Guidelines for Identifying and Controlling Alkali Aggregate Reactions

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Background

• Alkali-Aggregate Reactivity (AAR) is a common durability issue for concrete transportation structures
• Alkali-Silica Reaction (ASR) most common – manifests in 5-15 years
  • A chemical reaction between alkalis in the pore solution and reactive silica in the aggregate resulting in the formation of an expansive gel and the degradation of the aggregate particle
  • Map cracking over entire slab area and accompanying expansion-related distresses (joint closure, spalling, blowups).
  • Mitigation - Use of non-susceptible aggregates, addition of pozzolans to mixture, limiting total alkalis in concrete, minimizing exposure to moisture, addition of lithium compounds

ASR Distress

Background

• Alkali-Aggregate Reactivity (AAR) is a common durability issue for concrete transportation structures
• Alkali-Carbonate Reaction (ACR) not very common – manifests in 5-10 years; usually faster than ASR
  • Expansive reaction between alkalis in pore solution and certain dolomitic limestone aggregates causing dedolomitization and brucite formation
  • Map cracking over entire slab area and accompanying pressure-related distresses (spalling, blowups), less or no sign of gel.
  • Cannot be mitigated - avoid use of susceptible aggregates
Stanton’s Bridge (ca. 1930)

Fort Constitution, Battery Farnsworth, Portsmouth Harbor
New Castle, New Hampshire

- Fort was built in 1897 using natural cement from Rosendale, New York, excavated coarse aggregate from the outcropping it is built into and local beach sand
- Total 7000 yd$^3$ of concrete placed
- “Embarrassment” to the CoE due to poor workmanship and “leaking”
- Abandoned in 1917

Fort was built in 1897 using natural cement from Rosendale, New York, excavated coarse aggregate from the outcropping it is built into and local beach sand.

- Total 7000 yd$^3$ of concrete placed
- “Embarrassment” to the CoE due to poor workmanship and “leaking”
- Abandoned in 1917
Stanton 1940

- Stanton found the expansion of mortar bars was influenced by:
  - The alkali content of the cement
  - The type and amount of the reactive silica in the aggregate
  - The availability of moisture
  - Temperature
- Other findings
  - Expansion was negligible when the alkali content of the cement was below 0.60% Na$_2$O$_e$
  - Expansion could be reduced by using pozzolans

ASR Fundamentals

- Required ingredients – All are required
  - Source of alkalis
  - Reactive aggregate
  - Water
- Can be mitigated in most cases with SCMs (pozzolans or slag cement) or limiting the alkali loading
- Much research has been done to understand ASR

Guide Documents

- State-of-the-Art knowledge summarized in two available guide documents
- Some differences between the two documents but both based on the same research
- Summarized in recent MAP Brief

How to Use the Guides?

General Principles

- Alkali Loading *not* Alkali Content
- Stanton’s research (1940’s research) leads to the concept of “low alkali cement” which is NOT the important factor
- What matters is the total alkali in the concrete or alkali loading (2008 research)
- Depends on
  - Alkali content of cement
  - Amount of cement
  - Alkali content of other constituents

General Principles

- Two approaches provided in the Guide documents to establish ASR mitigation measures
  - Performance Requirements
    - Based on experience
    - Based on testing
  - Prescriptive Requirements

General Principles

- Alkali Loading *not* Alkali Content
  - wt. % Na₂Oeq = (wt. % Na₂O) + (0.658 x wt. % K₂O)
  - Alkali Loading of Cement lb/ycd³ [kg/m³] = Na₂Oeq x cement content lb/ycd³ [kg/m³]
  - Limit fly ash to 4.0 wt. % Na₂Oeq [4.5 wt. % Na₂Oeq in AASHTO R 80]

<table>
<thead>
<tr>
<th>Cement Alkali Content Na₂O eq %</th>
<th>Cement Content lb/ycd³ (kg/m³)</th>
<th>Concrete Alkali Loading lb/ycd³ (kg/m³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.50</td>
<td>500 (292)</td>
<td>2.5 [1.5]</td>
</tr>
<tr>
<td>0.50</td>
<td>700 (416)</td>
<td>3.5 [2.1]</td>
</tr>
<tr>
<td>0.70</td>
<td>500 (292)</td>
<td>3.5 [2.1]</td>
</tr>
<tr>
<td>0.70</td>
<td>700 (416)</td>
<td>4.9 [2.9]</td>
</tr>
</tbody>
</table>
Performance Approach

