Florida Department of TRANSPORTATION

FDOT Research Plans to Provide Guidance for the Mitigation of Cracking and Chemical Attack of Concrete

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Why FDOT Durability Research is Needed

- **Little research has been done on the strength development and durability of FDOT ternary concrete mix designs (and potential pozzolanic combinations with development of ASCMs).**
- Suitability of concrete for use in EAE (extremely aggressive environments) is currently **determined solely by surface resistivity** (SR, 29 kΩ-cm at 28d).
  - **Not adequate** for a classification based on pH, conductivity, chloride content, and sulfate content of the surrounding soil and water.
- Validity of SR use is based on correlation to RCPT, but the correlation is affected by the composition of the concrete being tested.

FDOT Concrete Mix Designs for EAE

Until recently, surface resistivity (SR) was only required when the concrete mix contained silica fume, since it was typically required for use in extremely aggressive exposures

Only FA and SF have been used extensively

Insufficient data

Ternary Components	Number of Mix Designs	Average Surface Resistivity (kΩ-cm)	Surface Resistivity Range (kΩ-cm)
PC-FA-SF	170	44.4	28.3 - 123.1
PC-FA-Slag	5	38.9	32.5 – 54.4
PC-FA-MK	6	49.0	29.5 – 86.8
PC-FA-UFFA	2	30.5	29.0 – 31.9
PC-Slag-SF	14	40.6	29.5 – 106.1
PC-Slag-MK	2	66.7	63.7-69.6

Questions to be Answered by Research

- What aspects of durability are important?
- What concrete durability properties are desired?
- What test methods are used for measurement?
- What correlations can be expected from a good test method?
- Are there more appropriate test methods?
- Are new test methods needed?
- What steps can be taken to improve durability?
- Can alternative cementitious materials be found to replace fly ash and will they affect the ability of FDOT to produce durable concrete?

Important Goals of Durability Research

- Determining which test methods are appropriate for determining the durability for each set of cementitious materials in the various exposure conditions (main focus on extremely aggressive).
- Determining durability of binary, ternary, and higher combinations of portland cement, currently available SCMs, and newly developed SCMs.
- Reducing usage of portland cement.
- Insuring the long-term supply of supplemental cementitious materials (SCMs) for FDOT concrete.
- Determining appropriate mass concrete placement and curing temperature restrictions
- Increasing use of recycled materials.

Focus of SMO Durability Study

Durability (ACI CT-13) is the ability of a material to resist weathering action, chemical attack, abrasion, and other conditions of service.

Emphasis is on improving resistance to chemical attack (ingress of deleterious ions)

- **Basic methods to improve concrete's resistance to chemical attack:**
  - **Decrease the permeability / penetrability**
  - **Prevent / mitigate cracking**

Durability Research Project Categories

Durability-related university research projects funded through the State Materials Office of FDOT can be loosely grouped into 3 categories, none of which are mutually exclusive. The main focus of each category is listed below.

1. **Evaluating or improving resistance to intrusion (permeability / penetrability / intrudability)**
2. **Prevention or mitigation of cracking**
3. **Development of alternative cementitious materials that can be substituted for fly ash**

The objectives of sixteen research projects will be presented: 8 current and 8 proposed projects.

Resistance to Intrusion

Evaluation of Porometry, Permeability and Transport of Structural Concrete (UF-Ferraro)

- Evaluate suitability of test methods
  1. Surface resistivity (AASHTO T 358)
  2. Bulk electrical conductivity (ASTM C1760)
  3. Bulk diffusion (ASTM C1556)
  4. Resistance to penetration of chloride ions (RCP) (ASTM C1202)
  5. Water permeability
  6. Mercury Intrusion Porosimetry (MIP)
- Test lab and field samples of known durability
- Evaluate microstructures, relate to test results

Resistance to Intrusion

Durability Evaluation of Ternary Mix Designs for Extremely Aggressive Exposures (UF-Riding)

