Florida Department of
TRANSPORTATION

Selected Review of Current Structural Concrete Research at SMO (Durability, Mitigation of Cracking, PC-Slag Durability, and Cement Replacement Projects)

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Selected FDOT-Sponsored Research

- Mitigation of Cracking in Florida Structural Concrete; UF BDV31-977-47; PI-Tia and PM-DeFord.
- Development of Calcined Clays as Pozzolanic Additions in Portland Cement Concrete Mixtures; USF; PI-Zayed and PM DeFord.
- Effects of Blast Furnace Slag Characteristics on Durability of Cementitious Systems for Florida Concrete Structures; USF BDV25-977-28; PI-Zayed and PM-DeFord.
- Durability Evaluation of Ternary Mix Designs for Extremely Aggressive Exposures; UF PI-Riding and PM-DeFord.
- Performance Improvement of High Early Strength (HES) Concrete for Pavement Replacement Slabs; USF BDV25-977-23; PI-Zayed and PM-DeFord.

Selected FDOT-Sponsored Research

Proposed for Next Fiscal Year

- Improving Portland Cement Concrete Durability by Optimizing Paste Content; UF; PI-Tia and PM-DeFord
- Recycled and Repurposed Materials for Use in Concrete (evaluating durability of mix designs with class F fly ash replaced with alternative materials such as ground, recycled container glass, sugarcane bagasse ash, and ground volcanic rock); UF; PI-Ferraro and PM DeFord.

Current Important Issues for SMO

Improve durability of FDOT concrete.

- Determine the **most reliable test methods** for measuring the properties that substantially influence concrete durability
- Use these test methods to **evaluate the durability** of concrete containing binary, ternary, and higher combinations of cementitious materials
- Determine which cementitious combinations are **appropriate for use** in extremely aggressive exposure conditions

Reduce usage of portland cement.

- Increase replacement of cement with pozzolans and fillers (including use of portland-limestone cement)
- Reduce concrete paste content

Focus of SMO Research Program

- ***Ways to Improve Concrete Durability***
  - **Use of SCMs to Improve Resistance to Chemical Attack**
    - Increases resistance of concrete to ingress of deleterious substances (chlorides and sulfates) by refining the pore structure, and effectively increasing the diffusion path length.
  - **Use of Internal Curing, SRAs, Improved Particle Packing / Reduced Paste Content, and Polymeric Fibers to Mitigate Cracking**
    - Thermal and shrinkage cracking increase the effective permeability of the concrete

Focus of SMO Research Program

- ***Ways to Reduce Use of PC***
  - **Reduce excess paste content in concrete - use fillers and intermediate-sized aggregates to reduce the volume of cement paste needed to yield plastic properties adequate for ease of placement.**
  - **Use IL blends (Portland Cement – Limestone blends) in place of Type I/II.**
  - **Develop / approve alternative SCMs to insure long-term availability of sufficient quantities of quality pozzolanic materials that can be used to replace fly ash.**

Potential Replacements for Fly Ash in FDOT Concrete

The following natural and recycled materials are available in Florida and development of these resources would help solve local supply shortages of SCMs and create jobs in Florida

- **Clays containing kaolin**
- **Recycled waste glass**
- **Sugarcane bagasse ash**
- **Glass sand (high purity silica sand)**
- **Commercial silica sand**

What is Concrete Durability?

- **ACI CT-16:** **durability** is defined as "**the ability of a material to resist weathering action, chemical attack, abrasion, and other conditions of service**."
- Reworded: **Concrete durability** refers **to the long-term ability of concrete to maintain an acceptable level of performance** by withstanding degradation from exposure to the in-service environment.
- Unlike material properties such as compressive strength, which can be described quantitatively by a measured value, **assessment of durability involves a performance-based, qualitative, composite property assessment,** based on measurement of multiple component properties.

Characteristics of a Good Durability Test

- **The test method must produce results that can be directly correlated to long-term concrete durability (need benchmarks for comparison)**
  - Use macro and microscopic evaluation of field samples taken from structures of various ages and conditions to qualitatively rate their levels of durability (“calibrate” test)
- **The test method must be sensitive enough to distinguish between the different levels of durability encountered in service**
  - Evaluate test methods based on their ability to produce results consistent with the levels of durability determined from the macro and microscopic evaluations

Typical Methods for Reducing the Cracking Potential of Concrete

- **Shrinkage Reducing Admixtures**
  - Reduce consolidation pressure by reducing the surface tension that drives capillary pressure
- **SCMs (Required for nearly all FDOT concrete)**
  - Reduce thermal cracking tendency by reducing Heat of Hydration due to reduction of cement content.
- **Reduce Paste Volume and Optimize Aggregate Gradation**
  - Reducing paste volume reduces thermal and shrinkage cracking by reducing aggregate interstitial volume. Reduces cement => reduces shrinkage, reduces temperature rise, reduces expansion-contraction (CTE)

Typical Methods for Reducing the Cracking Potential of Concrete

- **Internal Curing**
  - Reduces shrinkage cracking tendency by delaying onset of self-desiccation - reduces autogenous shrinkage.
- **Polymeric Fibers**
  - Help resist cracking, but when cracking occurs, they bridge cracks so that stress is relieved by formation of many microcracks (low permeability) instead of a few large cracks (high permeability).