Performance Requirements

- Determine aggregate reactivity
- Field History
- ASTM C1260 (AASHTO T 303)
  - 14-day mortar bar expansion
- ASTM C1293
  - 1-year concrete prism expansion
Performance Requirements

• Determine aggregate reactivity
• Field History
• ASTM C1260 (AASHTO T 303)
  • 14-day mortar bar expansion
• ASTM C1293
  • 1-year concrete prism expansion
**Performance Requirements**

- Establish the correlation between ASTM C1260 (AASHTO T 303) and ASTM C1293 for any aggregate source before relying on ASTM C1260 (AASHTO T 303) alone or using ASTM C1567

**Performance Requirements**

- Select Preventative Measures
  - Replace cement with SCMs in varying amounts
  - ASTM C1567
    - 14-day mortar bar expansion \([\leq 0.10\% @ 14 \text{ days}]\)
    - Requires correlation between ASTM C1260 [AASHTO T 303] and ASTM C1293
  - ASTM C1293
    - 2-year concrete prism expansion \([\leq 0.04\% @ 2 \text{ years}]\)

**Prescriptive Approach**

- Determine aggregate reactivity (R0 – R3)
- Determine the Level of ASR Risk (Level 1 – 6)
- Determine Structure Class (SC1 – SC4)
- Determine Level of Prevention (V – ZZ)

**Prescriptive Requirements**

<table>
<thead>
<tr>
<th>Aggregate Reactivity Class</th>
<th>Aggregate Reactivity in Test Method</th>
<th>3-Year Expansion in Test Method</th>
<th>14-Day Expansion in Test Method</th>
</tr>
</thead>
<tbody>
<tr>
<td>R0</td>
<td>Non-reactive</td>
<td>(-0.04)</td>
<td>(-0.10)</td>
</tr>
<tr>
<td>R1</td>
<td>Moderately reactive</td>
<td>(\leq -0.04, +0.12)</td>
<td>(\leq 0.10, +0.10)</td>
</tr>
<tr>
<td>R2</td>
<td>Highly reactive</td>
<td>(\geq 0.12, +0.24)</td>
<td>(\geq 0.30, +0.45)</td>
</tr>
<tr>
<td>R3</td>
<td>Very highly reactive</td>
<td>(\geq 0.24)</td>
<td>(\geq 0.45)</td>
</tr>
</tbody>
</table>
Prescriptive Requirements

• Determine aggregate reactivity (R0 – R3)
• Determine the Level of ASR Risk (Level 1 – 6)
• Determine Structure Class (SC1 – SC4)
• Determine Level of Prevention (V – ZZ)
Prescriptive Requirements

- Select Preventative Measures
  - Based on Alkali Loading
  - Based on use of SCMs

### TABLE 5: Maximum Alkali Loadings to Provide Various Levels of Prevention

<table>
<thead>
<tr>
<th>Prevention Level</th>
<th>Maximum Alkali Loading of Concrete</th>
<th>kg/m³</th>
<th>lb/1000 lb</th>
</tr>
</thead>
<tbody>
<tr>
<td>W</td>
<td>3.0</td>
<td>No Limit</td>
<td>5.0</td>
</tr>
<tr>
<td>X</td>
<td>2.4</td>
<td>4.0</td>
<td></td>
</tr>
<tr>
<td>Z</td>
<td>1.8</td>
<td>3.0</td>
<td></td>
</tr>
</tbody>
</table>

* SCMs may be used in Prevention Levels Z and ZZ.