- **Correlate ternary concrete mixture proportions to**
  1. **Surface resistivity (AASHTO T 358)**
  2. **Bulk resistivity (AASHTO TP 119)**
  3. **Formation Factor**
  4. **Rapid chloride permeability test (RCPT) (ASTM C1202)**
  5. **Rapid chloride migration test (RCMT) (AASHTO T 357)**
  6. **Water permeability**
  7. **Wicking / water absorption (ASTM C1585)**
  8. **MIP**
  9. **Bulk diffusion (ASTM C1556)**
  10. **Chloride binding experiments**
  11. **Sulfate resistance (modified ASTM C1012)**

Resistance to Intrusion

Effects of Blast Furnace Slag Characteristics on Durability of Cementitious Systems for Florida Concrete Structures (USF-Zayed)

- Investigate the effects of the chemical composition and physical characteristics of slag on sulfate durability of cementitious systems
- Establish ranges of chemical and physical parameters of slag cement that ensure durability
- Emphasis on
  - Strength
  - Sulfate durability (ASTM C1012)
  - Cracking potential

Resistance to Intrusion

Reducing Portland Cement Content and Improving Concrete Durability (UF-Tia)

Goal is to reduce paste content - the average paste content in FDOT concrete mixes is about 33 vol%. (26 vol% adequate)

Preliminary results indicate no loss of strength or workability

Reducing the volume fraction of cement paste

- ★ **Reduces shrinkage** - Less cement and water ⇒ less shrinkage.
- ★ **Reduces heat evolution / thermal gradients** - Less paste ⇒ less heat evolved, lower maximum temperatures and thermal gradients.
- ★ **Reduces cracking tendency due to lower shrinkage and thermal stresses**
- ★ **Reduces total porosity / permeability** – reducing paste content reduces water content which reduces the interconnected porosity formed by evaporation and hydration

Resistance to Intrusion

Durability Improvement and Weight Reduction of Structural Elements Using Very-High-Performance Concrete (VHPC) (UF-Riding & Ferraro) (Proposed for FY18-19)

Producer-driven: a concrete producer has already developed "UHPC"concrete mix designs reduced-weight (40-50%) precast element designs

- **Need to develop material specifications**
- **Need to develop product approval guidelines**
- **Need to determine strength-to-weight gains and post-peak strengths to identify appropriate uses**

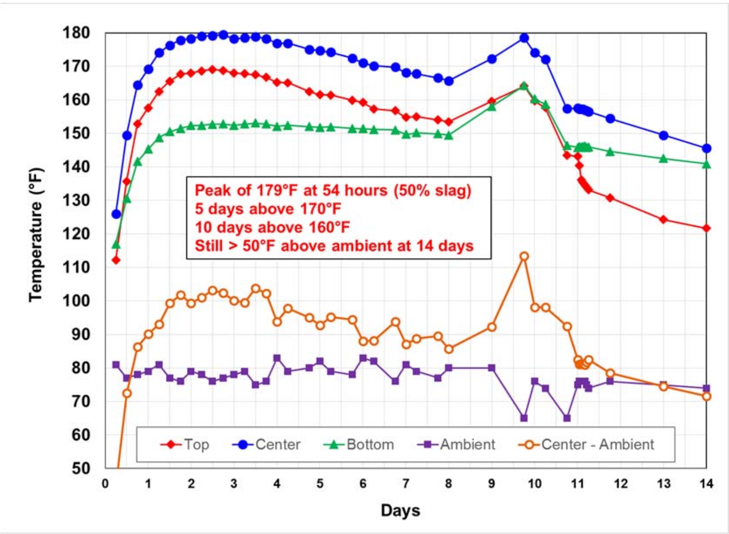
Resistance to Intrusion

Durability of Structural Concrete Exposed to High Temperatures During Curing (USF-Zayed) (Proposed for FY18-19)

Mass Concrete Field Problems

Extended periods of high temperatures

- Up to 5 days above 170°F
- Up to 10 days above 160°F
- Over 14 days with $T_{core\text{-}ambient}$ > 50°F



No existing research that documents the effects on durability of such extended periods of time at high temperatures

Research needed to determine effects on microstructure / properties

Resistance to Intrusion

Modification, Development, and Evaluation of Durability Test Methods that can be Reliably Correlated to Durability of Normal and Higher Performance Structural Concrete (UF, Riding & Ferraro) (Proposed for FY18-19)

