Alkali Aggregate Reactions (AAR)

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55º Congresso Brasileiro do Concreto

Gratitude to RS
Børge Johannes Wigum
Concrete durability

Pantheon, Rome
27 BC - 124 AD

Height 43 meters
Alkali Aggregate Reactions

AAR

- ASR – Alkali Silica Reaction
- ACR – Alkali Carbonate Reaction
Headlines of today:

- **WHAT** is AAR?
  - Mechanisms
  - Cases

- **HOW** to diagnose AAR in existing structures!

- **How** to prevent AAR in future structures!
  - Mitigating AAR
  - Test methods
  - Regulations

- **The path forward – the future!**
What is AAR?
Alkali Aggregate Reactions (AAR)

- Alkalies producing a silica-gel by dissolving soluble SiO$_2$ (e.g. Quartz) in the aggregate.
  - Gel has hygroscopic properties, leading to expansion under moist conditions.

- 5-50 years, depending on the type of aggregate and environmental conditions
Consequences

- Expansion and (map) cracking
- Constraining forces
  - Reduced capacity
- Influence on material properties
  - Reduced capacity
- Initialize other deterioration mechanisms
  - Frost damage
  - Rebar corrosion
Mechanisms of AAR

Reactive aggregates

Necessary parameters

Alkalies
(usually supplied by the cement, although external sources can exist).

Water
(or high moisture content)
Original situation of the surface of a SiO₂ structure

Acide-base reaction; Hydroxide from solution reacts with acidic silanol groups

H₂O is released

O⁻ is balanced with the Na⁺ ions that simultaneously diffuse into the structure

The siloxane bridges, that hold the whole mass together break and increase the capacity to absorb Na⁺ and H₂O

Na-Si-gel + H₂ are produced

The SiO₂ structure is disintegrated

Chemistry of AAR
The attack of alkali on:

- (A) - well crystallized silica
- (B) - poorly crystallized hydrous silica

Crystall structure affecting the reactivity
AAR Cases
Elgeseter Bridge Trondheim, Norway

- Built 1949-51
- Length 220 m
- Width 23 m
- Height 17 m
• Most cracked - west side
• Cracks 0,25 mm/year
• In-situ measurement of RH
Installation of new columns

200 mm
Confinement with Carbon Fibre Reinforcement Polymers (CFRP)
Dam Northern Norway
Dam Norway
Switzerland
How to diagnose AAR in existing structures?
Sampling concrete cores
Fluorescence impregnated **plane section**
- Damaging Rate Index (DRI)
Thin-section examination
AAR in thin-section

Aggregate particle unstable in alkali environment in the concrete

Silica in aggregate particle dissolve and produce alkali gel

Alkaligel is very hygroscopic - expands – make cracks in particles and concrete

Cement paste

plane polarized light (PPL)
Cross-polarized light (XPL)
How to prevent AAR in future concrete structures?
Mitigating AAR

- Limit the total alkali content of the concrete mix;
- Use a non-reactive aggregate combination;
- Limit the degree of saturation of the concrete with water

Other measures:
- **Fly ash** - replacing up to 30% of the Portland cement (by mass)
- **Natural pozzolanic materials** with low lime content (<2% CaO)
- **Silica fume** 4-6% (Iceland)
- Ground granulated blast furnace slag (GGBFS) (50% by mass)
- **Lithium** - amount can be high and varies depending on the aggregate
Test methods
Test methods by RILEM

- Three successive Technical Committees (TC)
- Initially focused on accelerated tests for aggregate reactivity
- Extended to:
  - Specification
  - Diagnosis and assessment
  - Appraisal and repair
  - Modelling of structures
  - Performance testing
  - Releasable alkalis in aggregates
  - Petrographic atlas
Test Methods

1. Petrographic examination (RILEM AAR-1) [ASTM 295]
2. Accelerated mortar bar test (RILEM AAR-2) [ASTM 1260]
3. Concrete prism tests (RILEM AAR-3 & 4) [ASTM 1293]

- Performance testing
- Field exposure sites
The petrographic method (RILEM AAR-1)

1-2 mm
1000 points counted

2-4 mm
1000 points counted

2-4 mm

The content of potentially alkali reactive rock types

Norway: 20% critical content
Alkali-Aggregate Reactions in Concrete
Properties, Classification and Testing of Norwegian Cataclastic Rocks

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December 1995

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Dissertation submitted in response for the academic degree

DOKTOR INGENIØR

Trondheim, November 2012

Norwegian University of Science and Technology
Faculty of Engineering Science and Technology
Department of Geology and Mineral Resources Engineering

Expansion (%) after 14 days

Total grain boundary area of quartz (m²/cm³)

y = 0.0725Ln(x) - 0.4143

R² = 0.89
Petrographic Atlas with Micrograph examples;

www.farin.no
Accelerated Mortar Bar Test (RILEM AAR-2)

