Improving the Guidance to ASTM C1778 for Preventing Alkali-Silica Reaction in Concrete

NCHRP 10-103

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American Concrete Institute – Boston, MA. – November 1, 2023

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Designation: C1778 – 22

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

This standard is issued under the fixed designation C1778; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope*

1.1 This guide provides guidance on how to address the potential for deleterious alkali aggregate reaction (AAR) in concrete construction. This guide addresses the process of identifying both potentially alkali-silica reactive (ASR) and alkali-carbonate reactive (ACR) aggregates through standardized testing procedures and the selection of mitigation options to minimize the risk of expansion when ASR aggregates are used in concrete construction. Mitigation methods for ASR aggregates are selected using either prescriptive or performance-based alternatives. Preventive measures for ACR aggregates are limited to avoidance of use. Because the potential for deleterious reactions depends not only on the concrete mixture but also the in-service exposure, guidance is provided on the type of structures and exposure environments where AAR may be of concern.

1.2 *Units*—The values stated in either SI units or inch-pound units are to be regarded separately as standard. The values stated in each system may not be exact equivalents; therefore, each system shall be used independently of the other. Combining values from the two systems may result in nonconformance with the standard.

1.3 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety, health, and environmental practices and determine the applicability of regulatory limitations prior to use.*

1.4 *This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.*

2. Referenced Documents

2.1 *ASTM Standards:*[2]

C33/C33M Specification for Concrete Aggregates
C114 Test Methods for Chemical Analysis of Hydraulic Cement
C125 Terminology Relating to Concrete and Concrete Aggregates
C150/C150M Specification for Portland Cement
C219 Terminology Relating to Hydraulic and Other Inorganic Cements
C294 Descriptive Nomenclature for Constituents of Concrete Aggregates
C295/C295M Guide for Petrographic Examination of Aggregates for Concrete
C311/C311M Test Methods for Sampling and Testing Fly Ash or Natural Pozzolans for Use in Portland-Cement Concrete
C586 Test Method for Potential Alkali Reactivity of Carbonate Rocks as Concrete Aggregates (Rock-Cylinder Method)
C595/C595M Specification for Blended Hydraulic Cements
C618 Specification for Coal Fly Ash and Raw or Calcined Natural Pozzolan for Use in Concrete
C823/C823M Practice for Examination and Sampling of Hardened Concrete in Constructions
C856 Practice for Petrographic Examination of Hardened Concrete
C989/C989M Specification for Slag Cement for Use in Concrete and Mortars
C1105 Test Method for Length Change of Concrete Due to Alkali-Carbonate Rock Reaction
C1157/C1157M Performance Specification for Hydraulic Cement
C1240 Specification for Silica Fume Used in Cementitious Mixtures
C1260 Test Method for Potential Alkali Reactivity of Aggregates (Mortar-Bar Method)

[1] This guide is under the jurisdiction of ASTM Committee C09 on Concrete and Concrete Aggregates and is the direct responsibility of Subcommittee C09.50 on Aggregate Reactions in Concrete.

Current edition approved March 1, 2022. Published April 2022. Originally approved in 2014. Last previous edition approved in 2020 as C1778 – 20. DOI: 10.1520/C1778-22.

[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

*A Summary of Changes section appears at the end of this standard

AASHTO Designation R80: (Similar to ASTM C1778)

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

AASHTO R80 and ASTM C1778 consist of two steps:

1. Evaluating aggregate reactivity
   - Alkali-silica and alkali-carbonate aggregates considered
2. Selecting preventive measures for alkali-silica reactive aggregates
   - Performance approach (expansion testing of mortar and/or concrete)
   - Prescriptive approach

Background on these guidance documents – Decades of Laboratory tests and Existing Outdoor Exposure Site Data

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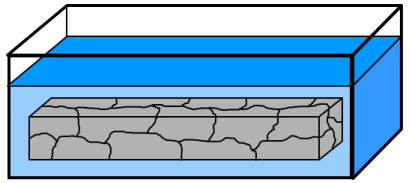
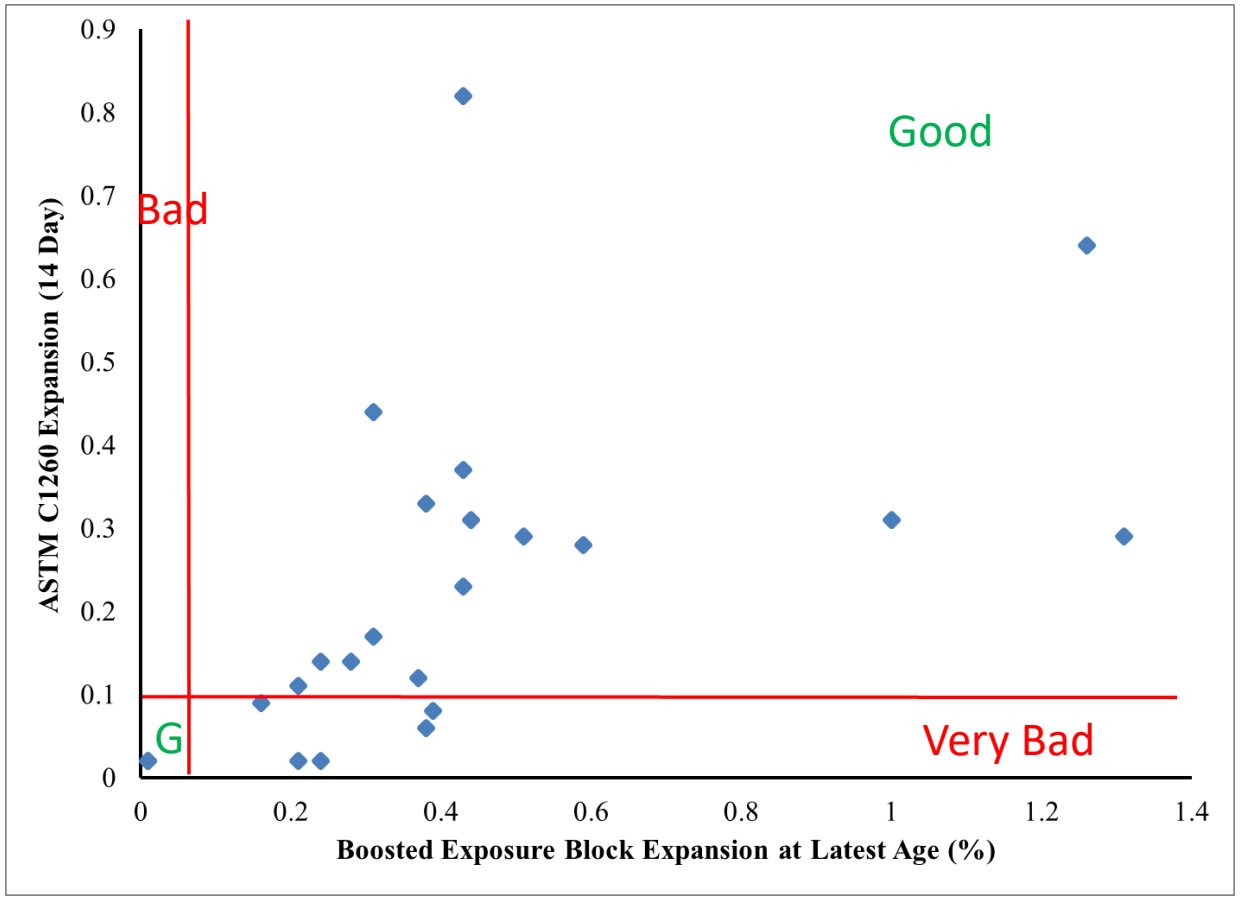
Existing Exposure Site Data – Aggregate Reactivity





