Evaluation of Test Methods for Permeability (Transport) and Development of Performance Guidelines for Durability

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National Concrete Consortium, Baton Rouge, April 8, 2008

Motivation for the Study

- Concrete specified and placed - prescriptive specifications
- Shift from prescriptive specifications to end result or performance based specifications.
- PRS
  - Slowed by a lack of testing procedures, especially relate to transport

Motivation for the Study

- Prescriptive specification
  - w/cm = 0.40
  - Cover (1.5 to 2.5 in.), chloride ion limits
  - 20% fly ash, 30% slag etc.
  - 705 lb/yd^3
  - Corrosion inhibitor
- Replace prescription with performance requirement for corrosion resistance

The Link Between Durability and Transport

- Each potential durability issue can be related in part to water penetration
  - Freeze-thaw, chloride penetration and corrosion, alkali aggregate attack, and sulfate attack.
- To specify more durable concrete, tests are needed:
  - Qualify the resistance of the concrete to water (or aggressive fluid) penetration.

Project Objectives

- Develop test procedure(s)
  - Directly evaluates the transport properties of concrete and relates these to anticipated performance with the use of exposure conditions
- Evaluate existing transport test procedures
- Develop new, or improve test procedures
- Correlate transport properties and existing ‘durability’ tests.
- Develop guidelines to relate
  - Permeability, exposure conditions, and field performance for use in specifications and quality control

Project Scope

- Phase I
  - Literature Review of Concrete Permeability (Transport) Test Procedures and Models that Link Tests with Performance
- Phase II
  - Evaluate Promising Concrete Permeability (Transport) Tests and Recommend Procedures for Further Use
- Phase III
  - Develop New or Improve Existing Permeability (Transport) Testing Procedures.
  - Develop Protocols to Use these Tests, Evaluate the Precision and Bias of these Tests

Project Scope

- Phase IV
  - Correlate Permeability (Transport) Tests with Laboratory Tests that Evaluate Durability
- Phase V
  - Develop Performance Criteria Guidelines that Relate Permeability (Transport) Tests with Exposure Conditions and Performance
- Phase VI
  - Preparation of Technology Transfer and Educational Materials

Example of Proposed Performance Tests

- Rapid Index Tests
  - RCP (ASTM C 1202)
  - RMT (AASHTO TP 64)
  - Sorptivity (ASTM C 1585)
  - Gas Permeability (RILEM-CEMBUREAU)
- Science-based Tests
  - Chloride Diffusion (ASTM C 1556)
  - Modified Chloride Diffusion (ASTM C 1556)

General Modeling Approach

For the main characteristics investigated in this work the following approach was used for modeling

Step 1
Assess Materials Using Standard AASHTO or ASTM tests

→

Step 2
Transform Test Results into Material Properties

→

Step 3
Relate Material Properties to Service Life Using Exposure

→

Step 4
Use Service Life to Establish Performance Grades

- Chloride Permeability and Corrosion
- Freeze Thaw Durability

Corrosion Model Approach

Step 1

Assess Materials Using Standard AASHTO or ASTM tests

→

Step 2

Transform Test Results into Material Properties

→

Step 3

Relate Material Properties to Service Life Using Exposure

→

Step 4

Use Service Life to Establish Performance Grades

Step 1

Measurement using RCPT

Results in Coulomb

→

Step 2

Transform RCPT results to Diffusivity

(D) (m^2/sec)