Prescriptive Requirements

- Select Preventative Measures
  - Based on Alkali Loading
  - Based on use of SCMs

### TABLE 6: Minimum Levels of SCM to Provide Appropriate Level of Prevention

<table>
<thead>
<tr>
<th>SCM Type</th>
<th>Alkali Content of SCM</th>
<th>Level W</th>
<th>Level X</th>
<th>Level Y</th>
<th>Level Z</th>
<th>Level ZZ</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fly ash</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>Slag cement</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>Silica fume</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
<td>0.0</td>
</tr>
</tbody>
</table>

* The SCM may be added directly to the concrete mix or may be a component of a blended cement. Fly ash should meet the requirements of Specification C618. Slag cement should meet the requirements of C595/595M. and silica fume should meet the requirements of Specification C610. Blended cements should meet the requirements of C595/595M or C150/C150M. The effectiveness of these high-calcium fly ashes should be evaluated using the performance-based testing outlined in AASHTO TP 89 and TP 93.

Summary

- Key Point: Alkali loading vs. alkali content
- Two approaches to prevention
  - Performance
  - Prescriptive
- All cases – need to know the aggregate reactivity
- Use tests as they were designed – modifications skew results
- Preventative measures include avoiding the aggregate but when not practicable, limit the alkali loading, use SCMs, or both
- Cannot test for the effect of limiting alkali loading
Questions at the End of the Webinar

or

Feel free to contact me

llsutter@mtu.edu
PennDOT: Implementing AASHTO R 80

History:
In 1990, cores were taken from I-84.
- The pavement was 12 years old and exhibited cracking and centerline deterioration.
- Earliest discovery of ASR on a Department owned pavement.
In 1991 Department tested several aggregates
Results showed a potential for highly reactive aggregates
A testing program was discussed with the aggregate industry
Started testing all aggregates in 1992
Tested aggregate using AASHTO T 303
Results: 464 aggregates – 75% had expansion test results over 0.10% linear expansion

Background of situation that prompted the recent change:
Significant ASR deterioration identified in pavement structures
- Districts 4, 6 and 8 (to date)
- Mix designs contained aggregates which were not identified as ‘reactive’, concrete placed after 1992.
- One Example (AASHTO T-303 expansion values)
  - FA Type A: 0.08%
  - CA #57: 0.01%
- Other Districts have reported preventive maintenance; overlays on concrete pavements less than 10 years old where distress likely was attributable to ASR however no forensic investigation was performed prior to repair and reconstruction.

What we did:
Who’s been involved in the process – Pro-team
Short Term solution – Standard Special Provision
Long Term solution
- AASHTO R 80
  - Review of the prescriptive approach
  - Basis for future specification developments
Pro-team

Pro-team developed
- September 5th, 2013 ‘kick off meeting’

Industry (PACA – ACPA – CABA/PPA)
- PennDOT Central Office, BOMO and District staff
- FHWA
  - Lead ASR researchers made available
    - Dr. Michael Thomas – Univ. of New Brunswick
    - Dr. Rogers – University Laval, Quebec – ASTM C-1293 evaluation assistance for 3rd party testing using Spratt aggregate

Stop Gap Measure - What was considered?

Risk of continuing with our current aggregate testing and ASR remediation is considered too high
- Need to protect future assets!

Most of our aggregates are already considered reactive and when used, remediation required.

Inability to identify aggregates solely via petrographic examination as 'reactive' or 'non-reactive'

Impacts to industry (SCM availability)

Decision – Mitigate all mixtures

Consider all aggregates as reactive until the latest research and remediation strategies can be implemented
- Stop Gap Measure
- Will require more SCM’s for use by industry
- Survey conducted of flyash and GGBFS producers
  - Industry indicated they have sufficient SCM’s available for this interim measure.

This was short term while all aggregate sources were tested.

Aggregate Evaluation

Letter drafted for Type A aggregate sources
- Will allow for their choice of four independent labs
  - National Ready Mix Concrete Association
  - Concrete Testing Laboratory
  - American Engineering Technology
  - Bowser Morner

Coordination with independent labs to make sure everyone was testing the same.
- Provided guidance on sample sizes, coordination with District and sample custody
- Sources advised that failure to perform testing would result in loss of use in cement concrete when further specification revisions made
Aggregate Evaluation (continued)

Conduct concrete prism testing (ASTM C1293) on aggregates.
- Industry and PennDOT to perform testing initially on aggregate sources with T-303 expansions less than or equal to 0.15% as first phase of implementation.
- The rest of the sources were tested the following year.

The Department purchased a warm room to begin evaluation of aggregates. We took random samples of aggregates sent to the private labs to conduct in-house evaluations also.