- **Main Focus:**
  - **Determining which test methods are appropriate for determining the durability for typically used binary and ternary concrete mix designs (emphasis on extremely aggressive).**
  - **Determining durability of binary and ternary combinations of PC, SCMs, and new SCMs.**

Resistance to Intrusion

Performance Comparison of Portland-Limestone Cement (PLC, Type 1L) with Type I/II in Structural Concrete (UF, Ferraro, Riding, & Tia) (Proposed for FY18-19)

Combination project driven by (1) FDOT approval of Type IL (PLC) cements (want full durability comparison), and (2) high time-temperature profiles for some mass elements

- **Durability comparison of Types IL and I/II**
- **Establish recommended maximum ambient and concrete placement temperatures necessary to reduce the times at high temperatures for binary and ternary mix designs**

Resistance to Intrusion

Use of Nonstandard Aggregate in Normal and Higher Performance Concrete (UF, Tia) (Proposed for FY18-19)

Evaluate the use of nonstandard aggregates as fillers to

- Improve particle packing in concretes,
- Enable paste content reduction
- Incorporate in VHPC and UHPC
- Part of "green" initiative to use out-of-spec aggregate that otherwise would not be used

Resistance to Intrusion

Mix Design Considerations to insure the Pumpability of Reduced Paste Concrete (UF, Riding) (Proposed for FY18-19)

The trend toward the use of multiple aggregate sizes to optimize particle packing and reduce paste content can have the unintended consequence of negatively affecting pumpability

- Establish pumpability versus paste content to identify minimum necessary paste contents
- Determine for normal and optimized aggregate gradations

Mitigation of Cracking

Mitigation of Cracking in Florida Structural Concrete (UF, Tia)

Evaluating methods to reduce cracking tendency of structural concrete

- **Internal curing**
- **Shrinkage reducing admixtures**
- **Paste reduction - aggregate optimization (using intermediate CA - #89 limerock)**
- **Polymeric microfibers**
- **Combinations of methods**

Mitigation of Cracking

Performance Improvement of High Early Strength (HES) Concrete for Pavement Replacement Slabs (USF, Zayed)

Evaluating methods to reduce cracking tendency of HES concrete

- Effects of different types of base restraint
- Internal curing
- Shrinkage reducing admixtures
- Paste reduction - aggregate optimization (using intermediate CA - #89 limerock)
- Polymeric microfibers

Mitigation of Cracking

Effects of Slag Composition on Cracking Tendency of Structural Concrete (USF, Zayed) (Proposed for FY18-19)

Establishing effects of slag components on

- Slag reactivity
- Strength
- Cracking tendency
- Permeability
- Sulfate resistance

Development of Alternative SCMs

Development of Calcined Clays as Pozzolanic Additions in Portland Cement Concrete Mixtures (USF, Zayed)

Follow-up to an alternative pozzolan project

- Evaluate the quality of various clay sources available in Florida in terms of their chemical and mineralogical composition and amorphous content
- Establish calcination temperatures to give optimum pozzolanic reactivity
- Determine the strength and durability of typical FDOT concrete mixes and compare performance to those with class F fly ash.

Development of Alternative SCMs

Evaluation of Silica-Based Materials for Use in Portland Cement Concrete (UF, Ferraro, Riding, & Townsend)

Follow-up to an alternative pozzolan project

- Evaluate the quality of alternative pozzolans available (or potentially available) in Florida in terms of their chemical and mineralogical composition and amorphous content
- Determine the strength and durability of typical FDOT concrete mixes and compare performance to those with class F fly ash.
  - **Ground recycled glass**
  - **Sugarcane bagasse ash**
  - **Ground sand**
  - **Ground volcanic rock**

Development of Alternative SCMs

Reclaimed Fly Ash - Feasibility of Beneficiation and Use of Florida Landfilled Fly Ash, Phase I
(UF, Ferraro, Riding, & Townsend)

Feasibility Project

- **Literature and industry review**
- **Determine**
  - **Availability**
  - **Quality**
  - **Estimate of cost to extract**
  - **Cost to beneficiate**
  - **Price to attain profitability**

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Questions?