Engineering Concrete Pavement Mixtures for Durability

National Concrete Pavement Technology Center
Iowa's Lunch–Hour Forum
In cooperation with the Iowa DOT
and the Iowa Concrete Paving Association

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Agenda

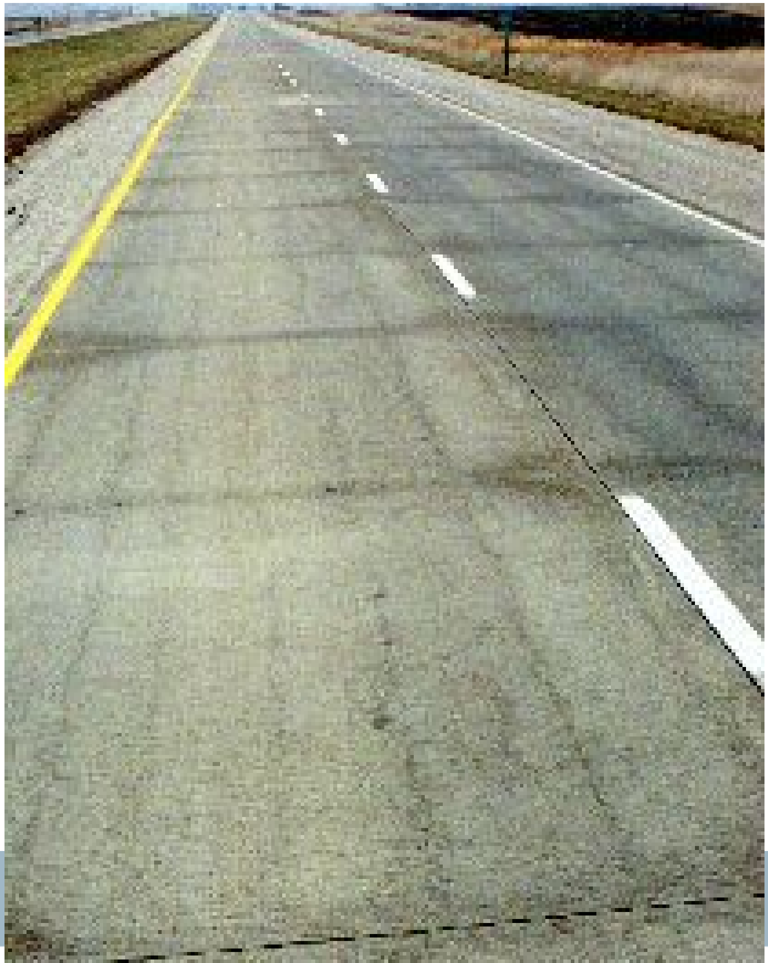
- A bit of Iowa concrete history
- Discussion of
  - Iowa DOT QM-C
  - SUDAS C-SUD
- Discussion of internal curing
- Questions

History – Concrete Paving in Iowa

- Long term service for many years
- Many over 40 years
  - 760 miles built prior to 1963 w/o overlay

History – Concrete Paving in Iowa

- 1991- Distress
  - Vibrator trails
  - Joint spalling
- Visible in 3 – 5 yrs
- Strength vs other properties?



Pavement Placement Problems

Excessive Vibration

- Aggregate segregation
- High mortar area
- Low Air <3%
- Poor Spacing Factors >0.35 mm

Upper 2-3%

lower 5-6%

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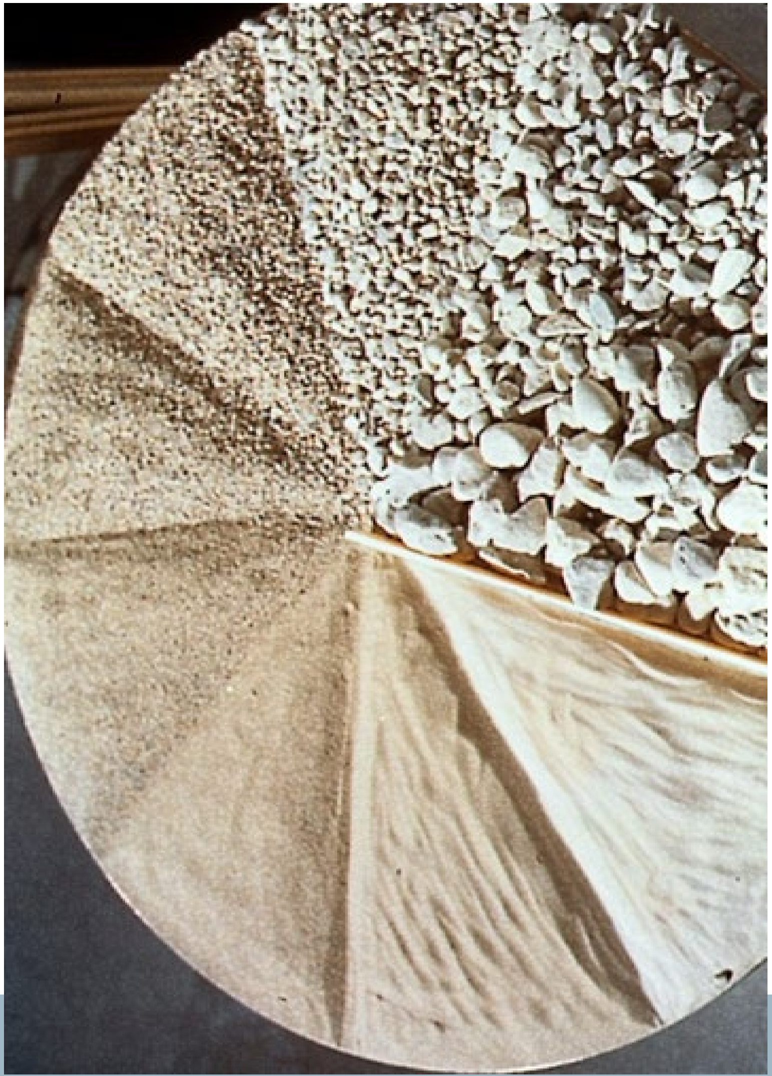
Optimized Mix Designs for Pavements



Based on Coarseness - Workability Factor Chart

- Economy – Cement Content
- Improved Placement Characteristics
- Response to vibrator
- Reduced Shrinkage
- Allows for Quality Control

Fundamentally

- Quality aggregates
- w/cm = 0.42
- Air
- Enough SCM

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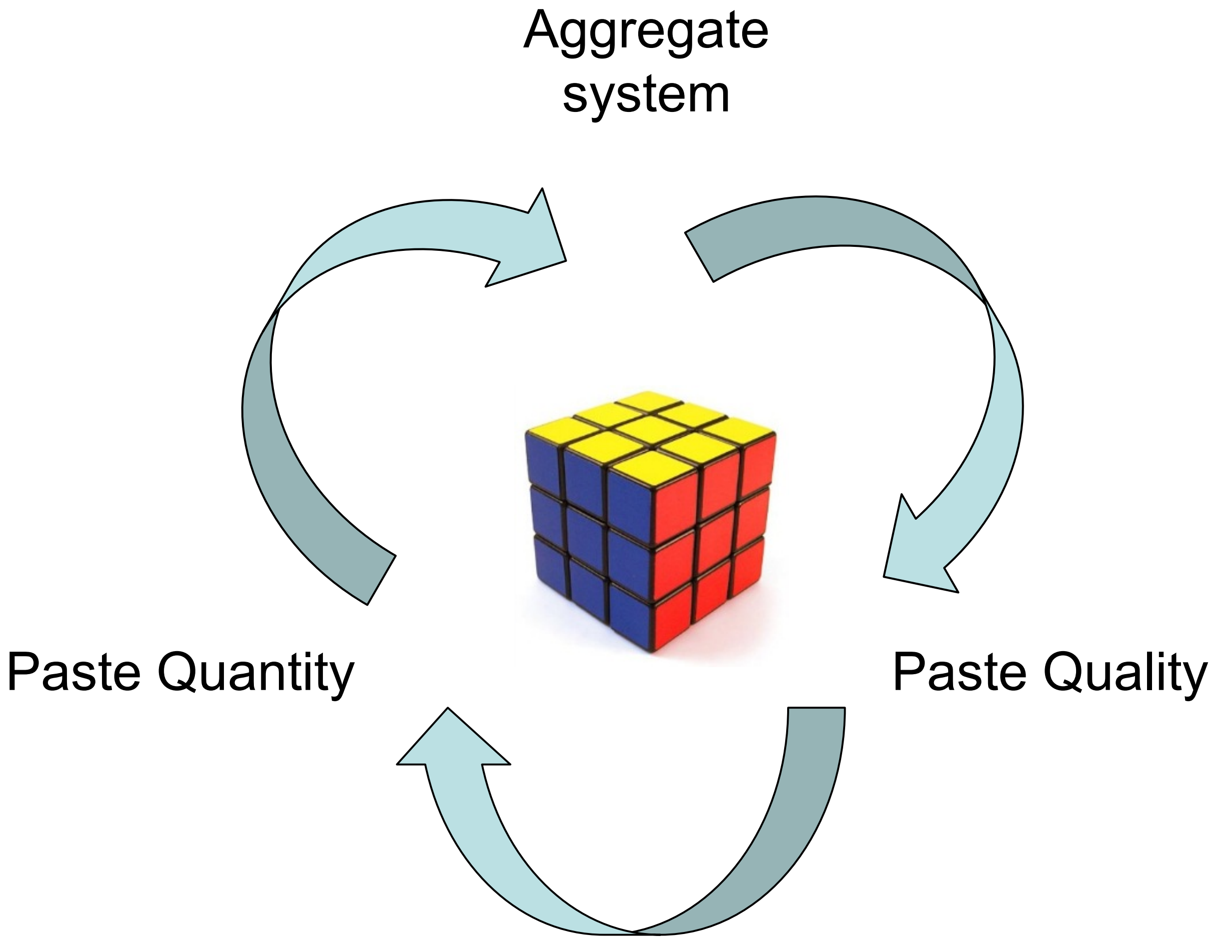
Proposed Mixture Proportioning Procedure



How do we proportion to achieve design goals?