The testing went well with the independent labs.

AASHTO R 80:

Protocol for Alkali Aggregate Reactivity
- ASR and ACR
- Selecting preventive measures for ASR reactive aggregates
  - Two approaches for ASR prevention:
    - Prescriptive approach – Involves a number of factors and decision-based methods. This was used for our specification.
    - Performance approach – Based on laboratory testing of the aggregates, SCM’s or lithium nitrates used to determine the amount required to control deleterious expansion.

- Involves a 2-year duration concrete prism test
- Several sources have opted to do this after getting their initial test results (ASTM C1293)
-looking at field performance as possible approach to how an aggregate performs

PennDOT Specification:

All fine and coarse aggregates for use in concrete were tested according to ASTM C 1293

New sources that want to be used in concrete will be tested according to AASHTO T 303 and ASTM C 1293.
- The Department has purchased an additional warm room. We have the capacity to test 100 samples.
- The AASHTO T 303 test result will be used for mitigation requirements until the ASTM C 1293 is finished.
  - Any new source with an expansion that indicates the aggregate is non-reactive (NR) will initially be listed with an expansion of 0.11% (R1) requiring ASR mitigation until ASTM C 1293 is completed.

A source may opt to do mixture qualification to determine the amount of pozzolan, metakaolin or lithium needed to mitigate.
- This is a two year test (ASTM C 1293).
- If the expansion of the concrete prism is less than 0.04% after two years, the preventive measure will be deemed effective with the reactive aggregate(s)

PennDOT Specification:

Prescriptive Approach: The Pro-Team made some minor changes to the tables in R 80

1. Classification of Aggregate Reactivity:

<table>
<thead>
<tr>
<th>Aggregate Reactivity</th>
<th>Description of Aggregate Reactivity</th>
<th>1-Year Expansion ASTM C-1293</th>
<th>14-day Expansion AASHTO T-303</th>
</tr>
</thead>
<tbody>
<tr>
<td>R0</td>
<td>Non-reactive</td>
<td>≤ 0.04</td>
<td>≤ 0.10</td>
</tr>
<tr>
<td>R1</td>
<td>Moderately reactive</td>
<td>&gt;0.04, ≤ 0.12</td>
<td>&gt;0.10, ≤ 0.30</td>
</tr>
<tr>
<td>R2</td>
<td>Highly reactive</td>
<td>&gt;0.12, ≤0.24</td>
<td>&gt;0.30, ≤0.45</td>
</tr>
<tr>
<td>R3</td>
<td>Very Highly reactive</td>
<td>&gt;0.24</td>
<td>&gt;0.45</td>
</tr>
</tbody>
</table>
PennDOT Specification:

2. Level of ASR Risk:PennDOT Specification

<table>
<thead>
<tr>
<th>Risk Level</th>
<th>R0</th>
<th>R1</th>
<th>R2</th>
<th>R3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Level of ASR Risk</td>
<td>R80</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Level of ASR Risk: R 80

<table>
<thead>
<tr>
<th>Non-reactive concrete in a dry environment</th>
<th>Level 1</th>
<th>Level 2</th>
<th>Level 3</th>
<th>Level 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reactive concrete in a wet environment</td>
<td>Level 1</td>
<td>Level 2</td>
<td>Level 3</td>
<td>Level 4</td>
</tr>
<tr>
<td>All concrete exposed to humid, moist, or inverted</td>
<td>Level 1</td>
<td>Level 2</td>
<td>Level 3</td>
<td>Level 4</td>
</tr>
<tr>
<td>All concrete exposed to alkaline in service</td>
<td>Level 1</td>
<td>Level 2</td>
<td>Level 3</td>
<td>Level 4</td>
</tr>
</tbody>
</table>

PennDOT Specification:

3. Determining the Level of Prevention: PennDOT Specification

<table>
<thead>
<tr>
<th>Classification of Structure</th>
<th>Level of ASR Risk (Table 1)</th>
<th>S1</th>
<th>S2</th>
<th>S3</th>
<th>S4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Risk Level 1</td>
<td>V</td>
<td>V</td>
<td>V</td>
<td>V</td>
<td>V</td>
</tr>
<tr>
<td>Risk Level 2</td>
<td>V</td>
<td>V</td>
<td>W</td>
<td>X</td>
<td>Y</td>
</tr>
<tr>
<td>Risk Level 3</td>
<td>W</td>
<td>X</td>
<td>Y</td>
<td>Y</td>
<td>Z</td>
</tr>
<tr>
<td>Risk Level 4</td>
<td>X</td>
<td>Y</td>
<td>Z</td>
<td>Z</td>
<td>Z</td>
</tr>
</tbody>
</table>

PennDOT Specification:

4. Structure Classification: R 80

<table>
<thead>
<tr>
<th>Structure Class</th>
<th>Consequences Acceptability of ASR</th>
<th>Sections</th>
</tr>
</thead>
</table>
| S1             | Safety and future maintenance consequences, small or negligible | slippery, small to moderate
| S2             | Some minor safety, future maintenance consequences if major deterioration were to occur | moderate risk of ASR acceptable
| S3             | Significant safety and future maintenance or replacement consequences if major deterioration were to occur | minimal risk of ASR acceptable
| S4             | Moderate risk of ASR acceptable | all other structures

PennDOT Specification:

4. Structure classification:

<table>
<thead>
<tr>
<th>Structure Class</th>
<th>Consequences Acceptability of ASR</th>
<th>Sections</th>
</tr>
</thead>
</table>
| S1             | Safety and future maintenance consequences, small or negligible | slippery, small to moderate
| S2             | Some minor safety, future maintenance consequences if major deterioration were to occur | moderate risk of ASR acceptable
| S3             | Significant safety and future maintenance or replacement consequences if major deterioration were to occur | minimal risk of ASR acceptable
| S4             | Moderate risk of ASR acceptable | all other structures

PennDOT Specification:
**PennDOT Specification:**

5. Minimum Levels of Supplementary Cementitious Materials: PennDOT Specification

Table G:

<table>
<thead>
<tr>
<th>Type of SCM</th>
<th>Alkali Level of SCM ((\text{CaO}/\text{Na}_2\text{O} \times 100))</th>
<th>Level V (%)</th>
<th>Level W (%)</th>
<th>Level X (%)</th>
<th>Level Y (%)</th>
<th>Level Z (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Class F or C flyash</td>
<td>≤ 3.0</td>
<td>-</td>
<td>15</td>
<td>20</td>
<td>25</td>
<td>35</td>
</tr>
<tr>
<td>Class F or C flyash</td>
<td>&gt;3.0, ≤ 4.5</td>
<td>-</td>
<td>20</td>
<td>25</td>
<td>30</td>
<td>40</td>
</tr>
<tr>
<td>GGBFS</td>
<td>≤ 1.0</td>
<td>-</td>
<td>25</td>
<td>30</td>
<td>35</td>
<td>40</td>
</tr>
<tr>
<td>Silica Fume</td>
<td>≤ 1.0</td>
<td>-</td>
<td>2.25</td>
<td>3.0 x LBA</td>
<td>3.5 x LBA</td>
<td>4.0 x LBA</td>
</tr>
</tbody>
</table>

---

**Example #1 — using draft specification**

Step #1:

Using a coarse aggregate with a reactivity of 0.18% and a fine aggregate with a reactivity of 0.03%

- According to Table C:
  - The coarse aggregate is a R2 reactivity class.
  - The fine aggregate is non-reactive or R0.
  - For mix designs use the highest reactivity level of any aggregates used.

---

**Example #1 continued**

Step #2:

The next step is to figure out the level of ASR risk

- According to Table D: Aggregate Reactivity Class

  - This aggregate would be at a Risk Level 3
Example #1 continued

Step #3:
Determine Level of prevention. The structure classification needs to be known in order to determine the level of prevention.

- See Table F:
  If this mix design was for concrete paving under section 506, then the structure class would be S2.
  If this mix design was for LLCP - long life concrete pavement under section 530, then the structure class would be S3.