Constructability versus Quality

- **Constructability issues, not quality, typically drive properties of cement and concrete, often leading to a reduction in durability.**
  - Contractors demand quicker strength gain for quicker constructability.
  - Concrete producers respond by increasing cement content, increasing cement fineness, or lowering w/cm.
  - **These changes typically lead to lower quality concrete that has higher shrinkage and thermal cracking tendencies without significant improvements in strength or strength gain.**

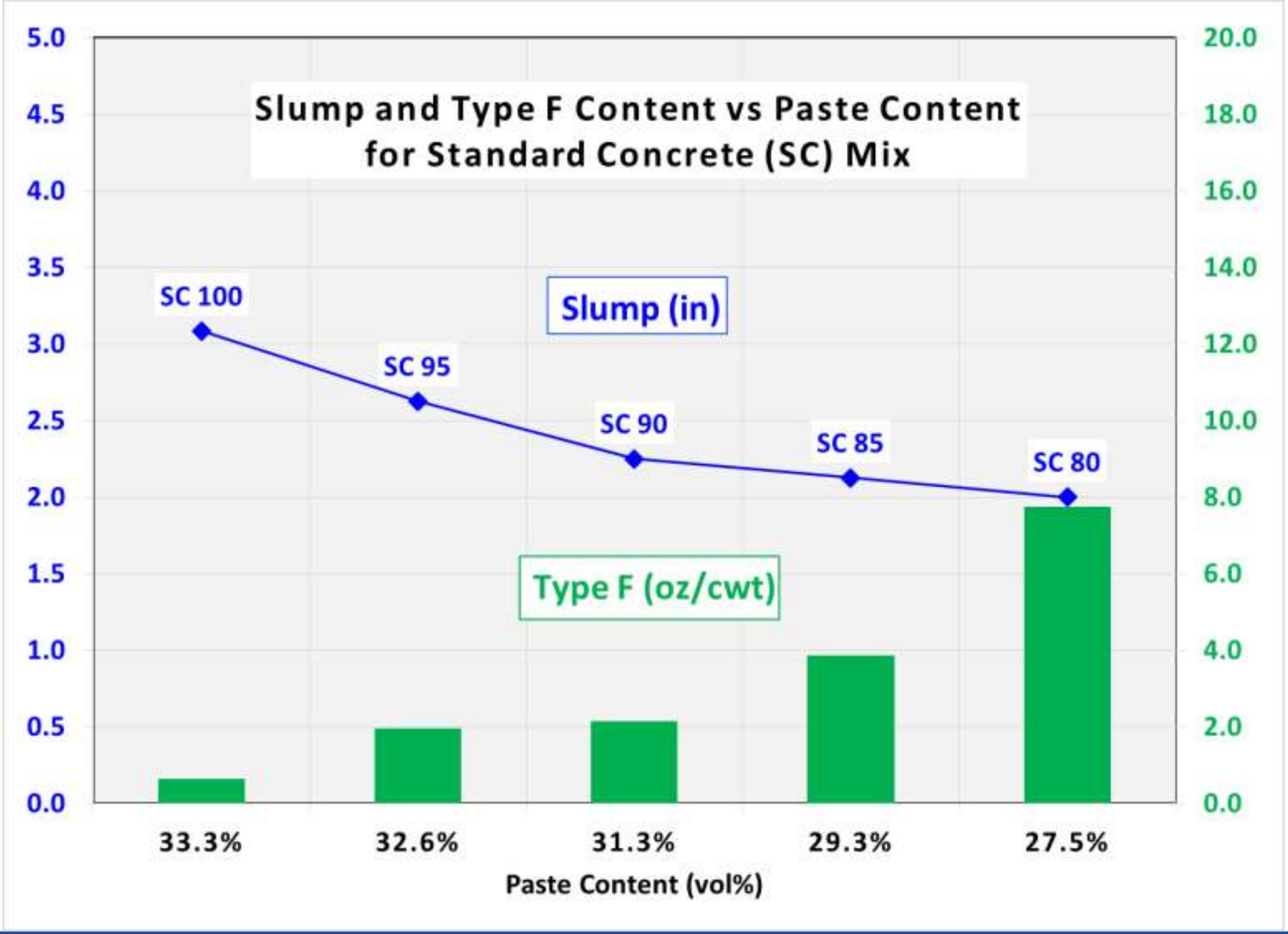
Paste Contents of FDOT Structural Concrete

- Average paste content of FDOT structural concrete mixes – about 33 vol% of concrete
- Average paste content needed for adequate placeability – 26-28 vol%, depending on aggregate gradation/packing density
- This indicates that at least 15-20 percent of paste (15-20% of cementitious material) could be replaced with aggregate without affecting the workability of the concrete (some admixture compensation needed)
- Thus 15-20% of cement is potentially wasted.