1N NaOH – 80°C – 14 days
bars 25 x 25 x 285mm

Used as a performance test?
Concrete Prism Tests

prisms 75 x 75 x 285mm

RILEM AAR-3
RILEM AAR-4
RILEM AAR-3, AAR-4, (ASTM C 1293 & Norwegian method)

- 38°C or 60°C
- Wrapped (W) or Unwrapped (U) prisms
- Prism cross section: 70 mm or 100 mm
- All methods: prisms stored on grids over water (~100 % RH)
RILEM AAR-3
100%Rh – 38°C – 1 year

RILEM AAR-4
100%Rh – 60°C – 20 weeks
Parameters affecting expansion

- Wrapped or unwrapped
- Temperature (38°C – 60°C – 80°C)
- Prism size
- Preconditions, curing etc.
Expansion primarily controlled by rate and extent of alkali leaching! Larger prism cross-section: less alkali leaching
Performance testing; lab. vs. field
Comparing apples and pears?

The outcome of accelerated laboratory tests may depend on the extent of leaching of alkalis.
Exposure Sites

BRE (UK)

University of Texas in Austin

CANMET in Ottawa
In the European aggregate standard, EN 12620:2002, it is stated;

- “When required the alkali-silica reactivity of aggregates shall be assessed in accordance with the provisions valid in the place of use and the results declared”.

National Recommendations

Norway

How to produce durable concrete with alkalireactive aggregates
Overview of critical limits for test methods for documentation of alkali-reactivity of single aggregates or blends of aggregates

<table>
<thead>
<tr>
<th>Documentation of</th>
<th>Petrographic analysis (1)</th>
<th>Accelerated mortar bar method (2)</th>
<th>Concrete prism method (3)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fine aggregate and blend of fine</td>
<td>20.0 %</td>
<td>0.14 %</td>
<td>0.040 %</td>
</tr>
<tr>
<td>Coarse aggregate and blend of coarse</td>
<td></td>
<td>0.08 %</td>
<td>0.040 %</td>
</tr>
<tr>
<td>Fine coarse aggregate</td>
<td></td>
<td>0.11 %</td>
<td>n/a</td>
</tr>
<tr>
<td>Blend of a fine- and coarse aggregate,</td>
<td>20.0 %</td>
<td>0.11 %</td>
<td>0.050 %</td>
</tr>
<tr>
<td>where the fine or coarse is alkali-reactive</td>
<td></td>
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</tbody>
</table>
Performance testing – Norwegian Concrete Test

- Binders tested with a specified highly reactive Norwegian aggregate combination (worst case); increasing alkali content.

![Graph showing determination of acceptance limit for alkali content](image)

- Limit for accepted expansion
- Limit for accepted alkali content
- Safety factor
- Point of intersection
### Requirements for maximum allowed alkali content for production of non-reactive concrete when using alkali reactive aggregate *(worst case)*

<table>
<thead>
<tr>
<th>Binder</th>
<th>Limit, alkali-content</th>
</tr>
</thead>
<tbody>
<tr>
<td>Norcem Standard FA Cement [CEM II/A-V, NS-EN 197-1, flyash &gt; 17 %]</td>
<td>$\text{Na}_2\text{O} \text{ eq.} \leq 7.0 \text{ kg/m}^3$</td>
</tr>
<tr>
<td>Portland cement + silica fume [CEM I, NS-EN 197-1 in combination with minimum 10 % silica fume (of cement weight)]</td>
<td>$\text{Na}_2\text{O} \text{ eq} \leq 5.5 \text{ kg/m}^3$</td>
</tr>
</tbody>
</table>
The path forward –
The future
RILEM deliverables

- AAR-1 Petrographic method
  - Petrographic Atlas (AAR-1.2)
- AAR-2 Accelerated mortar bar test
- AAR-3 Concrete prism test (38°C)
  - Performance test (AAR-3.3)
- AAR-4.1 Accelerated concrete prism test (60°C)
  - Performance test (AAR-4.2)
- AAR-5 Screening test for carbonates
- AAR-6.1 Diagnosis & Prognosis
- AAR-6.2 Appraisal & Repair
- AAR-7.1 ASR specification
- AAR-8 Releasable alkalis
- AAR-9 Modelling of structures
RILEM New TC (?)

- 2014 - ?
- Implementation of results & methods
  - Performance testing
  - Releasable alkalies
- Specification for very long term reactions in massive structures like dams follows liaison with ICOLD
- Web-based communication
- Chaired by BJW
International Centre of Research and Applied Technology for Alkali Aggregate Reactions

“Reducing the risks and minimising the consequences of expansive Alkali Aggregate Reactions in concrete”

www.mannvit.com/TestingResearchLab/
International Conference on Alkali Aggregate Reactions (ICAAR)

Chairman: Haroldo Bernardes

www.ibracon.org.br/icaar2016