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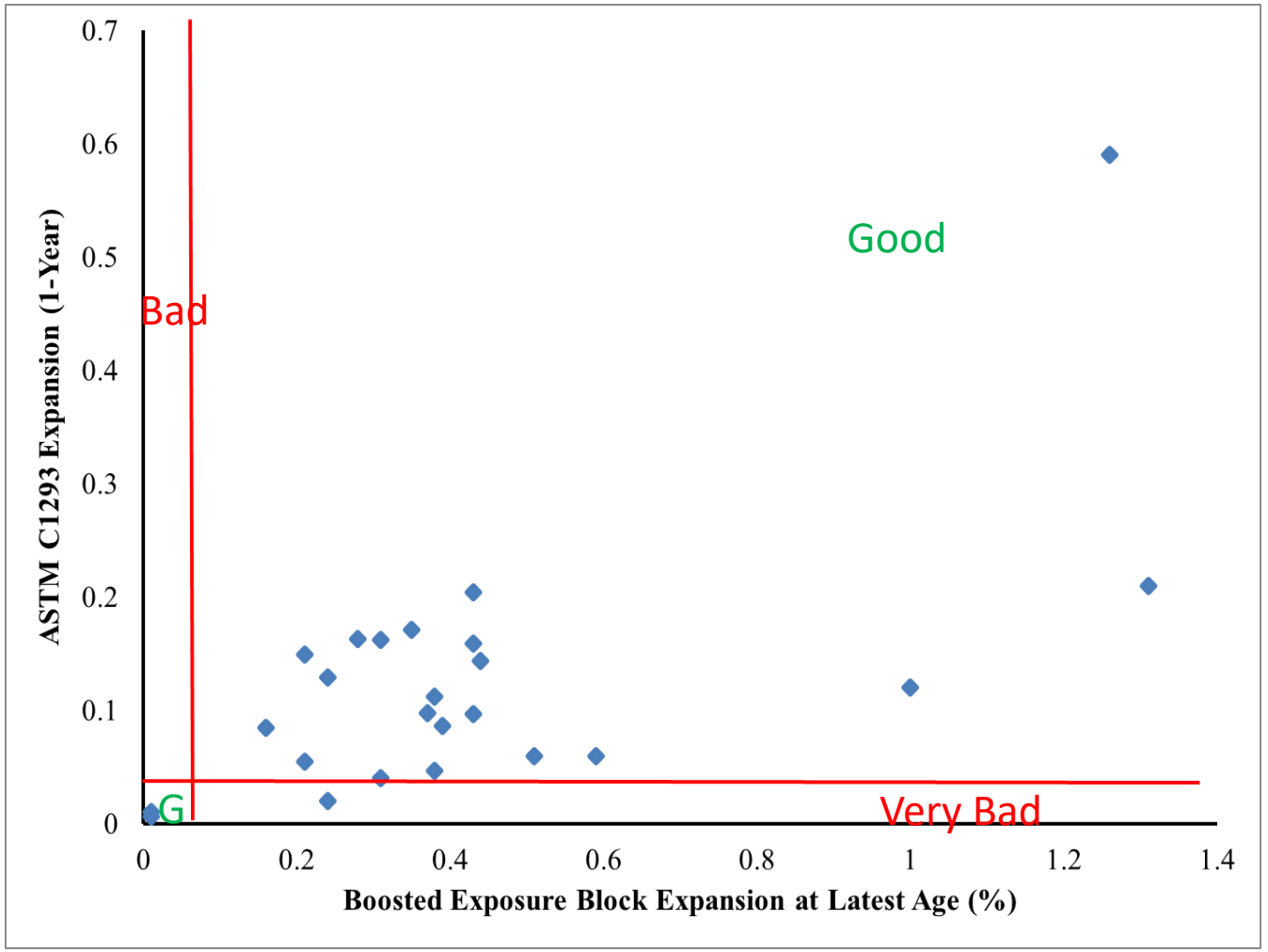

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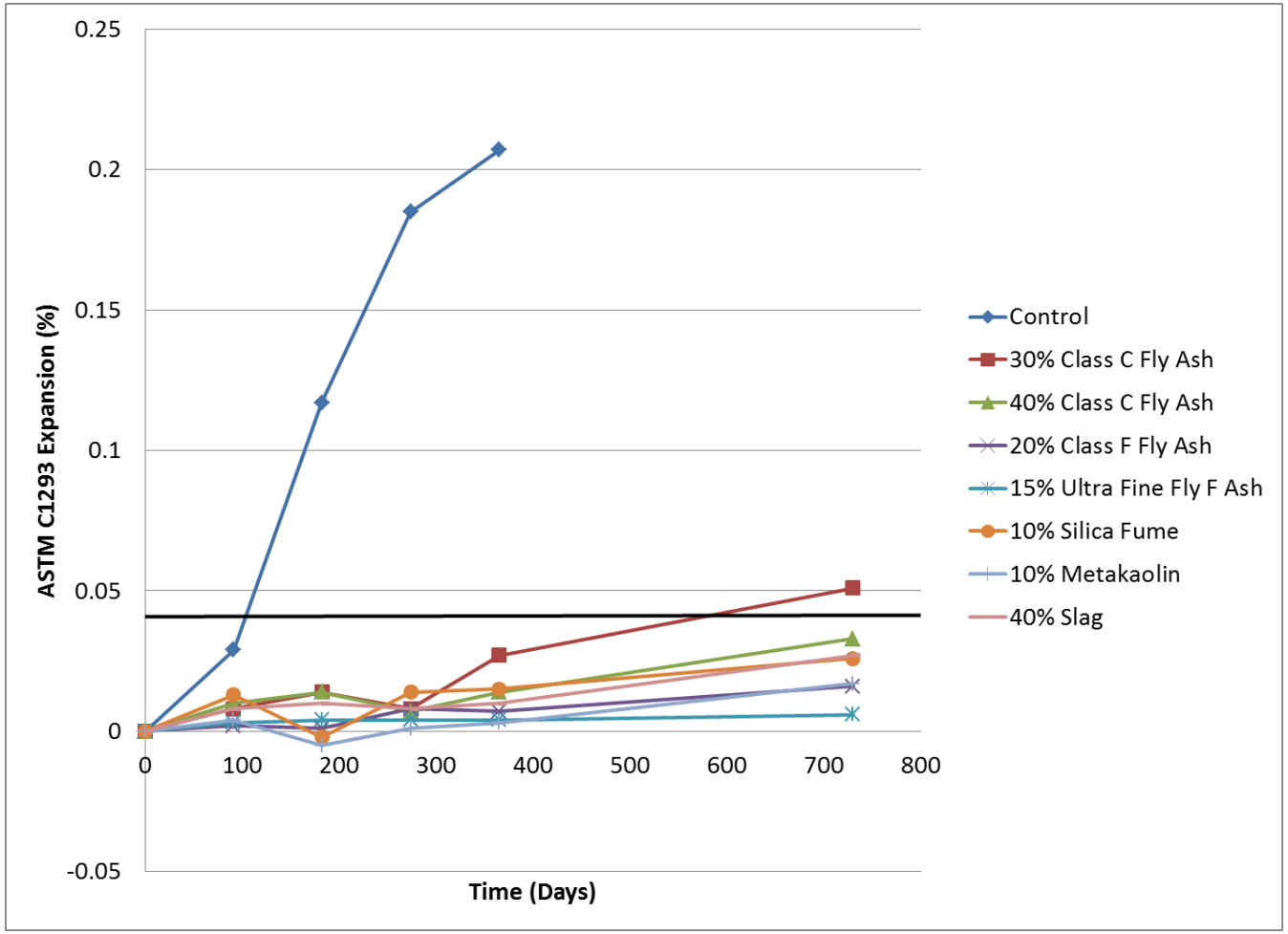
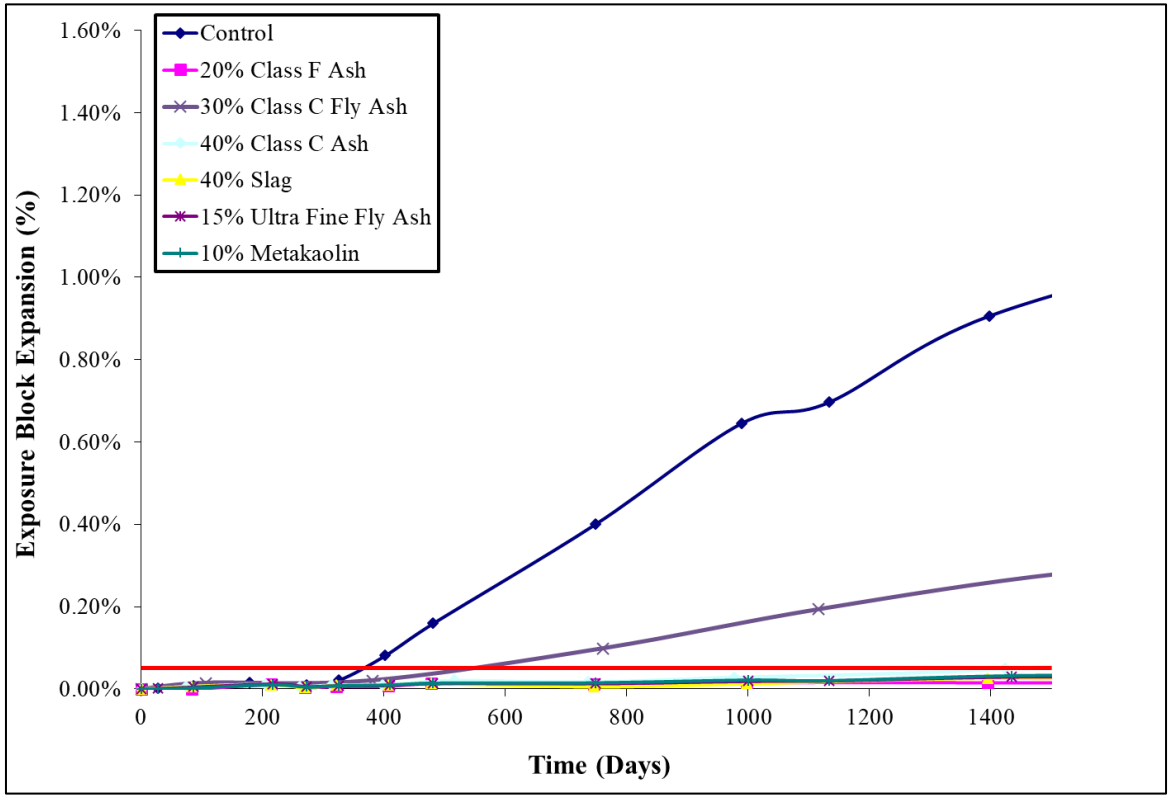
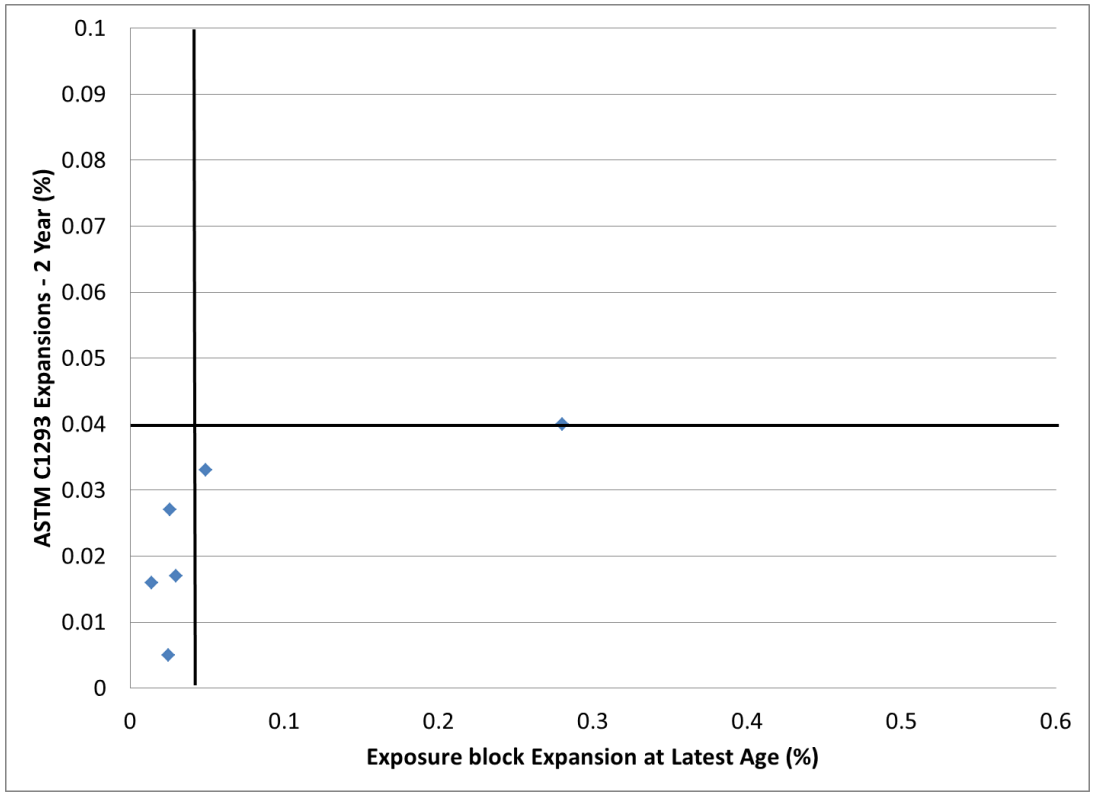
ASTM C1293 Mitigation Mixtures



