The Identification and Prevention of Alkali Silica Reactive (ASR) Aggregates

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What is Alkali Silica Reaction?

- **Definition**
  - A Process in which silica (found in aggregate) in the presence of moisture, is broken down by alkalis (sodium and potassium found in cement) and produces an expansive gel.

- **Three Step Process**
  - Alkali + Reactive Silica = Gel
  - Gel + Moisture = Gel Swelling Pressure
  - Gel Swelling Pressure > Concrete Tensile Strength = Concrete Cracking and Failure
Akali + Reactive Silica = Gel

Na⁺  
K⁺  
OH⁻  
ASR Aggregate

Na⁺  
K⁺  
K⁺  
Na⁺  
K⁺
Gel + Moisture = Gel Swelling

ASR Aggregate

H₂O

H₂O

H₂O

H₂O

H₂O

H₂O
Gel Pressure > Tensile Strength

H₂O

ASR Aggregate

H₂O

H₂O

H₂O

H₂O
MassDOT History with ASR

- **1996**
  - ASR found on Memorial Bridge in Springfield
  - FHWA advised MassDOT to test Aggregates for ASR

- **1998**
  - MassDOT requires producers to submit certified ASR Test Results Annually
    - “Modified” AASHTO T 303 Accelerated Mortar Bar Test (AMBT) results annually
    - ASTM C295 Petrographic Examination
MassDOT History with ASR

- **2003**
  - MassDOT performs in-house ASR testing
    - Discrepancy between MassDOT and producer test results
    - Identified an aggregate source used by several producers which was “very highly reactive”
  
- **2008**
  - MassDOT begins proficiency testing of independent laboratories for “Modified” AASHTO T303 (AMBT).
  - Established a qualified list of approved testing laboratories based on their proficiency test performance.
MassDOT History with ASR

2008

- Identified 40 construction projects completed between 7 and 12 years ago that used the “very highly reactive” aggregate identified in 2003.

- Developed research program to analyze concrete structures on the 40 projects, determine risk assessment and future management of the structures.
ASR Effected Precast Barrier

Contract 95505: Somerset-Fall River-Westport-Dartmouth, I-195 East, Precast Barrier At Highland Ave. Bridge
ASR Effected Sign Foundation

ASR Effected Sign Foundation

Contract 98106: Bridgewater-Raynham-Taunton-Berkley-Freetown, Exit 14B Route 24 South Bound
ASR Effected Culvert

Contract 96527: Somerset, Route 138 at Read Street, Precast Culvert South Side Riverside Avenue
ASR Effected Parapet Wall

Contract 97343: Middleborough, Miller Street / I-495 South Bound
Bottom of Parapet Wall on Outside of Bridge Approx. 12’ Left of the Southwest Corner of the Bridge
MassDOT History with ASR

- **2009**
  - MassDOT begins ASTM C1293 Concrete Prism Test (CPT) of a Canadian aggregate source known to be historically highly reactive

- **2011**
  - MassDOT is approached by the FHWA to build a long-term ASR Exposure Site

- **2012**
  - MassDOT and FHWA break ground on ASR Exposure site on June 6, 2012
MassDOT History with ASR

- **2016**
  - MassDOT begins experimenting with AASHTO TP 110 Mini Concrete Prism Test (MCPT)

- **2017**
  - MassDOT begins ASTM C1293 (CPT) on all MassDOT approved aggregate sources
  - 5 year anniversary of the long-term ASR exposure site study
MassDOT Future with ASR

- **2018**
  - MassDOT will perform AASHTO TP 110 (MCPT) on all MassDOT aggregates
  - MassDOT will utilize CCRL Proficiency Program for Independent Laboratory pre-qualification

- **2022**
  - 10 year anniversary of the long-term ASR exposure site study
    - Determine if field results correlate with lab tests
    - Prescribe treatments
“Screening” for ASR

Report on Determining the Reactivity of Concrete Aggregates and Selecting Appropriate Measures for Preventing Deleterious Expansion in New Concrete Construction