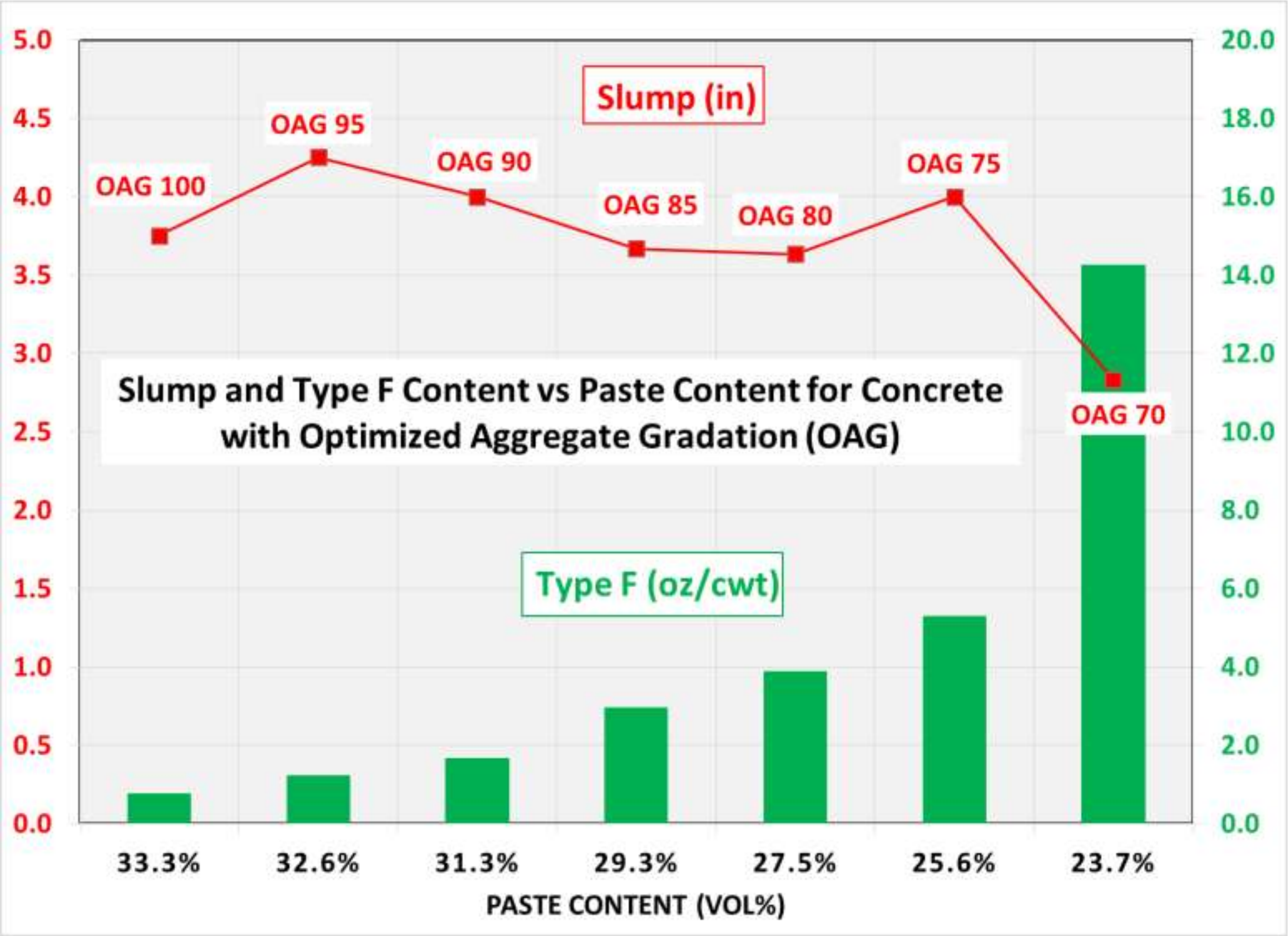
Benefits of Reducing Paste Content

- **Reducing the volume fraction of cement paste**
  - **Reduces shrinkage** - hydration products occupy less volume than reactants – causes plastic shrinkage followed by autogenous shrinkage after final set. Less paste $\Rightarrow$ less shrinkage.
  - **Reduces heat evolution / thermal gradients** – total heat is a function of cement content. Less paste $\Rightarrow$ 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 porosity formed by evaporation and hydration

