Summary of Selected Research Projects Funded by the Concrete Physical Lab of the State Materials Office

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Effects of Cement Particle Size on HOH

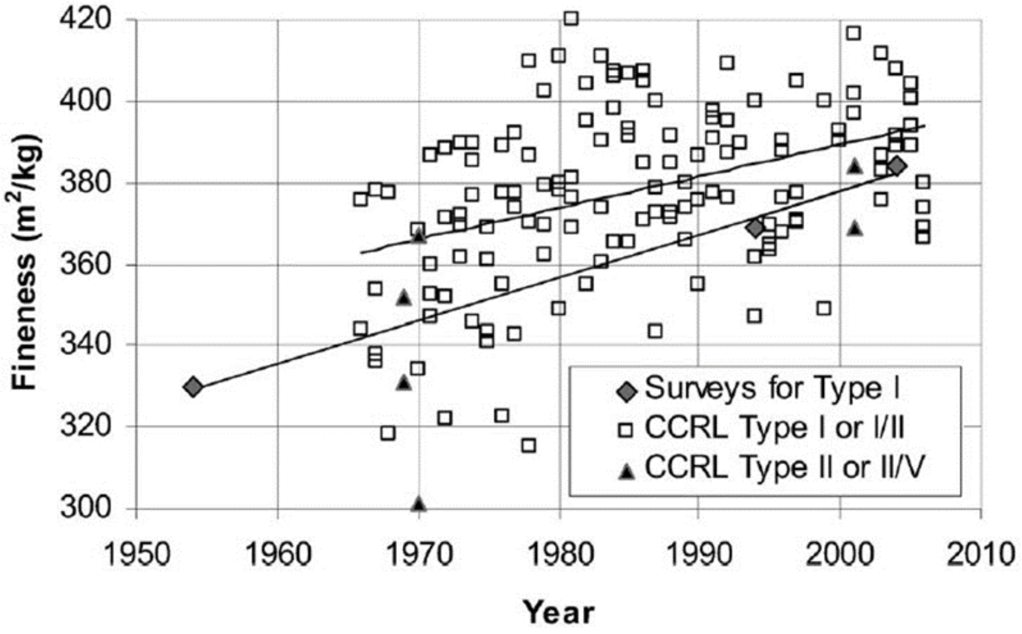
(Prof. Abla Zayed @ USF)

Rationale

- Current portland cement specifications do not address the effect of fineness on the HOH (potential for thermal cracking)
- Fineness affects potential for thermal cracking
  - It is commonly accepted that finer cements are more reactive, and higher reactivity results in a higher rate of heat generation
  - For mass concrete applications, a higher rate of heat generation increases the risk of thermal cracking
  - For high-early-strength concrete, a higher rate of heat generation is compounded by the use of an accelerating admixture

Trend Toward Much Finer Cements

Portland cement fineness has been steadily increasing over the past 50 years – driven by industry pressure to achieve higher early strengths to reduce construction times



Bentz et al. (2008). "Early-Age Properties of Cement-Based Materials. II: Influence of Cement Fineness", *J. Mater. Civ. Eng.*, 20(7), 502-508