→

Step 3

Relate Diffusivity to Life

D (m^2/sec) to Years

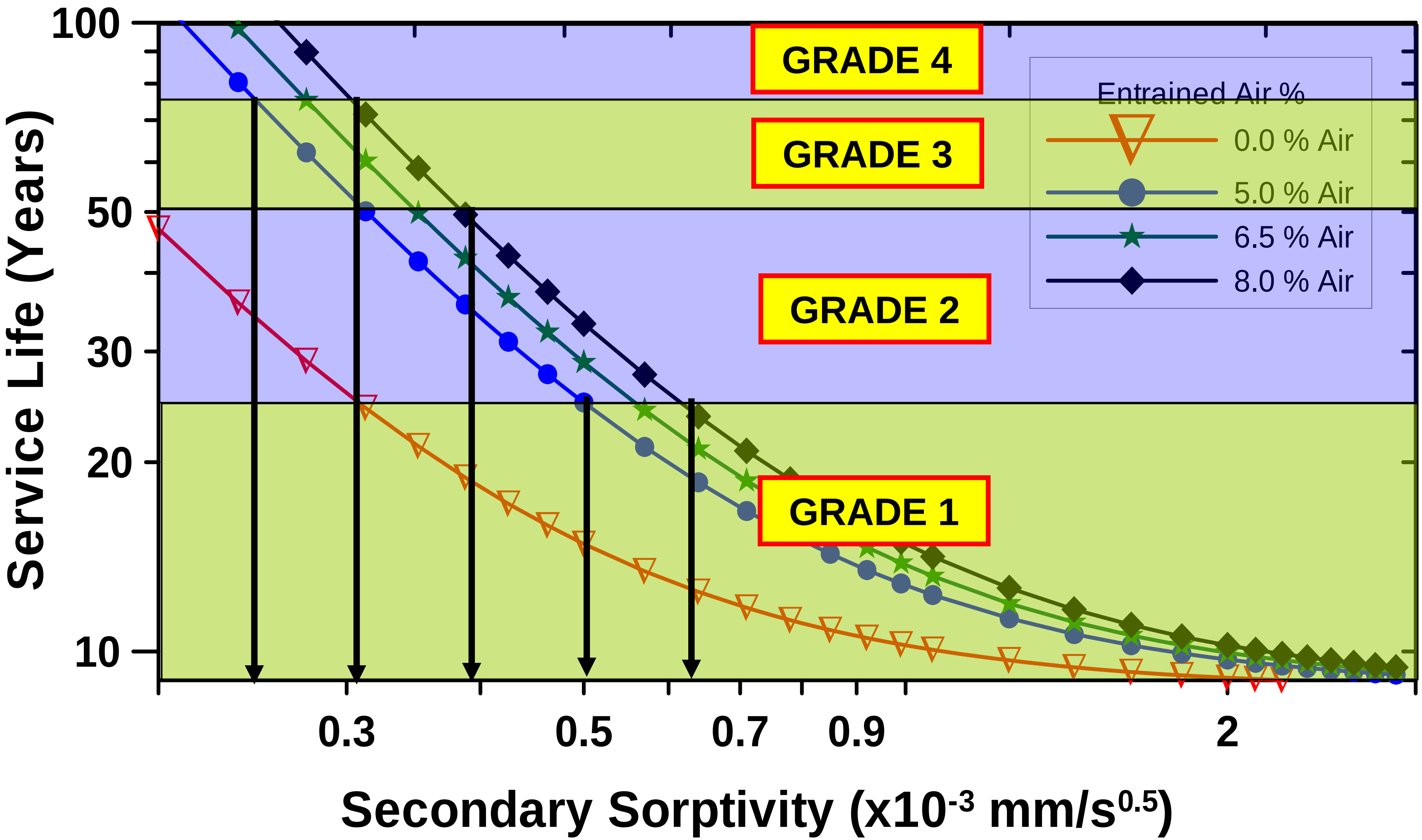
→

Step 4

Service life (t_{life}) to Material Grades

Grades

Performance Grades – Example



Recent Development

- ASTM C1202, *Standard Test Method for Electrical Indication of Concrete's Ability to Resist Chloride Ion Penetration*
- ASTM C1556, *Standard Test Method for Determining the Apparent Chloride Diffusion Coefficient of Cementitious Materials by Bulk Diffusion*
- Challenge
  - Can the RCPT results (< 90 days) rank mixtures in the same order as the chloride diffusion test?

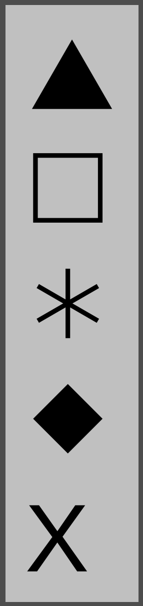
Recent Development

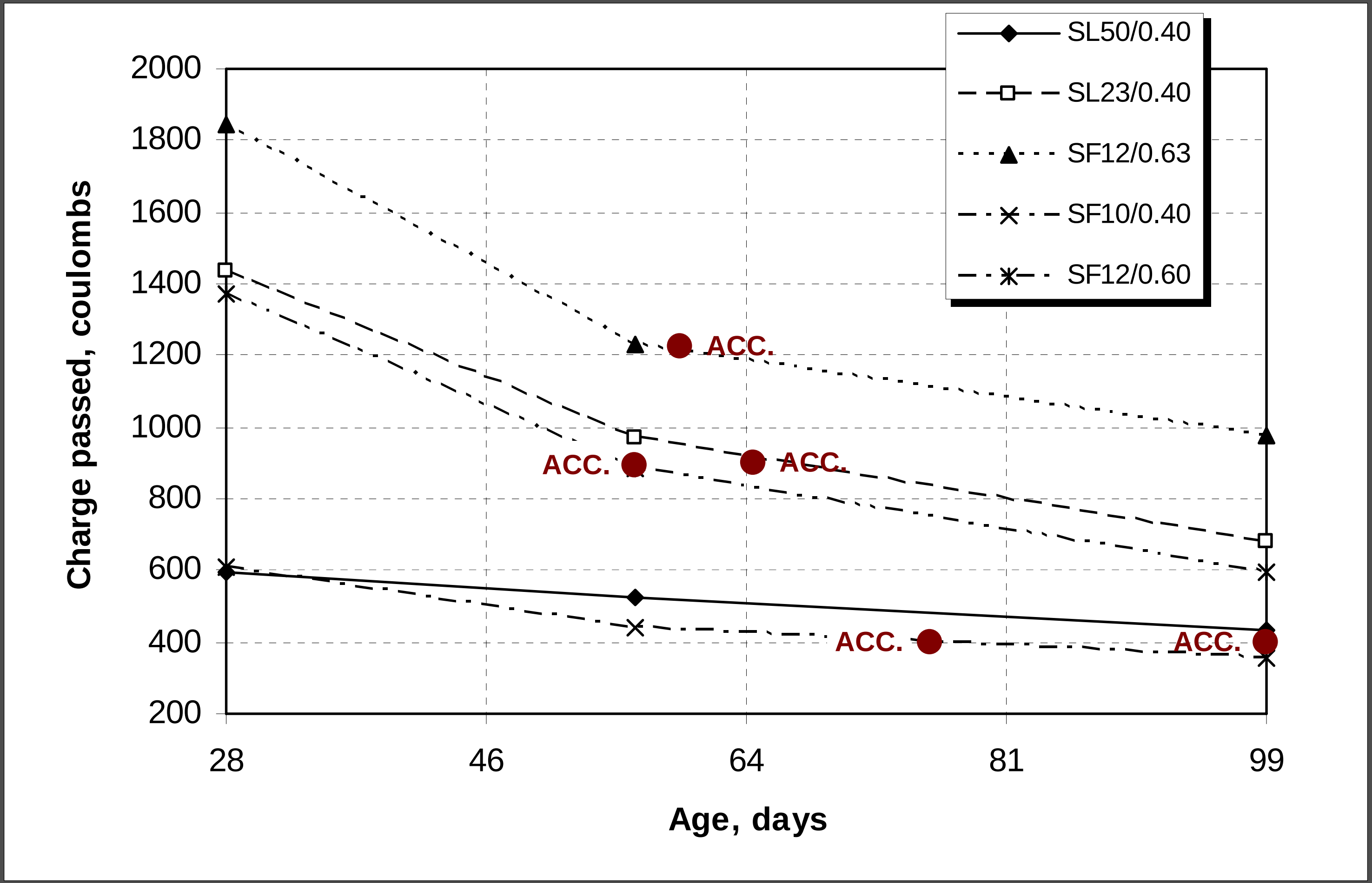
- Scenario 1
  - Low pore solution conductivity
  - Open pore structure
  - Low RCPT result and high chloride diffusion coefficient
- Scenario 2
  - Very high pore solution conductivity
  - Tight pore structure
  - High RCPT result and low chloride diffusion coefficient