Existing Exposure Site Data – Prevention Mixtures





Exposure Block Expansion Results at 4 Years

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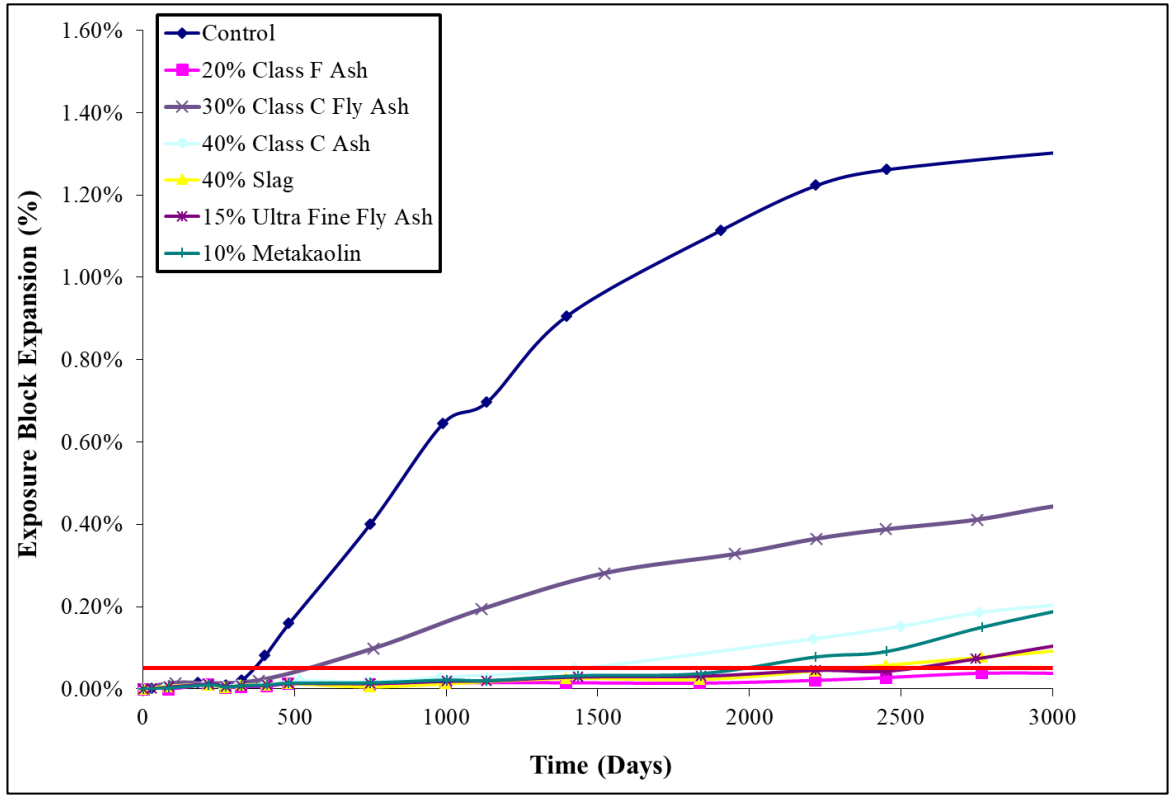
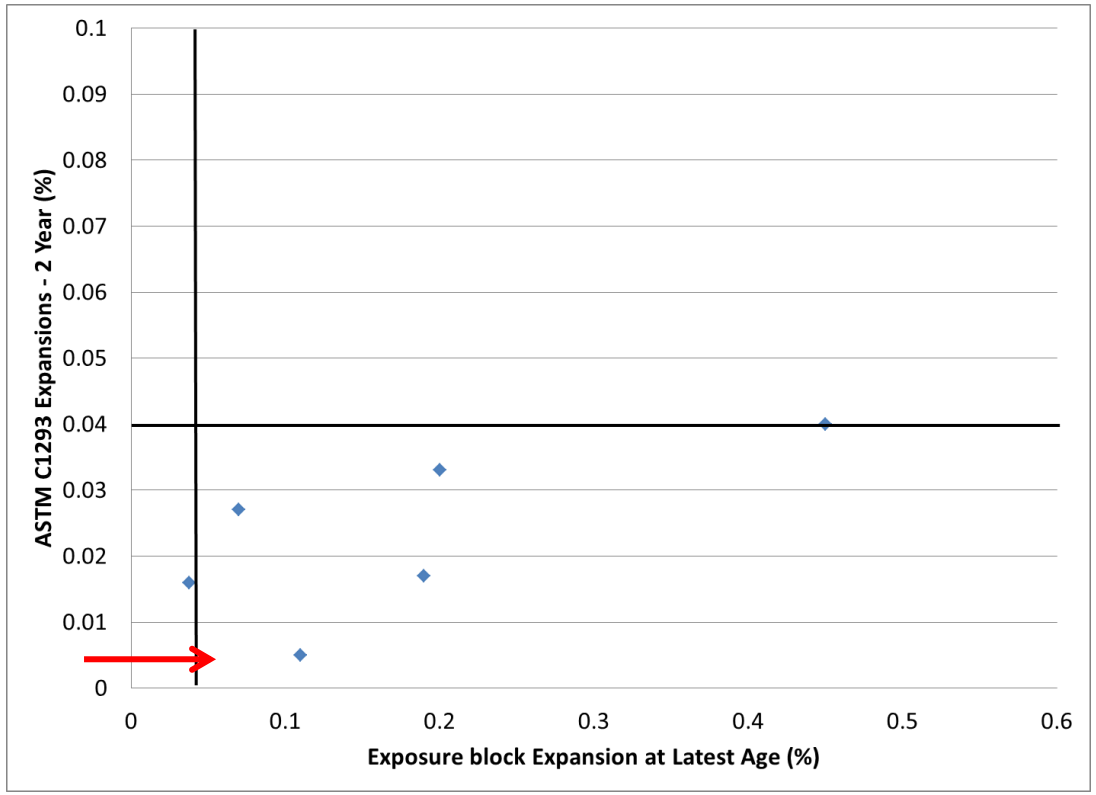
Existing Exposure Site Data – Prevention Mixtures