<table>
<thead>
<tr>
<th>Structure Class</th>
<th>Consequences</th>
<th>Acceptability of ASR</th>
<th>Structure/Asset type</th>
<th>Publication</th>
</tr>
</thead>
<tbody>
<tr>
<td>S1</td>
<td>Safety and future maintenance consequences small or negligible</td>
<td>Some deterioration from ASR may be tolerated</td>
<td>Temporary structures. Inside buildings. Structures or assets that will never be exposed to water.</td>
<td></td>
</tr>
<tr>
<td>S2</td>
<td>Some minor safety, future maintenance consequences if major deterioration were to occur</td>
<td>Moderate risk of ASR acceptable</td>
<td>Sidewalks, curbs and gutters, inlet tops, concrete barrier and parapet. Typically structures with service lives of less than 40 years.</td>
<td></td>
</tr>
<tr>
<td>S3</td>
<td>Significant safety and future maintenance or replacement consequences if major deterioration were to occur</td>
<td>Minimal risk of ASR acceptable</td>
<td>All other structures. Service lives of 40 to 75 years anticipated.</td>
<td></td>
</tr>
</tbody>
</table>

Example #1 continued

Step #4: Let's say the design is for concrete pavement (RPS – section 506)
- The Structure Classification would be S2
- From Table E – Determining the level of prevention

<table>
<thead>
<tr>
<th>Classification of Structure</th>
<th>Level of ASR Risk</th>
<th>Level</th>
<th>Level</th>
<th>Level</th>
<th>Level</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>V</td>
<td>W</td>
<td>X</td>
<td>Y</td>
</tr>
</tbody>
</table>

Example #1 continued

Step #5:
- Let's say we are going to pozzolan to mitigate for ASR.
- See Table G for the minimum replacement levels

<table>
<thead>
<tr>
<th>Type of SCM</th>
<th>Alkali Level of SCM (% Na₂Oe)</th>
<th>Level</th>
<th>Level</th>
<th>Level</th>
<th>Level</th>
<th>Level</th>
</tr>
</thead>
<tbody>
<tr>
<td>Class F or C flyash</td>
<td>≤ 3.0</td>
<td>15</td>
<td>20</td>
<td>25</td>
<td>35</td>
<td></td>
</tr>
<tr>
<td>Class F or C flyash</td>
<td>&gt;3.0, ≤ 4.5</td>
<td>20</td>
<td>25</td>
<td>30</td>
<td>40</td>
<td></td>
</tr>
<tr>
<td>GGBFS</td>
<td>≤ 1.0</td>
<td>25</td>
<td>35</td>
<td>50</td>
<td>65</td>
<td></td>
</tr>
<tr>
<td>Silica Fume</td>
<td>≤ 1.0</td>
<td>1.2 LBA</td>
<td>1.5 x LBA</td>
<td>1.8 x LBA</td>
<td>2.4 x LBA</td>
<td></td>
</tr>
</tbody>
</table>

The mix needs a Level X replacement so the pozzolan replacement levels would be:
- 20% for a Class F or C flyash with an alkali level of 3.0% or less
- 25% for a Class F or C flyash with an alkali level greater than 3.0% or less than or equal to 4.5%
- 35% for GGBFS
- 1.5 x LBA for Silica Fume but not less than 7%

Example #2 – using draft specification

Step #1:
Using a coarse aggregate with a reactivity of 0.10% and fine aggregate with a reactivity of 0.06%
- According to Table C:

<table>
<thead>
<tr>
<th>Aggregate Reactivity</th>
<th>Aggregate Reactivity</th>
<th>Aggregate Reactivity</th>
<th>Aggregate Reactivity</th>
</tr>
</thead>
<tbody>
<tr>
<td>R0 Non-reactive</td>
<td>≤ 0.04</td>
<td>≤ 0.10</td>
<td>≤ 0.10</td>
</tr>
<tr>
<td>R1 Moderately reactive</td>
<td>&gt;0.04, ≤ 0.12</td>
<td>&gt;0.10, ≤ 0.30</td>
<td>&gt;0.30, ≤ 0.45</td>
</tr>
<tr>
<td>R2 Highly Reactive</td>
<td>&gt;0.12, ≤0.24</td>
<td>&gt;0.30, ≤0.45</td>
<td>&gt;0.45, ≤0.60</td>
</tr>
<tr>
<td>R3 Very Highly Reactive</td>
<td>&gt;0.24</td>
<td>&gt;0.45</td>
<td>&gt;0.60</td>
</tr>
</tbody>
</table>