Recent Development

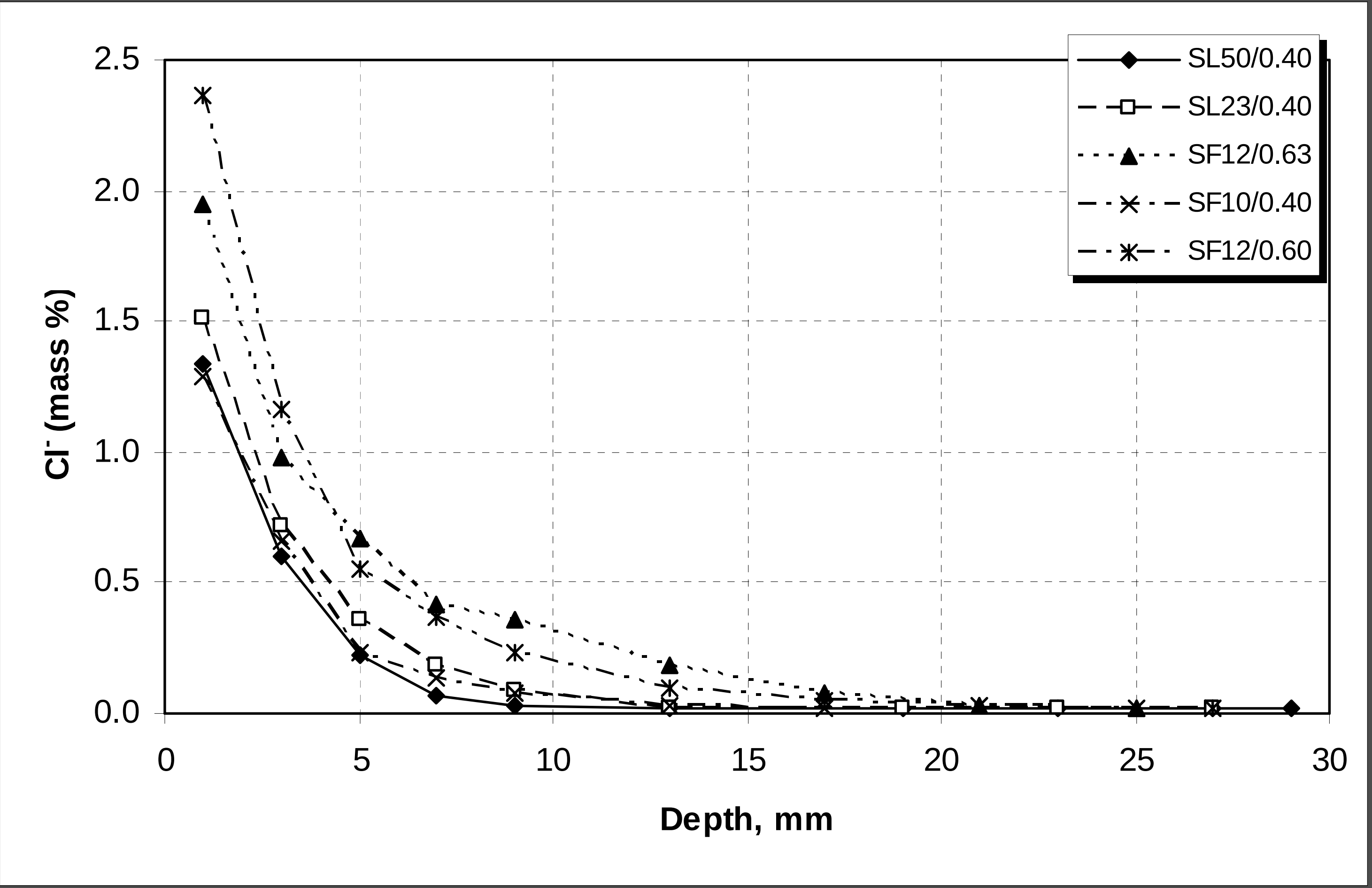
- Hypothesis
  - Accept mixtures with high chloride ion diffusion coefficients and low pore solution conductivities
  - Reject mixtures with low chloride ion diffusion and high pore solution conductivities
- The conductivity of the pore solution has no influence on chloride ion transport measured with ASTM C 1556
- Specifying concrete mixtures with low RCPT values are not a sound approach