Figure 2. Sequence of Laboratory Tests for Evaluating Aggregate Reactivity

1 This type of reaction only needs to be determined after the concrete prism test if the aggregate being tested is a quartz-rich carbonate that has been identified as being potentially alkali-carbonate reactive by chemical composition in accordance with test method CSA A533-26.
2 Note: The heavy dotted lines represent the preferred approach whereas the faint dotted lines represent a higher risk approach.
“Screening” for ASR

- ASTM C295
  - Petrographic Examination
- AASHTO T 303
  - Accelerated Mortar Bar Test (14 days)
- AASHTO TP 110
  - Mini Concrete Prism Test (56 to 84 days)
- ASTM C 1293
  - Concrete Prism Test (1 to 2 years)
- Long-Term Exposure Site (10 to 20 years)
ASR is identified by the dark areas around the aggregate. This specimen shows ASR gel cracks extending from the aggregate into the surrounding paste.
AASHTO T 303 (AMBT)

- **Duration**
  - 14 days

- **Specimen Size**
  - 1 x 1 x 10”
## AASHTO T 303 (AMBT)

<table>
<thead>
<tr>
<th>Reactivity</th>
<th>14-Day Expansion in AMBT, %</th>
<th>Expected Signs of ASR distress in the Field</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nonreactive</td>
<td>≤0.1</td>
<td>N/A</td>
</tr>
<tr>
<td>Moderately Reactive</td>
<td>&gt;0.1, ≤0.30</td>
<td>&gt;5 years, &lt;10 years</td>
</tr>
<tr>
<td>Highly Reactive</td>
<td>&gt;0.30, ≤0.45</td>
<td>&lt;5 years</td>
</tr>
<tr>
<td>Very highly Reactive</td>
<td>&gt;0.45</td>
<td>&lt;5 years</td>
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</tbody>
</table>
AASHTO TP 110 (MCPT)

- **Duration**
  - 56 to 84 days (depends on rate of reactivity)

- **Specimen Size**
  - 2 x 2 x 10”
## AASHTO TP 110 (MCPT)

<table>
<thead>
<tr>
<th>Reactivity</th>
<th>56-Day Expansion in MCPT, %</th>
<th>Average 2-Week Rate of Expansion from 8 to 12 Weeks</th>
<th>Expected Signs of ASR distress in the Field</th>
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<tr>
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<td>≤0.03</td>
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<td>N/A</td>
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<tr>
<td>Nonreactive</td>
<td>&gt;0.03, ≤0.04</td>
<td>≤0.01 per 2 weeks</td>
<td>N/A</td>
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<tr>
<td>Low/slow Reactive</td>
<td>&gt;0.03, ≤0.04</td>
<td>&gt;0.01 per 2 weeks</td>
<td>&gt;10 years</td>
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<td>Moderately Reactive</td>
<td>&gt;0.04, ≤0.12</td>
<td>N/A</td>
<td>&gt;5 years, &lt;10 years</td>
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<tr>
<td>Highly Reactive</td>
<td>&gt;0.12, ≤0.24</td>
<td>N/A</td>
<td>&lt;5 years</td>
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<tr>
<td>Very highly Reactive</td>
<td>&gt;0.24</td>
<td>N/A</td>
<td>&lt;5 years</td>
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## AASHTO TP 110 (MCPT)

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<th>Efficiency of Mitigation</th>
<th>56-Day Expansion in MCPT, %</th>
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<tr>
<td>Effective</td>
<td>≤0.020</td>
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<tr>
<td>Uncertain</td>
<td>&gt;0.020, ≤0.025</td>
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<tr>
<td>Not Effective</td>
<td>&gt;0.025</td>
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ASTM C 1293 (CPT)

- **Duration**
  - 1 to 2 years (depends on use of mitigation)

- **Specimen Size**
  - 3 x 3 x 10”

Environmental Chamber
### ASTM C 1293 (CPT)

<table>
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<th>Reactivity</th>
<th>1-Year Expansion in CPT, %</th>
<th>Expected Signs of ASR distress in the Field</th>
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<td>≤0.04</td>
<td>N/A</td>
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<tr>
<td>Moderately Reactive</td>
<td>&gt;0.04, ≤0.12</td>
<td>&gt;5 years, &lt;10 years</td>
</tr>
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<td>&lt;5 years</td>
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<tr>
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<td>&gt;0.24</td>
<td>&lt;5 years</td>
</tr>
</tbody>
</table>
Long-Term Exposure Site