Effect of Paste Reduction on SC Slump



Effect of Paste Reduction on OAG Slump



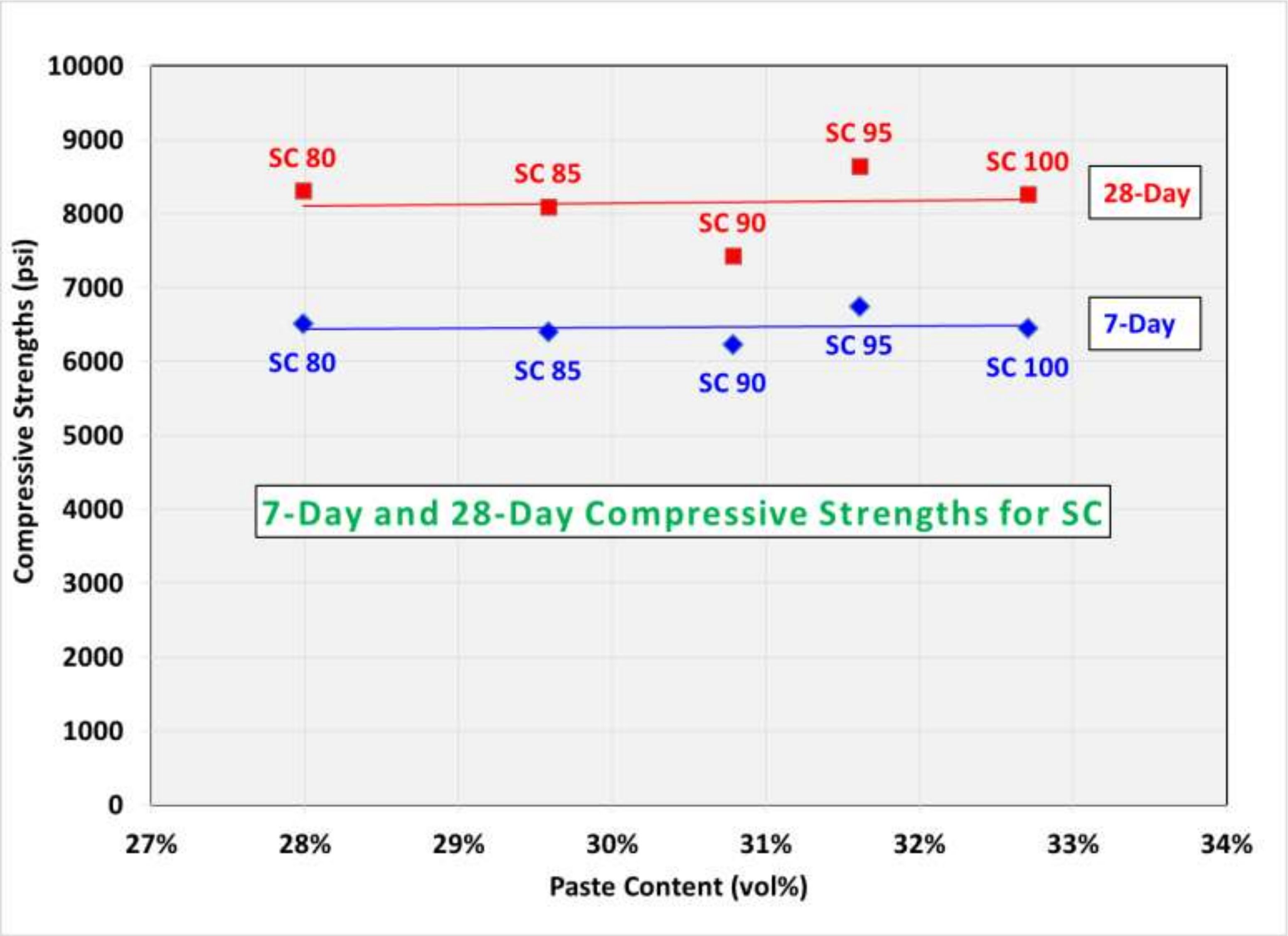
Effect of Paste Reduction on Properties

Class IV Concrete Mix Design

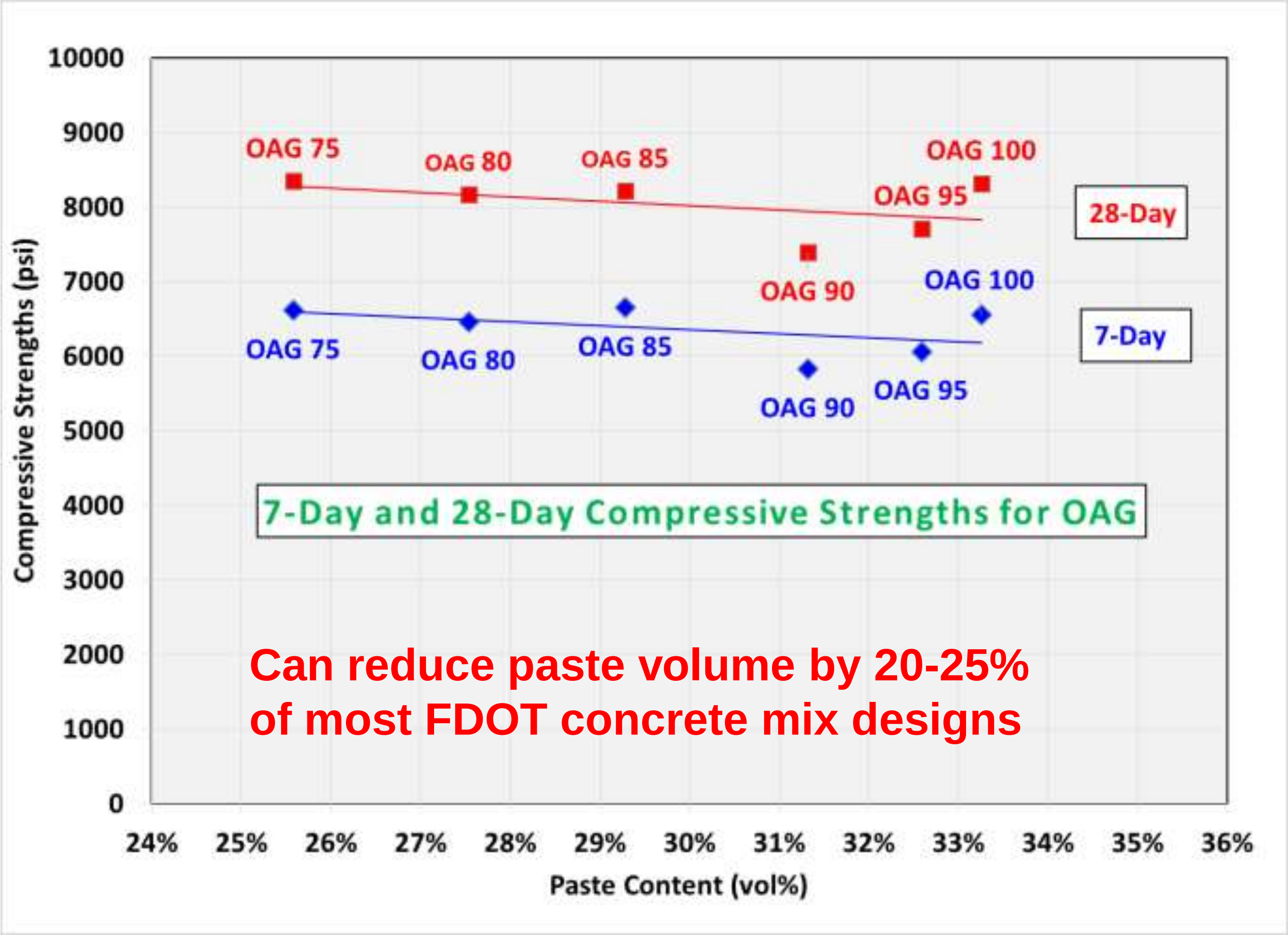
	Control Mix 2		Mix 2-OAG - No Paste Redution		Mix 2-OAG - 15% Paste Reduction		Mix2-OAG - 25% Paste Reduction	
CM	690 lb	690 lb	690 lb	690 lb	587 lb	587 lb	518 lb	518 lb
Paste w/o air	30.03 %	30.04 %	30.04 %	30.03 %	25.55 %	25.55 %	22.52 %	22.52 %
Paste w/ air	32.23 %	32.74 %	33.14 %	33.23 %	27.95 %	28.35 %	26.22 %	25.92 %
28-day compressive strength	8160 psi		7790 psi		8510 psi		8010 psi	
28-day flexural strength	832 psi		832 psi		897 psi		840 psi	
28-day splitting tensile strength	595 psi		520 psi		500 psi		600 psi	
28-day MOE	5.25 Mpsi		5.05 Mpsi		5.50 Mpsi		5.85 Mpsi	
28-day CTE	8.00E-06 in/in/°C		8.10E-06 in/in/°C		8.40E-06 in/in/°C		8.00E-06 in/in/°C	
28-day RCPT	3533 C		3152 C		2630 C		2722 C	
28-day SR	10.6 kΩ-cm		10.4 kΩ-cm		13.3 kΩ-cm		12.3 kΩ-cm	
Restrained Ring Time-To-Crack	29 days		54 days		66 days		70 days	

Strength	**Comparable**
CTE	**Comparable**
Permeability	**Reduced**
Cracking Tendency	**Reduced**

Reduction of Paste Content Without Reducing Strength of Concrete (SC)

