Mitigation of Alkali-Silica Reaction in Volcanic Aggregate CONCRETE USING PFA AND GGBS

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Outline

1. What is Alkali-silica Reaction (ASR)?
2. Cases of ASR damage in Hong Kong
3. Aggregates for concrete in Hong Kong
4. GEO’s study on mitigating ASR in concrete using supplementary materials
5. Closing Remarks
Alkali-Silica Reaction (ASR)

- Alkalis in the pore water of concrete
- Reactive silica components of aggregates
- Water
- Gel-like products
- Expand and damage the concrete
Cases of ASR Damage

1. The first recognized cases of ASR damage: seawall, schools, and bridge piers in USA, in late 1930.
2. The first case in Hong Kong, a sewage treatment plant, in 1991.
## Cases of ASR in HK

<table>
<thead>
<tr>
<th>Structures</th>
<th>Year built</th>
<th>Year map pattern cracks found</th>
</tr>
</thead>
<tbody>
<tr>
<td>A sewage treatment plant</td>
<td>1981</td>
<td>1991 (10 years)</td>
</tr>
<tr>
<td>A footbridge</td>
<td>1982</td>
<td>1998 (16 years)</td>
</tr>
<tr>
<td>A school building</td>
<td>1987</td>
<td>1999 (12 years)</td>
</tr>
<tr>
<td>A road bridge</td>
<td>1982</td>
<td>1997 (15 years)</td>
</tr>
</tbody>
</table>

- **Time for ASR to be visible**: 10 – 15 years.
Cases of ASR in HK

- First ASR case found in 1991
Cases of ASR in HK

- Not Architectural Finishes
Cases of ASR in HK

- A recent case in bridge footing.
Visual features of structures affected by ASR

- Map pattern cracks
- Cracks parallel to the reinforcement
- Cracks occur 10+ years after the structures built
- Pop-outs or swelling of concrete
Consequences

- Loss of concrete strength
- Concrete more permeable
- Reduced capacity
- Reduced service life
- Very costly to rectify
a) Section 16 of General Specification for Civil Engineering Works (2006)
   1. Aggregates in the “Alkali-Reactive” category shall not be used.
   2. Alkali content (eq. Na2O): no more than 3 Kg / m³ of concrete.

b) SCCT – Construction Standard CS3:2013
   Aggregate for Concrete
   Aggregate producers/suppliers must have a quality control system to ISO 9001 implemented.
Control Measures in Public Works (2)

c) ETWB TC 57/2002 - Quality Assurance for Structural Concrete

Structural concrete for public works must be obtained from concrete suppliers certified by the Quality Scheme for the Production and Supply of Concrete (QSPSC).

d) GEO regularly collect aggregate/rock samples from concrete batching plants and local/PRC quarries and carry out ultra-accelerated mortar bar tests and petrographic examinations.
Aggregates for Concrete Production in HK
UAMBT Results of Commonly Available Aggregates
Local geology and aggregate suppliers

- Lam Tei Quarry
- Anderson Rd. Quarry

- Granite
- Volcanic or others
Lam Tei Quarry
Anderson Road Quarry

- The volcanic tuff from Anderson Road Quarry is highly alkali-reactive.
Volcanic aggregates used in concrete in Hong Kong

- Volcanic tuff aggregates have been used in ICC and IFC towers:
  - High concrete strength: 90+ MPa
  - High E-modulus value: 39+ GPa

By courtesy of: Alliance, CPA
To explore the use of volcanic rock as aggregates in concrete

- The volcanic tuff aggregate from tunnel / underground / cavern projects presents a Better utilization of local aggregate resources; and

- Offers engineering and environmental benefits by development of specialist high strength concrete of great potential to:
  1) Reduce structural member sizes,
  2) Use less concrete,
  3) Increase usable floor areas, and
  4) Improve structural performance.
Previous Study on ASR


- Findings and recommendation:
  1. Volcanic tuff aggregates from Anderson Road Quarry can be used in concrete provided a minimum of 25% PFA is included;
  2. Volcanic tuff aggregates should not be used in concrete that will be exposed to aggressive marine conditions.
GEO’s current study on mitigating ASR in concrete using supplementary cementitious materials

- **Our objective:**
  1. An indicative concrete design mix using SCM (GGBS, PFA, and CFS) to mitigate ASR in concrete with local volcanic aggregates; and
  2. A correlation between laboratory results and field measurements in the long term.