Preliminary Results

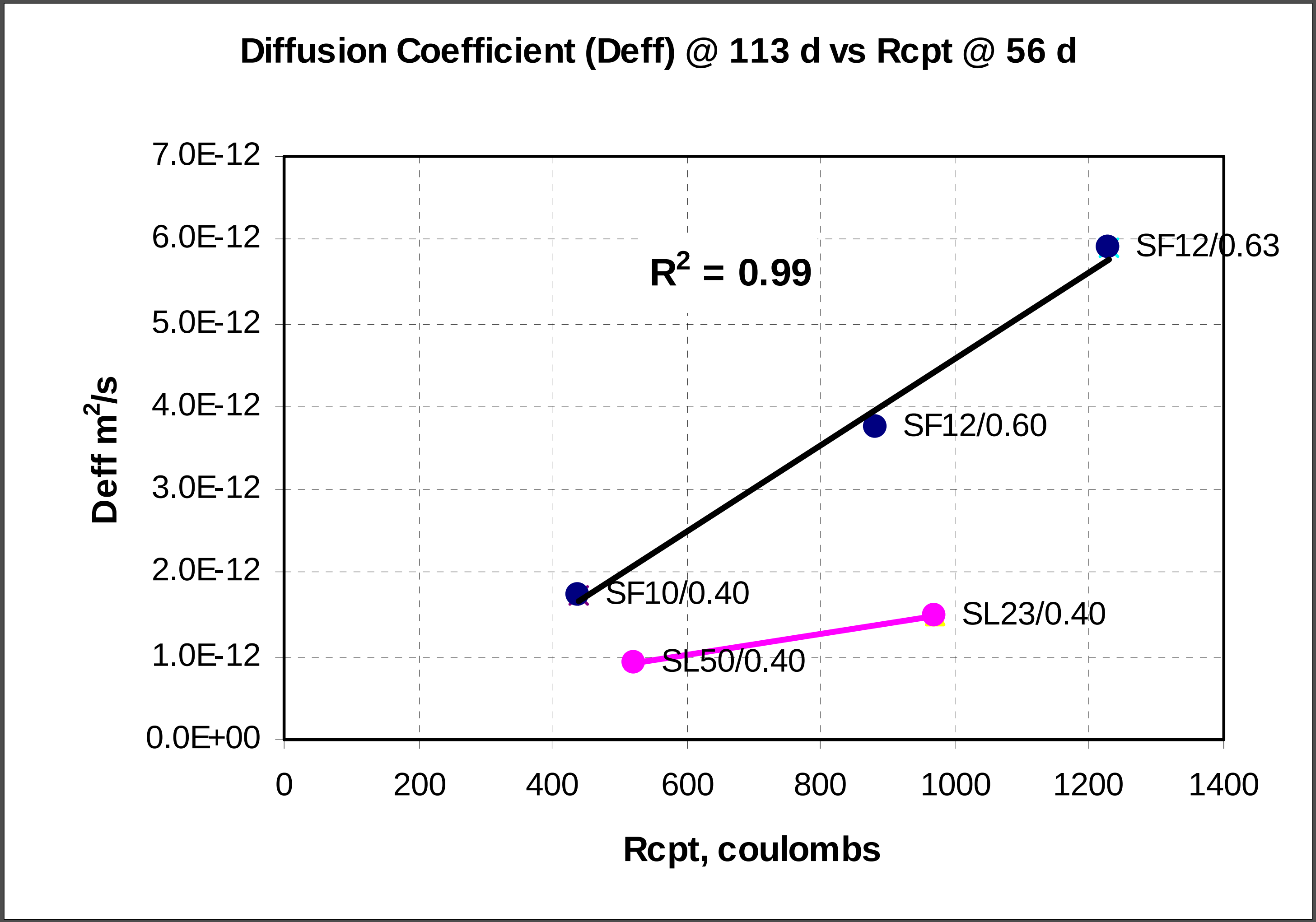




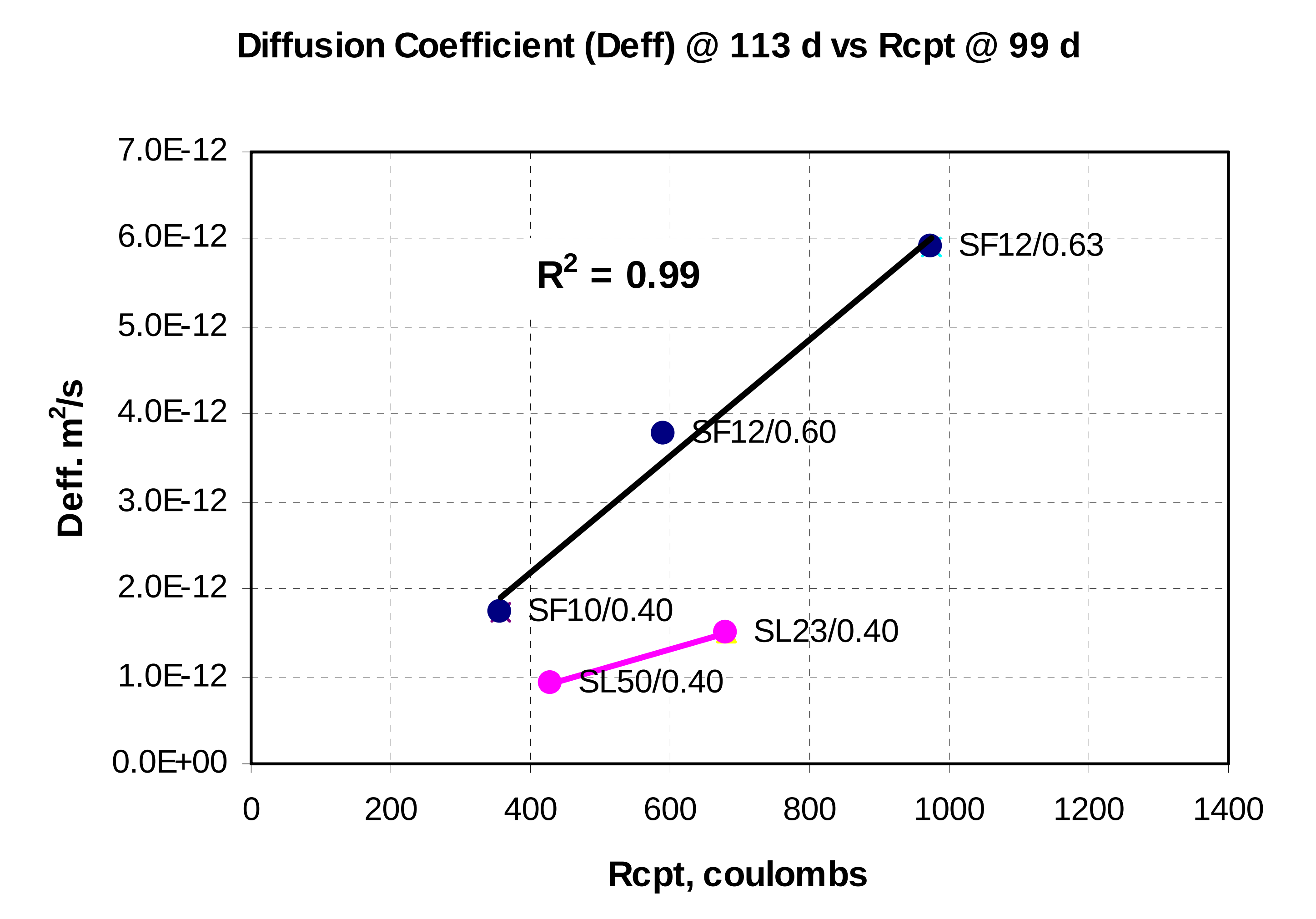
Preliminary Results



Preliminary Results



Preliminary Results



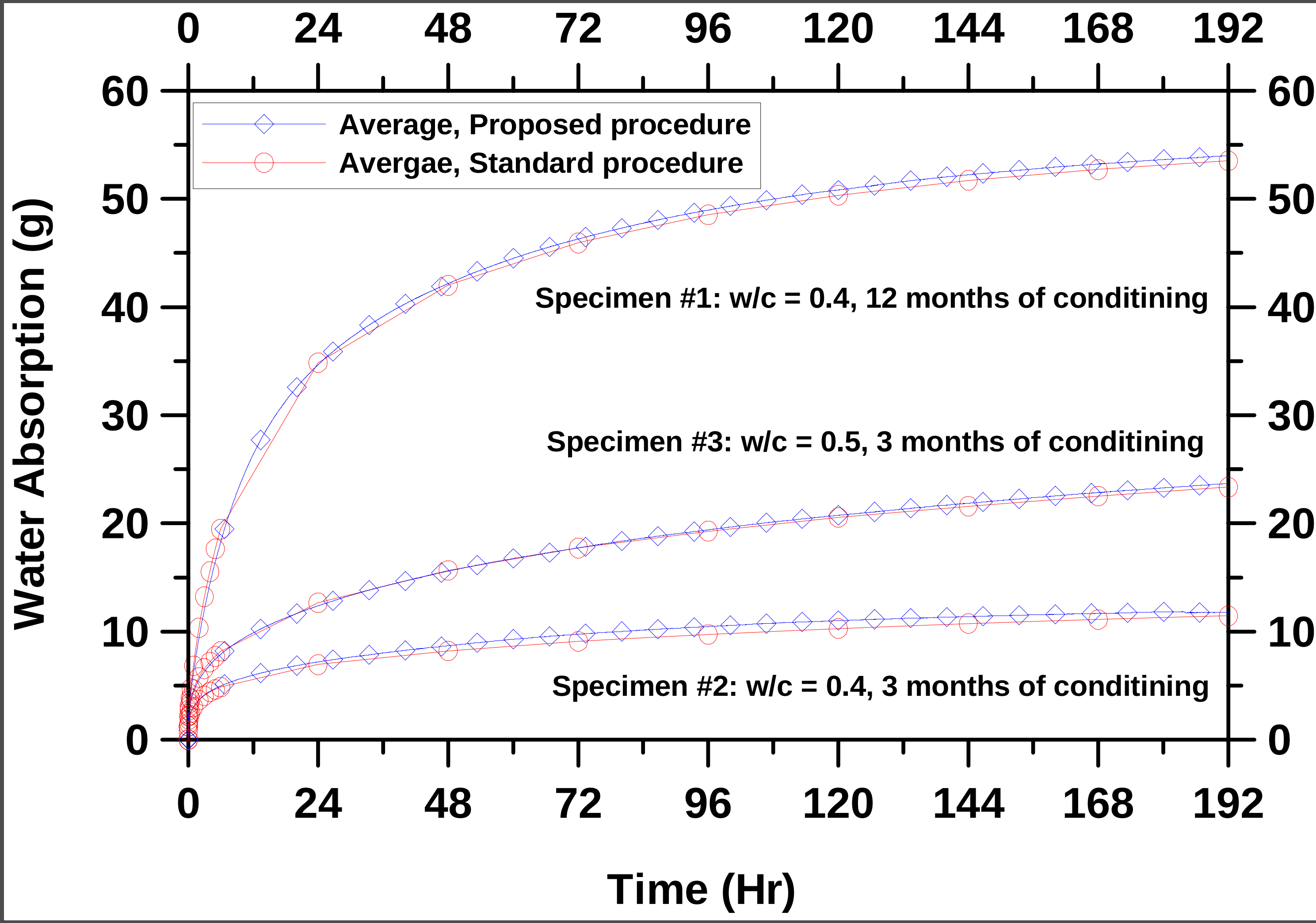
Preliminary Conclusions

- Mixture with “very low” (975 Coulombs) chloride ion penetrability (ASTM C 1202) has a high chloride ion diffusion coefficient (SF12/0.63)