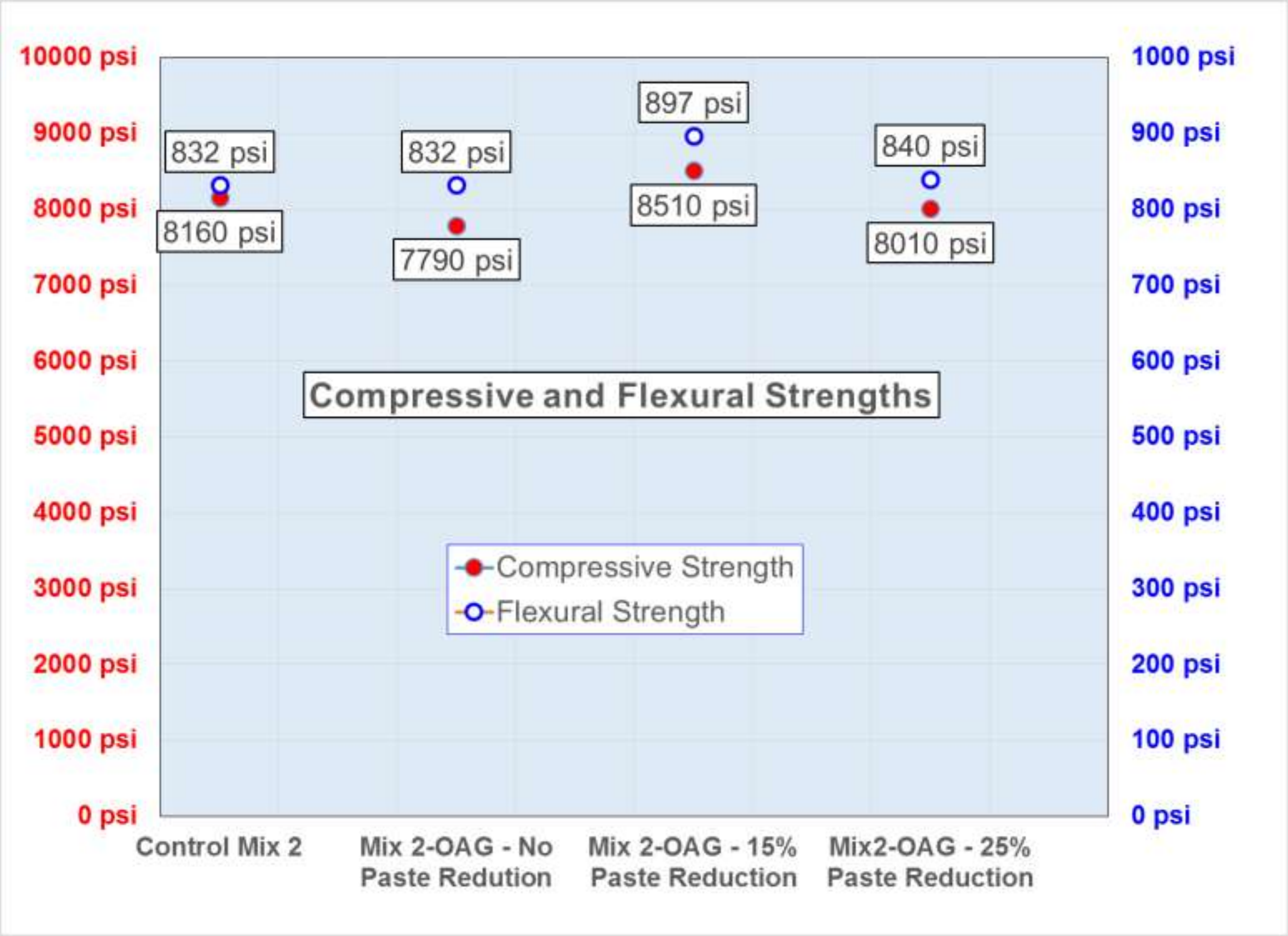


Reduction of Paste Content Without Reducing Strength of Concrete (OAG)