Objectives and Approach

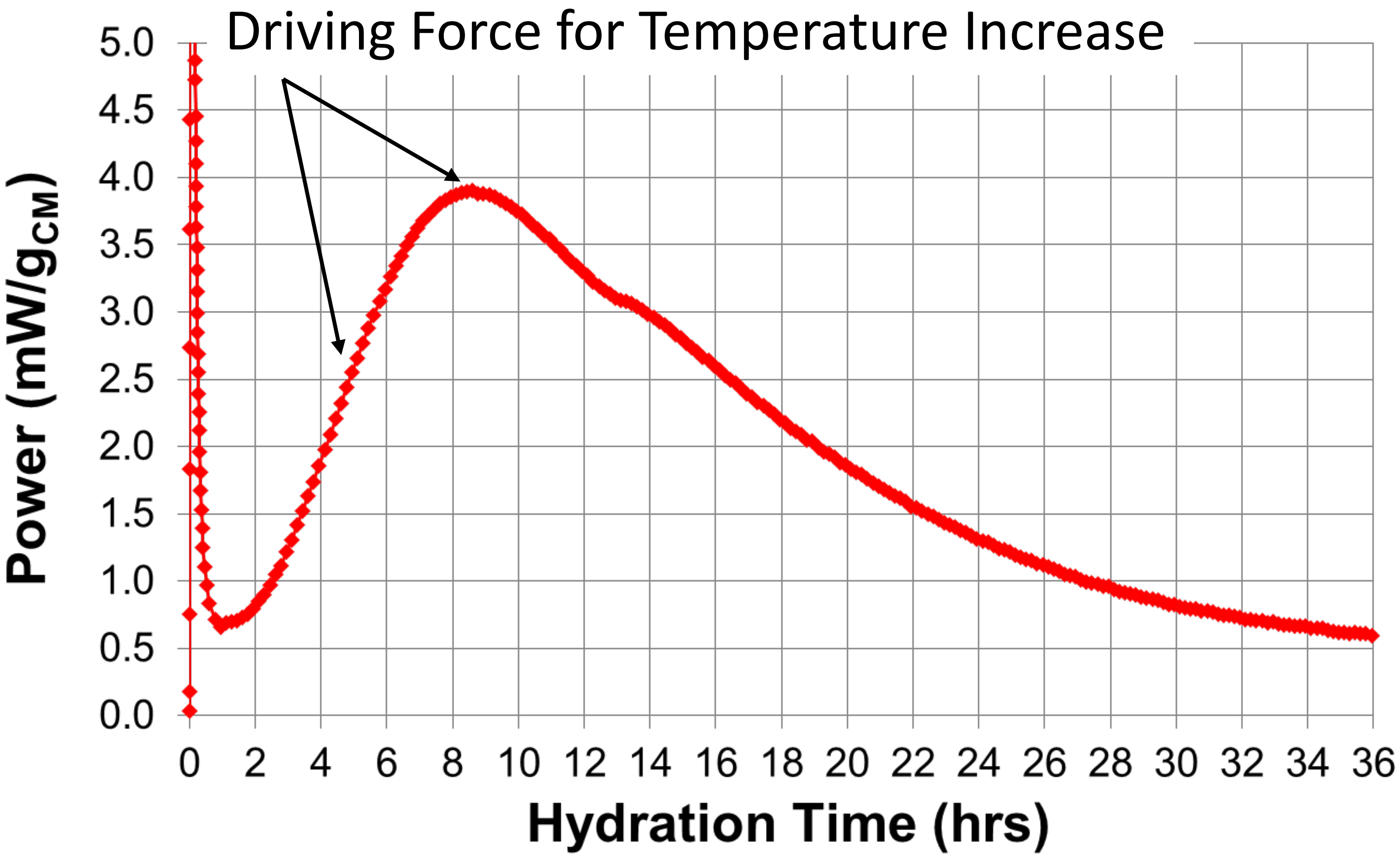
Objective

- Determine how cement particle size affects the quantity of heat generated during cement hydration.