- Both aggregates are a R1 reactivity class.
Example #2 continued

Step #2:
The next step is to figure out the level of ASR risk
- According to Table D: Aggregate Reactivity Class

<table>
<thead>
<tr>
<th>Risk Level</th>
<th>R0</th>
<th>R1</th>
<th>R2</th>
<th>R3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Risk Level 2</td>
<td>Y</td>
<td>N</td>
<td>Y</td>
<td>V</td>
</tr>
</tbody>
</table>

- This aggregate would be at a Risk Level 2

Example #2 continued

Step #3:
Determine level of prevention. The structure classification needs to be known in order to determine the level of prevention.
- See Table F:

If this mix design was for concrete paving under section 506, then the structure class would be S2.
If this mix design was for LLCP: long life concrete pavement under section 530, then the structure class would be S3.

Example #2 continued

Step #4: Let's say the design is for long life concrete pavement (section 530)
- The Structure Classification would be S3
- From Table E – Determining the level of prevention

<table>
<thead>
<tr>
<th>Level of Risk</th>
<th>S1</th>
<th>S2</th>
<th>S3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Risk Level 1</td>
<td>V</td>
<td>V</td>
<td>V</td>
</tr>
<tr>
<td>Risk Level 2</td>
<td>V</td>
<td>W</td>
<td>X</td>
</tr>
<tr>
<td>Risk Level 3</td>
<td>W</td>
<td>X</td>
<td>Y</td>
</tr>
<tr>
<td>Risk Level 4</td>
<td>X</td>
<td>Y</td>
<td>Z</td>
</tr>
</tbody>
</table>

- With a Risk Level of 2 and a S3 classification, this mix needs a prevention level X

Example #2 continued

Step #5:
- Let's say we are going to use a pozzolan to mitigate for ASR.
- See Table G for the minimum replacement levels

<table>
<thead>
<tr>
<th>Type of SCM</th>
<th>Alkali Level (Na2Oe)</th>
<th>Level</th>
<th>Level</th>
<th>Level</th>
<th>Level</th>
</tr>
</thead>
<tbody>
<tr>
<td>Class F or C flyash</td>
<td>≤ 3.0</td>
<td>15</td>
<td>20</td>
<td>25</td>
<td>35</td>
</tr>
<tr>
<td>Class F or C flyash</td>
<td>&gt;3.0, ≤ 4.5</td>
<td>15</td>
<td>20</td>
<td>25</td>
<td>35</td>
</tr>
<tr>
<td>GGBFS</td>
<td>≤ 1.0</td>
<td>25</td>
<td>35</td>
<td>50</td>
<td>65</td>
</tr>
<tr>
<td>Silica Fume</td>
<td>≤ 1.0</td>
<td>1.2</td>
<td>1.2</td>
<td>1.5</td>
<td>1.8</td>
</tr>
</tbody>
</table>

- The mix needs a Level X replacement so the pozzolan replacement levels would be:
  - 20% for a Class F or C flyash with an alkali level of 3.0% or less
  - 25% for a Class F or C flyash with an alkali level greater than 3.0% or less than or equal to 4.5%
  - 35% for GGBFS
  - 1.5 x LBA for Silica Fume but not less than 7%
ASTM C 1293

Results as of August 2017:
Currently, 36% of our aggregates are reactive compared to 75% prior to starting the ASTM C 1293 testing

<table>
<thead>
<tr>
<th>Reactivity Level</th>
<th>Number of Aggregates</th>
</tr>
</thead>
<tbody>
<tr>
<td>R0</td>
<td>240</td>
</tr>
<tr>
<td>R1</td>
<td>99</td>
</tr>
<tr>
<td>R2</td>
<td>33</td>
</tr>
<tr>
<td>R3</td>
<td>2</td>
</tr>
</tbody>
</table>

