Guidelines for Identifying and Controlling Alkali Aggregate Reactions

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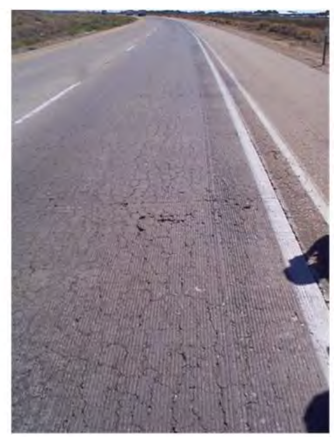
Background

- 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

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

ASR Distress



Stanton's Bridge (ca. 1930)

 Alkali-Aggregate Reactivity (AAR) Facts Book. Thomas, M.D.A., Fournier, B., Folliard, K.J.

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**

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_2O_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

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

AASHTO Designation: R 80-17[1]
Technical Section: 3c, Hardened Concrete

https://intrans.iastate.edu/app/uploads/2020/12/MAPbriefWinter2020.pdf

ASTM INTERNATIONAL
Designation: C1778 – 20

Standard Guide for
Reducing the Risk of Deleterious Alkali-Aggregate Reaction in Concrete[1]

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

- Alkali Loading *not* Alkali Content

wt. % Na_2O_{eq} = (wt. % Na_2O) + (0.658 x wt. % K_2O)

Alkali Loading of Cement lb/yd^3 [kg/m^3] = Na_2O_{eq} x cement content lb/yd^3 [kg/m^3]

Limit fly ash to 4.0 wt. % Na_2O_{eq} [4.5 wt. % Na_2O_{eq} in AASHTO R 80]

Table 1. Example calculations of alkali loading for two different alkali contents and two different portland cement contents

Cement Alkali Content Na_2O_{eq} %	Cement Content lb/yd^3 [kg/m^3]	Concrete Alkali Loading lb/yd^3 [kg/m^3]
0.50 0.50	500 [297] 700 [415]	2.5 [1.5] 3.5 [2.1]
0.70 0.70	500 [297] 700 [415]	3.5 [2.1] 4.9 [2.9]

General Principles

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

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

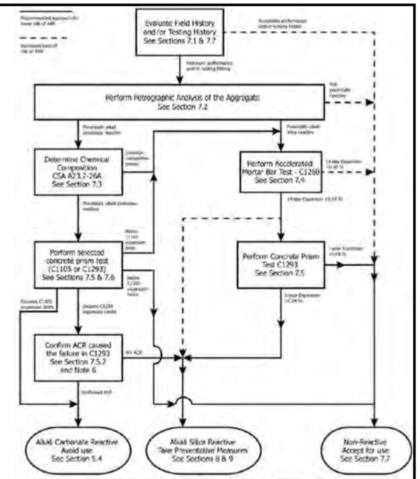


FIG. 1 Sequence of Laboratory Tests for Evaluating Aggregate Reactivity

Performance Requirements

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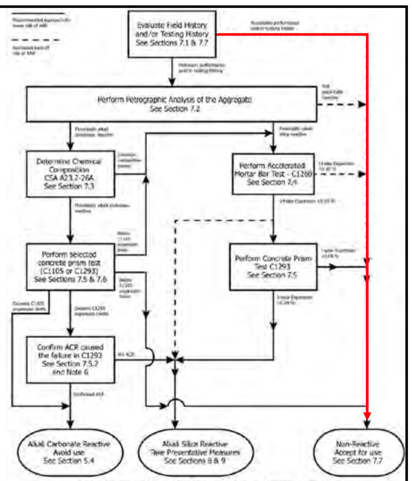
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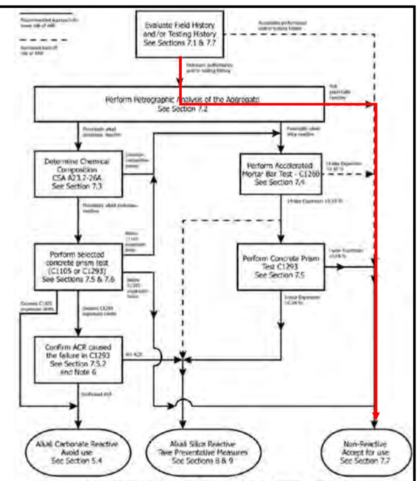
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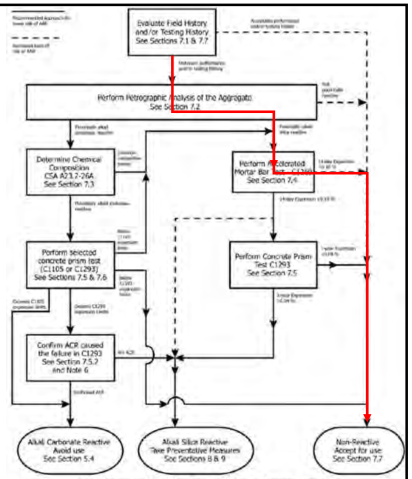