Approach

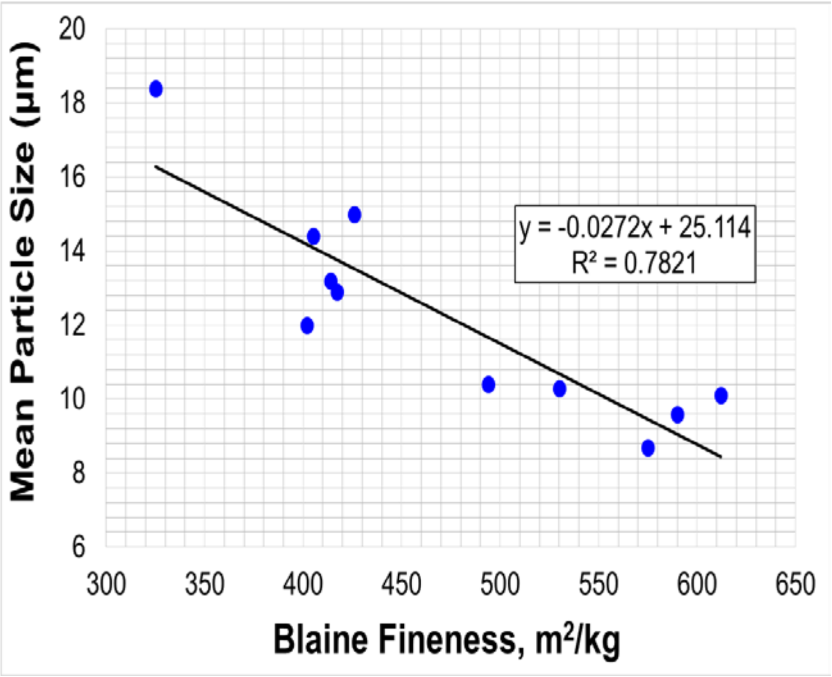
- Test and compare cements from multiple cement manufacturers having a large range of fineness.
  - For each cement, different finenesses obtained from same clinker to minimize compositional effects.
  - Evaluate fineness with Blaine and laser particle size analysis.
  - Evaluate heat generation with isothermal calorimetry and semi-adiabatic calorimetry (SAC).

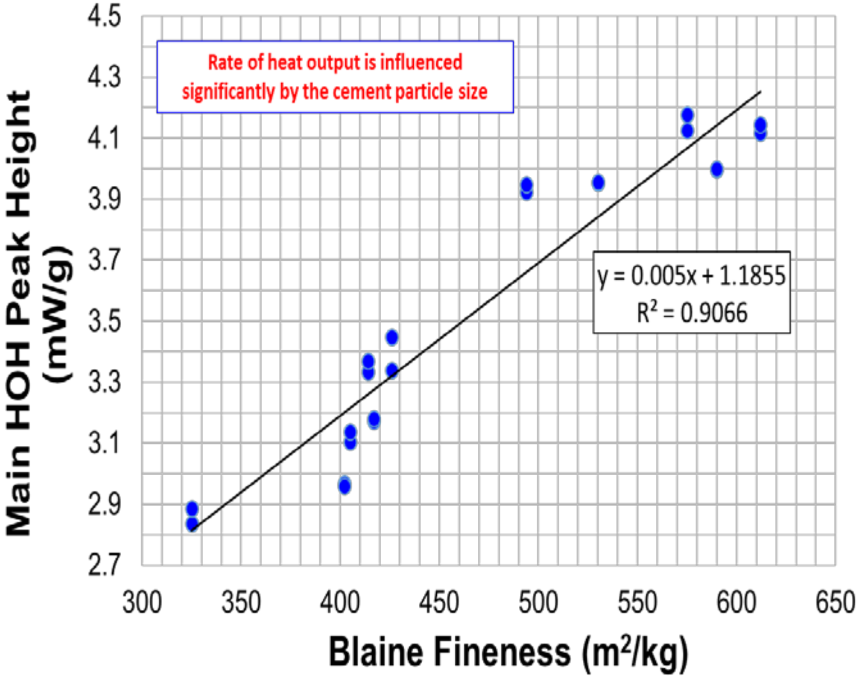
Typical Power Curve for Type I/II Cement