Supported by SCCT, HKCI, CPA, HKU, PolyU, Nanjing University of Technology, and Rilem Technical Committee AAA. (International Union of Laboratories and Experts in Construction Materials, Systems and Structures)
GEO’s current study on mitigating ASR in concrete using supplementary cementitious materials

- **Methodology**

<table>
<thead>
<tr>
<th>Test Method</th>
<th>Test duration/remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Petrographic examination</td>
<td>Rock thin sections</td>
</tr>
<tr>
<td>Rilem AAR 1</td>
<td></td>
</tr>
<tr>
<td>2. Ultra-accelerated Mortar Bar Test</td>
<td>14 days</td>
</tr>
<tr>
<td>CS1:2010 (Rilem AAR 2)</td>
<td>(extended to 3 months)</td>
</tr>
<tr>
<td>3. Concrete Prism Test</td>
<td>52 weeks</td>
</tr>
<tr>
<td>CS1:2010 (Rilem AAR 3)</td>
<td>(to be extended to 2 years)</td>
</tr>
<tr>
<td>4. Accelerated Concrete Prism Test</td>
<td>20 weeks</td>
</tr>
<tr>
<td>(Rilem AAR 4)</td>
<td>(extended to 26 weeks)</td>
</tr>
<tr>
<td>5. Field works</td>
<td>Long term, say 10 years)</td>
</tr>
</tbody>
</table>
GEO’s current study on mitigating ASR in concrete using supplementary cementitious materials

Rilem AAR 1 - Petrographic examination

Thin section of rock + A petrographic microscope

To identify potentially reactive constituents in the rock
GEO’s current study on mitigating ASR in concrete using supplementary cementitious materials

Rilem AAR2(UAMBT), Rilem AAR3(CPT) & AAR4(ACPT):

- Basic concept behind:

  To simulate the long term ASR effects by increasing the alkali level, temperature, and humidity to speed up the alkali-silica reaction (expansion) in the test specimens.
GEO’s current study on mitigating ASR in concrete using supplementary cementitious materials

Materials:

- **Norcem:** Norway (alkaline content: 1.0)
- **OPC:** 青洲英泥 (alkaline content: 0.5)
- **GGBS:** 廣東韶鋼
- **PFA:** CLP
- **CSF:** Elkem
- **Volcanic Aggregates:**
  - (i) Anderson Road Quarry and
  - (ii) Lam Tei Quarry
  - (from XRL Tse Uk Tsuen to Shek Yam tunnel section)

Mix design by K. Wah and 144 concrete prism specimens produced in Alliance’s laboratory in Hung Hom and subsequently tested in the laboratory of Fugro Technical Service Ltd.
GEO’s current study on mitigating ASR in concrete using supplementary cementitious materials

**Test Programme**

<table>
<thead>
<tr>
<th>Mix No.: PFA or GGBS replacement level</th>
<th>Norcem +PFA%</th>
<th>Norcem +GGBS%</th>
</tr>
</thead>
<tbody>
<tr>
<td>M1: 0%</td>
<td></td>
<td>Norcem only as control</td>
</tr>
<tr>
<td>M2: 35%</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>M3: 30%+5%csf</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>M4: 50%</td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>M5: 70%</td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>M6: 50%+5%csf</td>
<td></td>
<td>X</td>
</tr>
</tbody>
</table>
GEO’s current study on mitigating ASR in concrete using supplementary cementitious materials

**Study Programme**

- Commencement: August 2014
- Petrographic examinations on rock samples: March 2015
- Accelerated concrete prism tests (AAR4): June 2015
- Concrete prism tests (CS1:2010, AAR3): December 2015
Rilem AAR2, AAR3 and AAR4 Tests

- **AAR2: Ultra-accelerated Mortar Bar Test**
  To measure the expansion of the mortar bar after 14 days of immersion in 80°C NaOH solution.

- **AAR3: Concrete Prism Tests**
  To measure the expansion of the concrete prism after 52 weeks under 38°C.

- **AAR4: Accelerated Concrete Prism Tests**
  To measure the expansion of the concrete prism after 20 weeks under 60°C, RH 90% or above.

- **Long term on site exposure.**
Accelerated mortar bar tests (CS1:2010, AAR2)

Making mortar bar

1 M NaOH solution

Length measurement

Oven, 80°C
Concrete Prism tests (CS1:2010, AAR 3)

Making concrete prism → Container for concrete prism

Humidity chamber, 38 ± 2°C
Test results – Rilem AAR 1 - Petrographic examination

- Volcanic Rock/Aggregate samples:
  1) Rock samples from Anderson Road Quarry: Alkali-reactive; and
  2) Aggregate samples from Lam Tei Quarry (from XRL Tse Uk Tsuen to Shek Yam tunnel section): Potentially alkali-reactive.
Interpretation of Results

- **Ultra-accelerated Mortar Bar Test (AAR-2)**

<table>
<thead>
<tr>
<th>Expansion after 14 Days of Immersion in 1M NaOH solution (%)</th>
<th>Potential Reactivity</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; 0.10</td>
<td>Non-reactive</td>
</tr>
<tr>
<td>0.10 to 0.20</td>
<td>Potentially reactive</td>
</tr>
<tr>
<td>&gt; 0.20</td>
<td>Reactive</td>
</tr>
</tbody>
</table>

- **Concrete Prism Test (AAR-3 and AAR-4)**

<table>
<thead>
<tr>
<th>Pass (No risk of deleterious ASR)*</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>AAR-3 : Expansion after 52 Weeks (%)</td>
<td>&lt; 0.05</td>
</tr>
<tr>
<td></td>
<td>(&lt;=0.04%)*</td>
</tr>
<tr>
<td>AAR-4 : Expansion after 20 Weeks (%)</td>
<td>&lt; 0.03</td>
</tr>
</tbody>
</table>