Exposure Block Expansion Results at 8 Years

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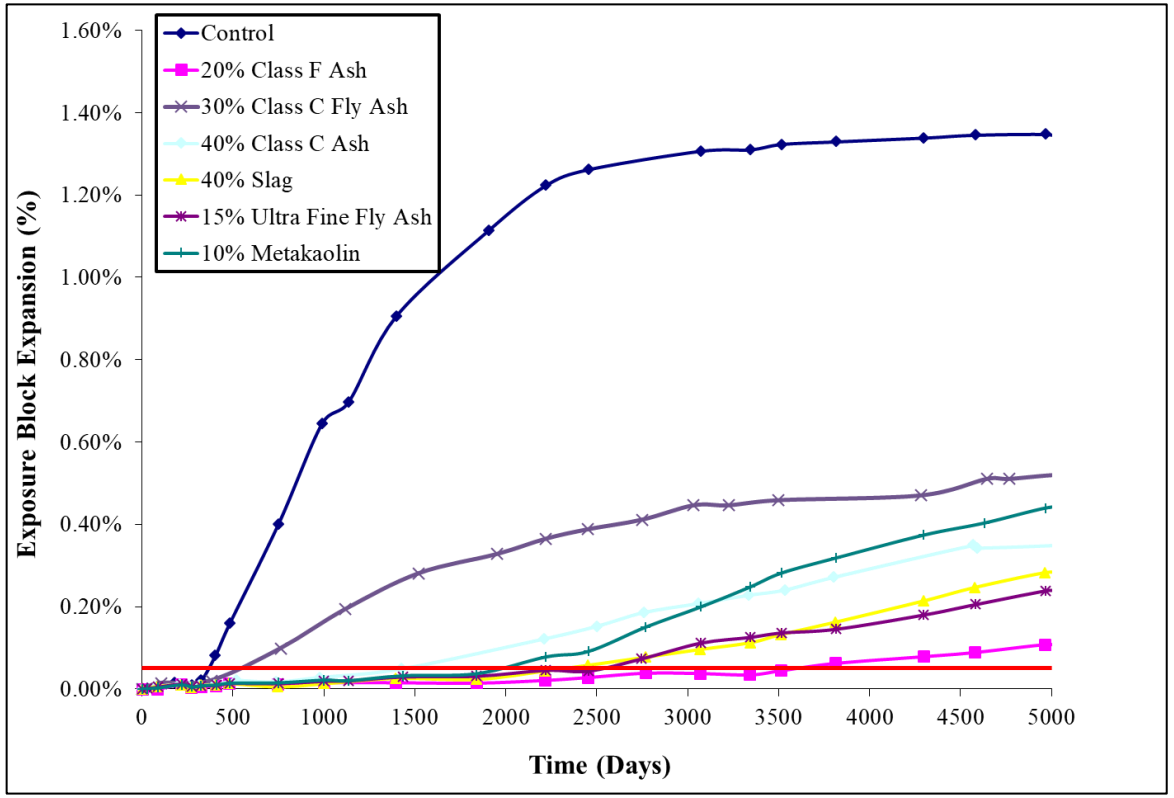

