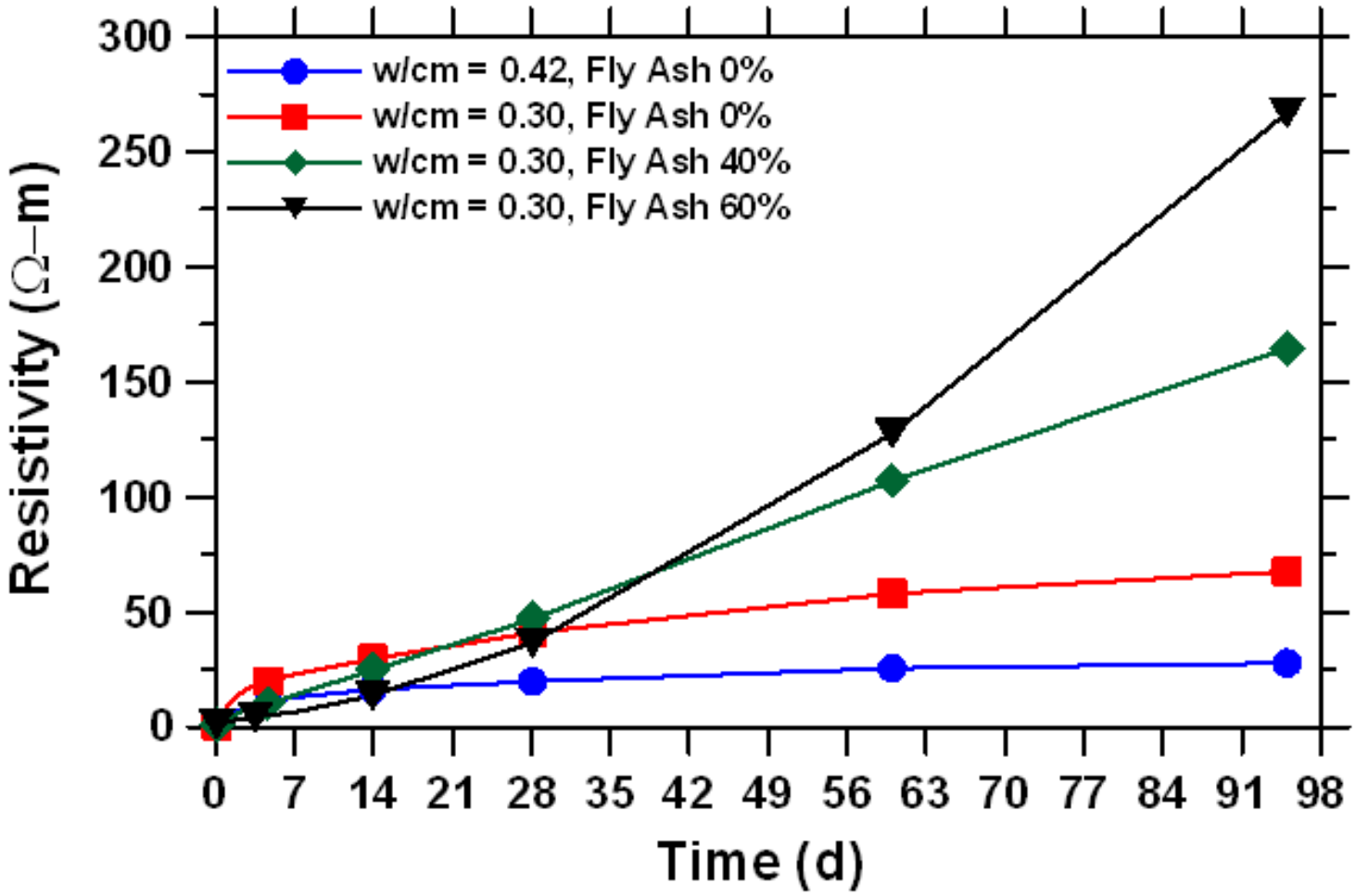

Restrained Shrinkage

Background

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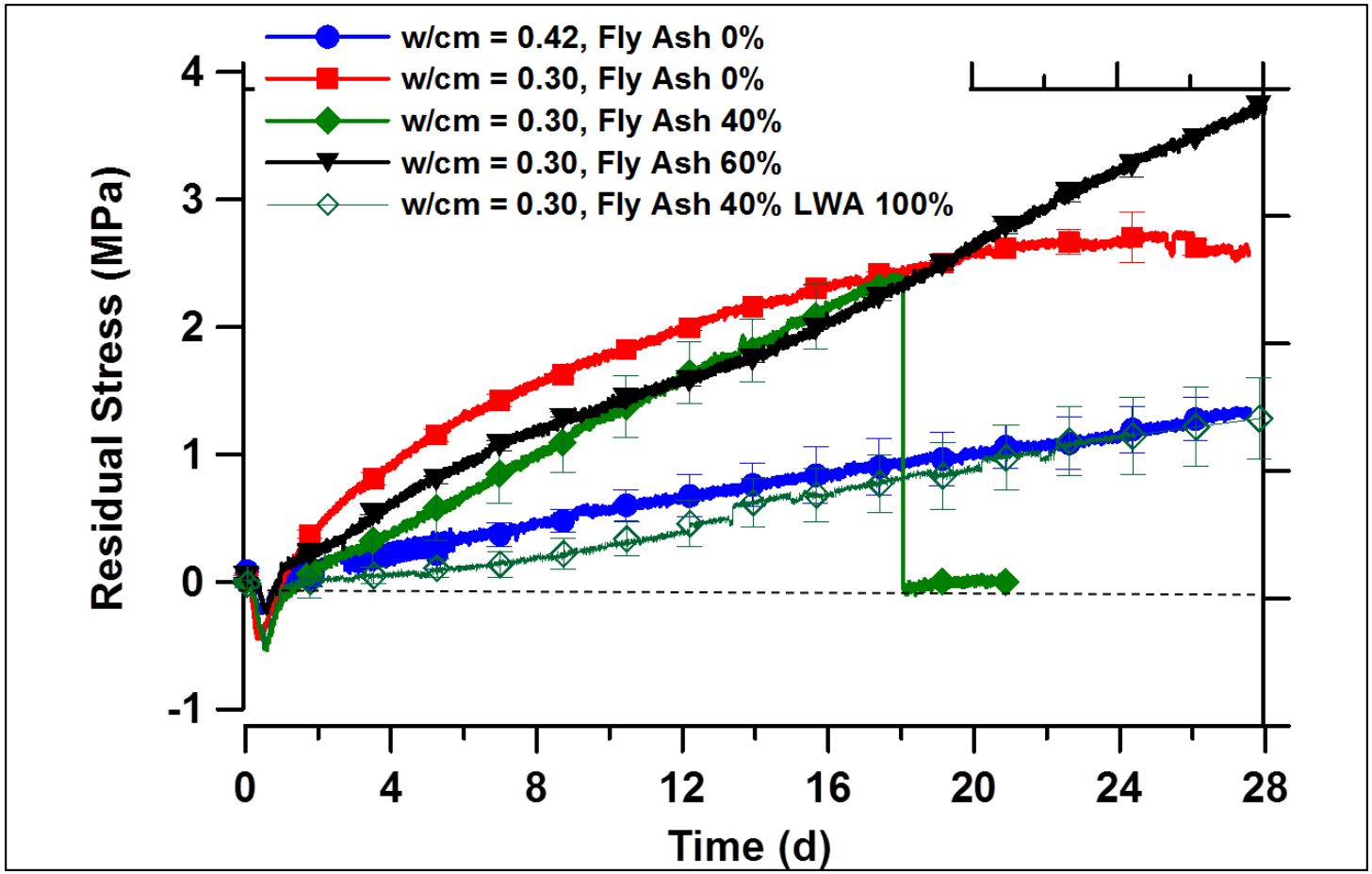

SCM – Rate; Shrinkage Rate

In Florida Look to Walt Disney

"If you can dream it, you can do it. Always remember that this whole thing was started with a dream and a mouse."

If We Dream It, We Can Cure It

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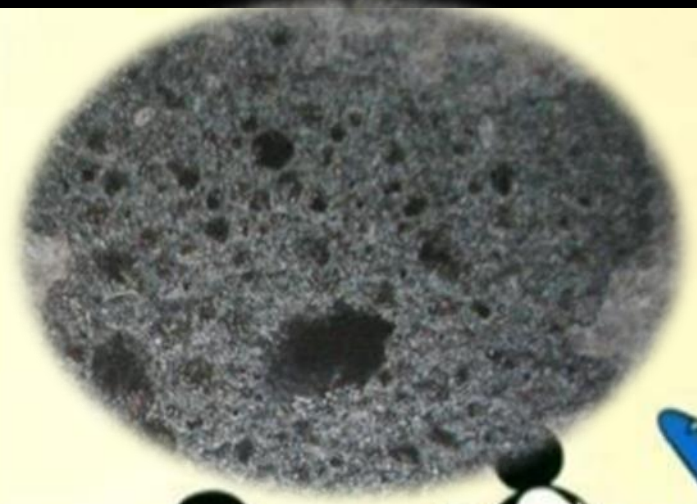
- Crack Free (Reduced Bridge Deck Cracks)
- Lower Curling/Cracking in Pavements
- Reduced Cracking in High Early Strength Pavement Patches
- Enhanced Reactions with SCM

- Lower Cost CRCP? (steel)
- Longer Joint Spacing (cost, ride) ?
- Durability Tighter Microstructure
- Slipforming on Decks Nice Lower σ
- Reduced Plastic and Thermal Cracking

In Florida Look to Walt Disney



"If you can dream it, you can do it. Always remember that this whole thing was started with a Dream and Some Porous Rocks