PRODUCING DURABLE CONCRETE IN CONCRETE INDUSTRY

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Hong Kong Construction Materials Association
Technical Committee of Ready Mixed Concrete Committee
Presented by KW Leung and Kenny Sun
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Presented by Kenny Sun
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Presented by K. W. Leung
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Introduction
Definition of Durability of Concrete

Ability to withstand its design service conditions for a design life without significant deterioration.”

- Resistance to weathering, including freezing and thawing
- Chemical resistance
- Corrosion resistance
- Resistance to alkali-silica reaction (ASR)
- Abrasion resistance
Durable Concrete from Designers’ Perspectives
Particular structure types need special attention (Severe Exposure Condition)

- Marine structure, e.g. bridge decks, bridge piers especially exposed to salt water
- Structure under continuous abrasion, e.g. parking structure, pavements
- Structure with potential exposure to chemical attack, e.g. waste treatment plant, chemical plant, nuclear power station, etc
- Structure in region which undergo continuously freezing and thawing
- Structure with long design life, e.g. 120 years design life
<table>
<thead>
<tr>
<th>Class / Designation</th>
<th>Description of environment</th>
<th>Informative example where exposure classes may occur</th>
</tr>
</thead>
<tbody>
<tr>
<td>XS1</td>
<td>Exposed to airborne salt but not in direct contact</td>
<td>Structures near to on the coast</td>
</tr>
</tbody>
</table>

**EN 206-1:2000 Table 4 - Exposure Classes**
### Exposure Conditions

<table>
<thead>
<tr>
<th>Exposure classes</th>
<th>Chloride-induced corrosion</th>
<th>Sea Water</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Maximum w/c</strong></td>
<td>0.5</td>
<td><strong>XS1</strong></td>
</tr>
<tr>
<td><strong>Minimum strength class</strong></td>
<td>C30/37</td>
<td><strong>-</strong></td>
</tr>
<tr>
<td><strong>Minimum cement content, kg/m³</strong></td>
<td>360</td>
<td><strong>-</strong></td>
</tr>
<tr>
<td><strong>Minimum air content, percent</strong></td>
<td><strong>-</strong></td>
<td><strong>-</strong></td>
</tr>
</tbody>
</table>

**EN 206-1:2000 Table 5 - Recommended limiting values for composition and properties of concrete**

<table>
<thead>
<tr>
<th>Exposure classes</th>
<th>Chloride- induced corrosion</th>
<th>Sea Water</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Maximum w/c</strong></td>
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</tr>
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<td>360</td>
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</tr>
<tr>
<td><strong>Minimum air content, percent</strong></td>
<td><strong>-</strong></td>
<td><strong>-</strong></td>
</tr>
</tbody>
</table>
Designed Life

**HK-ZH-MO Bridge**
Design Life: 120 Years

**Tsing Ma Bridge**
Design Life: 120 Years

**Stonecutter Bridge**
Design Life: 120 Years

Concrete durability is essential for the long design life of 120 years for major infrastructure projects.
Specification on Durability of Concrete

Major considerations base on different exposure conditions

• Minimum and/or maximum cementitious content
• Water to cementitious content ratios
• Placing temperature / in-situ peak temperature / temperature gradient of the structure
• Limit on reactive alkali, i.e. Alkali-aggregate reaction (AAR) control
• Addition of supplementary cementitious content, e.g. PFA, CSF, GGBS, etc.
• Addition of chemical, e.g. SRA, WP, Corrosion Inhibitor, etc.
• Chloride content in concrete mix
## Specification for marine concrete

<table>
<thead>
<tr>
<th>Mix Parameter</th>
<th>Acceptable limits</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water/cementitious content ratio</td>
<td>Not exceeding 0.38</td>
</tr>
<tr>
<td>Cementitious content</td>
<td>380-450kg/m³</td>
</tr>
<tr>
<td>Supplementary cementitious materials</td>
<td>Either PFA or GGBS, and CSF to be incorporated</td>
</tr>
<tr>
<td>If PFA added, PFA content</td>
<td>25-40%</td>
</tr>
<tr>
<td>If GGBS added, GGBS content</td>
<td>60-75% (normal application) Or 60-90% (low heat application)</td>
</tr>
<tr>
<td>CSF content</td>
<td>5-10%</td>
</tr>
<tr>
<td>Characteristic strength</td>
<td>45MPa</td>
</tr>
</tbody>
</table>
• DSD Project – Power Station Cooling Water System

• Watertight admixture with HPI to reduce water absorption to 1% or below as measured by BS1881: Part 122: 1983

• SRA to reduce shrinkage by 30% or more at 28 days as measured by ASTM C157-93
• DSD Project – Harbour Area Treatment

• Limitation on cementitious content to 380-450kg/m3

• Incorporated of SCM, 25-40% of PFA & 5-10% of condensed silica fume
• BD Project – Residential Development At Tai Po Town

• Watertight admixture with HPI to reduce water absorption to 1% or below as measured by BS1881: Part 122: 1983

• Superplasticizer is to be included

3.2 PERFORMANCE SPECIFICATION FOR HYDROPHOBIC PORE BLOCKING INGREDIENT (HPI) CONCRETE

Corrosion-proof and waterproof concrete shall comply with the conditions and requirements as set out in Section 3.2.