FIG. 1 Sequence of Laboratory Tests for Evaluating Aggregate Reactivity

Michigan Technological University

Performance Requirements

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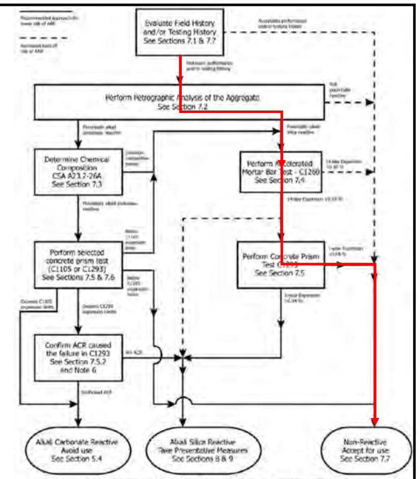

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Michigan Technological University

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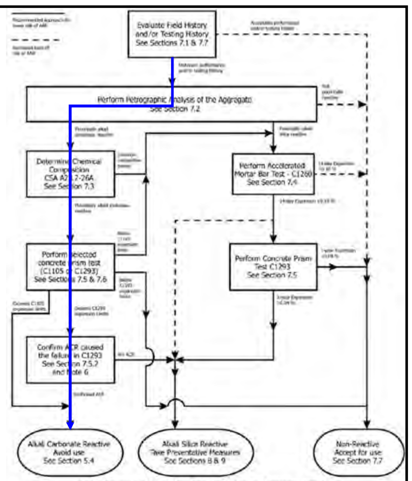

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Michigan Technological University

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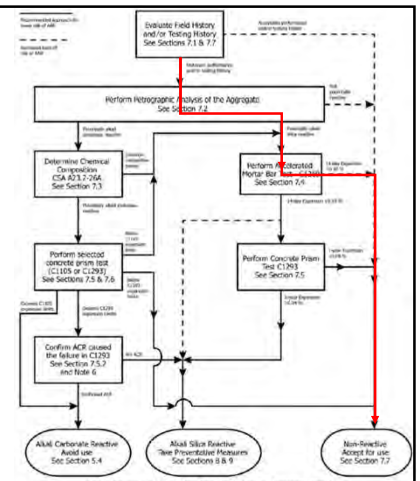

FIG. 1 Sequence of Laboratory Tests for Evaluating Aggregate Reactivity

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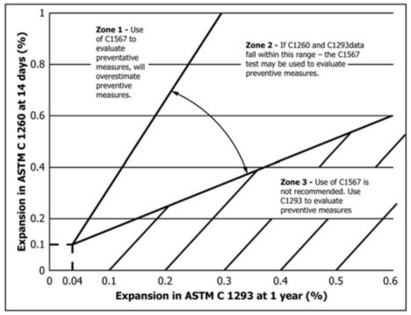
Performance Requirements

- 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 [≤0.10% @ 14 days]
    - *Requires* correlation between ASTM C1260 [AASHTO T 303] and ASTM C1293
  - ASTM C1293
    - 2-year concrete prism expansion [≤0.04% @ 2 years]

Prescriptive Approach

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)

TABLE 1 Classification of Aggregate Reactivity

Aggregate-Reactivity Class	Description of Aggregate Reactivity	1-Year Expansion in Test Method C1293, %	14-Day Expansion in Test Method C1260, %
R0	Non-reactive	<0.04	<0.10
R1	Moderately reactive	≥0.04, <0.12	≥0.10, <0.30
R2	Highly reactive	≥0.12, <0.24	≥0.30, <0.45
R3	Very highly reactive	≥0.24	≥0.45