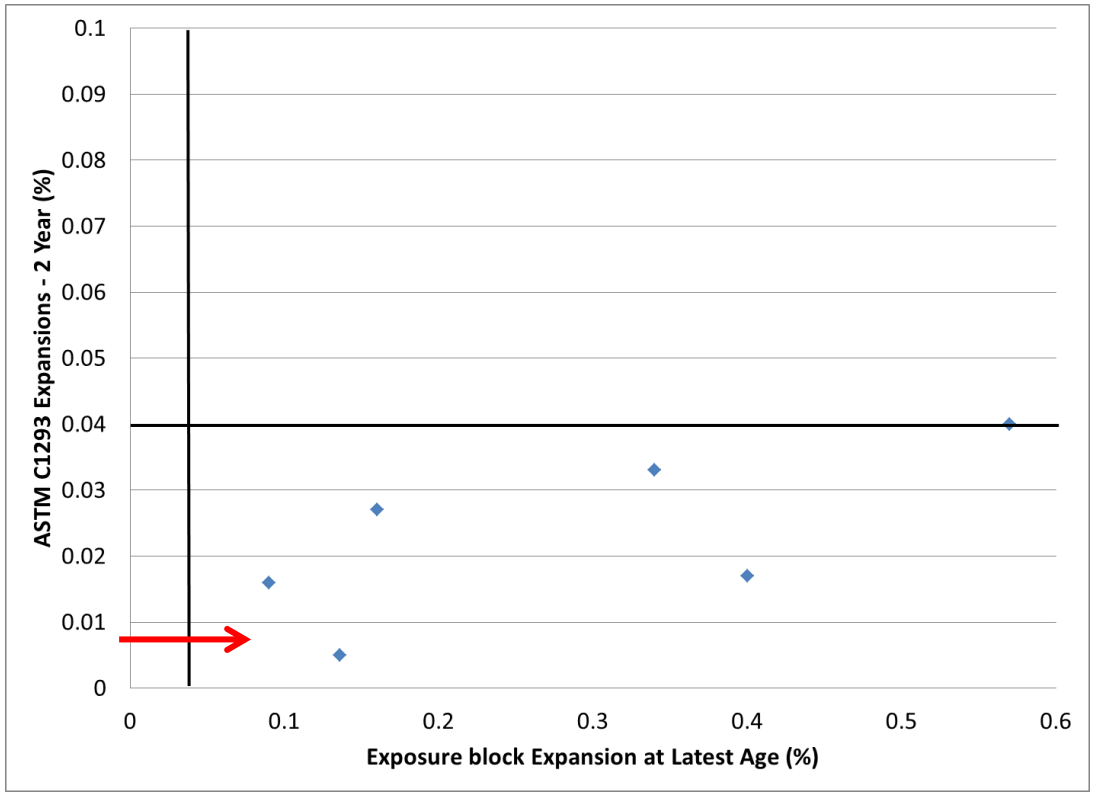

Exposure Block Expansion Results at 12 Years

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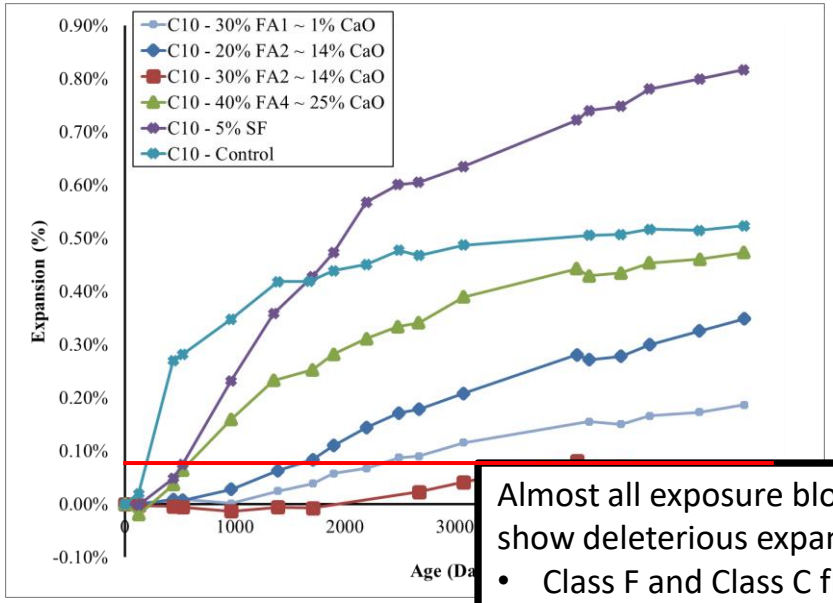
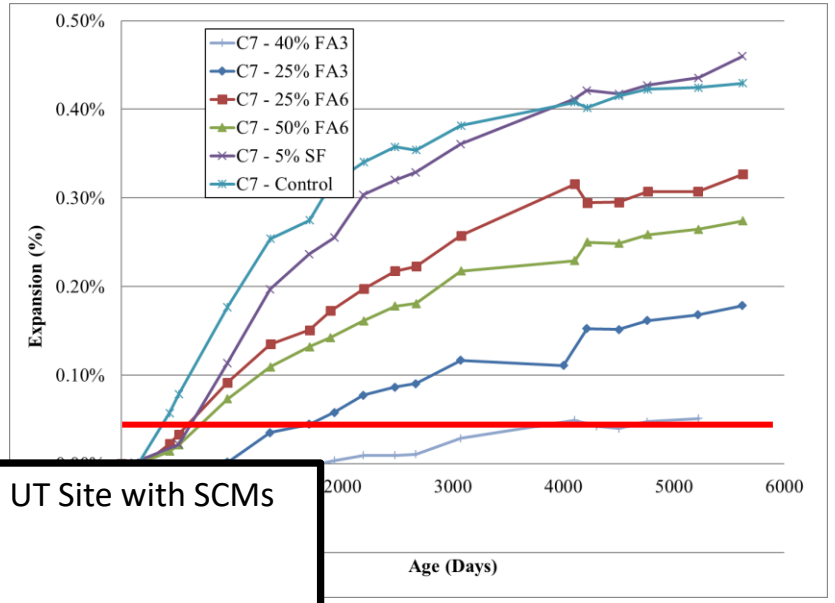
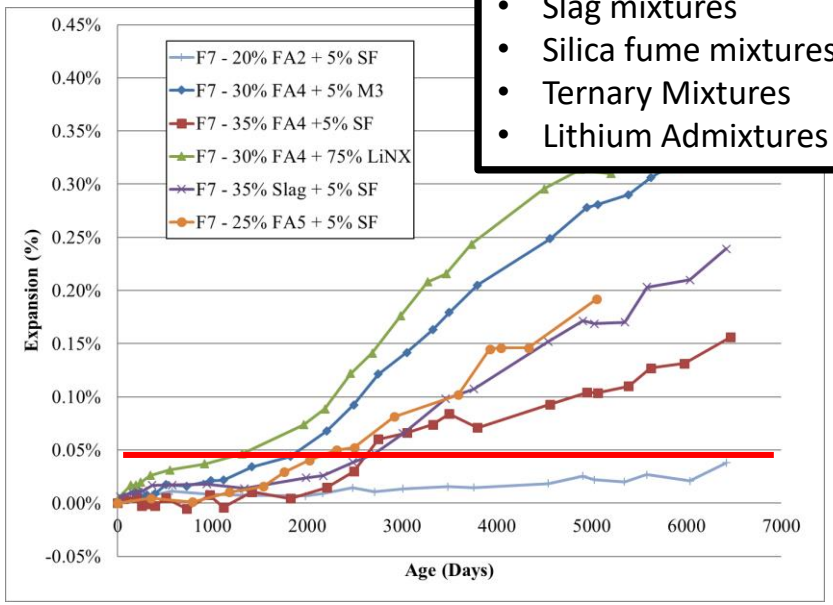
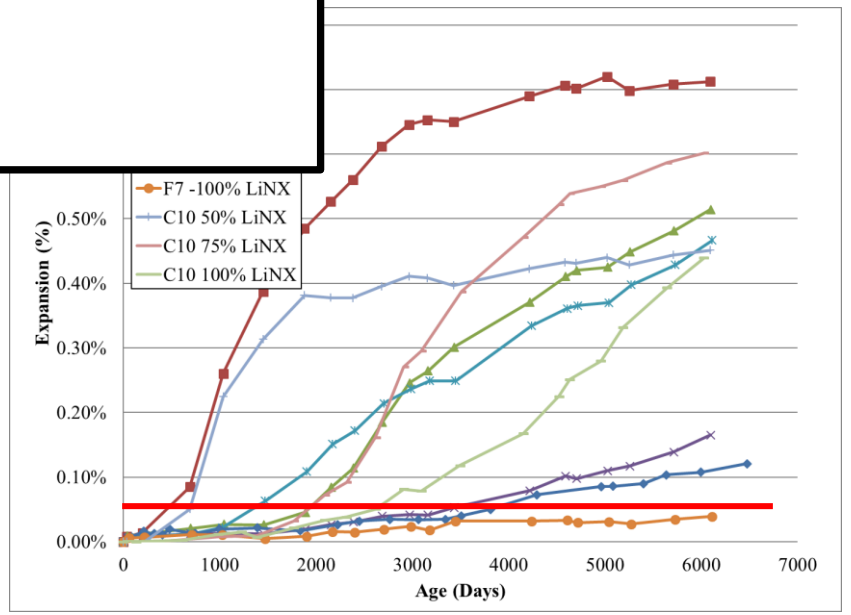




Almost all exposure blocks at the UT Site with SCMs show deleterious expansion

- Class F and Class C fly ash
- Slag mixtures
- Silica fume mixtures
- Ternary Mixtures
- Lithium Admixtures





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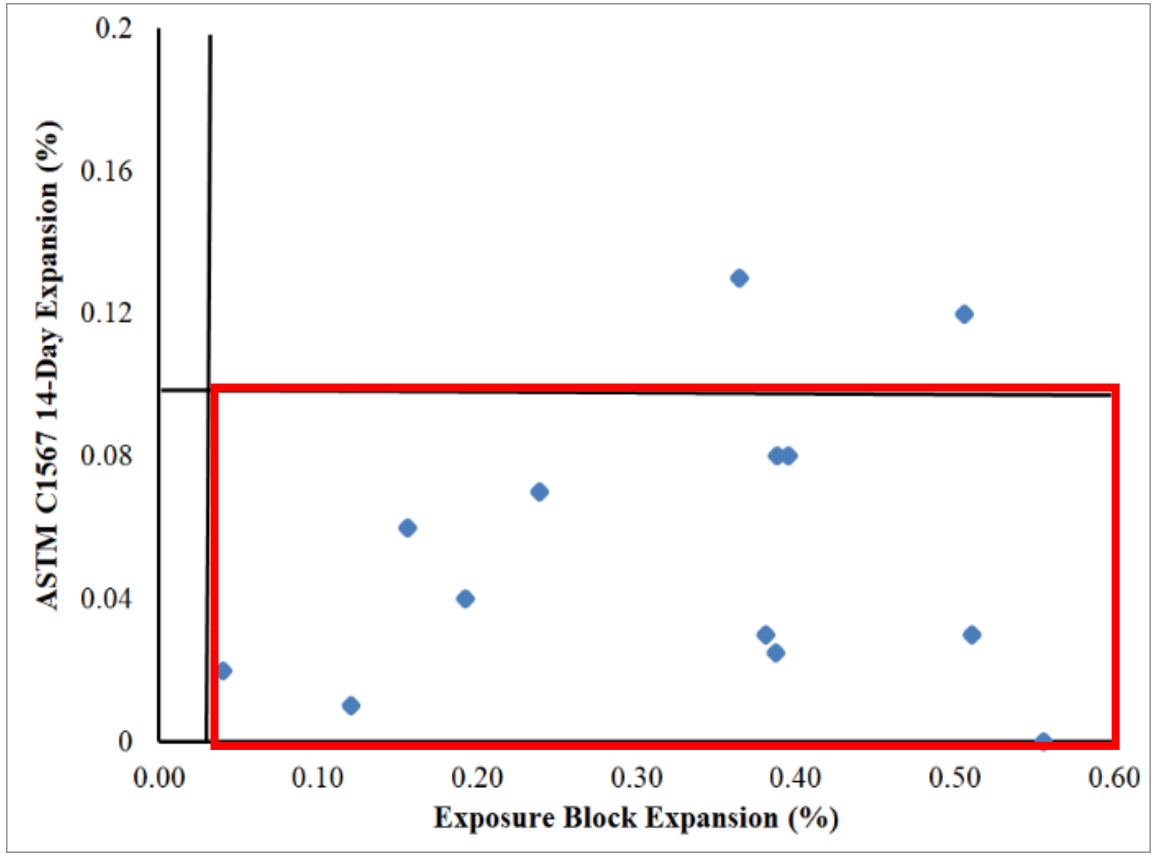
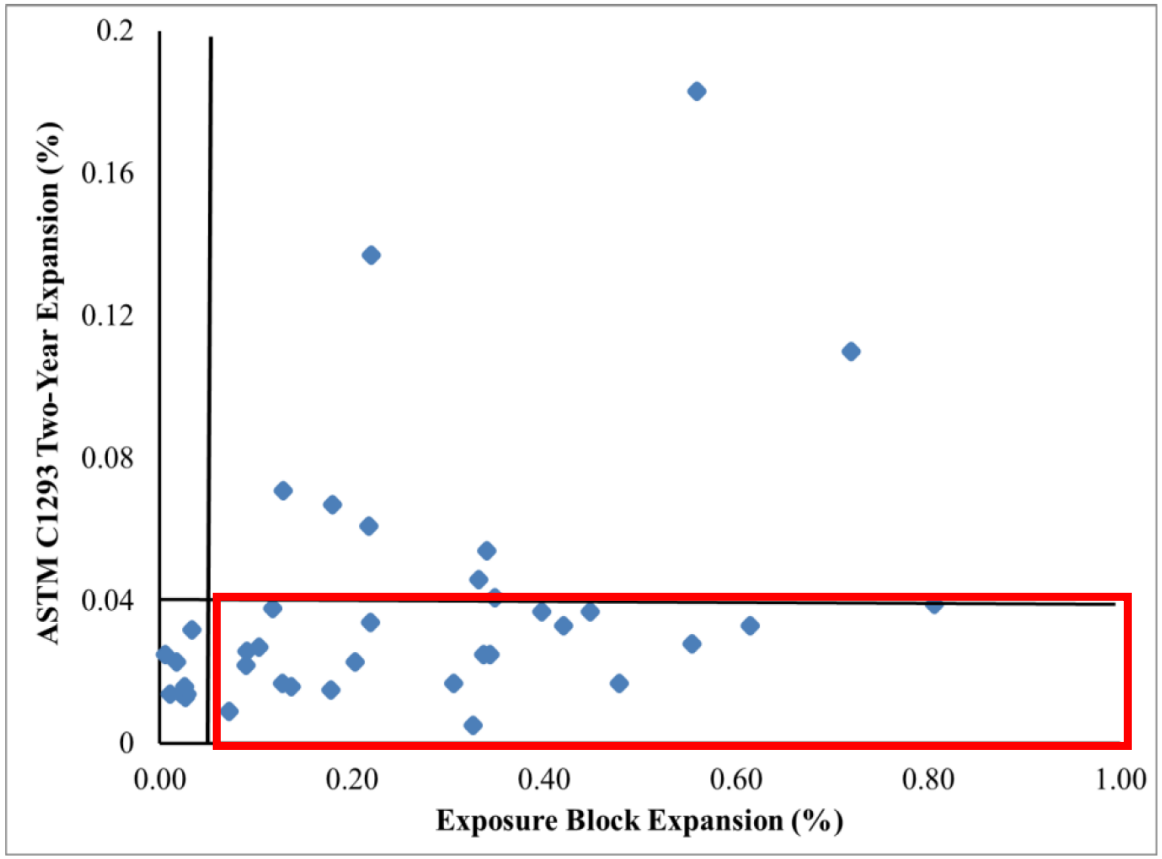
Correlation between Standardized Test Methods and Exposure blocks (SCM Mixtures)