All concrete in the designated areas shall conform with all specified requirements and also the following:

a) The cement content of the concrete shall be no less than 350 kilograms per cubic metre.

b) The concrete shall contain a time-proven effective Hydrophobic Pore Blocking Ingredient (HPI) or proven equal and approved in writing, strictly in accordance with Manufacturers’ Detailed Technical Specifications, producing concrete with a Hydrophobic Matrix throughout as well as dispersed polymer particles suitable for use as a pore-blocking agent.

c) The concrete shall further contain an approved High Range Water Reducing admixture or superplasticiser such that the free (water + HPI): cement ratio shall not exceed 0.45 and the concrete will be of adequate workability for void-free placement and compaction.

d) The Hydrophobic Pore Blocking Ingredient (HPI) concrete shall conform to all specified requirements and shall further be shown to produce concrete with a corrected 28 minutes absorption of not greater than 1% (one percent), as measured by BS 1881: Part 122: 1983, except that the age at test shall be 7 days.
Intended Use – e.g. Water-Retaining Structure

Hydrophobic Pore-blocking Ingredient (HPI)

- Materials developing polymer barriers inside pores during the hydration process.
- The nature of the polymers can cause water to form a water drop on the surface of the concrete.
- The surface tension of the water itself keeps it from being able to penetrate the wall.
Intended Use – e.g. Water-Retaining Structure

- Low water/cementitious ratio w/c ≤ 0.38
- High workability e.g. Slump ≥ 175MM
- Use of superplasticizer
  - enhance workability
  - reduce the amount of pores
  - better dispersion of cement particles
  - increase concrete density
  - reduce permeability
- Use of waterproof admixture
  - further improve permeability properties

Effect of w/c ratio on permeability
(Powers et al, 1954)
Intended Use – e.g. basement below water level

Treated and Non-treated concrete
Durable Concrete from Construction Sites’ Perspectives
Placing and Compaction

Excessive free fall may lead to concrete segregation.

Long pumping distance may reduce air content and workability.

Over-vibration may lead to segregation. Under-vibration may lead to inadequate compaction thus homey combing.
Placing and Compaction

Inadequate Vibration - Honeycombing
Curing and Concrete Cover

Curing at different stages
- Moisture retention / Reduce plastic shrinkage crack
- Enhance hydration process
- Proper strength development
- Reduce chemical attack

Concrete cover
- Determine the ease of ingress of aggressive agents and corrosion rate of reinforcement.
Durable Concrete from Concrete Producers’ Perspectives
Durable Concrete From Concrete Producers’ Perspectives

• Permeability of concrete affected by:
  – Surface tension in capillary pores
  – Hydrostatic pressure
  – External factors such as inadequate compaction and curing
Durable Concrete From Concrete Producers’ Perspectives

• Shrinkage of concrete affected by:
  – Plastic Shrinkage
  – Autogenous Shrinkage
  – Drying Shrinkage
  – Intrinsic tensile stresses to cause shrinkage cracking due to drying shrinkage / autogenous shrinkage if concrete is restrained, thus adversely affecting durability.
Durable Concrete From Concrete Producers’ Perspectives

• Common Performance parameters of Concrete in HK
  – Permeability
  – Water Absorption
  – Rapid Chloride Permeability
  – Permeability Coefficient
  – Water Penetration Depth
  – Sorptivity
  – Shrinkage
  – Temperature
Durable Concrete From Concrete Producers’ Perspectives

Example on Specification Requirements

**CEDD Specification**

<table>
<thead>
<tr>
<th>Test</th>
<th>Type</th>
<th>Compliance Criteria</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sorptivity</td>
<td>Plant Trial</td>
<td>Equal to or less than 0.07 mm/min^{0.5} at 28 days.</td>
</tr>
<tr>
<td></td>
<td>Shaft, lining</td>
<td>Equal to or less than 0.07 mm/min^{0.5} at 28 days.</td>
</tr>
<tr>
<td>Chloride Diffusion</td>
<td>Plant Trial</td>
<td>Equal to or less than 1000 coulombs at 28 days.</td>
</tr>
<tr>
<td></td>
<td>Shaft, lining</td>
<td>Equal to or less than 1000 coulombs.</td>
</tr>
</tbody>
</table>

**MTRC Specification**

For Category A concrete the results of the RCPT shall be average 35 day electrical resistance less than 1500 Coulombs.