- Mixtures with “higher” chloride ion penetrability (ASTM C 1202) has a lower chloride diffusion (SL23/0.40 vs SF12/0.60)
- The RCPT does not rank mixtures in the same order as the chloride ion diffusion.

Preliminary Result from Purdue

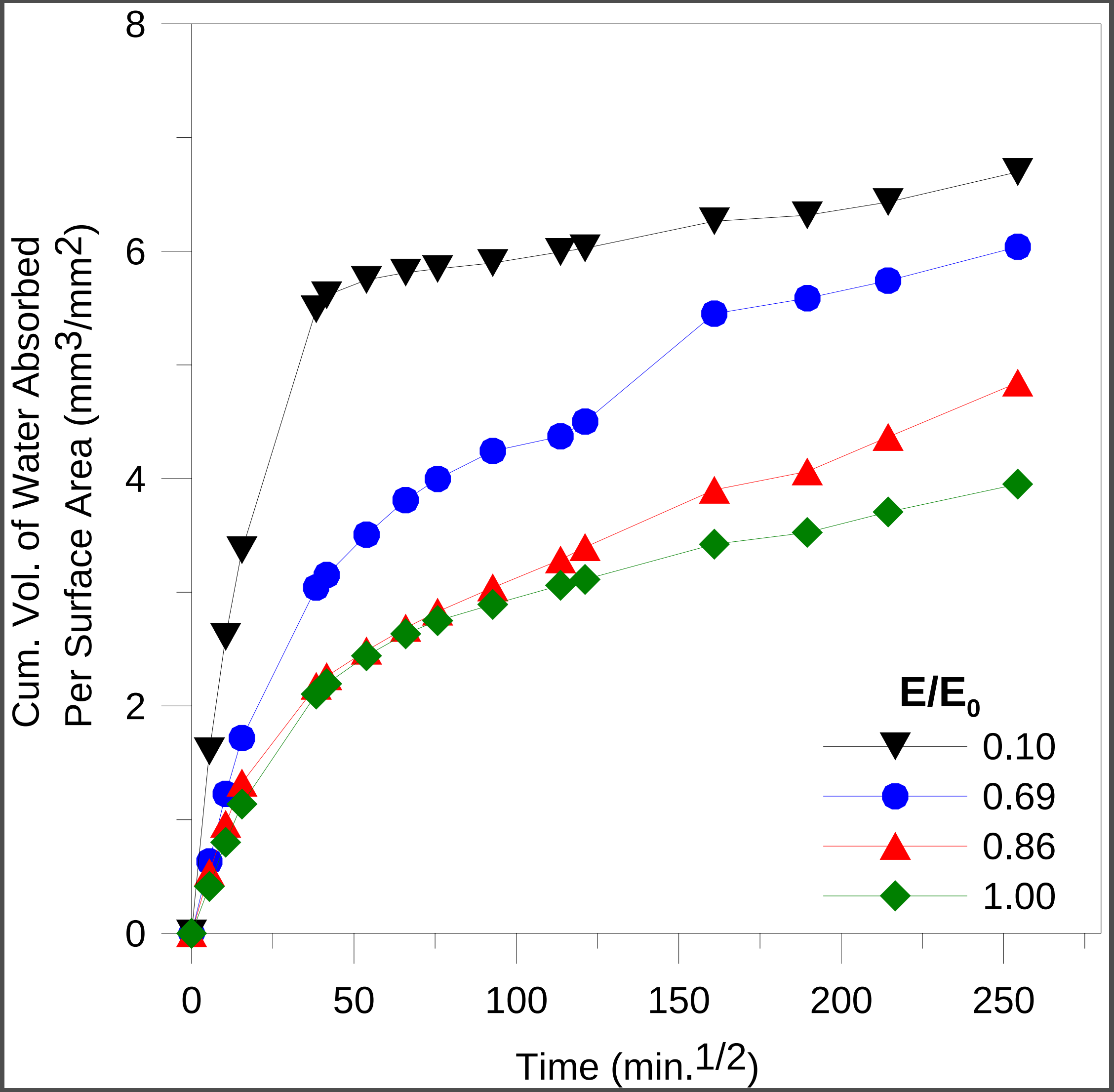
- Measurement of Water Absorption Using a Semi-Automated Procedure
- Significance of Sample Orientation
- Detailed Analysis of Water Penetration Depth at Early Ages