		Workability	Transport	Strength	Cold weather	Shrinkage	Aggregate stability
Aggregate System	Type, gradation	✓✓	-	-	-	-	✓✓
Paste quality	Air, w/cm, SCM type and dose	✓	✓✓	✓✓	✓✓	✓	✓
Paste quantity	Vp/Vv	✓	-	-	-	✓✓	-

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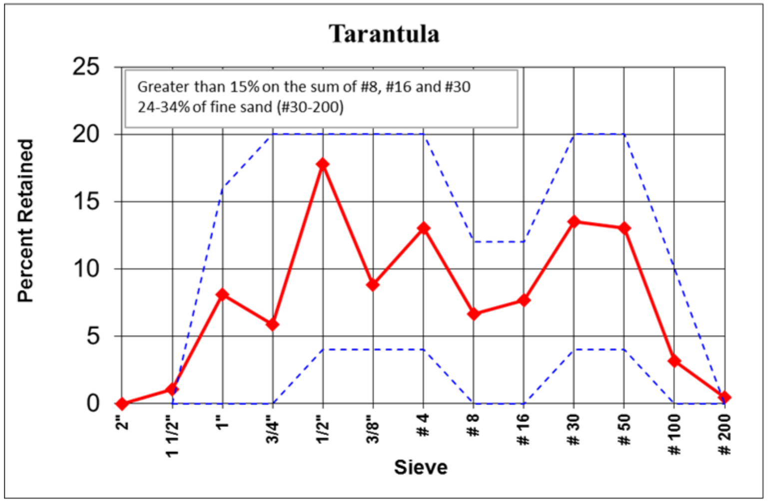
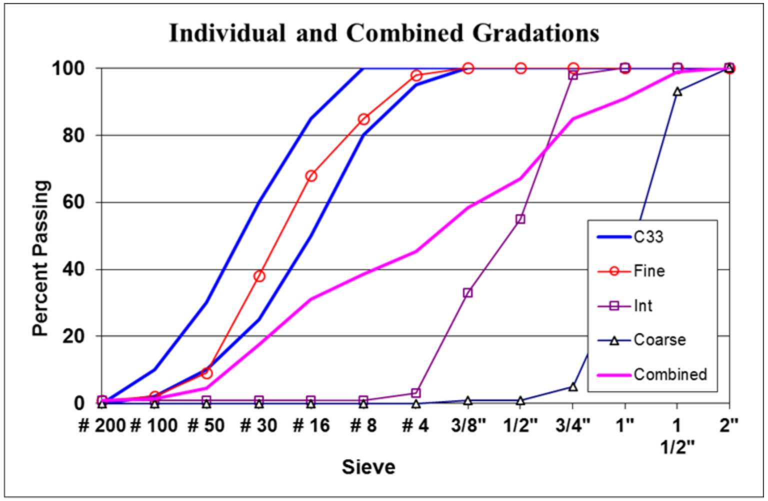
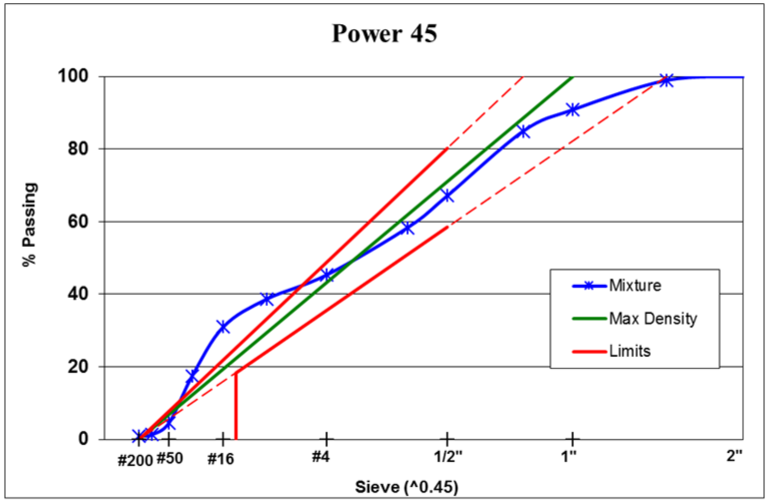
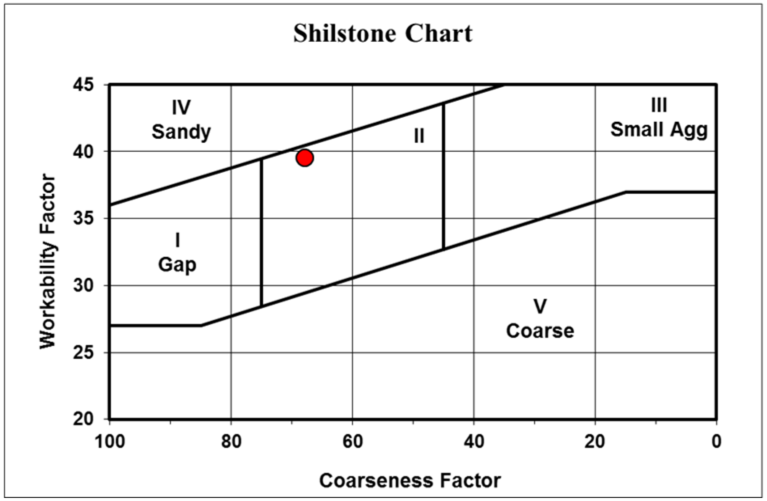
Better mixtures









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Durability Mixes – Iowa DOT QMC

- Quality Management Concrete (QMC) mix
  - Iowa DOT DS-15038
  - Well- graded aggregate combination (IM 532)
  - 44-48% coarse, 10-15% intermediate, and 38-42% fine aggregate.
  - Basic w/cm ratio is 0.40
  - Max. w/cm ratio is 0.42
  - Min. absolute volume of cementitious is 10.6%

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Durability Mixes – Iowa DOT QMC

Iowa DOT C-5WR Mix (Gap Graded)

Iowa DOT QMC Mix (Well Graded)

Mix Appears Rocky at Paver

Closeup of Mix on Grade

Responds Well to Vibration

Excellent Slab Behind Paver

Similar placement whether it's-
Contractor A

Contractor B

Contractor C

Contractor D

QMC Development

- Partnership with contractors expedited changes
- Placement impacts long term durability
- Well graded aggregates improve placement characteristics
- Aggregate shape and texture affect paste content
- Supplementary cementitious materials and well graded aggregates reduces permeability

SCMs and Permeability

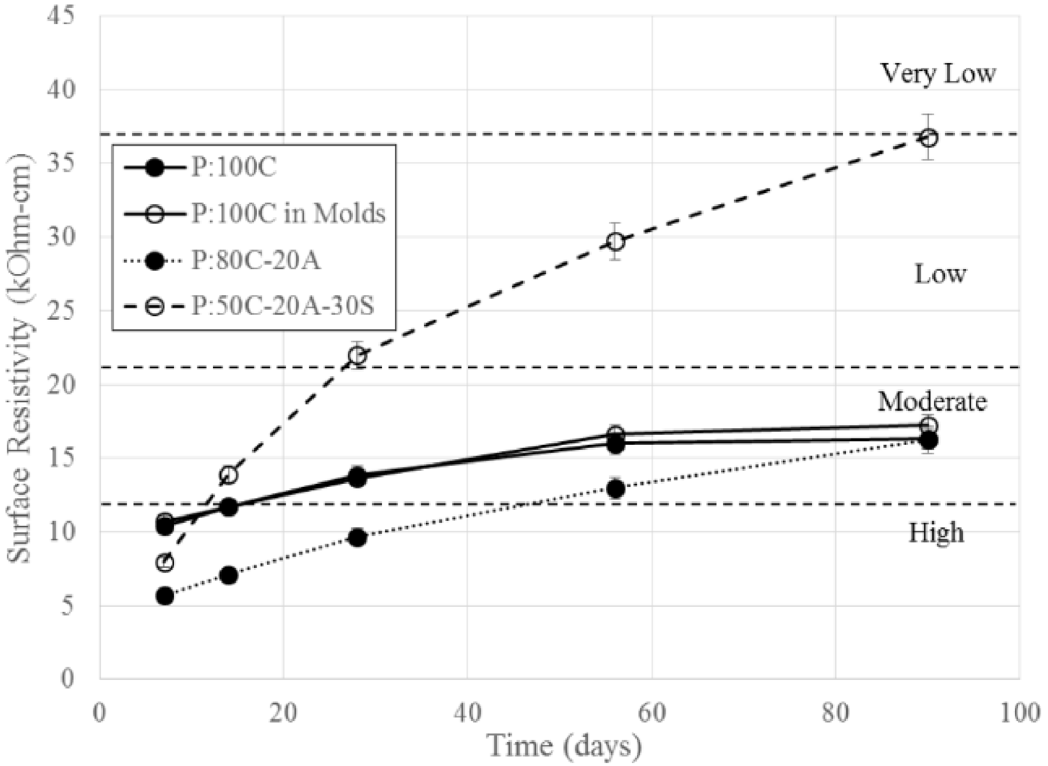

FIGURE 3. Surface Resistivity Results for Paving Mixtures

Same gradation and cementitious content

- 20% C ash equal to cement at 90 days
- 50% replacement, much lower permeability