For Category A concrete the results of the absorption tests shall be average absorption value at 28 days of less than 1.5%.
Durable Concrete From Concrete Producers’ Perspectives

Example on Specification Requirements

Private Project Specification

- Water absorption at 7 days shall not be greater than 1.0%

The integral waterproofing concrete shall contain a time-proven hydrophobic pore-blocking ingredient or proven equal and approved in strict accordance with the Waterproofing Materials Manufacturer’s detailed technical specifications. Once the approval has been given, the Contractor shall not change the approved ingredients without the Engineer’s approval.
Example on Specification Requirements

Requirements for Stormwater Storage Structure

- With Shrinkage Reducing Admixture
- Min. cement content: 360kg/m³
- Max. cementitious content: 410kg/m³
- With 25% PFA replacement
- Max. water/cementitious ratio: 0.45
- Min. shrinkage reduction of 30% to control mix at 28days is required
Durable Concrete From Concrete Producers’ Perspectives

• Reduce Permeability of Concrete Mix by:
  – Lower Water/Cementitious ratio
  – Incorporating SCMs (e.g. PFA, GGBS & CSF)
  – Use of chemical admixtures

• Reduce Drying Shrinkage of Concrete Mix by:
  – Lower water / cementitious ratio
  – Increasing aggregate content (i.e. Reduce paste volume)
  – Use of chemical admixtures
Durable Concrete From Concrete Producers’ Perspectives

- Type of Admixtures
  - Air-entraining
  - Retarding
  - Accelerating
  - Water reducing
  - High range water reducing
  - Shrinkage reducing
  - Waterproofing
  - Viscosity modifying
  - Etc...
Durable Concrete From Concrete Producers’ Perspectives

Report on Chemical admixtures for concrete

ACI 212.3R-10 VS ACI 212.3R-16

ACI 212.3R-10
18 Admixture Types

ACI 212.3R-16
23 Admixture Types
Durable Concrete From Concrete Producers’ Perspectives

Trial mix results – Example of Using SCMS and Superplasticiser

<table>
<thead>
<tr>
<th>Grade</th>
<th>Designed Slump</th>
<th>OPC</th>
<th>PFA</th>
<th>CSF</th>
<th>Superplasticiser (PC)</th>
<th>W/C ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>45/20</td>
<td>175mm</td>
<td>314 kg/m³</td>
<td>114 kg/m³</td>
<td>23 kg/m³</td>
<td>5.5 lit/m³</td>
<td>0.38</td>
</tr>
<tr>
<td></td>
<td>(25%)</td>
<td>(5%)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
## Durable Concrete From Concrete Producers’ Perspectives

**Trial mix results – Example of Using SCMS and Superplasticiser**

<table>
<thead>
<tr>
<th></th>
<th>7 days</th>
<th>28 days</th>
<th>58 days</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average Compressive Strength (MPa)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sample One</td>
<td>56.3</td>
<td>78.6</td>
<td>88.2</td>
</tr>
<tr>
<td>Sample Two</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Average</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>Sample One</th>
<th>Sample Two</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chloride Diffusion at 28 days (Coulombs)</td>
<td>433</td>
<td>418</td>
<td>423</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>Sample One</th>
<th>Sample Two</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sorptivity at 28 days (mm/min^{0.5})</td>
<td>0.06</td>
<td>0.06</td>
<td>0.06</td>
</tr>
</tbody>
</table>
Durable Concrete From Concrete Producers’ Perspectives

• Concrete with Hydrophobic Pore-Blocking Ingredient (HPI)
  – Hydrophobic Pore-blocking Admixture
    • Produce hydrophobic water repelling properties
    • Improve water repellency
    • Reducing water absorption of concrete
    • Reduce the permeability of concrete to enhance the durability of concrete

– Application
  • Water retaining structures
  • Water tank
  • Swimming pool, etc.
Durable Concrete From Concrete Producers’ Perspectives

Trial mix results – Example of Using Hydrophobic Pore-blocking Admixture

<table>
<thead>
<tr>
<th>Grade</th>
<th>Designed Slump</th>
<th>OPC</th>
<th>PFA</th>
<th>Superplasticser (PC)</th>
<th>HPI</th>
<th>W/C ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>45/20</td>
<td>175mm</td>
<td>340 kg/m$^3$</td>
<td>110 kg/m$^3$</td>
<td>4.5 lit/m$^3$</td>
<td>4.5 lit/m$^3$</td>
<td>0.38</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>(24.4%)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
# Durable Concrete From Concrete Producers’ Perspectives