Sorption Measurements



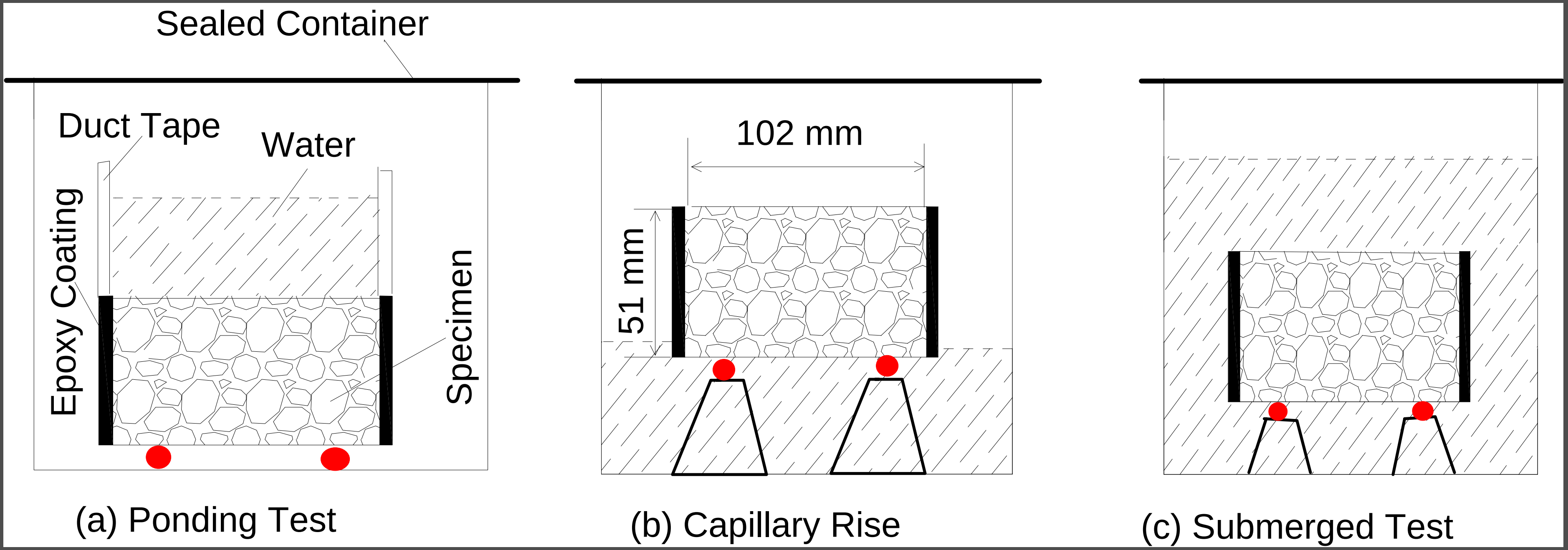
Sorptions Measured in Cracked Concrete

- **Sealing – Side epoxy sealed, tape bonded and sealed**
- **Preconditioning: 14 days @ 20ºC, 50% RH**
- **Mass gain - recorded regularly**