Kevern, J.T., Halmen, C., Hudson, D. and Trautman, B. “Evaluation of Surface Resistivity for Concrete Quality Assurance in Missouri,” Transportation Research Record: Journal of the Transportation Research Board, No. 2577, Transportation Research Board of the National Academies Washington D.C., pp. 53-59, 2016. DOI: 10.3141/2577-07.

Implementation in Iowa

- Johnston, 2016
  - QMC mix with limestone chip as third aggregate
    - Mix could have been specified as C-SUD – same mix requirements
  - SCM replacement:
    - 20% Class C Fly Ash
    - 20% slag

Implementation in Iowa

- 2016 Performance Notes
  - Set time concerns in Johnston and Council Bluffs
    - Extended time to reach opening strength
      - Upwards of 10-14 days in Johnston <u>later in the season</u>
    - Narrowing of sawing window
    - Some instances of raveling
    - Not as significant a concern with higher cement mixes?
  - No issues currently with long-term strength

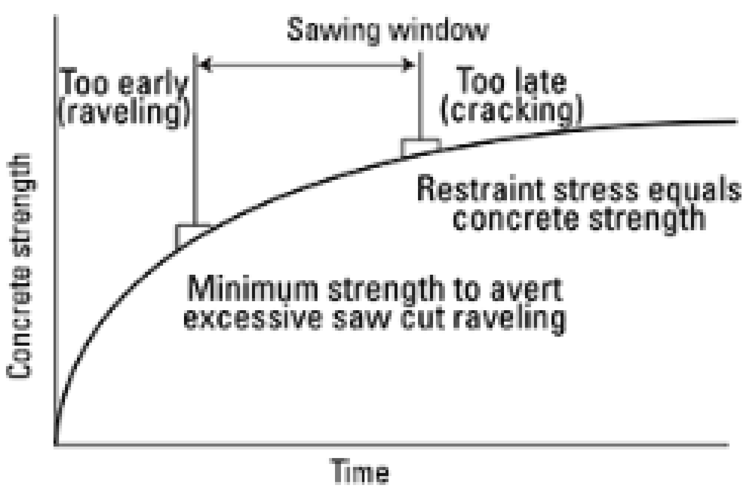

Figure 3-3. Sawing window

Implementation in Iowa

Johnston (paved 2016):

Urban Durability Mix (C-SUD)

C-SUD (SUDAS Mix)

- Lower w/cm for durability
- Target w/cm = 0.40, Max. w/cm = 0.42
- More durable concrete with low permeability
- Can consider 3 aggregate mixes for greater workability and lower permeability
- Should add SCM for enhanced freeze-thaw durability
- Higher durability to reduce joint deterioration

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Urban Durability Mixes (C-SUD)

Table 4, Iowa DOT I.M. 529

Proportion Table 4
SUDAS Concrete Mixes
Using Article 4110 and 4115 Aggregates
Basic Absolute Volumes of Materials Per Unit Volume of Concrete

C-SUD MIXES Basic w/c = 0.400 Max w/c = 0.420

Mix No.	**Cement**	**Water**	**Air**	**Fine**	**Coarse**
C-SUD	0.106	0.133	0.060	*	*

Above mixture is based on Type I or Type II cements (Sp. G = 3.14). Mixes using blended cements (Type IP or IS) must be adjusted for cement gravities listed in IM 401. These mixes require optimized aggregate proportioning in accordance with the specifications.

Using Class V Aggregates (4117) Combined with Limestone
Basic Absolute Volumes of Materials Per Unit Volume of Concrete

CV-SUD MIXES Basic w/c = 0.400 Max w/c = 0.420

Mix No.	**Cement**	**Water**	**Air**	**Class V.**	**Coarse Limestone**
CV-SUD	0.114	0.135	0.060	0.379	0.311

Above mixture is based on Type IP cements.

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Urban Durability Mixes (C-SUD)

- Fly ash substitution rates
  - Class C 30-35%
  - Class F 20-25%
- Maximum combination rate is 20% Class C fly ash and 20% slag

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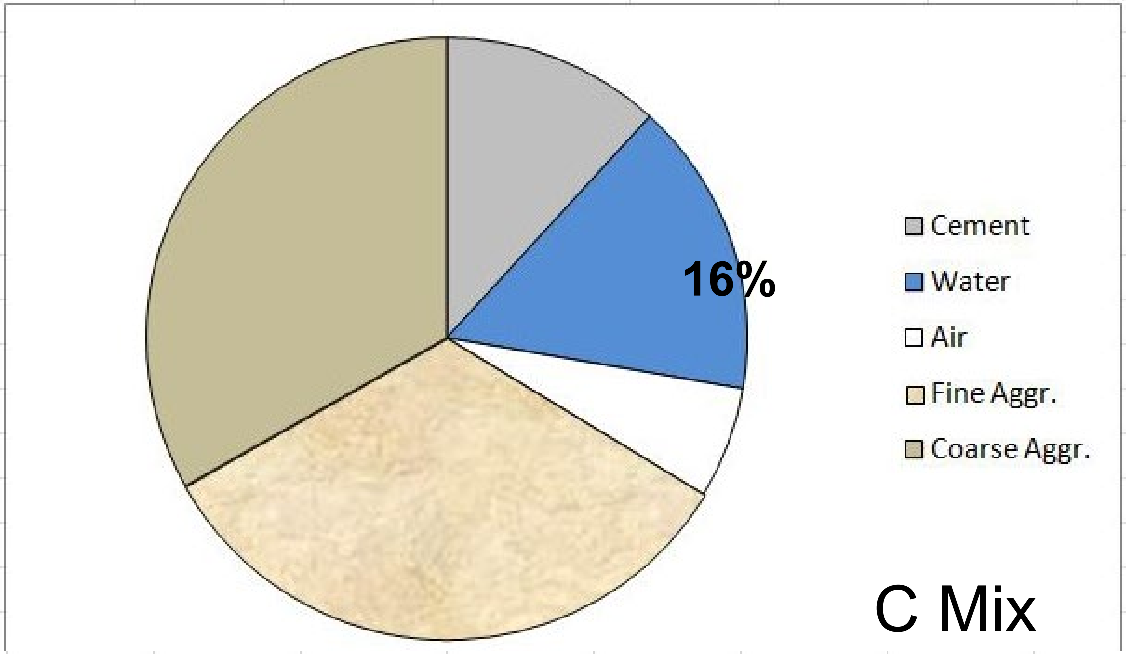
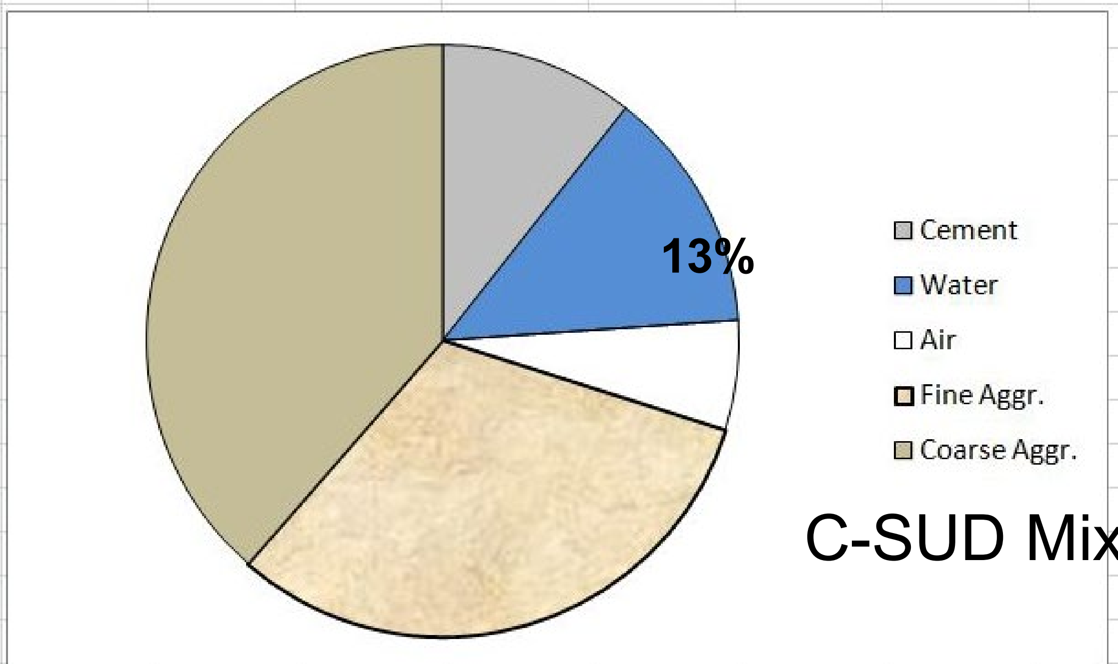
Class C & Class C-SUD (Per by Vol.)