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)

TABLE 2 Determining the Level of ASR Risk

Size and Exposure Conditions	Aggregate-Reactivity Class			
	R0	R1	R2	R3
Non-massive[A] concrete in a dry[B] environment	Level 1	Level 1	Level 2	Level 3
Massive[A] elements in a dry[B] environment	Level 1	Level 2	Level 3	Level 4
All concrete exposed to humid air, buried or immersed	Level 1	Level 3	Level 4	Level 5
All concrete exposed to alkalies in service[C]	Level 1	Level 4	Level 5	Level 6

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)

TABLE 3 Structures Classified on Basis of the Severity of Consequences Should ASR[A] Occur (Modified for Highway Structures from RILEM TC 191-ARP)

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Class	Consequence of ASR	Acceptability of ASR	Examples[B]
Class SC1	Safety, economic, or environmental consequences small or negligible	Some deterioration from ASR may be tolerated	Non-load-beanng elements inside buildings Concrete elements not exposed to moisture Temporary structures (service life < 5 years)
Class SC2	Some safety, economic, or environmental consequences if major deterioration	Moderate risk of ASR is acceptable	Sidewalks, curbs, and gutters Elements with service life < 40 years
Class SC3	Significant safety, economic, or environmental consequences if minor damage	Minor risk of ASR may be acceptable	Pavements Foundations elements Retaining walls Culverts Highway barriers Rural, low-volume roads Precast elements in which economic costs of replacement are severe Service life normally 40 to 74 years
Class SC4	Serious safety, economic, or environmental consequences if minor damage	ASR cannot be tolerated	Major bridges Power plants Dams Nuclear facilities Water treatment facilities Waste water treatment facilities Tunnels Critical elements that are very difficult to inspect or repair Service life normally ≥75 years

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)

TABLE 4 Determining Level of Prevention

Level of ASR Risk (Table 2)	Classification of Structure (Table 3)			
	Class SC1	Class SC2	Class SC3	Class SC4
Risk Level 1	V	V	V	V
Risk Level 2	V	V	W	X
Risk Level 3	V	W	X	Y
Risk Level 4	W	X	Y	Z
Risk Level 5	X	Y	Z	ZZ
Risk Level 6	Y	Z	ZZ	[A]

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

Prevention Level	Maximum Alkali Loading of Concrete	
	kg/m^3	lb/yd^3
V	No Limit	
W	3.0	5.0
X	2.4	4.0
Y	1.8	3.0
Z[A]	Table 8	
ZZ[A]		

[A] 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

Type of SCM[A]	Alkali Content of SCM (% Na_2Oeq)	Minimum Replacement Level[D] (% by mass)				
		Level W	Level X	Level Y	Level Z	Level ZZ
Fly ash[B] (CaO ≤ 18 %)	<3.0	15	20	25	35	Table 8
	3.0 – 4.0	20	25	30	40	
Slag Cement	<1.0	25	35	50	65	
Silica Fume[C] (SiO_2 > 85 %)	<1.0	2.0 × KGA or 1.2 × LBA	2.5 × KGA or 1.5 × LBA	3.0 × KGA or 1.8 × LBA	4.0 × KGA or 2.5 × LBA	

[A] The SCM may be added directly to the concrete mixer or it may be a component of a blended cement. Fly ash should meet the requirements of Specification C618, slag cement should meet the specifications of C989/C989M, and silica fume should meet the requirements of Specification C1240. Blended cements should meet the requirements of Specification C595/C595M or C1157/C1157M.
[B] Fly ashes with greater than 18 % CaO can mitigate ASR. The efficacy of these higher calcium fly ashes should be evaluated using the performance-based testing outlined in 8.2 and 8.3.
[C] The minimum level of silica fume (as a percentage of cementing material) is calculated on the basis of the alkali loading of the concrete expressed in either units of kg/m^3 (KGA) or lb/yd^3 (LBA). Regardless of the calculated value, the minimum level of silica fume may not be less than 7 % when it is the only method of prevention.
[D] Note—the use of high levels of SCM in concrete may increase the risk of problems as a result of deicer salt scaling if the concrete is not properly proportioned, finished, and cured.