AMBT



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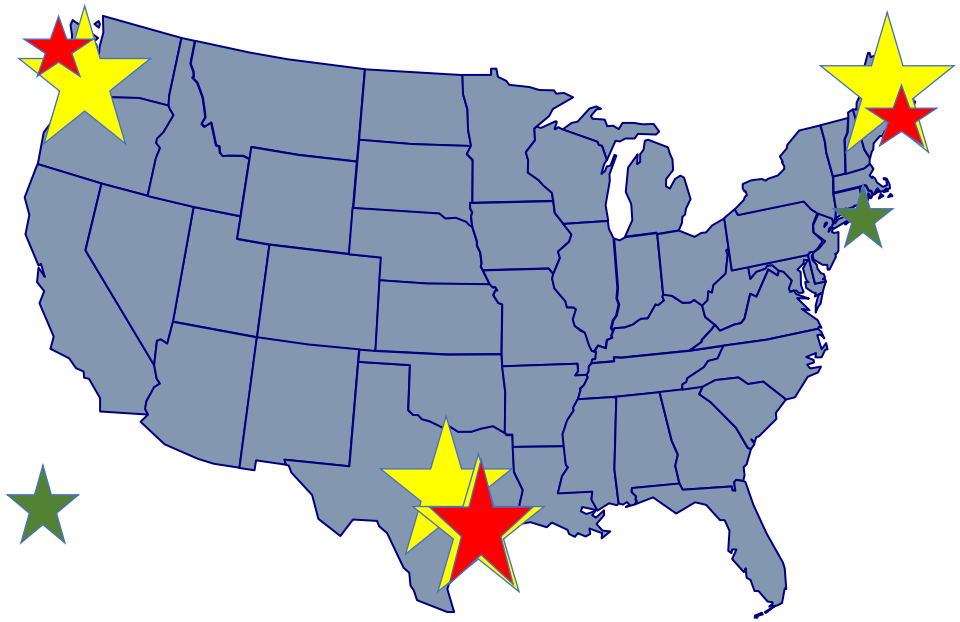
NCHRP 10-103 Objective

The goal of this research project is to improve the Guidance of AASHTO R 80/ASTM C 1778 for Alkali-Silica Reactivity (ASR) Potential and Mitigation through:

1. **Construct and evaluate field exposure blocks with varying concrete materials placed in diverse environmental conditions to supplement the existing information.**
2. Enable improved benchmarking of current performance and job mixture tests that have been or are being developed currently.

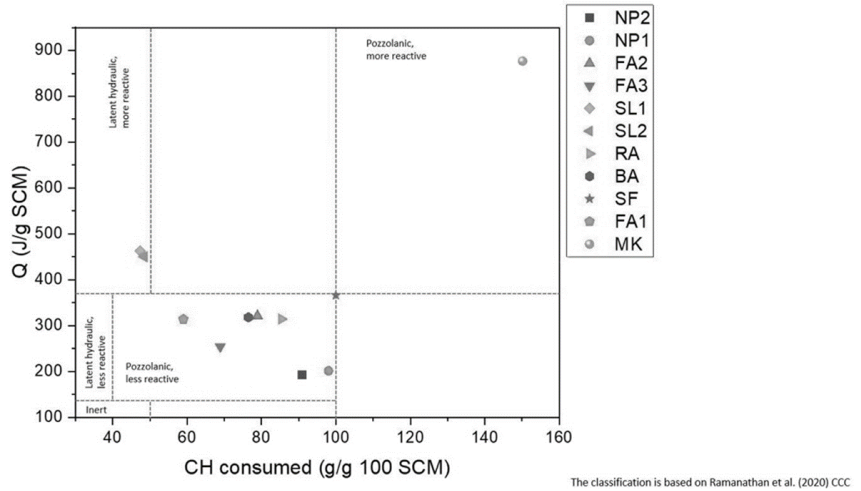
Casting of New Concrete Exposure Blocks

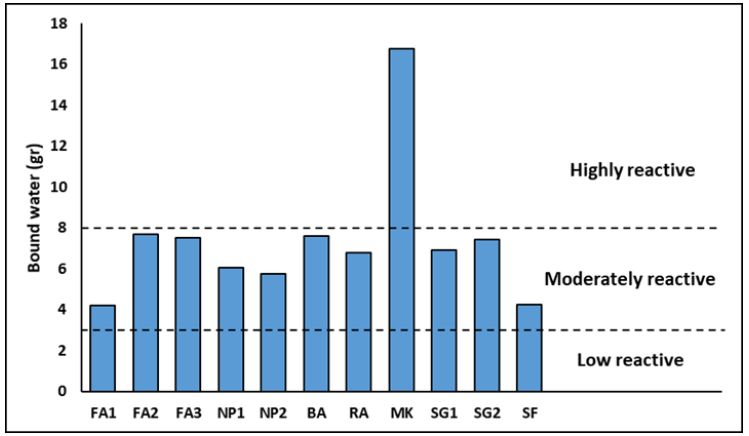
- Cast 450 exposure blocks
  - Focus on lower aggregate reactivity (R1 and R2 aggregates)
  - Focus on lower alkali loadings
  - Representative of highway infrastructure mixture designs
  - SCMs
    - Reclaimed Fly Ash
    - Bottom Ash
    - Natural pozzolans
    - Metakaolin
    - Slag Cement
  - Environmental Factors