Trial mix results – Example of Using Hydrophobic Pore-blocking Admixture

<table>
<thead>
<tr>
<th>Trial Mix Results - Concrete Mix with HPI VS Control Mix</th>
<th>Average Compressive Strength (MPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control Mix 7 days</td>
<td>59.2MPa</td>
</tr>
<tr>
<td>Mix With HPI</td>
<td>57.1MPa</td>
</tr>
<tr>
<td>Control Mix 28 days</td>
<td>85.9MPa</td>
</tr>
<tr>
<td>Mix With HPI</td>
<td>77.8MPa</td>
</tr>
</tbody>
</table>
Durable Concrete From Concrete Producers’ Perspectives

Trial mix results – Example of Using Hydrophobic Pore-blocking Admixture

**Trial Mix Results – Concrete Mix with HPI VS Control Mix**

- **Control Mix**: 2.0% water absorption at 7 days
- **Mix With HPI**: 0.9% water absorption at 7 days
Durable Concrete From Concrete Producers’ Perspectives

Findings Based on Trial of Concrete Using Hydrophobic Pore-blocking Admixture

- By using HPI in concrete, the water absorption at 7 days was reduced by 55.0% and compressive strength of 7 days and 28 days were reduced by 3.5% and 9.4% respectively.

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Water absorption at 7 days</td>
<td>↓ 55.0%</td>
</tr>
<tr>
<td>Compressive Strength at 7 days</td>
<td>↓ 3.5%</td>
</tr>
<tr>
<td>Compressive Strength at 28 days</td>
<td>↓ 9.4%</td>
</tr>
</tbody>
</table>
Durable Concrete From Concrete Producers’ Perspectives

- Application of Shrinkage Reducing Admixture
  - Water retaining structure
  - Large area concrete Slab
  - Minimizing cracking by using SRA which allowing reduction of joints (i.e. Water Storage Tank)
### Durable Concrete From Concrete Producers’ Perspectives

Trial mix results – Example of Using Shrinkage Reducing Admixture

<table>
<thead>
<tr>
<th>Grade</th>
<th>Designed Slump</th>
<th>OPC</th>
<th>PFA</th>
<th>Superplasticiser (PC)</th>
<th>SRA</th>
<th>W/C ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>45/20</td>
<td>175mm</td>
<td>298 kg/m³</td>
<td>112 kg/m³</td>
<td>7.0 lit/m³</td>
<td>5.5 lit/m³</td>
<td>0.38 (27.3%)</td>
</tr>
</tbody>
</table>
Durable Concrete From Concrete Producers’ Perspectives

Trial mix results – Example of Using Shrinkage Reducing Admixture

<table>
<thead>
<tr>
<th></th>
<th>Control Mix</th>
<th>Mix With SRA</th>
<th>Control Mix</th>
<th>Mix With SRA</th>
</tr>
</thead>
<tbody>
<tr>
<td>7 days</td>
<td>52.7MPa</td>
<td>50.1MPa</td>
<td>70.1MPa</td>
<td>66.7MPa</td>
</tr>
<tr>
<td>28 days</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Durable Concrete From Concrete Producers’ Perspectives

Trial mix results – Example of Using Shrinkage Reducing Admixture

Trial Mix Results – Concrete Mix with SRA VS Control Mix

- Shrinkage at 28 days (%)

-0.019%

Control Mix

Mix With SRA

-0.010%

7 days
Durable Concrete From Concrete Producers’ Perspectives

Findings Based on Trial Using Shrinkage Reducing Admixture

- By using SRA in concrete, the shrinkage at 28 days was reduced by 47.4% and compressive strength of both 7 days and 28 days were reduced 4.9%.

<table>
<thead>
<tr>
<th>Shrinkage at 28 days</th>
<th>47.4%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Compressive Strength at 7 days</td>
<td>4.9%</td>
</tr>
<tr>
<td>Compressive Strength at 28 days</td>
<td>4.9%</td>
</tr>
</tbody>
</table>

- Base on ACI 212.3R-10, adding some SRA to concrete at a 2% dosage by mass of cement can reduce the strength as much as 15% at 28 days.
Durable Concrete From Concrete Producers’ Perspectives

• Measures & Concerns (1)

• Proportioning of Concrete Mix

  – Optimal proportion to meet the desired performance.

  – Compatibility of different types of admixtures and their dosage

  – The effects on fresh & hardened concrete properties
Durable Concrete From Concrete Producers’ Perspectives

• Measures & Concerns (2)

• Concrete Production
  – Mixing time and batching sequence
  – Stringent quality control measures
  – Supervision by competent person / well-trained staff
  – Proper storage
Durable Concrete From Concrete Producers’ Perspectives

Conclusion

Concrete durability is enhanced by:

- Using well proportioning concrete mix
- Use of SCMs or advance chemical admixtures
- Proper workmanship (i.e. placing, compacting & curing of concrete)
- Close supervision