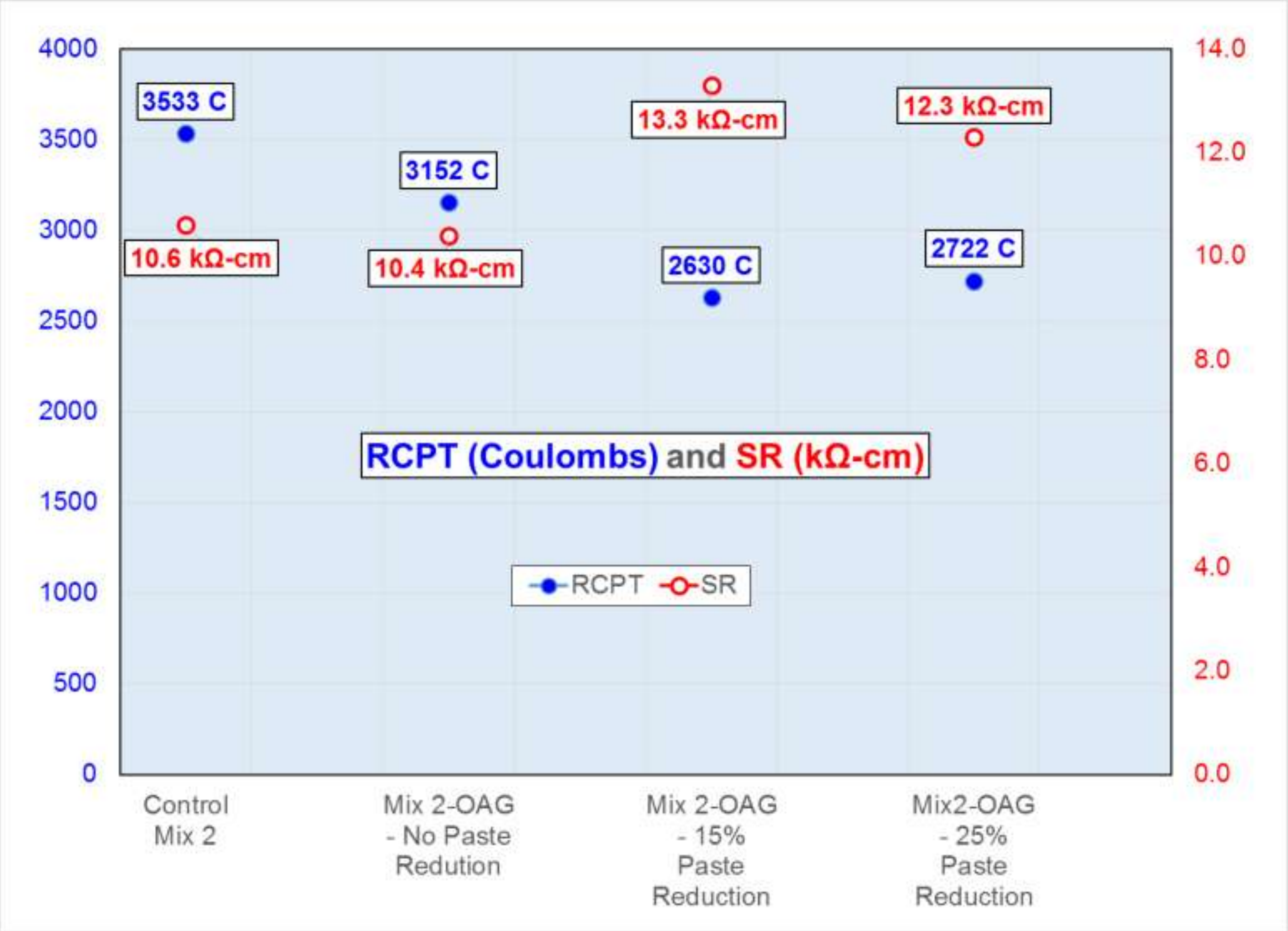


Data from BDV31-977-47 Mitigation of Cracking in Florida Structural Concrete

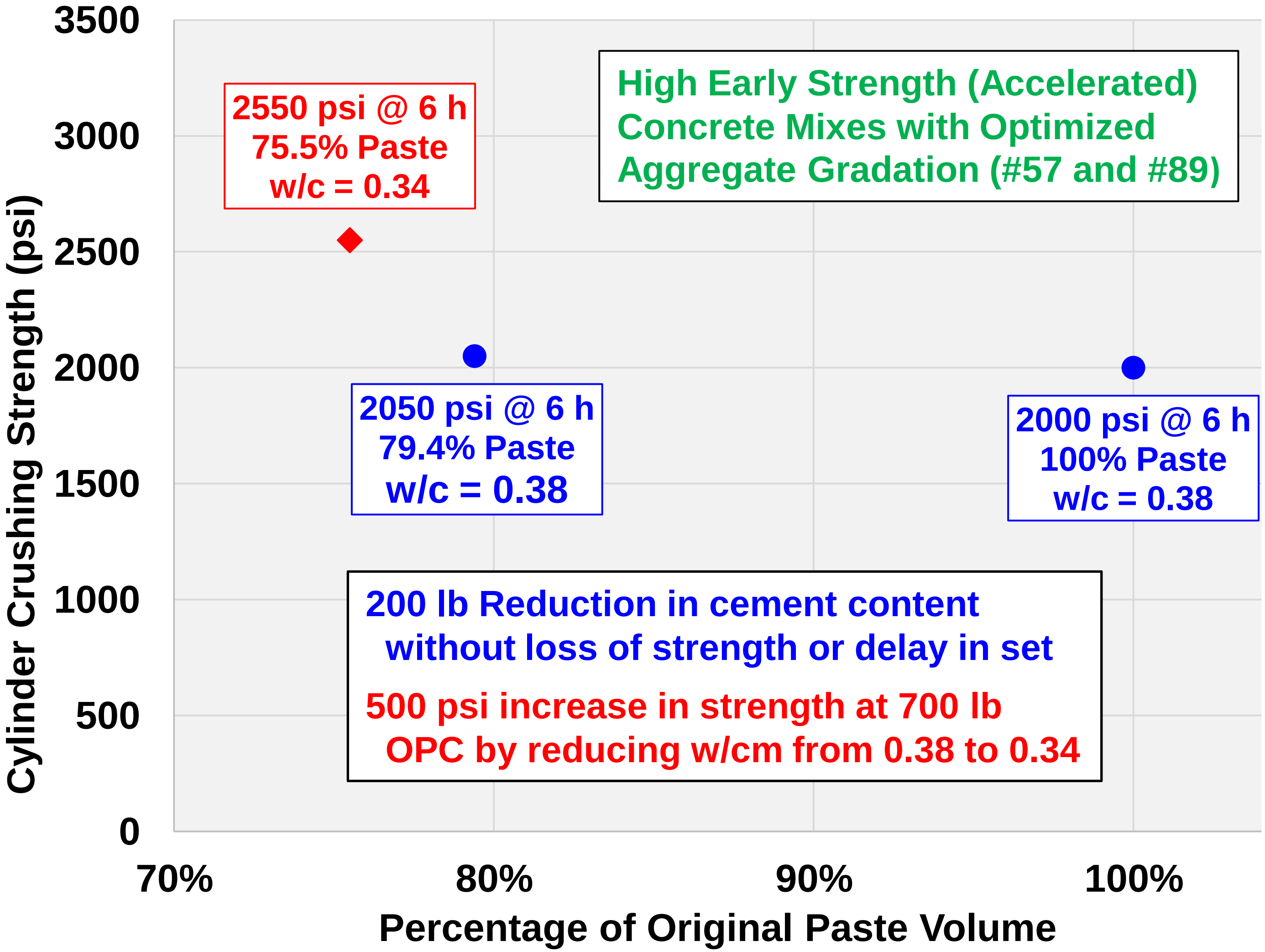
Effect of Paste Reduction on Strength



Effect of Paste Reduction on "Permeability"

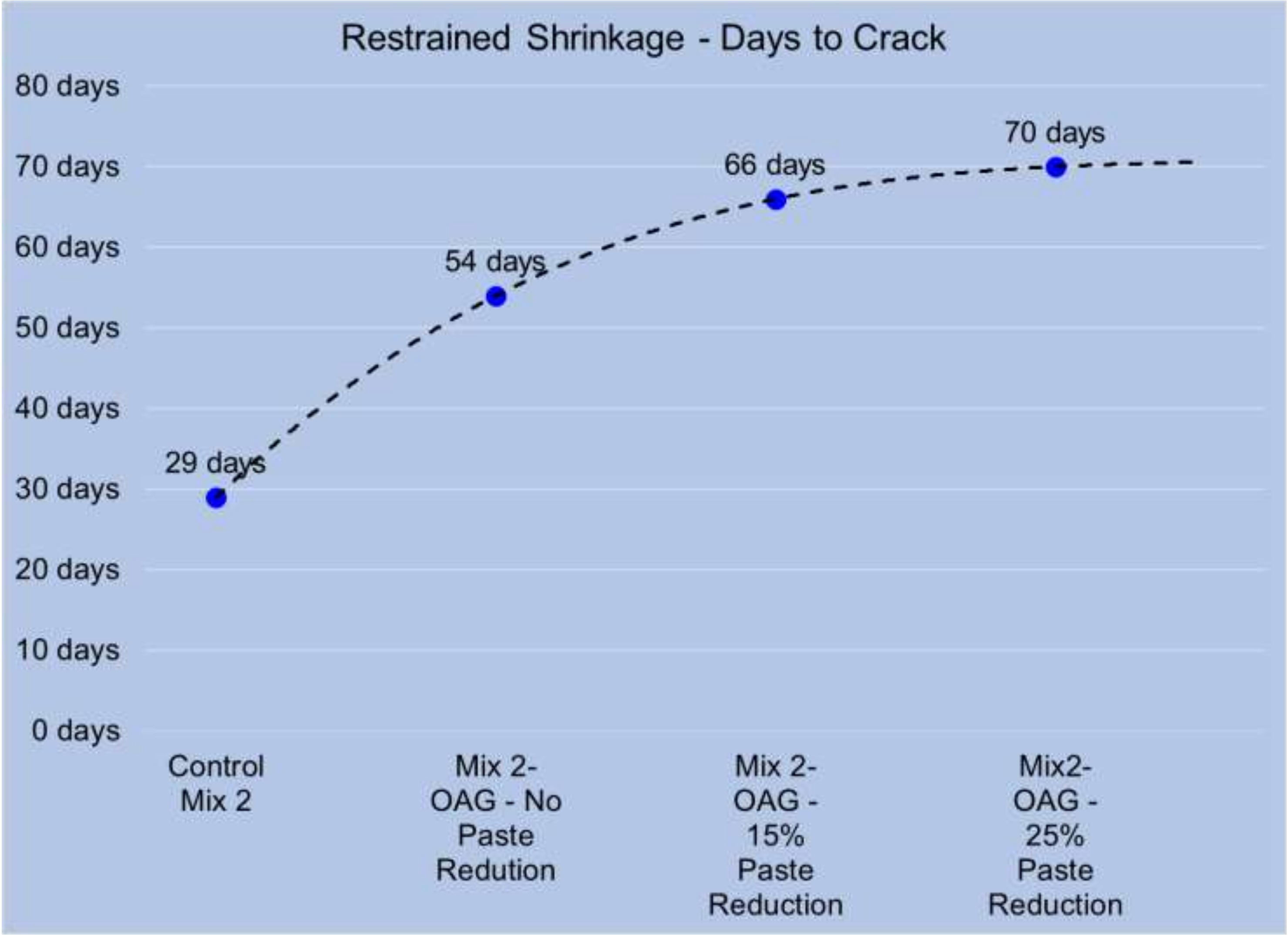


Reduction of Paste Content Without Reducing Strength or Increasing Set of HES Concrete



Data from BDV25-977-28 Effects of Blast Furnace Slag Characteristics on Durability of Cementitious Systems for Florida Concrete Structures

Effect of Paste Reduction on Restrained Shrinkage



Questions?