Class C-4 Mix

Cement	0.118
Water	**0.159**
Air	0.06
Fine Aggr.	0.331
Coarse Aggr.	0.332



Class C-SUD Mix

Cement	0.106
Water	**0.133**
Air	0.06
Fine Aggr.	0.315
Coarse Aggr.	0.386

C-SUD Projects

Ankeny

2018, full-depth repairs

- 0.42 w/cm ratio
- 51% coarse
- 4% intermediate (pea gravel)
- 45% fine
- 35% Class C Fly Ash
- Water reducer, retarder

C-SUD Projects

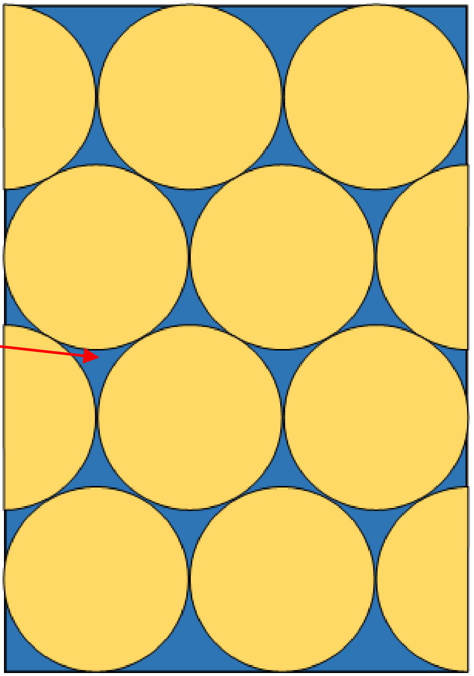
Ankeny

2017, Reconstruction

- 0.40 w/cm ratio
- 44% coarse
- 15% intermediate (pea
- 41% fine
- 20% Class C Fly Ash
- Retarder
- Water reducer (handwork)

Doing the Sums

The wonders of
a spreadsheet and a
solver function…



Measure
V_a

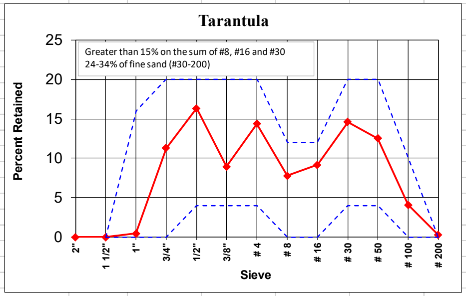
Aggregate System

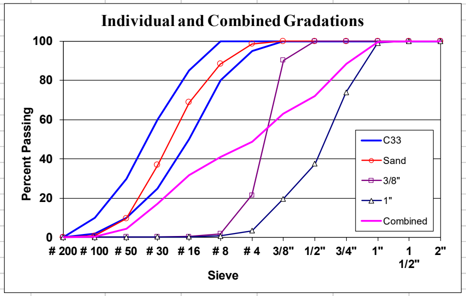
National Concrete Pavement Technology Center
Iowa State University
Institute for Transportation

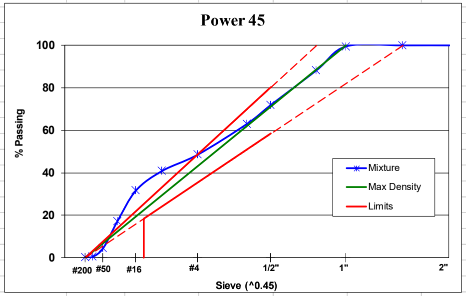
Project	Effect of gradation	9/29/2016			
Materials				Blue= Input Data	
				Red = Calculation	Don't touch!
Cementitious		472		Yellow = Output	Don't touch!
Coarse Agg		1"		Black = Working	Don't touch!
Fine Agg		Sand			
Intermediate		3/8"			
Sieve Analysis Data					
Max nominal aggregate size		1.00	inch (0.75, 1.0 or 1.5)		

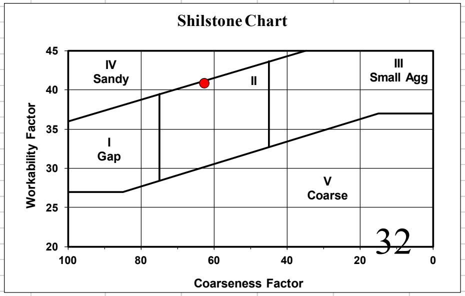
		Coarse	1"	Fine	Sand	Intermediate	3/8"	Combined			Fineness Modulus
								Percent	Cum.	Sieve	
Percent mass	100.0		44.9		45.7		9.4	Passing	Retained	Retained	
Sieve:		% Pass	% Mix	% Pass	% Mix	% Pass	% Mix	%	%	%	
2"		100.0	44.9	100.0	45.7	100.0	9.4	100.0	0.0	0.0	
1 1/2"		100.0	44.9	100.0	45.7	100.0	9.4	100.0	0.0	0.0	
1"		99.0	44.4	100.0	45.7	100.0	9.4	99.6	0.4	0.4	
3/4"		73.9	33.2	100.0	45.7	100.0	9.4	88.3	11.7	11.3	
1/2"		37.5	16.8	100.0	45.7	100.0	9.4	71.9	28.1	16.3	
3/8"		19.7	8.8	100.0	45.7	90.2	8.5	63.0	37.0	8.9	0.0
# 4		3.5	1.6	98.6	45.1	21.6	2.0	48.7	51.3	14.4	1.4
# 8		0.8	0.4	88.3	40.3	2.0	0.2	40.9	59.1	7.8	11.7
# 16		0.4	0.2	68.9	31.5	0.6	0.1	31.7	68.3	9.2	31.1
# 30		0.4	0.2	37.0	16.9	0.4	0.0	17.1	82.9	14.6	63.0
# 50		0.3	0.1	9.7	4.4	0.4	0.0	4.6	95.4	12.5	90.3
# 100		0.3	0.1	0.8	0.4	0.3	0.0	0.5	99.5	4.1	99.2
# 200		0.3	0.1	0.2	0.1	0.3	0.0	0.3	99.7	0.3	
											2.97

Coarsness Factor	62.55	Power 45 least difference	31.0		Tarantula error	0.0	4.5
Workability Factor	40.89	Power 45 error	350.2				113.7
Adjustments	0.00						
Adjusted Workability Factor	40.89	Fine	31.5	24-34			
		Coarse	31.5	>15			