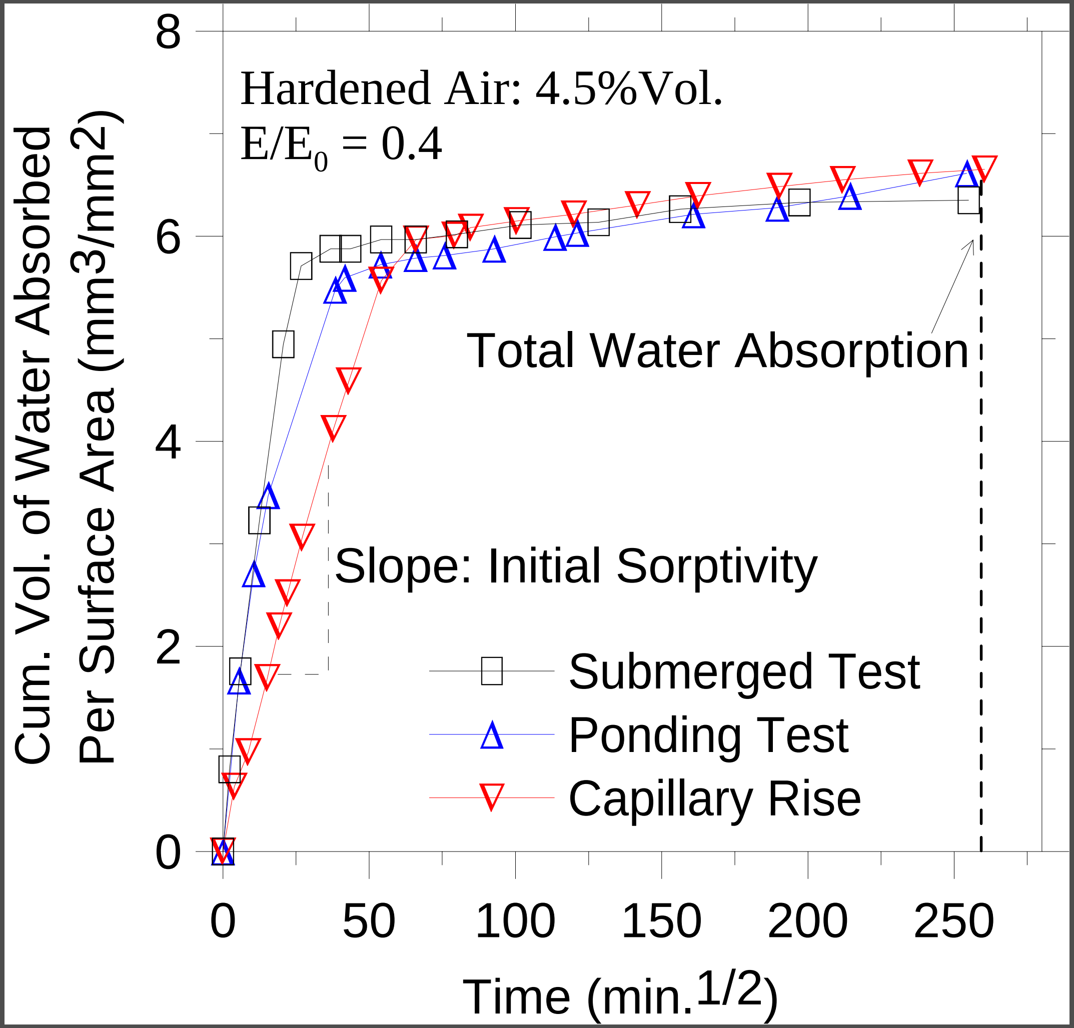
Test Methods Compared

- Several Different Sorption tests were evaluated to relate this property to exposure conditions

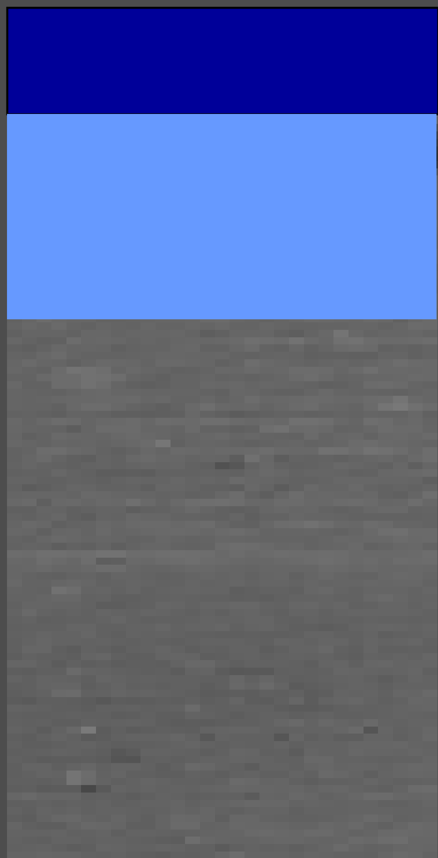


Typical Results

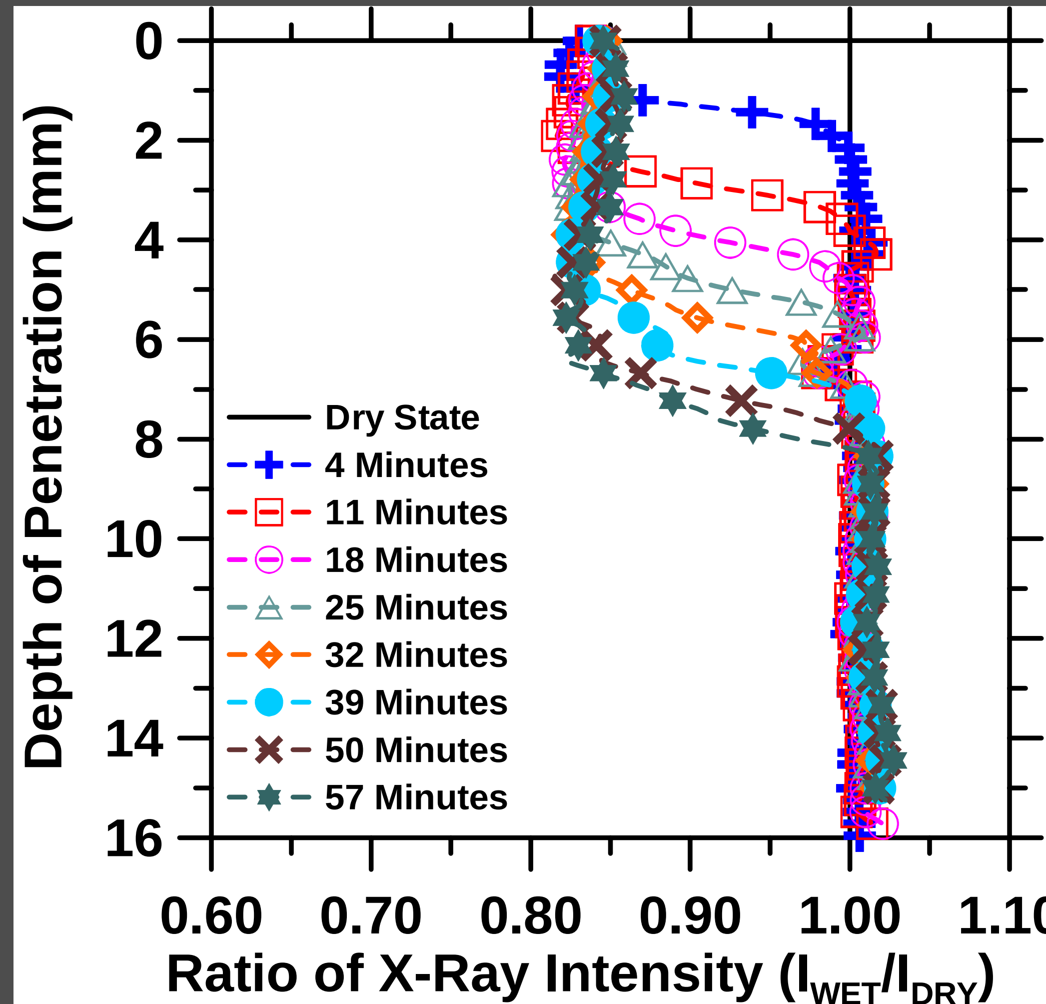
- Absorption in damaged samples
- Rate of absorption can change significantly
- Total absorption is very similar