Findings

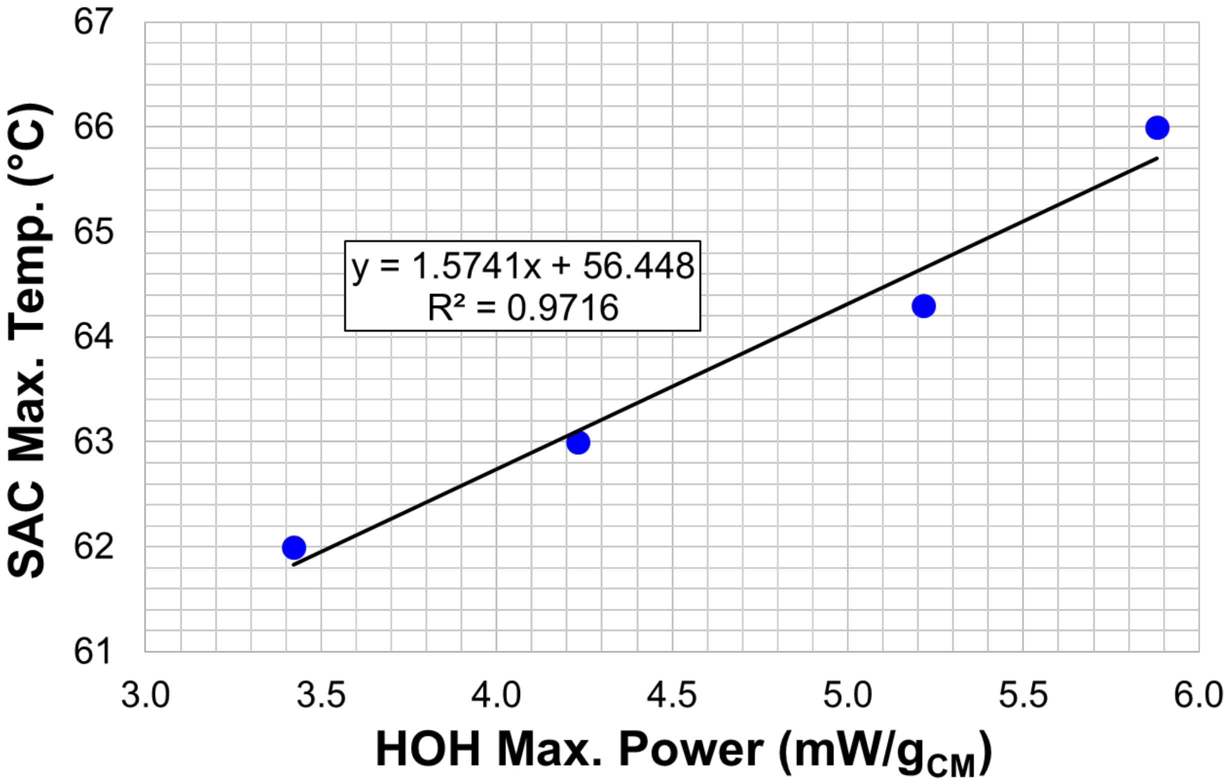
Mean Particle Size % Blaine Fineness % Main Cement Hydration Peak Height




Rate of heat output is influenced significantly by the cement particle size

Findings

Correlation Between Hydration Peak Height and SAC Temperature Maximum



Correlation Between Hydration Peak Height and Cement Reactivity

- The peak height of the main cement hydration peak obtained from the HOH power curve correlates very well with:
  - Fineness,
  - Reactivity, and
  - Temperature rise.
- The peak height correlation with fineness and reactivity of cement is much better than the typically used metrics:
  - The heat index ($C_3S + 4.75\ C_3A \leq 100$) and
  - The 7-day heat of hydration value.

Evaluation of Alternative Pozzolanic Materials for Partial Replacement of Portland Cement in Concrete

(Professor Chris Ferraro @ UF)

Rationale

- Class F fly ash specified in almost all of FDOT concrete mixes.
- Shortages of Class F fly ash in the past few years.
- Concern that natural gas, rather than coal, will be used to fuel new power plants.

Objective

- Develop new sources of pozzolanic materials that can replace some or all fly ash to meet the pozzolan needs of future FDOT concrete mixes.