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Internal Curing

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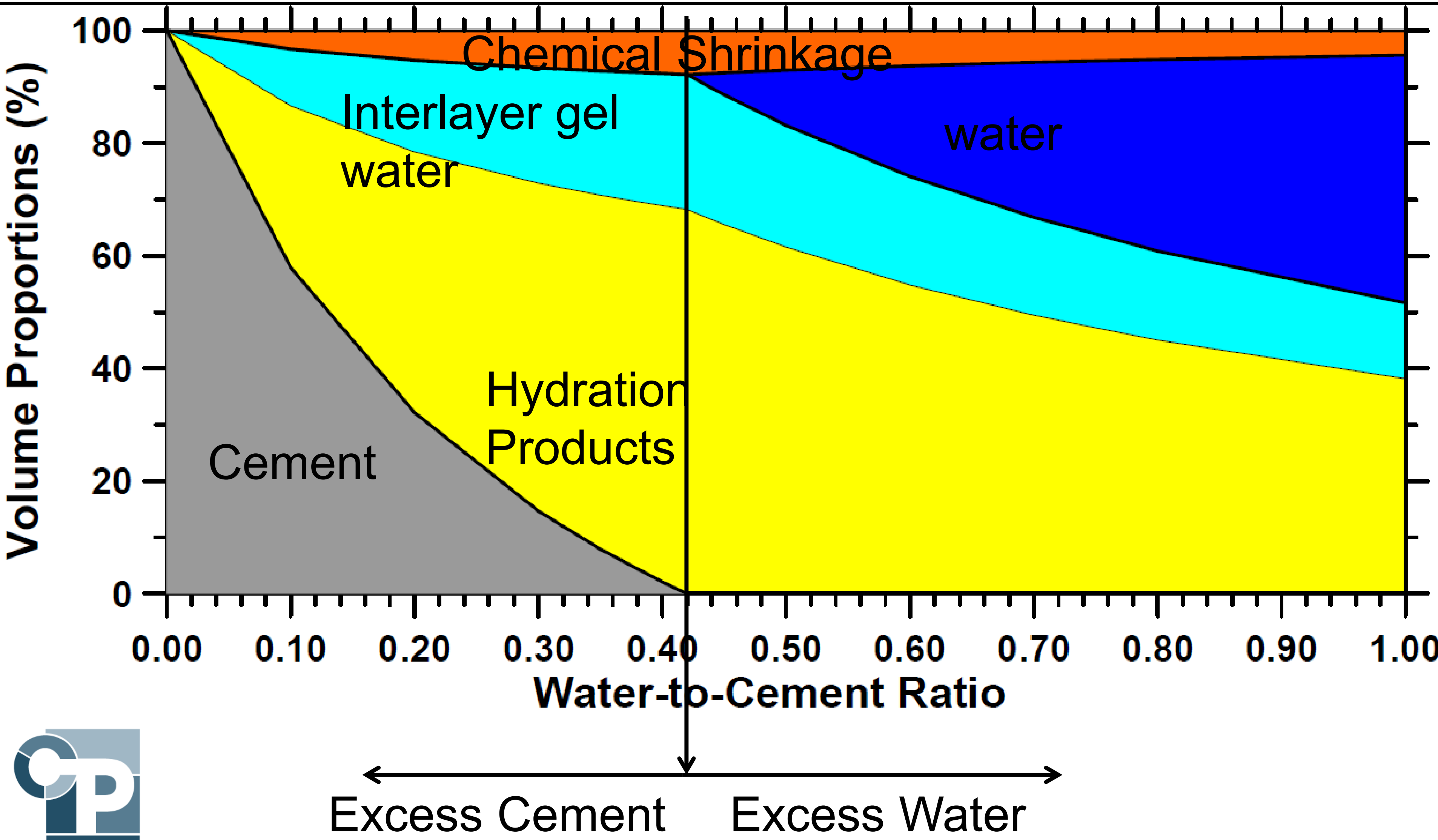
Influence of w/c on hydration



Internal Curing for Concrete

- Concrete needs water for hydration
- At w/c 0.42 and below, self-desiccation (autogenous shrinkage) causes significant internal stresses
- Supplying external water to low w/c mixes only impacts the surface

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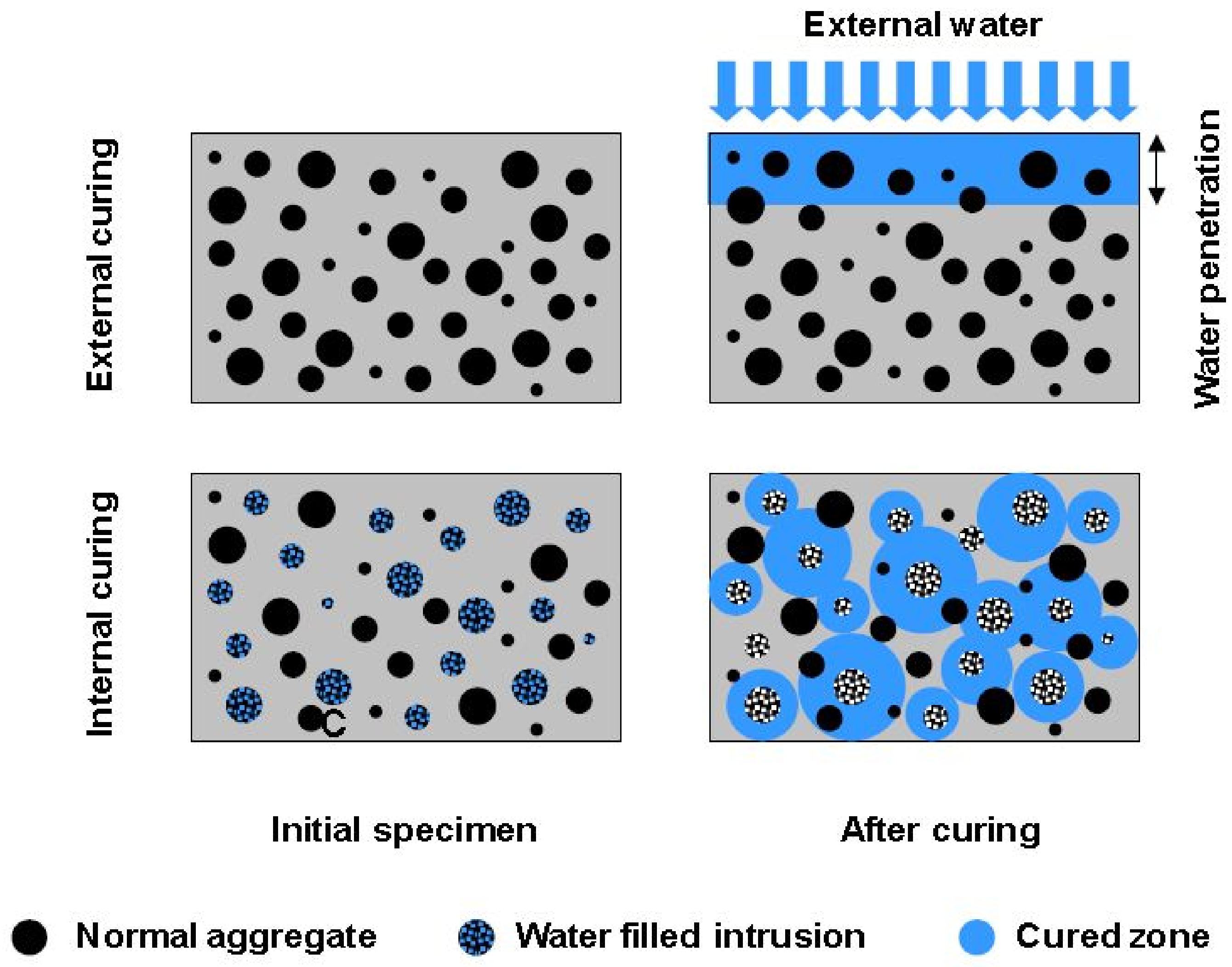
Internal Curing - Why



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Internal Curing - How

- Expanded fine aggregate
- Super Absorbent Polymers

Internal Curing - Benefits

- Better hydration & SCM reaction
  - Improved durability
  - Less cement

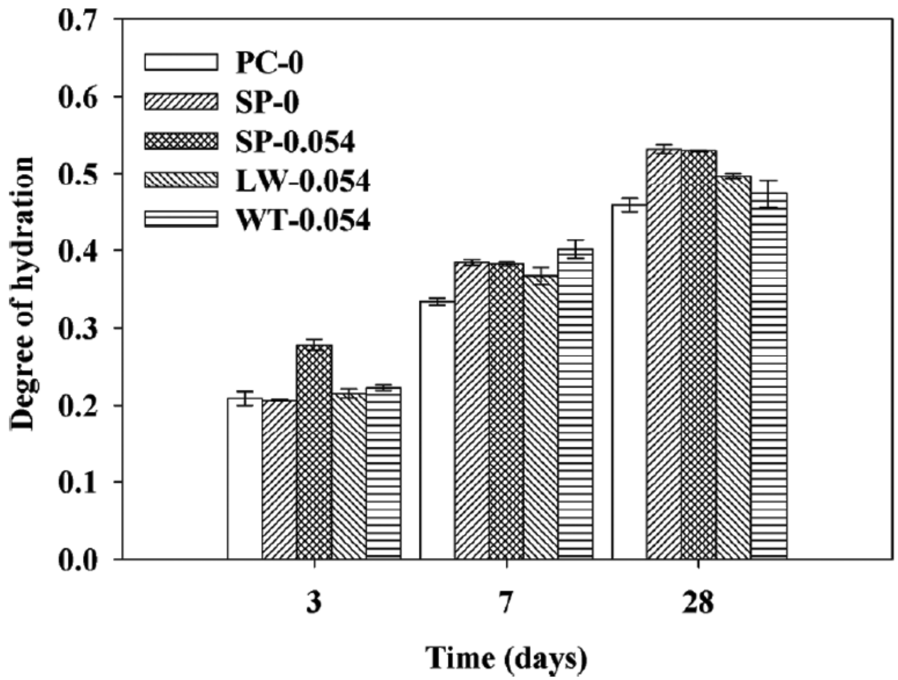

Fig. 5—Comparison of degree of hydration calculated from all groups at different age cured at 50% RH. (Note: Error bars represent standard error.)

Legend Summary
- PC-control
- SP – Super absorbent, no water
- SP0.054- SAP increased w/c
- LW – lightweight fines
- WT – Drinking water treatment waste

Nowasell, Q. and Kevern, J.T. "Using Drinking Water Treatment Waste as a Low Cost Internal Curing Agent for Concrete," ACI Materials Journal, V. 112, No. 1, Jan-Feb 2015, pp. 69-77.