Prescriptive Requirements

- Select Preventative Measures

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

Type of SCM[A]	Alkali Content of SCM (% Na_2Oeq)	Minimum Replacement Level[D] (% by mass)				
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	3.0 – 4.0	20	25	30	40	
Slag Cement	<1.0	25	35	50	65	
Silica Fume[C] (SiO_2 > 85 %)	<1.0	2.0 × KGA or 1.2 × LBA	2.5 × KGA or 1.5 × LBA	3.0 × KGA or 1.8 × LBA	4.0 × KGA or 2.5 × LBA	

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[D] Note—the use of high levels of SCM in concrete may increase the risk of problems as a result of deicer salt scaling if the concrete is not properly proportioned, finished, and cured.

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

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PennDOT: Implementing AASHTO R 80

PATRICIA BAER
PENNDOT
BUREAU OF PROJECT DELIVERY
CONSTRUCTION AND MATERIALS DIVISION

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 participated in the first meeting
    - Dr. Rogers – University Lavalle, 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% a 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 C 1293)
      - 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 rooms. 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 (R0) 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 :

Aggregate Reactivity Class	Description of Aggregate Reactivity	1-Year Expansion in ASTM C-1293 (percent)	14-d Expansion in AASHTO T-303 (percent)
R0	Non-reactive	≤ 0.04	≤ 0.10
R1	Moderately reactive	>0.04, ≤ 0.12	>0.10, ≤ 0.30
R2	Highly Reactive	>0.12, ≤0.24	>0.30, ≤0.45
R3	Very Highly Reactive	>0.24	>0.45

PennDOT Specification:

2. Level of ASR Risk: PennDOT Specification

R0	R1	R2	R3
Risk Level 1	Risk Level 2	Risk Level 3	Risk Level 4

Level of ASR Risk: R 80

Table 2. Determining the level of ASR risk.

	Aggregate-Reactivity Class			
Size and exposure conditions	**R0**	**R1**	**R2**	**R3**
Non-massive[2] concrete in a dry[3] environment	Level 1	Level 1	Level 2	Level 3
Massive[2] elements in a dry[3] environment	Level 1	Level 2	Level 3	Level 4
All concrete exposed to humid air, buried or immersed	Level 1	Level 3	Level 4	Level 5
All concrete exposed to alkalis in service[4]	Level 1	Level 4	Level 5	Level 6

PennDOT Specification:

3. Determining the Level of Prevention: PennDOT Specification

Classification of Structure

Level of ASR Risk	S1	S2	S3
Risk Level 1	V	V	V
Risk Level 2	V	W	X
Risk Level 3	W	X	Y
Risk Level 4	X	Y	Z

Determining the Level of Prevention: R 80

Table 3. Determining the level of prevention.

	Classification of Structure (Table 4)			
Level of ASR Risk (Table 2)	**S1**	**S2**	**S3**	**S4**
Risk Level 1	V	V	V	V
Risk Level 2	V	V	W	X
Risk Level 3	V	W	X	Y
Risk Level 4	W	X	Y	Z
Risk Level 5	X	Y	Z	ZZ
Risk Level 6	Y	Z	ZZ	††

†† It is not permitted to construct a Class S4 structure (see Table 4) when the risk of ASR is Level 6. Measures must be taken to reduce the level of risk in these circumstances.

PennDOT Specification:

4. Structure Classification: R 80

Table 4. Structures classified on the basis of the severity of the consequences should ASR[5] occur (modified for highway structures from RILEM TC 191-ARP).