- **Duration**
  - 10 to 20 year study on the “efficacy” of the trialed “Treatments”

- **Specimen Size**
  - 15 x 15 x 28”

- **Specimens**
  - 73 Blocks
## Long-Term Exposure Site

<table>
<thead>
<tr>
<th>Reactivity</th>
<th>10 to 20 year Expansion (%)</th>
<th>Expected Signs of ASR distress in the Field</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nonreactive</td>
<td>≤0.04</td>
<td>N/A</td>
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</table>
“Candidates” for Prevention
“Candidates” for Prevention

<table>
<thead>
<tr>
<th>Reactivity Class</th>
<th>AMBT Range</th>
<th>Agg. ID</th>
<th>Mineralogy</th>
<th>AMBT (14 days)</th>
<th>CPT (360 days)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>AMB (14 days) Mass DOT</td>
<td>U of Texas</td>
<td>Mass DOT</td>
</tr>
<tr>
<td>Nonreactive</td>
<td>&lt;0.10</td>
<td>1</td>
<td>Diorite (mainly); granitic &amp; volcanic (traces)</td>
<td>0.05 - 0.09</td>
<td>0.095</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2</td>
<td>Mixed Diorite/gneiss/granite/schist</td>
<td>0.04 - 0.09</td>
<td>0.066</td>
</tr>
<tr>
<td>Moderately Reactive</td>
<td>0.10 - 0.29</td>
<td>3</td>
<td>Pinkish meta-granite</td>
<td>0.20 - 0.32</td>
<td>0.072</td>
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<td>Highly Reactive</td>
<td>0.30 - 0.45</td>
<td>4</td>
<td>Mixed gneiss/granitic</td>
<td>0.30 - 0.30</td>
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<tr>
<td>Very Highly Reactive</td>
<td>&gt;0.45</td>
<td>5</td>
<td>Mixed gneiss/schist/quartzite</td>
<td>0.50 - 0.54</td>
<td>0.063</td>
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<tr>
<td></td>
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<td>6</td>
<td>Greywacke/sandstone</td>
<td>0.58 - 0.62</td>
<td>0.573</td>
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<tr>
<td></td>
<td></td>
<td>UT1</td>
<td>Rhyolitic volcanic rocks with quartz and granite</td>
<td>-</td>
<td>0.82</td>
</tr>
</tbody>
</table>
## “Candidates” for Prevention

<table>
<thead>
<tr>
<th>Reactivity Class</th>
<th>AMBT Range</th>
<th>Agg. ID</th>
<th>Mineralogy</th>
<th>AMBT (14 days) Mass DOT</th>
<th>U of Texas</th>
<th>CPT (360 days) Mass DOT</th>
<th>U of Texas</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nonreactive</td>
<td>&lt;0.10</td>
<td>7</td>
<td>Mixed gneiss/quartzite/quartz/feldspar sand</td>
<td>0.09 - 0.10</td>
<td>0.066</td>
<td>0.06</td>
<td>0.024</td>
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<tr>
<td>Moderately Reactive</td>
<td>0.10 - 0.29</td>
<td>8</td>
<td>Mixed quartzite/gneiss/quartz/feldspar sand</td>
<td>0.20 - 0.21</td>
<td>0.147</td>
<td>0.05</td>
<td>0.07</td>
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<td>9</td>
<td>Mixed gneiss/quartzite/quartz/feldspar sand</td>
<td>0.20 - 0.26</td>
<td>0.239</td>
<td>0.05</td>
<td>0.028</td>
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<tr>
<td>Highly Reactive</td>
<td>0.30 - 0.45</td>
<td>10</td>
<td>Mixed gneiss/schist/quartzite/quartz/feldspar sand</td>
<td>0.38 - 0.40</td>
<td>0.327</td>
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<td>0.051</td>
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<tr>
<td>Very Highly Reactive</td>
<td>&gt;0.45</td>
<td>UT2</td>
<td>Mixed quartz/chert/feldspar sand</td>
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<td>UT3</td>
<td>Mixed quartz/chert sand</td>
<td>-</td>
<td>0.29</td>
<td>0.27</td>
<td></td>
</tr>
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</table>
Do Lab Test Methods Correlate?
Circled University of Texas T 303 results differ from MassDOT results quite substantially.