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Internal Curing - Benefits

- Less shrinkage, cracking, curling, longer time to cracking

SAP-Super Absorbent Polymer

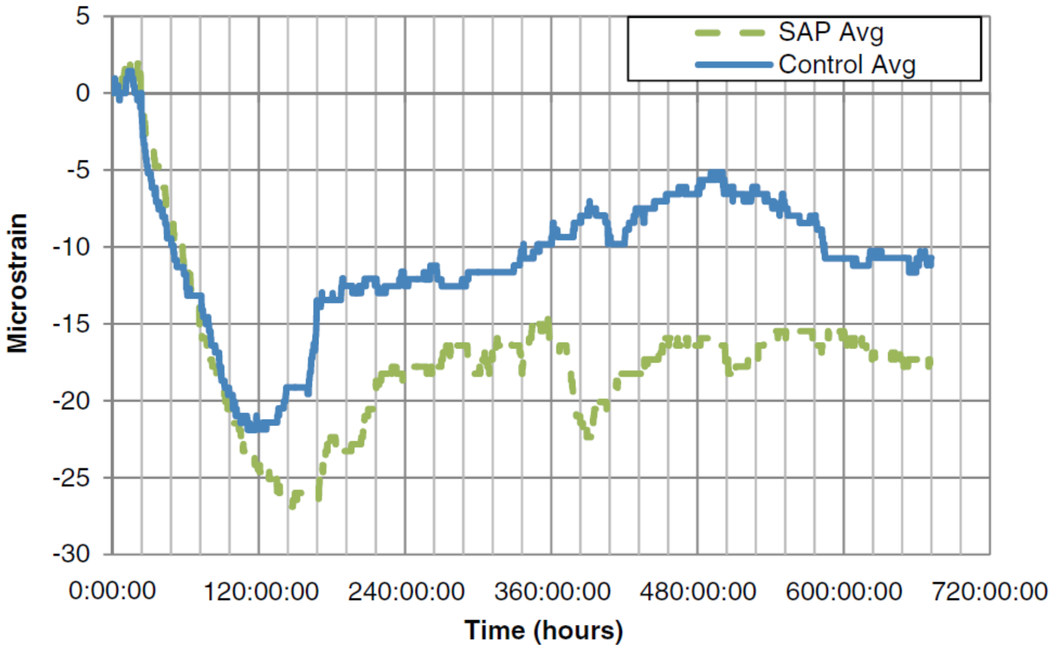

FIGURE 6 Restrained ring shrinkage results (avg = average).

>24 hours longer to crack at much higher strength

Kevern, J.T. and Farney, C. "Reducing Curing Requirements for Pervious Concrete Using a Superabsorbent Polymer for Internal Curing." Transportation Research Record: Journal of the Transportation Research Board, No. 2290, Transportation Research Board of the National Academies, Washington, D.C., 2012, pp. 115–121. DOI: 10.3141/2290-15

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Internal Curing - Benefits

- Extended service life, lower permeability
- Increased sustainability

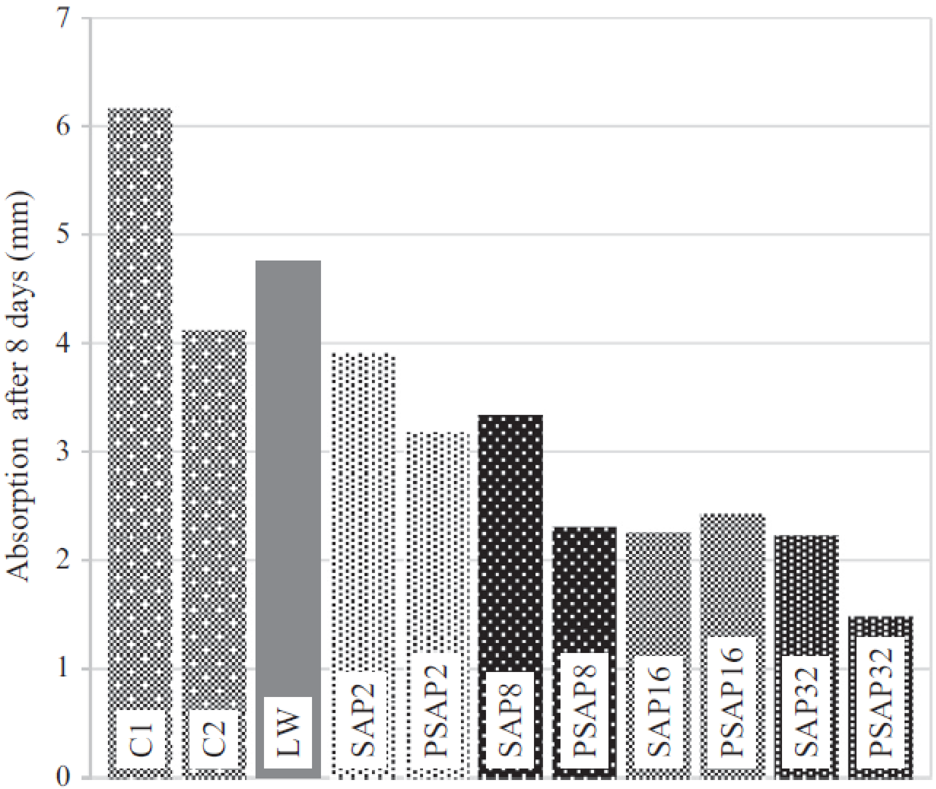

Fig. 10. Absorption at 8 days.

Legend Summary
- C1 – Non-air entrained control
- C2 – Air entrained control
- LW – Non-AEA Lightweight fine aggregate
- SAP 2-32 – Non-AEA, SAP dose in oz/cwt

Internal Curing - How

- Material should
  - Hold sufficient water
  - Hold the water until needed and not effect w/c
  - Give up water at high RH (desorption)
  - Not adversely effect the concrete quality

No air | Air | Lightweight Fines

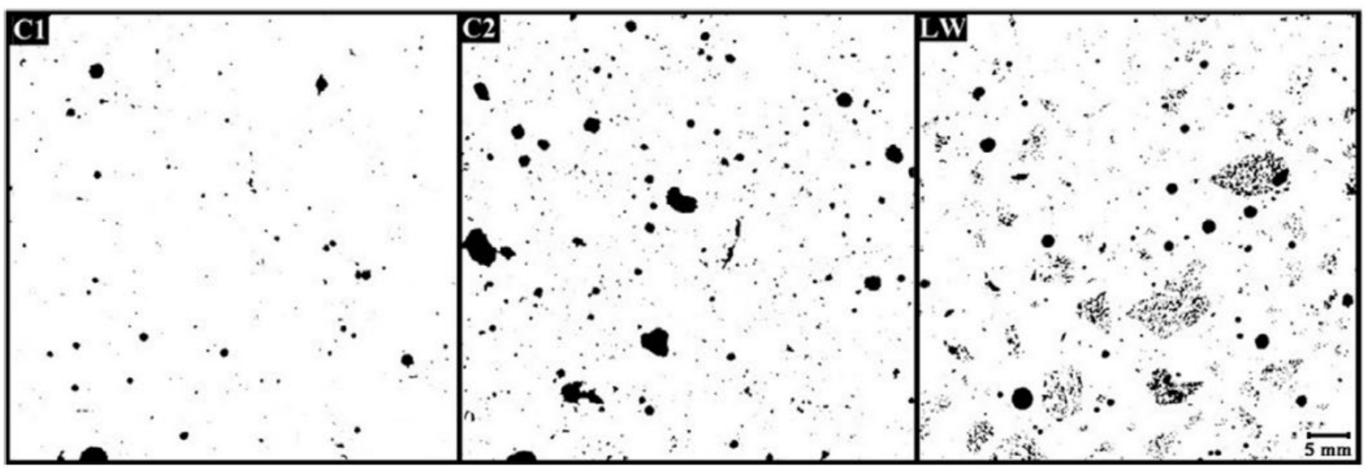

Fig. 2. Binary image of controls and lightweight aggregates specimens.