Class	Consequences of ASR	Acceptability of ASR	Examples[7]
S1	Safety, economic, or environmental consequences small or negligible	Some deterioration from ASR may be tolerated	• Non-load-bearing elements inside buildings • Temporary structures (e.g. < 5 years)
S2	Some safety, economic, or environmental consequences if major deterioration	Moderate risk of ASR is acceptable	• Sidewalks, curbs, and gutters • Service life < 40 years
S3	Significant safety, economic, or environmental consequences if minor damage	Minor risk of ASR acceptable	• Pavements • Culverts • Highway barriers • Rural, low-volume bridges • Large numbers of precast elements where economic costs of replacement are severe • Service life normally 40 to 75 years
S4	Serious safety, economic, or environmental consequences if minor damage	ASR cannot be tolerated	• Major bridges • Tunnels • Critical elements that are very difficult to inspect or repair • Service life normally > 75 years

PennDOT Specification:

4. Structure classification:

PennDOT Specification

Structure Class	Consequences	Acceptability of ASR	Structure/Asset type	Publication 408 Sections
S1	Safety and future maintenance consequences small or negligible	Some deterioration from ASR may be tolerated	Temporary structures. Inside buildings. Structures or assets that will never be exposed to water	627, 620, 621, 624, 627, 628 643, 644, 859, 874, 930, 932, 934, 952, 953, 1005
S2	Some minor safety, future maintenance consequences if major deterioration were to occur	Moderate risk of ASR acceptable	Sidewalks, curbs and gutters, inlet tops, concrete barrier and parapet. Typically structures with service lives of less than 40 years	303, 501, 505, 506, 516, 518, 523, 524, 525, 528, 540, 545, 605,607, 615, 618, 622, 623, 630, 633, 640, 641, 658, 667, 673, 674, 675, 676, 678, 714, 875, 852, 875, 910, 948, 951, 1025, 1001, 1040, 1042, 1043, 1086, 1201, 1210, 1230, Miscellaneous Precast Concrete
S3	Significant safety and future maintenance or replacement consequences if major deterioration were to occur	Minimal risk of ASR acceptable	All other structures. Service lives of 40 to 75 years anticipated.	530, 1001, 1006, 1031, 1032, 1040, 1080, 1085, 1107, MSE walls, Concrete Bridge components and Arch Structures

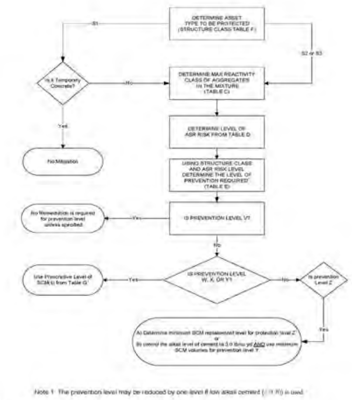
PennDOT Specification:

5. Minimum Levels of Supplementary Cementitious Materials: PennDOT Specification

Table G:

Type of SCM (1)	Alkali Level of SCM (%Na2Oe) (2) (3)	Level V (4)	Level W	Level X	Level Y	Level Z (5) (11)
Class F or C flyash (6)	≤ 3.0	-	15	20	25	35
Class F or C flyash (6)	>3.0, ≤ 4.5	-	20	25	30	40
GGBFS	≤ 1.0	-	25	35	50	65
Silica Fume (7) (8) (9) (10)	≤ 1.0	-	1.2 LBA	1.5 x LBA	1.8 x LBA	2.4 x LBA

PennDOT Specification:



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:

Aggregate Reactivity Class	Description of Aggregate Reactivity	1-Year Expansion in ASTM C-1293 (percent)	14-d Expansion in AASHTO T-303 (percent)
R0	Non-reactive	≤ 0.04	≤ 0.10
R1	Moderately reactive	>0.04, ≤ 0.12	>0.10, ≤ 0.30
R2	Highly Reactive	>0.12, ≤0.24	>0.30, ≤0.45
R3	Very Highly Reactive	>0.24	>0.45

- 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

R0	R1	R2	R3
Risk Level 1	Risk Level 2	Risk Level 3	Risk Level 4

- This aggregate would be at a Risk Level 3

Example #1 continued

Step #3:

Determine Level of prevention. The structure classification needs to be know 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.