Circled University of Texas T 303 results differ from MassDOT results quite substantially.
AASHTO TP 110 (MCPT) 56 Day Expansion (%) for 100% Cement

Circled TP 110 results differ from what we previously classified to be Highly Reactive from historical T 303 data.

MASSDOT AASHTO TP 110 (56 DAY)  
Reactivity Limits
AASHTO T 303 (AMBT) vs ASTM C1293 (CPT)
Expansion (%) for 100% Cement

Circled aggregates cannot be tested with AASHTO T 303…Does not correlate with ASTM C 1293.
The diagram illustrates the expansion of 100% cement samples tested using AASHTO PP 65 AMBT and ASTM C1293 (CPT) methods.

- **AASHTO PP 65 AMBT vs ASTM C1293 (CPT):** Expansion (%) for 100% Cement

  - **0.00%** to **0.80%** on the y-axis represents the expansion percentage for AASHTO PP 65 AMBT 14 days after completion.
  - **0.00%** to **0.60%** on the x-axis represents the expansion percentage for ASTM C1293 1 Year.

- **Circled aggregates cannot be tested with AASHTO T 303 to evaluate preventive measures.**

- **If AMBT vs. CPT data fall within this range, the AMBT may be used to evaluate preventive measures.**

**Legend:**
- MassDOT Results
- U of Texas Results
- AASHTO PP 65 Correlation Limits
If TP 110 vs. C1293 data fall within the classified range limits, then the MCPT may be used to evaluate ASR.

Circled aggregates cannot be tested with TP 110…Does not correlate with C1293.
“Clinical” Trials (Exposure Site)
“Clinical” Trials (Exposure Site)

- **Duration**
  - 10 to 20 year study on the “efficacy” of the trialed “Treatments”

- **Specimen Size**
  - 15 x 15 x 28”

- **Specimens**
  - 73 Blocks
“Clinical” Trials (Exposure Site)
Gauge Measurement Locations
“Clinical” Trials (Exposure Site)

- Simulate
- Correlate
- Prescribe
“Placebo”

33 “Placebo” (Control) Blocks

- No preventative measures
- 10 local aggregates at 3 levels of alkalinity of Portland Cement
  - 0.66, 0.88, and 1.10% Na2Oe
- 3 non-local aggregates (Texas) at 1.10% Na₂Oe
## “Placebo”

<table>
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<tr>
<th>AGG Reactivity</th>
<th>Block</th>
<th>AGG</th>
<th>Na₂Oe</th>
<th>CEM</th>
<th>FA</th>
<th>SLAG</th>
<th>SF</th>
<th>Lithium</th>
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<td><strong>Highly Reactive</strong></td>
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Preventative “Treatments”
Preventative “Treatments”

- ASR only occurs if ALL THREE Conditions are met! Eliminate One!

- SUFFICIENT ALKALI
- REACTIVATION
- SUFFICIENT MOISTURE
- LKALI
- STOP
- STOP
- STOP
- STOP
Preventative “Treatments”

- Nonreactive Aggregate
- Fly Ash
- Slag
- Silica Fume
- Lithium
- Low Alkali Cement
Preventative “Treatments”

- 40 “Treatment” (Preventative Measure) Blocks
  - 4 of the most reactive local “Candidates” (Aggregates) chosen
  - 2 levels of alkalinity of Portland Cement
    - 0.88 and 1.11% Na$_2$Oe
  - 7 preventative measures
    - 20% Class F fly ash
    - 30% Class F fly ash
    - 35% slag
    - 50% slag
    - 4% silica fume + 15% fly ash
    - 4% silica fume + 20% slag
    - 100% standard dose of lithium nitrate (0.55 gal of 30% lithium nitrate per pound of Na$_2$Oe)
Preventative “Treatments”

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## Preventative “Treatments”

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## Preventative “Treatments”

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Which “Patients” really need preventative “treatment”?