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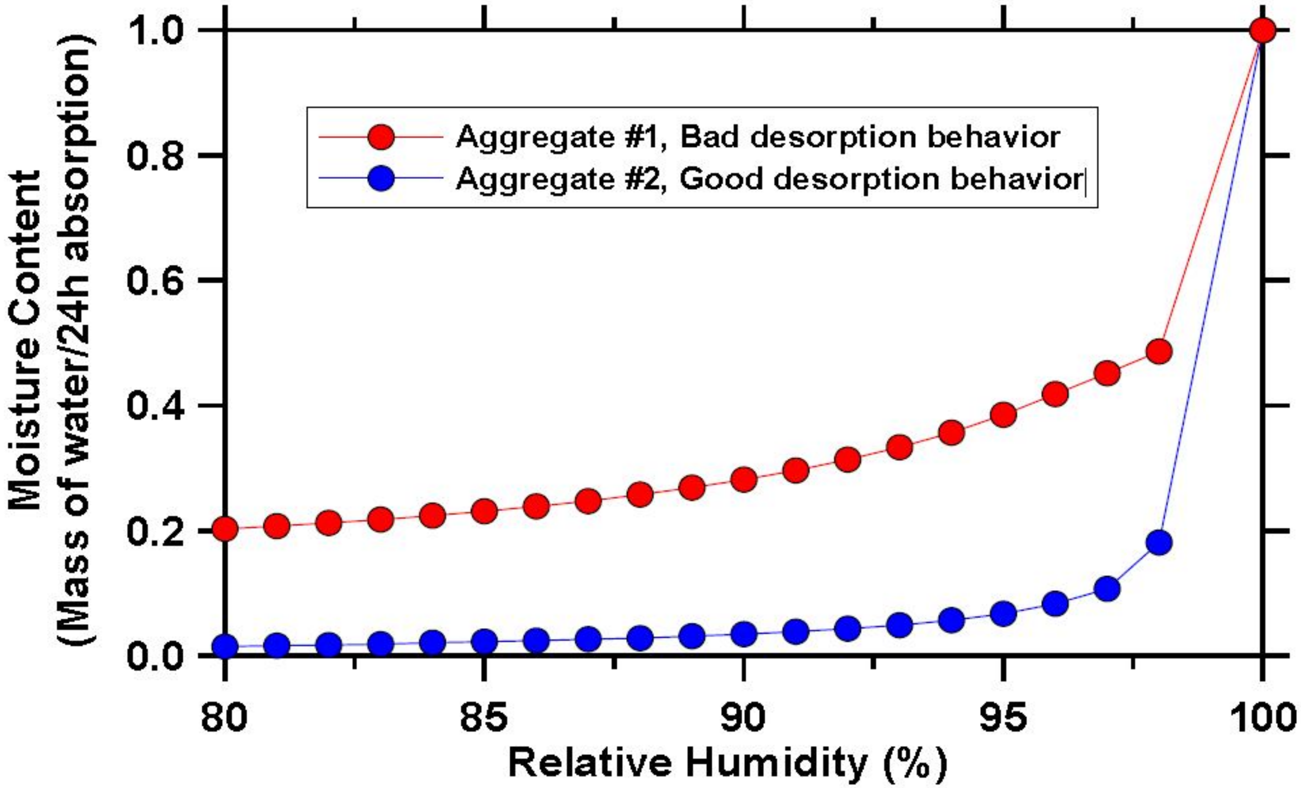
Internal Curing - How

Desorption (ASTM C1761)



- Virtually all moisture available at 94% RH

Castro 2011

How Much?

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

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).

Or… about 7lb IC water for 100 lb cement

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Bentz & Snyder (1999), Bentz, Lura, & Roberts (2005):

NY State DOT Specifications

- Proper amount of water
- 30% replacement of fine aggregate
- Minimum 15% absorbed moisture (15-40% common)
- Place under sprinkler for minimum of 48 hours
- Allow stockpiles to drain for 12 to 15 hours immediately prior to use

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Internal Curing - How

- Can we do without internal curing?
- Nope!
  - Still have to keep the surface hydrating
  - That's where the abuse happens

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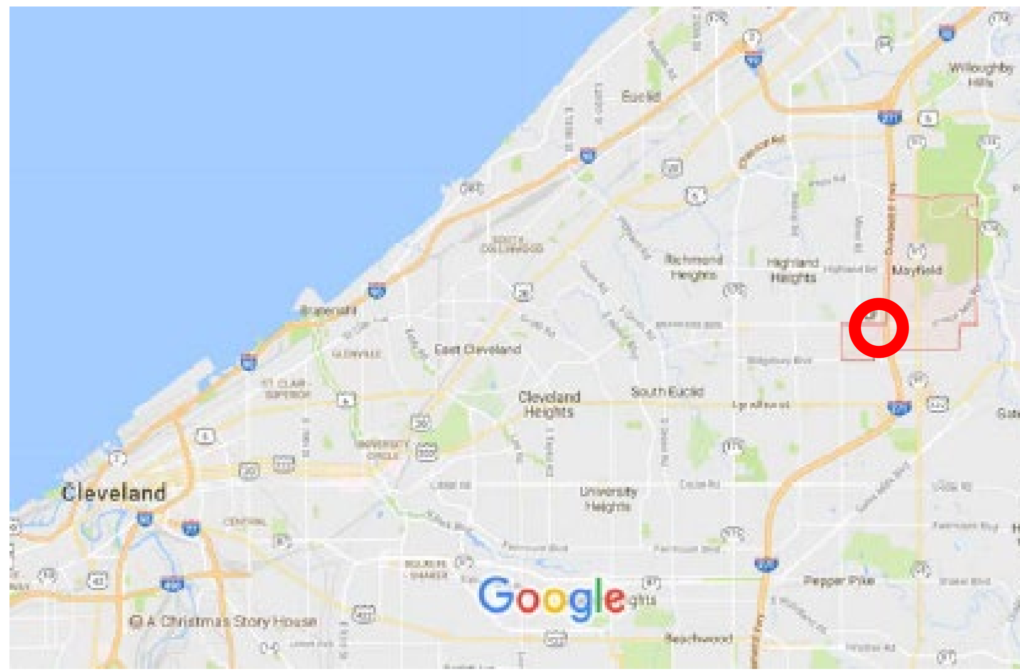
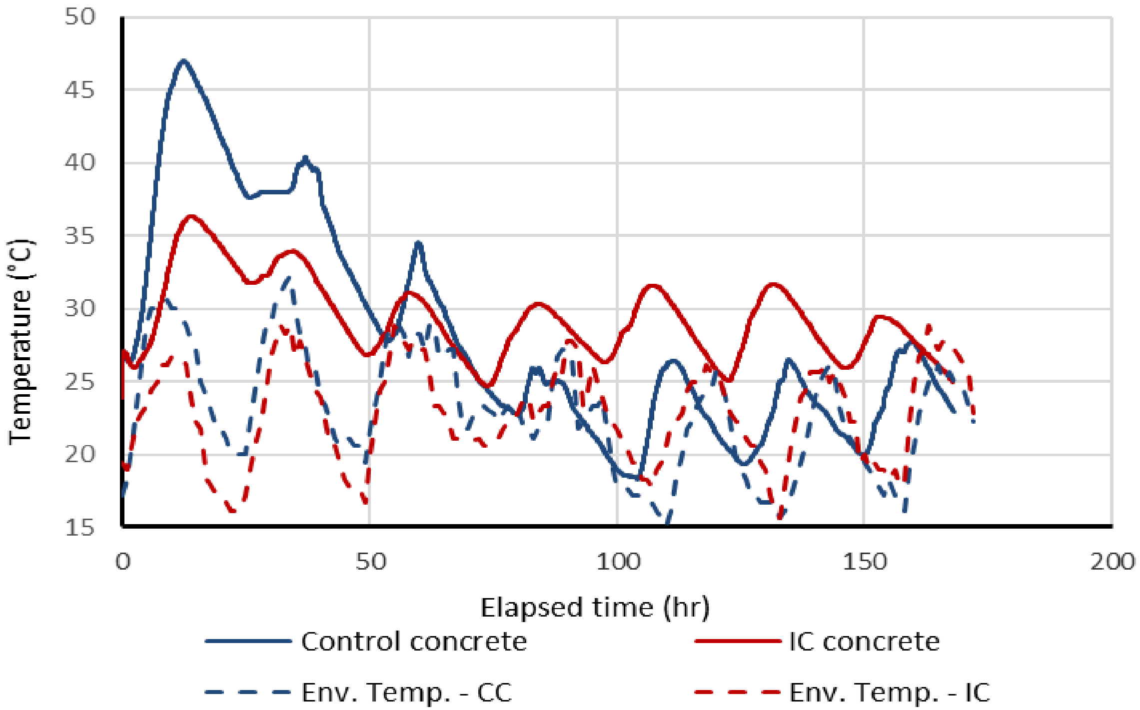
Bridge Deck Performance-Field

- Two bridge decks, control and test
- Route 271, Mayfield, OH
- Placed 1 to 7 AM on:
  - Control: August, 1st
  - Test: August, 11th