Structure Class	Consequences	Acceptability of ASR	Structure/Asset type	Publication 408 Sections
S1	Safety and future maintenance consequences small or negligible	Some deterioration from ASR may be tolerated	Temporary structures. Inside buildings. Structures or assets that will never be exposed to water	627, 620, 621, 624, 627, 628 643, 644, 859, 874, 930, 932, 934, 952, 953, 1005
S2	Some minor safety, future maintenance consequences if major deterioration were to occur	Moderate risk of ASR acceptable	Sidewalks, curbs and gutters, inlet tops, concrete barrier and parapet. Typically structures with service lives of less than 40 years	303, 501, 505, 506, 516, 518, 523, 524, 525, 528, 540, 545, 605,607, 615, 618, 622, 623, 630, 633, 640, 641, 658, 667, 673, 674, 675, 676, 678, 714, 875, 852, 875, 910, 948, 951, 1025, 1001, 1040, 1042, 1043, 1086, 1201, 1210, 1230, Miscellaneous Precast Concrete
S3	Significant safety and future maintenance or replacement consequences if major deterioration were to occur	Minimal risk of ASR acceptable	All other structures. Service lives of 40 to 75 years anticipated.	530, 1001, 1006, 1031, 1032, 1040, 1080, 1085, 1107, MSE walls, Concrete Bridge components and Arch Structures

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

Classification of Structure

Level of ASR Risk	S1	S2	S3
Risk Level 1	V	V	V
Risk Level 2	V	W	X
Risk Level 3	W	X	Y
Risk Level 4	X	Y	Z

- With a Risk Level of 3 and a S2 classification, this mix needs a prevention level X

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

Type of SCM (1)	Alkali Level of SCM (% Na2Oe) (2) (3)	Level V (4)	Level W	Level X	Level Y	Level Z (5) (11)
Class F or C flyash (6)	≤ 3.0	-	15	20	25	35
Class F or C flyash (6)	>3.0, ≤ 4.5	-	20	25	30	40
GGBFS	≤ 1.0	-	25	35	50	65
Silica Fume (7) (8) (9) (10)	≤ 1.0	-	1.2 LBA	1.5 x LBA	1.8 x LBA	2.4 x LBA

- 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:

Aggregate Reactivity Class	Description of Aggregate Reactivity	1-Year Expansion in ASTM C-1293 (percent)	14-d Expansion in AASHTO T-303 (percent)
R0	Non-reactive	≤ 0.04	≤ 0.10
R1	Moderately reactive	>0.04, ≤ 0.12	>0.10, ≤ 0.30
R2	Highly Reactive	>0.12, ≤0.24	>0.30, ≤0.45
R3	Very Highly Reactive	>0.24	>0.45

- 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

R0	R1	R2	R3
Risk Level 1	Risk Level 2	Risk Level 3	Risk Level 4

- This aggregate would be at a Risk Level 2

Example #2 continued

Step #3:

Determine Level of prevention. The structure classification needs to be know 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.

Structure Class	Consequences	Acceptability of ASR	Structure/Asset type	Publication 408 Sections
S1	Safety and future maintenance consequences small or negligible	Some deterioration from ASR may be tolerated	Temporary structures. Inside buildings. Structures or assets that will never be exposed to water	627, 620, 621, 624, 627, 628 643, 644, 859, 874, 930, 932, 934, 952, 953, 1005
S2	Some minor safety, future maintenance consequences if major deterioration were to occur	Moderate risk of ASR acceptable	Sidewalks, curbs and gutters, inlet tops, concrete barrier and parapet. Typically structures with service lives of less than 40 years	303, 501, 505, 506, 516, 518, 523, 524, 525, 528, 540, 545, 605,607, 615, 618, 622, 623, 630, 633, 640, 641, 658, 667, 673, 674, 675, 676, 678, 714, 875, 852, 875, 910, 948, 951, 1025, 1001, 1040, 1042, 1043, 1086, 1201, 1210, 1230, Miscellaneous Precast Concrete
S3	Significant safety and future maintenance or replacement consequences if major deterioration were to occur	Minimal risk of ASR acceptable	All other structures. Service lives of 40 to 75 years anticipated.	530, 1001, 1006, 1031, 1032, 1040, 1080, 1085, 1107, MSE walls, Concrete Bridge components and Arch Structures

Example #2 continued

Step #4: Let's say the design is for long life concrete pavement (section 530)

- The Structure Classification would be S

- From Table E – Determining the level of prevention

	Classification of Structure		
Level of ASR Risk	S1	S2	S3
Risk Level 1	V	V	V
Risk Level 2	V	W	X
Risk Level 3	W	X	Y
Risk Level 4	X	Y	Z