“Patients” that exhibit expansions >0.04 are considered to need preventative “treatment”
Long-term Exposure Site Expansion (%) for 1.10% Na$_2$Oe*; 100% Cement

Note* Aggregate 1 was tested using 0.88% Na$_2$Oe; Aggregate 9 is being tested twice.

Circled Exposure Site results currently differ from what we previously classified the reactivity of these aggregates from historical T 303 data.
If C1293 vs. Exposure Site data fall within the classified range limits, then the C1293 correlates with the LTES, thus validating the results.

Circled Exposure Site results do not currently correlate with C1293.
“Clinical” Trials: Day 1828 (5 yr)

- How well are the Low Alkali “treatments” working?
100% Cement; Aggregate No. 1 (Nonreactive)

- MOD. REACTIVE
- HIGHLY REACTIVE
- VERY HIGHLY REACTIVE

Non-Reactive Aggregate No. 1
100% Cement; Aggregate No. 6 (Very Highly Reactive)

\[ y = 1.6724x + 0.0033 \]

\[ R^2 = 0.98032 \]
$y = 11.866x + 0.0027$

$R^2 = 0.85463$

100% Cement; Aggregate No. 10 (Highly Reactive)
“Clinical” Trials: Day 1828 (5 yr)

- How well are the Mitigation “treatments” working?
  - Fly Ash
  - Slag
  - Silica Fume
  - Lithium
Long-term Exposure Site Expansion (%) for Aggregate No. 5 (Very Highly Reactive)

5 Year Expansion (%)

-0.01% 0.00% 0.01% 0.02% 0.03% 0.04% 0.05% 0.06% 0.07% 0.08% 0.09%

Block Identification No.

100% CEM

30% FA

20% FA

15% FA; 4% SF

50% SLAG

35% SLAG

20% SLAG; 4% SF

LITHIUM

100% CEM

9% FA

20% FA

50% SLAG

35% SLAG

100% CEM

61

1.10% Alkalinity

0.88% Alkalinity

0.66% Alkalinity

Very Highly Reactive Aggregate No. 5

ASTM C1293 Reactivity Limit
Long-term Exposure Site Expansion (%) for Aggregate No. 10 (Highly Reactive)

Block Identification No.

34
37
33
36
32
35
38
31
30
29

30% FA
20% FA; 4% SF
20% FA
15% FA; 4% SF
50% SLAG
35% SLAG
LITHIUM
100% CEM
100% CEM

1.10% Alkalinity
0.88% Alkalinity
0.66% Alkalinity

0.00% 0.01% 0.02% 0.03% 0.04% 0.05% 0.06% 0.07% 0.08%

1645 Day Expansion (%)
Long-term Exposure Site Expansion (%) for Aggregate No. 6 (Very Highly Reactive)

Block Identification No. vs. 1645 Day Expansion (%)

- 30% FA
- 20% FA; 4% SF
- 20% FA
- 15% FA; 4% SF
- 50% SLAG
- 35% SLAG
- LITHIUM
- 100% CEM

Very Highly Reactive Aggregate No. 6

0.00% - 0.45%

ASTM C1293 Reactivity Limit

0.66% Alkalinity

0.88% Alkalinity

1.10% Alkalinity
Patient: UT 2 (Jobe, TX), No. 48
Patient: UT 2 (Jobe, TX), No. 48

1.16% Average Expansion (that’s a lot)!
MassDOT Moving Forward

- Evaluate Exposure Site (10 to 20 yrs)
- Establish Trends
- Correlate Field Performance with Lab Tests
- Verify Aggregate Reactivity
- Decrease ASR Lab Test Frequency
- Implement AASHTO TP 110 (56 – 84 Days) and ASTM C 1293 (1 – 2 Years)
- Identify appropriate preventative “Treatment” to MassDOT aggregates to slow down or eliminate ASR
Conclusion

- Eliminate only ONE of the three conditions to eliminate ASR all together
- “Screen” “Patients” for ASR using various laboratory test methods
- “Prescribe” the proper “treatment” and “dosage” of “medicine” to the “Patients”
- Remember! Different “Patients” may react drastically dissimilar to the same “medicine”!
- Identify Nonreactive / reactive aggregates with confidence
- Correlate aggregates with appropriate lab tests
Conclusion

- There is no Silver Bullet