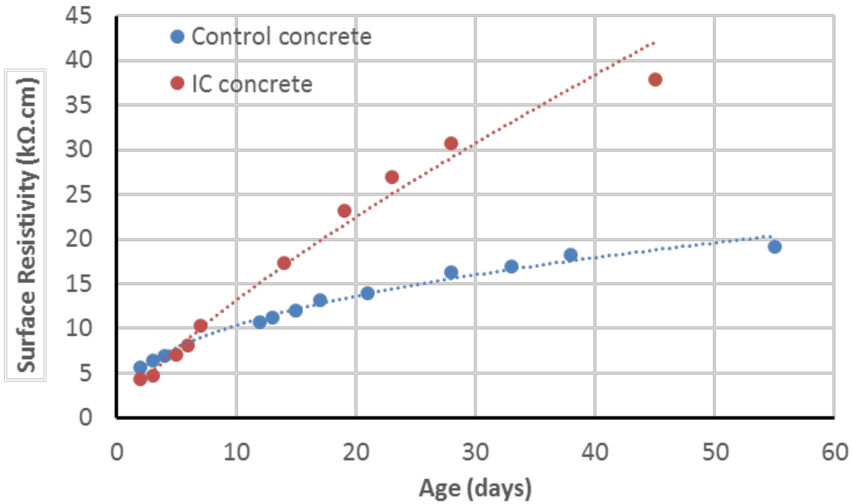
Embedded temperature sensor

- IC stayed warmer longer
- Likely due to continued hydration

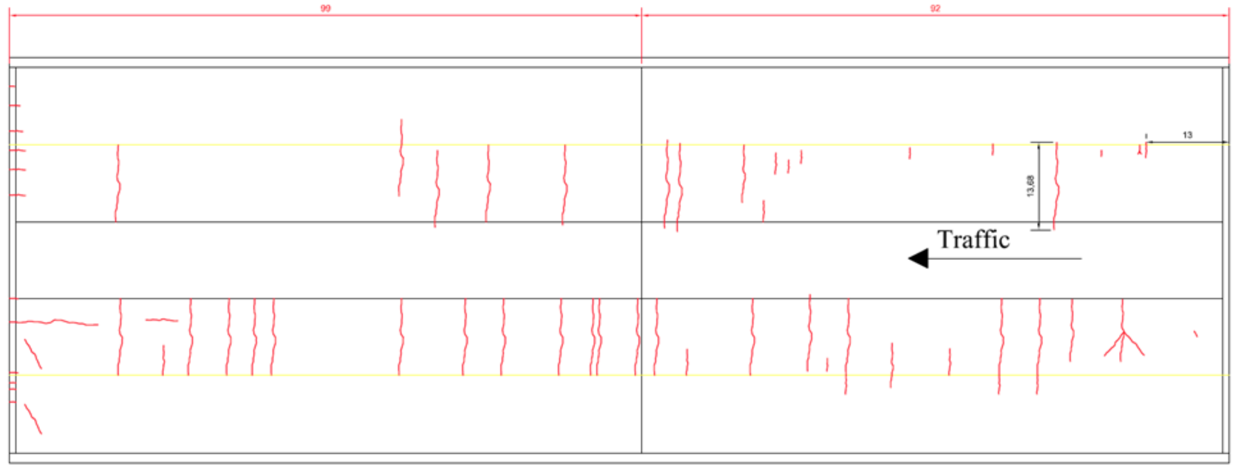


Transport properties

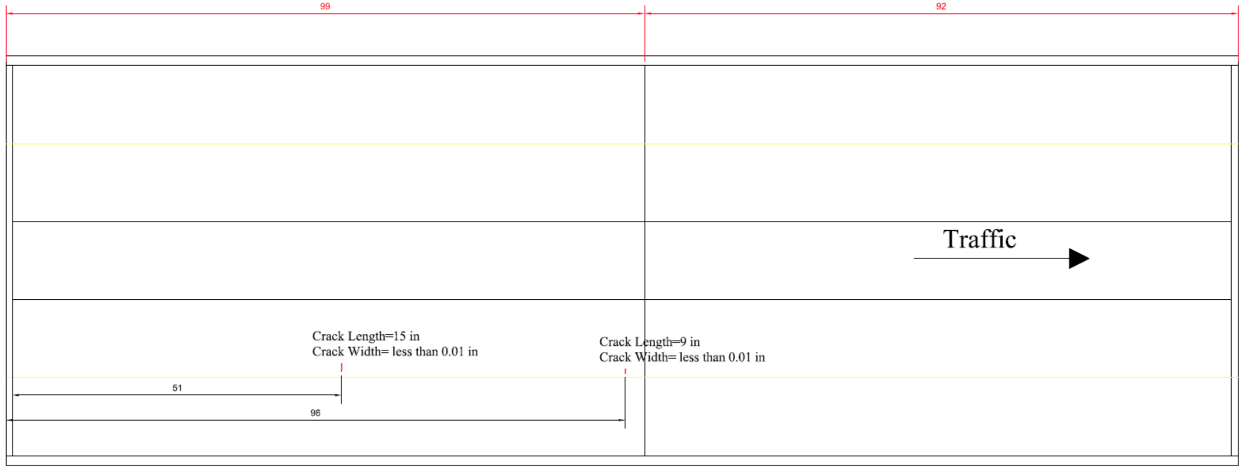
- Surface electrical resistivity
  - Higher degree of hydration because of IC
  - Improved microstructure with slag cement
- Leads to potentially longer life



One-Year Review



Conventional Concrete Deck



IC Deck

Missouri Bridge Deck Performance

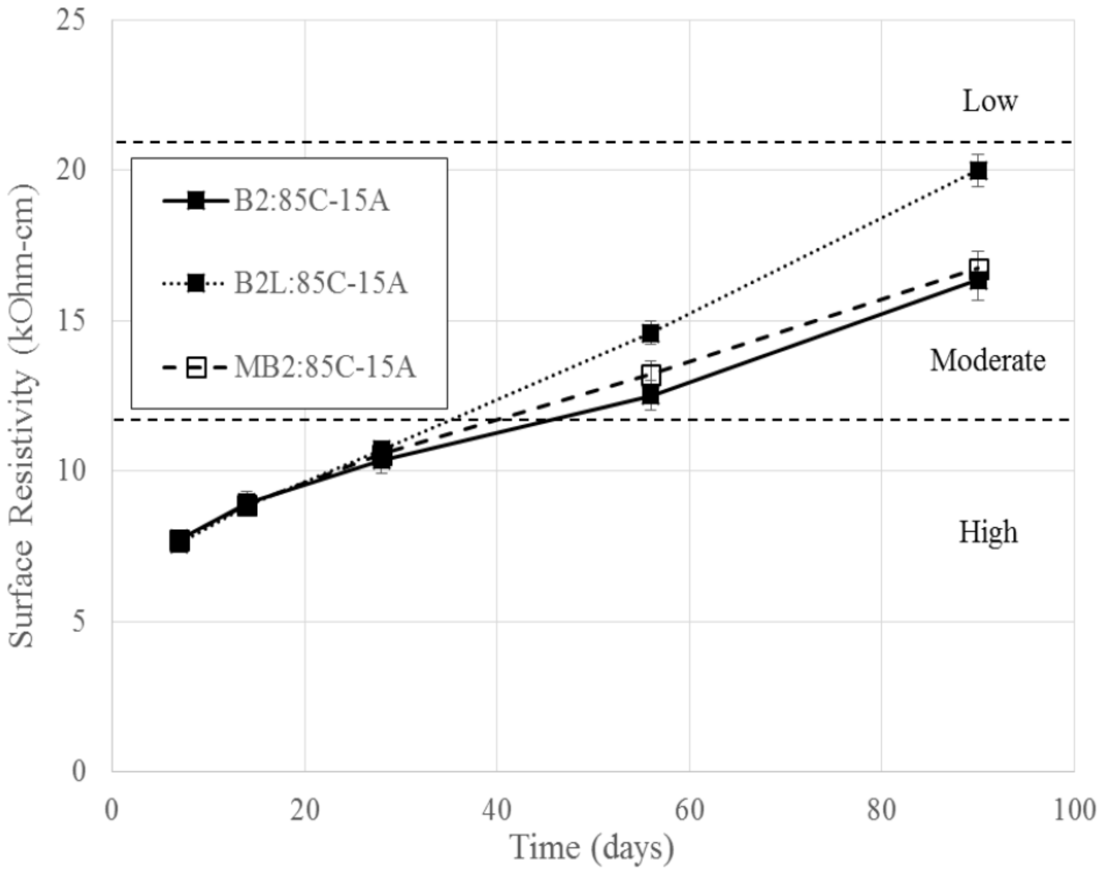


FIGURE 4. Surface Resistivity Results for Bridge Deck Mixtures

- •B
- \- 600 pcy cement
- \- 105 pcy C ash
- •MB
- \- 510 pcy cement
- \- 90 pcy C ash
- •BL
- \- Same a B, but 135pcy prewetted lightweight fines (10% replacement)

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Kevern, J.T., Halmen, C., Hudson, D. and Trautman, B. "Evaluation of Surface Resistivity for Concrete Quality Assurance in Missouri," Transportation Research Record: Journal of the Transportation Research Board, No. 2577, Transportation Research Board of the National Academies Washington D.C., pp. 53-59, 2016. DOI: 10.3141/2577-07.

So

- Good concrete should have:
  - Low w/cm
  - Good air
  - Enough cementitious – and no more
  - Well graded aggregate
- Can be further improved by internal curing using lightweight fine aggregate or super absorbent polymers.

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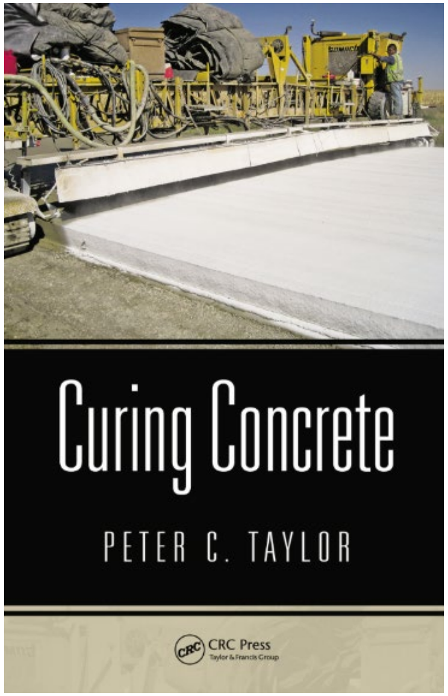
Thank You

Peter Taylor



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