Issues:
- Pilot projects were implemented on sidewalks and sections of pavement.
  - Mitigations levels of X, Y and Z were placed (using flyash and slag cement)
  - No noticeable differences on the pavement
  - Premature wearing of the hand finished sidewalks were noticed
    - Issues noticed on some sidewalks not involved with the pilot projects
      - Investigation determined that it was a lack of proper curing
    - Department is making some changes to address this issue
  - Classify sidewalks as S1 instead of S2 in our specification
  - Program to certify concrete finishers and train construction inspection staff
  - Sidewalk specification is being drafted

Next Steps:
- Developed a five year cycle for testing
- Currently in the first year of the next cycle of testing
- Department and Industry are still evaluating and looking at new test methods that are being developed.
- Continue Review of on-going research (mini-concrete prism test, alternate SCM’s etc.)
- Identify additional ASR affected assets and document using AASHTO ASR inventory tool.

Contact Information:
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Initial Industry Concerns

Aggregate and Concrete Producers of PA
An Increase in levels of mitigation would bring:
- An Increase in Scaling
- Strength Gain Issues
- Reduction in Aggregate Availability

PennDOT / Industry Proteam

Pennsylvania geology

We are a Limestone State

PA Results C1293 vs C1260
We are a Limestone State

SR 119 South of Greensburg
SR 662 Fleetwood

ASR Workplan – Two Projects
Rich Jucha, P.E.  ACPA-PA

Three Levels of Mitigation

<table>
<thead>
<tr>
<th>SCM</th>
<th>Level W</th>
<th>Level X</th>
<th>Level Z</th>
</tr>
</thead>
<tbody>
<tr>
<td>Class F Flyash</td>
<td>15%</td>
<td>25%</td>
<td>35%</td>
</tr>
<tr>
<td>Slag Cement</td>
<td>25%</td>
<td>50%</td>
<td>65%</td>
</tr>
</tbody>
</table>

Strength Gains / Sidewalk Scaling

www.pacaweb.org www.specifyconcrete.org

www.pacaweb.org www.specifyconcrete.org

www.pacaweb.org www.specifyconcrete.org

www.pacaweb.org www.specifyconcrete.org
Scaling

A great quote:

This is not a finisher problem. This is not a producer problem. This is not a specifier problem.

This is an industry problem!

Reducing Scaling of Concrete Surfaces
A STIC Initiative
State Transportation Innovation Council
Construction and Materials TAG

1. Finisher certification:
   ACI Flat Work Finisher or NRMCA exterior concrete finisher

2. A Training Module for Construction Insp.
   (Concrete QIC working on a sidewalk specification)

Finisher certification: ACI Flat Work Finisher or NRMCA exterior concrete finisher

Clearance Transmittal Issued – Into effect April 2022

Not just a concern on sidewalks
What we gained and learned

- We now mitigate smarter
  - Aggregate Availability
  - New cost of mitigation
  - Reduced side effects (scaling & strength gain)
- Mix design preparation and approval
  - *It is not that hard* !!
- Get everyone at the table from the beginning

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Education is the Key!

**Aggregate and Concrete Producers**
- Mix Design
- Aggregate Classification – What does it mean

**State DOT’s**
- Mix design approval
- Specification revision
- Assign proper service life
- Adjust Acceptance time – 56 days
- Training and **Expectations** of Field Inspection Personnel

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Education is the Key!

**Construction Personnel:**
Get the information to those who need it.
- The Finishers
  - **Critical need for curing to produce durable concrete**
- Strength Gain Expectations

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Limitations and Expectations

For Pennsylvania AASHTO R80 provided a timely improvement
C1293 provided us benefits over C1260 but it is limited!!
Our current test methods do not match most expectations
Keep all at the table while ASR Knowledge Continues to Advance

• **Use of Field History**
  – R80 and C1778

• **Advantages for Producers**
  – Bridge the disconnect
  – A more complete understanding of their material

• **Advantage for Specifiers /Owners**
  – Reduce the cost of over mitigation in $ and side effects
  – Improved Aggregate Availability

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**Research on New Test Methods and Materials**

FHWA T-Fast Method
• Terry Arnold, FHWA

Accelerated Concrete Cylinder Test
• Anol Mukhopadhyay, Texas Transportation Institute
  – April 2021 ASSHTO Publication

Alternative Concrete Pozzolans for Transportation Infrastructure
• Farshad Rajabipour, Penn State

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We will be glad to help

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