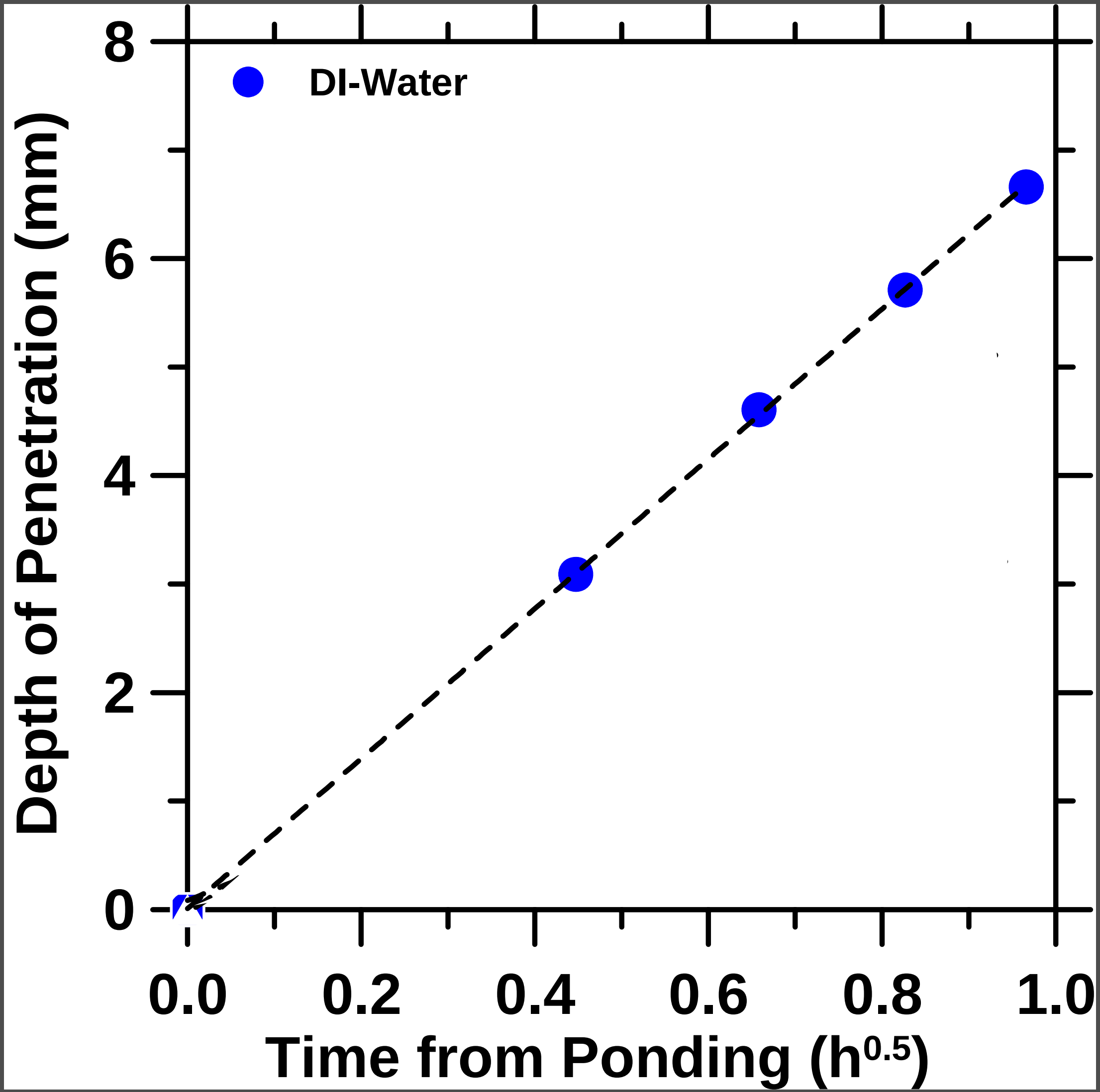
Typical Absorption Measurements



Change in normalized intensity with ingress



Depth of Penetration



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Summary

- Work is currently assessing fluid transport in concrete
- Work shown today describes water sorption techniques that show promise
- Additional Work (Not Shown) is investigating diffusion and permeability

Project Team

INDOT

- Tommy E. Nantung, Ph.D., P.E., Section Manager

Purdue University

- Jason Weiss, Ph.D., Professor and Associate Head
- Jan Olek, Ph.D., P.E., Professor
- Mark Baker is the Laboratory Manager
- Post Doctoral Assistants, Graduate Assistants and Hourly Labor

NRMCA

- Karthik Obla, Ph.D., P.E. Senior Director of Research and Materials Engineering,
- Haejin Kim, Laboratory Manager/Materials Engineer
- Soliman Ben Barka, Senior Laboratory Technician
- Colin Lobo, Ph.D., P.E. Vice President of Engineering
- Gary Mullings Senior Director of Operations and Compliance.

Project Funding

- Funding
  - $883,000 Pooled Fund
    - 4 year Project
      - $25,000 each year for the first three years and $12,000 for the fourth year.
    - $100,000 FHWA
  - $335,100 Matching Dollars from Industry
  - $135,515 In Kind Matching