- 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

Type of SCM (1)	Alkali Level of SCM (% Na2Oe) (2) (3)	Level V (4)	Level W	Level X	Level Y	Level Z (5) (11)
Class F or C flyash (6)	≤ 3.0	-	15	20	25	35
Class F or C flyash (6)	>3.0, ≤ 4.5	-	20	25	30	40
GGBFS	≤ 1.0	-	25	35	50	65
Silica Fume (7) (8) (9) (10)	≤ 1.0	-	1.2 LBA	1.5 x LBA	1.8 x LBA	2.4 x LBA

- 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

Reactivity Level	Number of Aggregates
R0	240
R1	99
R2	33
R3	2

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:

Patricia Baer

- PennDOT Materials and Testing Lab
- Email: patrbaer@pa.gov

Initial Industry Concerns

Aggregate and Concrete Producers of PA

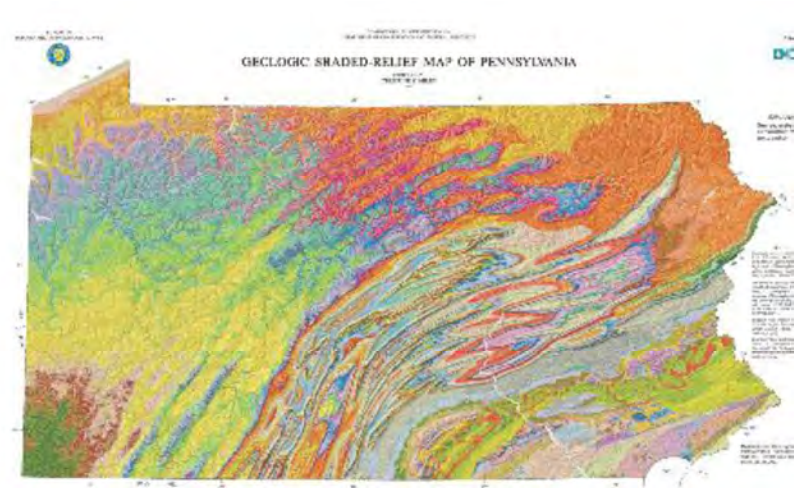
An Increase in levels of mitigation would bring:

- **An Increase in Scaling**
- **Strength Gain Issues**
- **Reduction in Aggregate Availability**

PennDOT / Industry Proteam

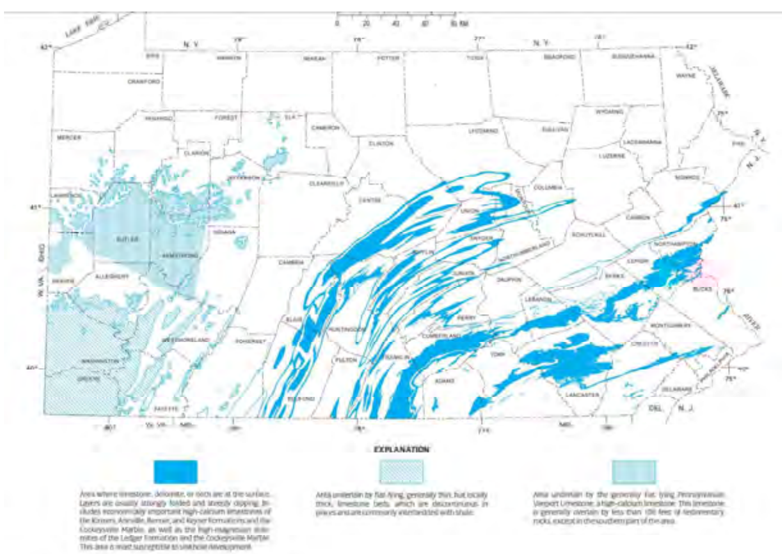
www.pacaweb.org PACA www.specifyconcrete.org