Methodology

Approach

- Determine suitability of any highly siliceous materials with particle size < 45 µm (passing 325-mesh)
- Preference given based on availability and sustainability
- Testing of portland cement-pozzolan samples
  - Elemental and mineralogical composition (XRF and XRD)
  - Particle size distribution
  - Heat of Hydration
  - Compressive strength
  - Modulus of elasticity
  - Splitting tensile strength
  - Length change
  - Flexural strength
  - Coefficient of thermal expansion
  - Surface resistivity

Findings

Materials Chosen for Evaluation

- Class C fly ash
- Pulverized waste glass
- Recycled zeolite catalyst
- Rice husk ash
- Sugarcane bagasse ash
- Wood ash

Class C fly ash is commercially available and is in common use in other parts of the country. Quick implementation.

Waste glass is abundantly available - requires considerably more research and development. Implementation will require development of supply chain and grinding facilities.

Testing

Underway, but results are not complete.

Internally Cured Concrete for Pavement and Bridge Deck Applications

Professor Tia @ UF

Rationale

- Bridge deck cracking is a common problem and needs to be reduced to increase durability.

Objective

- Reduce cracking in structural applications such as bridge decks through combinations of
  - Internal curing (main focus),
  - Shrinkage-Reducing Admixtures (SRAs)
  - Optimize packing density
  - Polymeric micro-fibers

Methodology

Approach

- **Internal Curing:**
  - Fine lightweight aggregate (LWA, expanded shale) used to partially replace normal fine aggregate.
  - LWA acts as an internal water reservoir, providing water as needed for curing, preventing self-desiccation that can lead to cracking.
  - Concrete stronger and more durable due to faster and more complete curing.
- **Shrinkage Reducing Admixtures:**
  - Lowers capillary forces that tend to pull particles together, reducing drying and autogenous shrinkage.

Methodology

Approach

- **Optimize Packing Density:**
  - Optimize packing using multiple coarse aggregate size gradations (apply Shilstone's methods).
  - Reduces paste content due to lower void space.
  - Lower paste volume results in
    - Lower shrinkage (lower volume of high-shrinkage cement paste).
    - Lower thermal expansion (greater volume of low-shrinkage aggregate).
- **Polymeric Micro-Fibers:**
  - Fibers resist shrinkage that can cause early-age cracking. If cracking occurs, the fibers induce micro-cracks rather than large cracks that can lead to degradation and corrosion of underlying steel reinforcement.

Benefits Attributed to Internal Curing

- ***Durability (Reduced Cracking and Permeability)***
  - Reduced cracking due to reduced plastic shrinkage and autogenous shrinkage (early-age shrinkage)
  - Improved hydration – no self-desiccation, denser interfacial transition zone
  - Reduced permeability – less ingress of chlorides, etc.
  - Reduced slab curling and warping
- ***Structural Endurance (Reduced Cracking & Fatigue)***
  - Small reduction in weight
  - Lower elastic modulus
  - Lower coefficient of thermal expansion
  - Small increase in strength

Literature Data

Comparison of Internally-Cured with Normally-Cured HPC

Property	Normally-Cured HPC (w/c=0.35)	Internally-Cured HPC (w/c=0.35)	Improvement Made by Internal Curing
Amount of IC Water, w/c_{ic} (kg/kg)	0	0.075	
C-S-H Content at 28d (%)	10.2	12.3	21%
Compressive Strength at 7d (MPa)	45	50	11%
Compressive Strength at 28d (MPa)	60	65	8%
Water Permeability (m/s)	2.1 x 10-11	1.7 x 10-11	19%
Chloride Permeability (Coulomb)	553	415	25%
Freeze-Thaw Resistance, mass loss (%)	0.60	0.26	
Salt Scaling Resistance, mass loss (%)	0.46	0.30	

Internal Curing Results in a Higher Degree of Hydration Which Improves Durability

Source: Cusson and Margeson (2010)

