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

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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
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)
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

Barde et al. 2006
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

Transform RCPT results to Diffusivity 
$(D)$ $(\text{m}^2/\text{sec})$

Step 3: Relate Diffusivity to Life

$D$ $(\text{m}^2/\text{sec})$ to Years

Step 4: Service life $(t_{\text{life}})$ to Material Grades

Barde et al. 2006
Performance Grades – Example

Barde et al. 2006
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

<table>
<thead>
<tr>
<th>SL50/0.40</th>
<th>SL23/0.40</th>
<th>SF12/0.63</th>
<th>SF10/0.40</th>
<th>SF12/0.60</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age, days</td>
<td>28</td>
<td>46</td>
<td>64</td>
<td>81</td>
</tr>
<tr>
<td>Charge passed, coulombs</td>
<td>2000</td>
<td>1800</td>
<td>1600</td>
<td>1400</td>
</tr>
</tbody>
</table>

ACC. SL50/0.40
ACC. SL23/0.40
ACC. SF12/0.63
ACC. SF10/0.40
ACC. SF12/0.60
Preliminary Results

![Graph showing Cl concentration vs depth](image-url)
Preliminary Results

Diffusion Coefficient (Deff) @ 113 d vs Rcpt @ 56 d

- SL50/0.40
- SL23/0.40
- SF12/0.63
- SF10/0.40
- SF12/0.60
- R2 = 0.99

Graph showing the relationship between Rcpt (coulombs) on the x-axis and Deff (m²/s) on the y-axis. The data points are marked with different colors and labels.
Preliminary Results

Diffusion Coefficient ($D_{eff}$) @ 113 d vs Rcpt @ 99 d

- SL50/0.40
- SL23/0.40
- SF12/0.63
- SF12/0.60
- R2 = 0.99

Rcpt, coulombs

Deff, m$^2$/s
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

Specimen #1: w/c = 0.4, 12 months of conditioning
Specimen #2: w/c = 0.4, 3 months of conditioning
Specimen #3: w/c = 0.5, 3 months of conditioning

Water Absorption (g) vs. Time (Hr)

Average, Proposed procedure
Average, Standard procedure
Sorptions Measured in Cracked Concrete

- **Sealing** – Side epoxy sealed, tape bonded and sealed
- **Preconditioning**: 14 days @ 20°C, 50% RH
- **Mass gain** - recorded regularly
Several Different Sorption tests were evaluated to relate this property to exposure conditions.

- (a) Ponding Test
- (b) Capillary Rise
- (c) Submerged Test
- 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

Sant et al. 2008
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
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