*Civieltechnisch Centrum Uitvoering Research en Regelgeving (CUR) recommendation 89, the Netherlands*
Test results – AAR2: AMBT

Results of AMBT (Norcem+SCM)
(Fine aggregates, Anderson Road Quarry)

- MF0, 100% OPC
- MF1, 35%pfa
- MF2, 35%pfa+5%csf
- MF3, 50% ggbs
- MF4, 50% ggbs+5%csf
- MF5, 70% ggbs

Expansion, %

Time, Day
Test results – AAR2: AMBT

Results of AMBT (Norcem+SCM)
(Coarse aggregates, Anderson Road Quarry)

- MC0, 100%OPC
- MC1, 35%pfa
- MC2, 35%pfa+5%csf
- MC3, 50%ggbs
- MC4, 50%ggbs+5%csf
- MC5, 70%ggbs

Expansion, %

Time, Day
Test results (46 weeks) – AAR3: CPT (38°C)

Interim Test Results of CPT - AAR3
(Lam Tei Quarry)

Expansion, %

Time, week

- ML0, 100% Norcem
- ML1, 35%pfa
- ML2, 35%pfa+5%csf
- ML3, 50%ggbs
- ML4, 50%ggbs+5%csf
- ML5, 70%ggbs
Test results (46 weeks) – AAR3: CPT (38°C)

Interim Test Results of CPT - AAR3
(Anderson Road Quarry)

- MA0, 100% Norcem
- MA1, 35%pfa
- MA2, 35%pfa+5%csf
- MA3, 50%ggbs
- MA4, 50%ggbs+5%csf
- MA5, 70%ggbs

Expansion, %

Time, week
Test results –
AAR4: Accelerated CPT (60°C)
Closing Remarks

1. Use of local volcanic aggregates in concrete: Possible
2. Important engineering and environmental benefits
3. Indicative concrete mix design by using GGBS, PFA, and silica fume to mitigate ASR in volcanic aggregate concrete

In the long term,

- Find a correlation between laboratory test results and field measurements; and
- Draft guidelines/specification on the use of local volcanic aggregates for concrete production in Hong Kong.
Acknowledgements

- Hong Kong Concrete Institute
- Hong Kong Concrete Producers Association
- Prof. Albert Kwan, HKU
- Prof. Y L Wong, PolyU
- Prof. Deng Min (鄧敏教授), Nanjing University of Technology
- Prof. Duyou Lu (盧都友教授), Nanjing University of Technology
- RILEM Technical Committee (TC), AAA (2014 – 2019) : Avoiding Alkali Aggregate Reactions in Concrete - Performance Based Concept.
End of Presentation

Thank You!
### Lam Tei Quarry

<table>
<thead>
<tr>
<th>Mix</th>
<th>Compressive Strength 7-Day (MPa)</th>
<th>Compressive Strength 28-Day (MPa)</th>
<th>E-modulus (MPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>ML0, 100%Norcem</td>
<td>69.25</td>
<td>78.20</td>
<td>-</td>
</tr>
<tr>
<td>ML1, 35%pfa</td>
<td>53.65</td>
<td>76.35</td>
<td>37750</td>
</tr>
<tr>
<td>ML2, 35%pfa+5%csf</td>
<td>58.55</td>
<td>77.80</td>
<td>35000</td>
</tr>
<tr>
<td>ML3, 50%ggb</td>
<td>81.50</td>
<td>86.70</td>
<td>32250</td>
</tr>
<tr>
<td>ML4, 50%ggb+5%csf</td>
<td>80.00</td>
<td>91.45</td>
<td>35500</td>
</tr>
<tr>
<td>ML5, 70%ggb</td>
<td>69.90</td>
<td>81.35</td>
<td>34000</td>
</tr>
</tbody>
</table>

### Anderson Road Quarry

<table>
<thead>
<tr>
<th>Mix</th>
<th>Compressive Strength 7-Day (MPa)</th>
<th>Compressive Strength 28-Day (MPa)</th>
<th>E-modulus (MPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>MA0, 100%Norcem</td>
<td>67.15</td>
<td>80.30</td>
<td>-</td>
</tr>
<tr>
<td>MA1, 35%pfa</td>
<td>58.20</td>
<td>81.70</td>
<td>47000</td>
</tr>
<tr>
<td>MA2, 35%pfa+5%csf</td>
<td>62.15</td>
<td>83.05</td>
<td>30500</td>
</tr>
<tr>
<td>MA3, 50%ggb</td>
<td>82.75</td>
<td>93.55</td>
<td>38750</td>
</tr>
<tr>
<td>MA4, 50%ggb+5%csf</td>
<td>80.45</td>
<td>95.50</td>
<td>34250</td>
</tr>
<tr>
<td>MA5, 70%ggb</td>
<td>67.05</td>
<td>88.55</td>
<td>35750</td>
</tr>
</tbody>
</table>