Findings

Cost, Service Life, and Life-Cycle Predictions

Property	Normally-Cured Normal Concrete (w/c=0.40)	Normally-Cured HPC-SCM (w/c=0.35)	Internally-Cured HPC-SCM (w/c=0.35)
Concrete Costs	\$450/m^3	\$600/m^3	\$624/m^{3*}
Service Life Predictions	22 years	40 years	63 years
Life-Cycle Cost Predictions (60-yr Analysis)	\$783/m^2	\$470/m^2	\$292/m^2
Approximate Cost Above Normal Concrete	0%	33%	39%
Increase in Service Life Above Normal Concrete	0%	82 %	186%
Decrease in Life-Cycle Cost Above Normal Concrete	0%	40%	63%

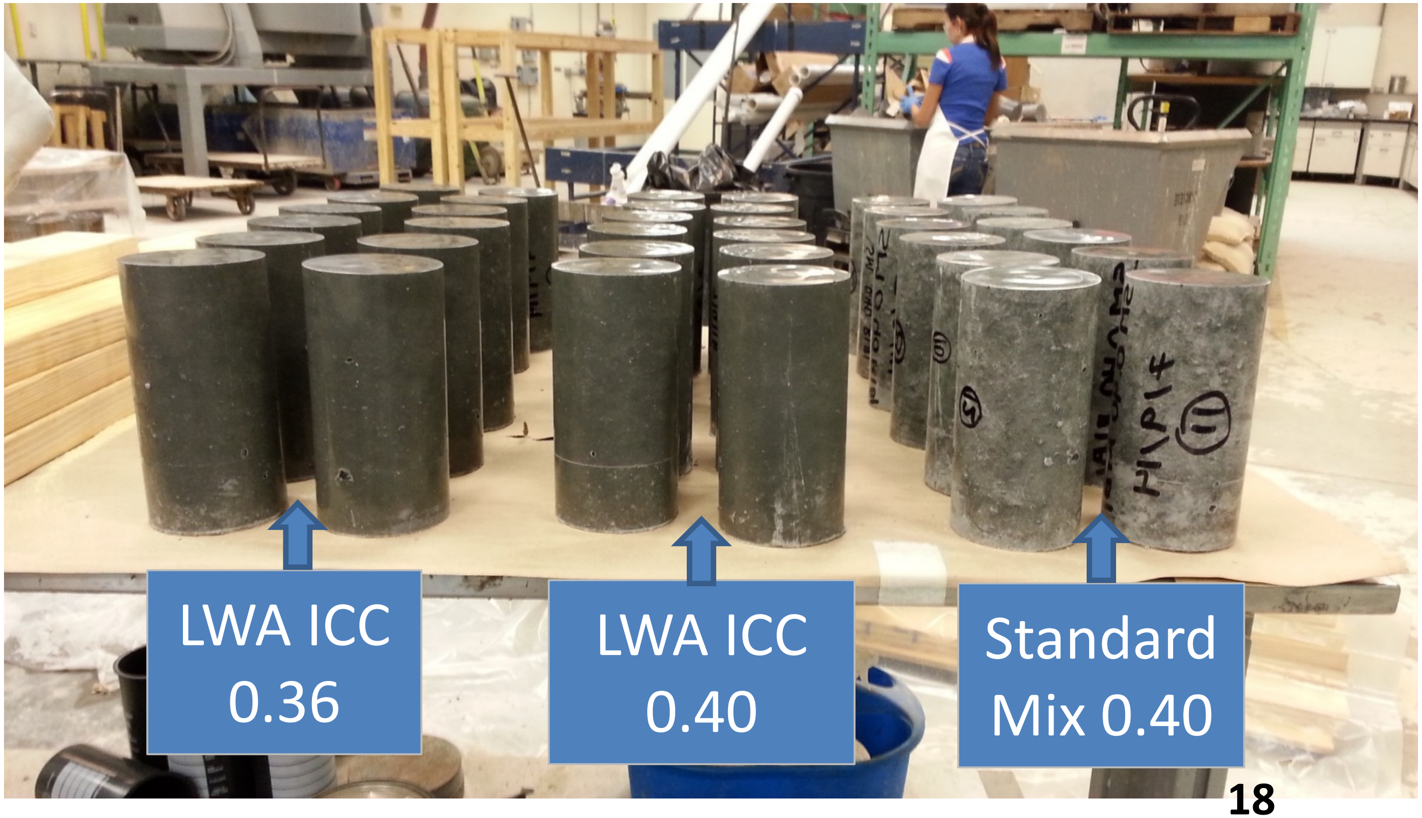
Compared to normally-cured HPC, internally-cured HPC:

- ***Costs about \$24/m^3 more (4%)***
- ***Increases service life by 23 years (58%)***
- ***Reduces life-cycle costs by \$178/m^2 (38%)***

Source: Adapted from Cusson, Lounis, and Daigle (2010)

Findings

- ***Cylinders Just After Demolding***



Findings

- ***Recent Strengths and MOE Values***

Mixture 0.36 w/c ratio	Compressive Strength (psi)		Modulus of Elasticity (Mpsi)		Flexural Strength (psi)	
	7 days	28 days	7 days	28 days	7 days	28 days
Control mix	5,250	6,830		4.45	635	725
LWA ICC	5,090	6,620		3.80	655	705
Difference	-3.0%	-3.1%		-14.6%	3.1%	-2.8%

Summary

- ***When properly sized, proportioned, and mixed in HPC (low w/cm), prewetted LWA provides well-dispersed reservoirs that continually supply water for hydration, maintaining a saturated condition to***
  - ***Prevent self-desiccation, which reduces shrinkage strains***
  - ***Reduce early-age cracking due to reduced shrinkage strains***
- ***For no more than a modest increase in placement cost (4% or less), internal curing can***
  - ***Increase predicted service life of HPC by over 50% and***
  - ***reduce predicted life-cycle costs by almost 40%.***

Evaluation of Shelf Life in Post-Tensioning (P-T) Grout

Prof. Trey Hamilton @ UF

Rationale

- The properties of bagged P-T grouts were found to significantly degrade before reaching the Manufacturer’s shelf life date.
  - Most P-T grout durability problems stem from unacceptable bleeding and segregation, and degradation due to aging (rheological problems).

Objectives

- Determine chemical and rheological effects of aging on P-T grouts

Evaluation of Shelf Life in Post-Tensioning (P-T) Grout

Prof. Trey Hamilton @ UF

Approach

- Quantify rheological behavior of properly formulated grouts as a function of time and exposure conditions.
- Establish procedures to identify improperly formulated grouts.

Findings

- None yet - second phase of project recently started.

Development of HES Concrete Guidelines to Reduce Cracking

Prof. Zayed @ USF

Rationale

- High-early strength (HES) concrete used for pavement slab replacement has a tendency to crack.
  - High cement contents (800-950 lb/ft^3)
  - High additions of accelerators (3-4 gal/lb/ft^3)
  - Curing compound used to minimize surface evaporation
  - Tight sawing window – too long and the slab may crack
  - Opening-to-traffic times can be as little as 4-5 hours

Approaching mass concrete conditions

Objectives

- Develop guidelines and procedures that could be used to minimize or eliminate the incidence of cracking in HES concrete pavement replacement slabs.
- Develop mix design guidelines that can be used to tailor concrete mixes to reach strength at desired times without cracking. This would give the contractor more flexibility to meet opening-to-traffic times.

Methodology

- Identify combinations of admixtures that favorably affect relative rates of strength and stress development
  - Early-age stress developed does not exceed strength developed in the concrete.
- Evaluate effects of shrinkage-reducing admixtures on HES cracking potential
- Evaluate benefits of polymeric microfiber reinforcement to control cracking potential in HES
- Compare strength/stress development for chloride-based versus non chloride-based accelerators

Methodology

- Evaluate effect of base condition on cracking – impact on strain developed
  - Base surface compaction
  - Base moisture content – wicking could cause moisture gradient
  - Resistance to slab movement
  - Low-friction lining (single or double plastic sheet) might allow essentially free shrinkage

Findings

- New Project