Pennsylvania geology



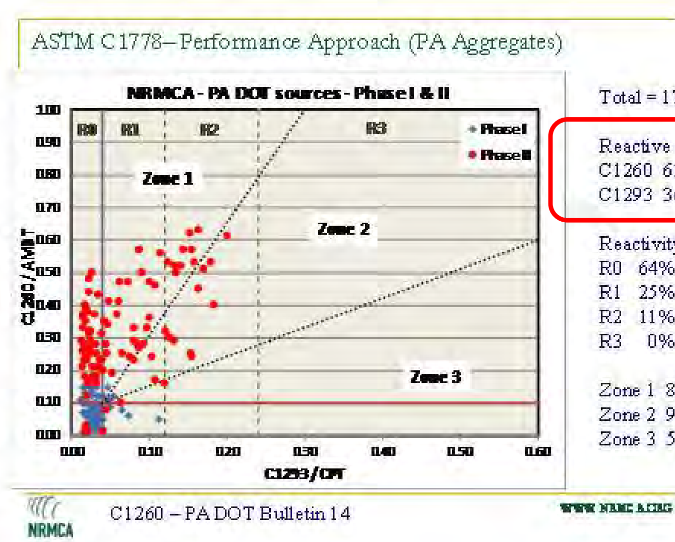
www.pacaweb.org PACA www.specifyconcrete.org

We are a Limestone State



www.pacaweb.org PACA www.specifyconcrete.org

PA Results C1293 vs C1260



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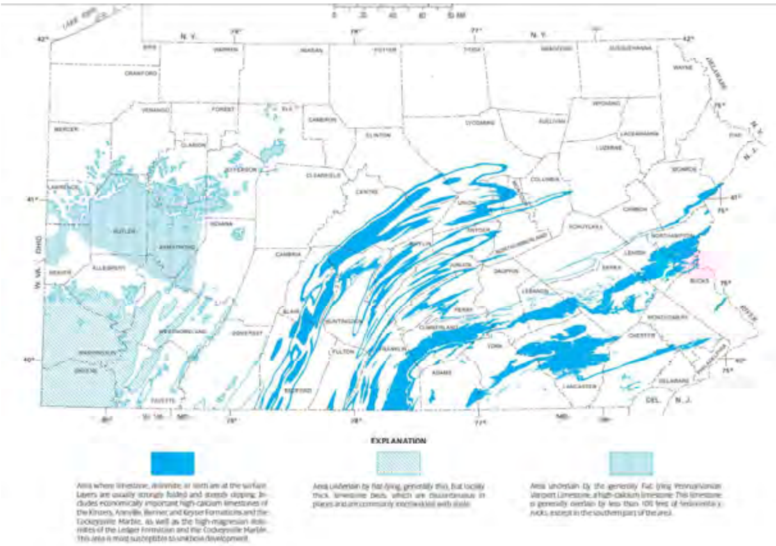


ASR Workplan – Two Projects
Rich Jucha, P.E. ACPA-PA

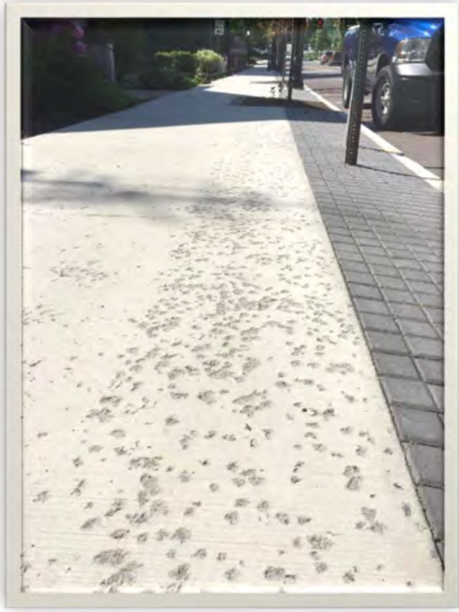
SR 119 South of Greensburg

SR 662 Fleetwood

Three Levels of Mitigation

SCM	Level W	Level X	Level Z
Class F Flyash	15%	25%	35%
Slag Cement	25%	50%	65%

Strength Gains / Sidewalk Scaling



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

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

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

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

ASTM C1260

ASTM C1293

Long Term Exposure Blocks

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

Keep all at the table while ASR Knowledge Continues to Advance

- 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

We will be glad to help

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