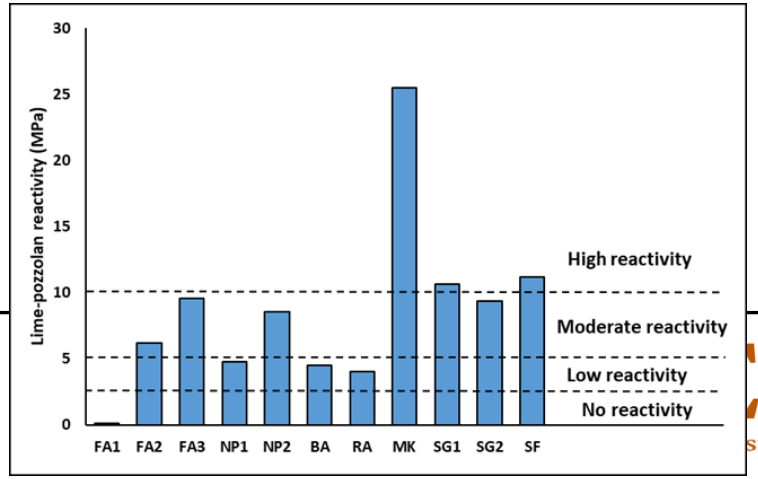


Aggregates	Aggregate ID	Location	Coarse/Fine	Initial Reactivity
University of Texas	NR1	Central Texas	Coarse	R0
	NR2	Central Texas	Fine	R0
	RAT1	Central Texas	Fine	R1
	RAT2	South Texas	Fine	R2
Oregon State University	RAO1	NE California	Fine	R3
	RAO2	SW Oregon	Fine	R3
University of New Brunswick	NR3	Newfoundland	Coarse	R0
	NR4	Newfoundland	Fine	R0
	RAC1	New Brunswick	Coarse	R3
	RAC2	Nova Scotia	Coarse	R2
Common Aggregates	CA1	Pennsylvania	Coarse	R1
	CA2	Wyoming	Coarse	R1
	CA3	North Carolina	Coarse	R1
	CA4	Virginia	Coarse	R1
Historical Aggregates	Jobe	West Texas	Fine	R3
	Spratt	Ontario	Coarse	R3
	Placitas	New Mexico	Coarse	R3
	Sudbury	Ontario	Coarse	R2

Cement	Location/ Source	Specific Material Property
ASTM C150 lower alkali	CM1	0.50 (Na_2O_{eq})
ASTM C150 higher alkali	CM2	1.13 (Na_2O_{eq})
ASTM C595 IL	CM3	IL
SCMs		
Class F Ash 1	FA1	5% CaO
Class F Ash 2	FA2	13% CaO
Class C Ash	FA3	24% CaO
Slag 1	LH	From United States
Slag 2	LH	Imported
Silica Fume (SF)	SF	Densified
Metakaolin	MK	Highly reactive
Natural Pozzolan 1	NP1	Volcanic glass
Natural Pozzolan 2	NP2	Pumiceous Tuff
Reclaimed Ash	RA	2.7 CaO
Blended Fly Ash	BA	15.7
Lithium Nitrate	Li	30% lithium nitrate solution







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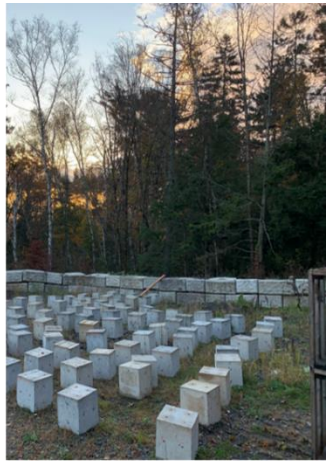
Austin, TX., USA

Corvallis, OR., USA



Fredericton, NB. , Canada

Port Aransas, TX. USA

Newport, OR., USA

Treat Island, ME., USA

Boston, MA., USA

Honolulu, HI., USA

NCHRP 10-103 Objective

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1. Construct and evaluate field exposure blocks with varying concrete materials placed in diverse environmental conditions to supplement the existing information.
   - Less severe blocks (lower alkali loadings, lower aggregate reactivity)
   - SCMs
   - Time!

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2. **Enable improved benchmarking of current performance and job mixture tests that have been or are being developed currently.**

Existing Standard Laboratory Tests

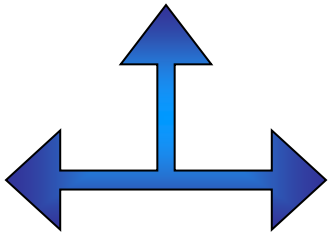
Laboratory Tests have to "benchmarked" against tests on concrete in real exposure conditions

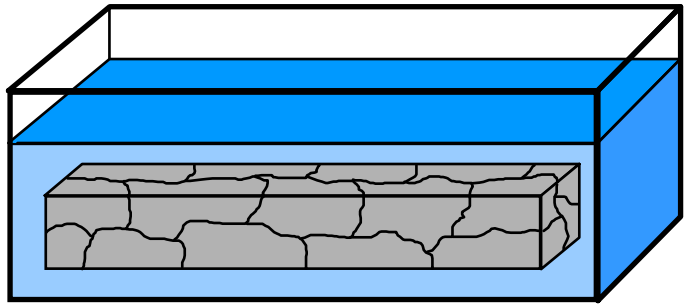
Concrete Prism Test (CPT)

Field exposure of large blocks

- CSA, ASTM C1778, and AASHTO R80 are all bench-marked against high-alkali exposure blocks.
- CSA guidelines rely upon CPT only, whereas ASTM/AASHTO allow CPT and/or AMBT.

Accelerated Mortar Bar Test (AMBT)





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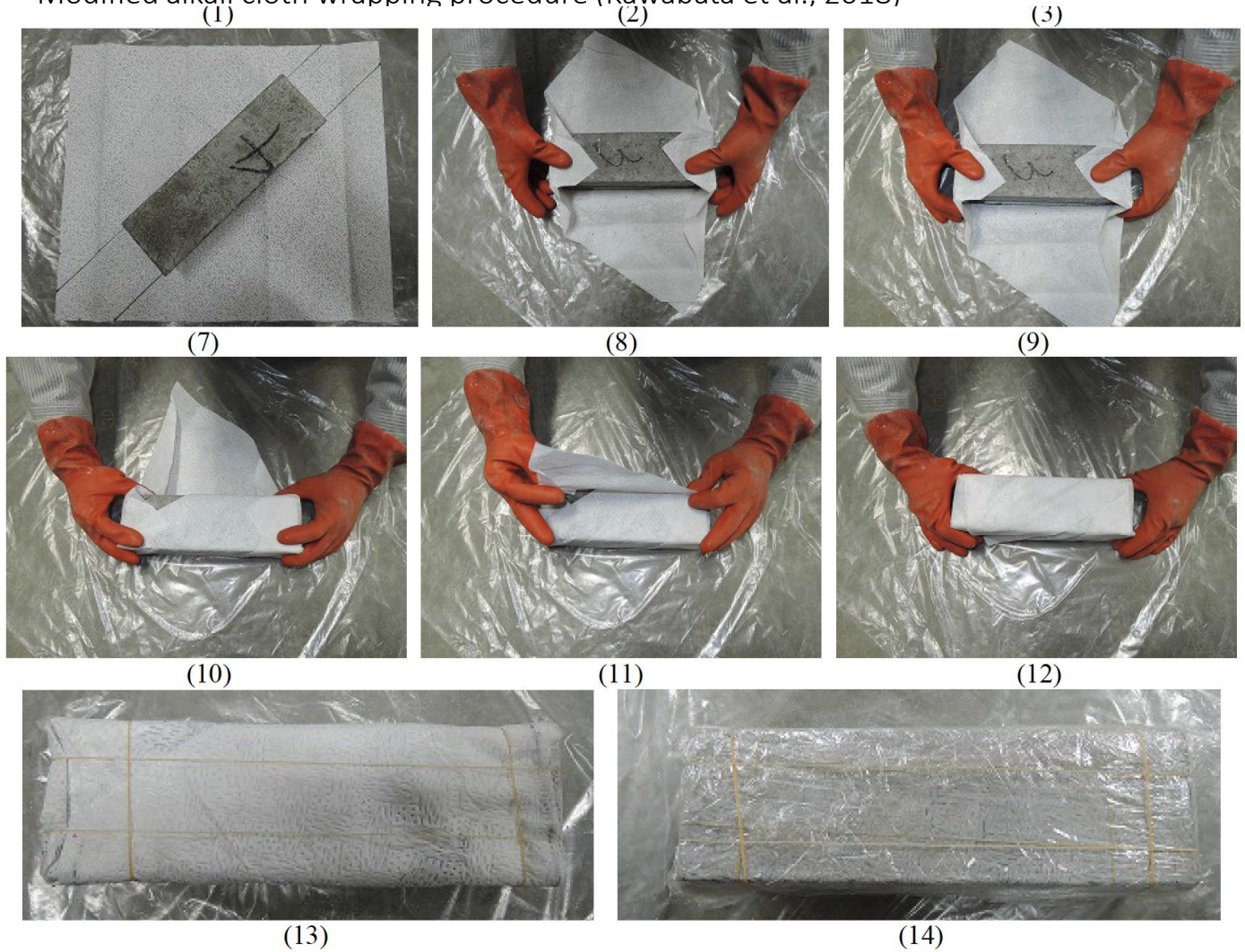
New/Modified Laboratory Tests

Several new and revised test methods were included:

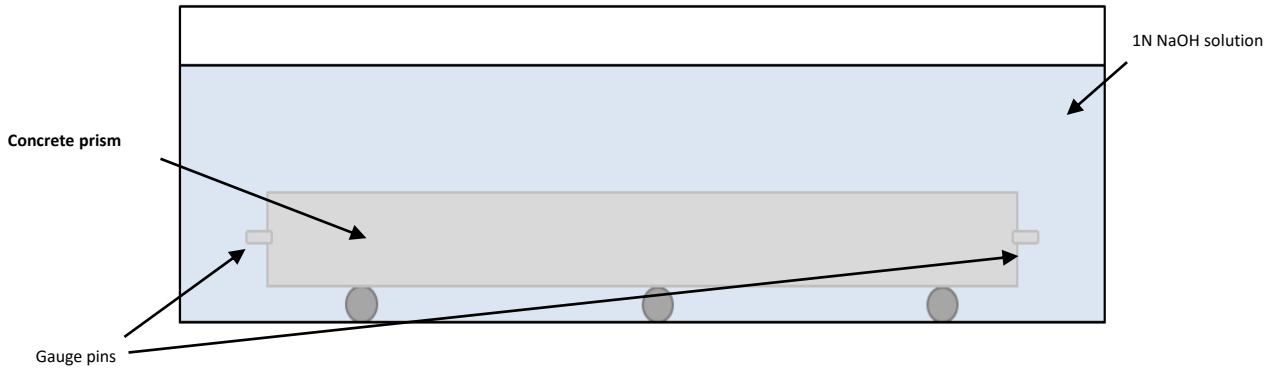
- AASHTO T380 (miniature concrete prism test)
- UNBCCT (University of New Brunswick Concrete Prism Test)
- T-Fast
- Variations of ASTM C1293, including wrapping of prisms (to reduce leaching)

RILEM AAR-13

Modified alkali cloth wrapping procedure (Kawabata et al., 2018)



AASHTO T380 (Miniature Concrete Prism Test)



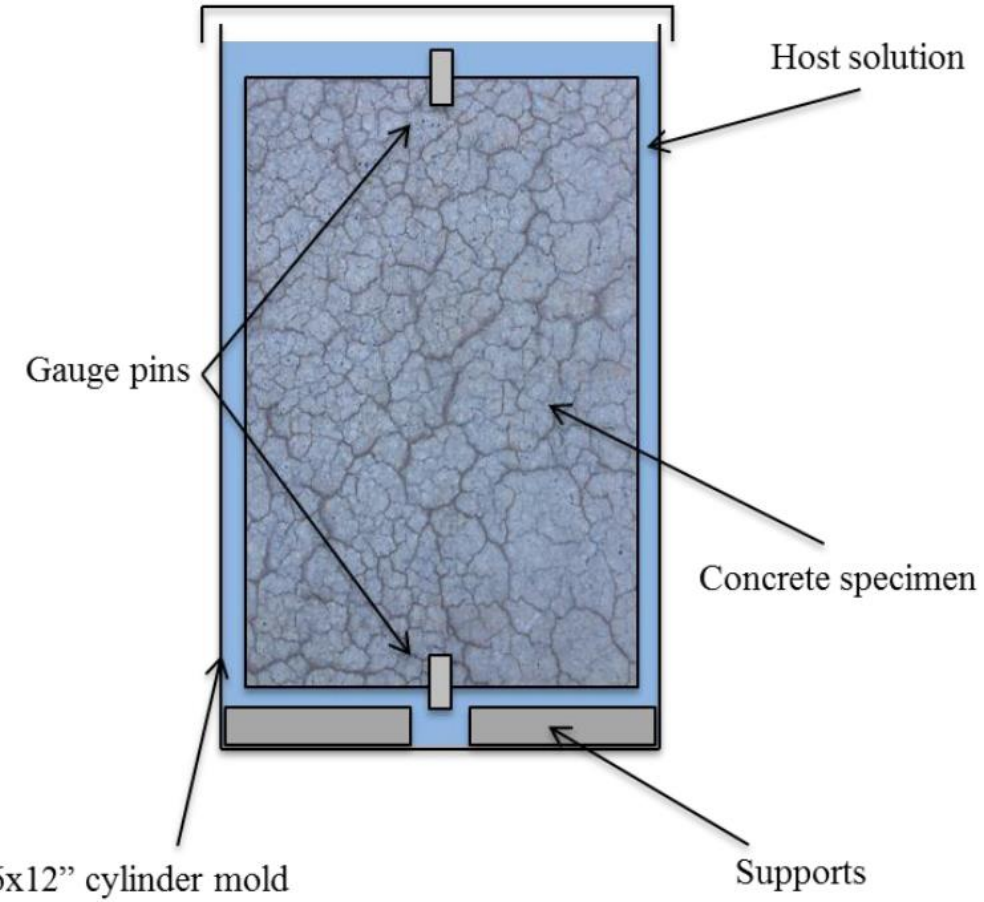
MCPT

Latifee and Rangaraju, 2015

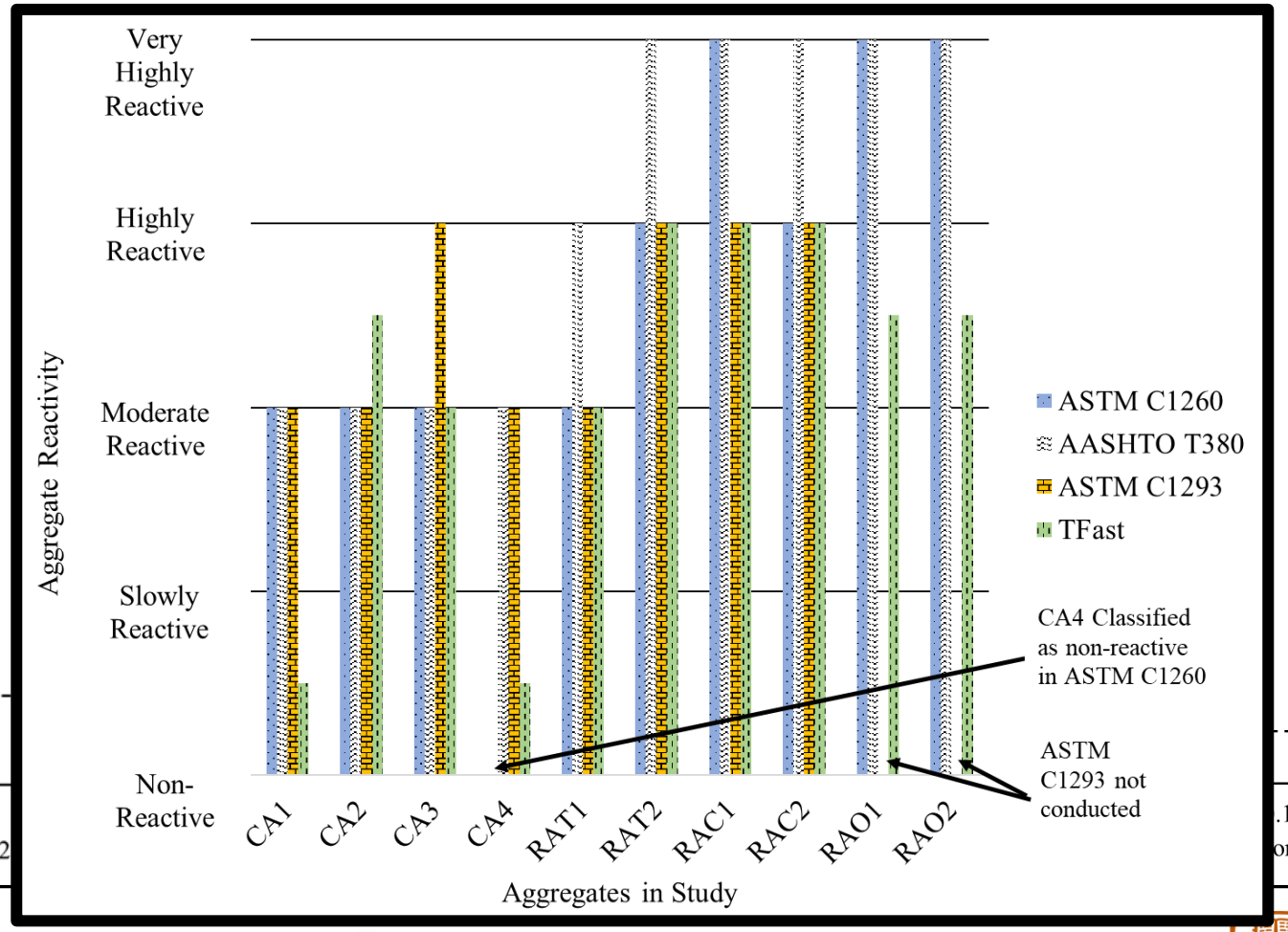
- Miniature concrete prism test
- 2 x 2 x 11.25 in. (50 X 50 X 285mm) bar
- 140 F (60 C) exposure
- 1 N NaOH (current standard)
- 56 or 84 day duration

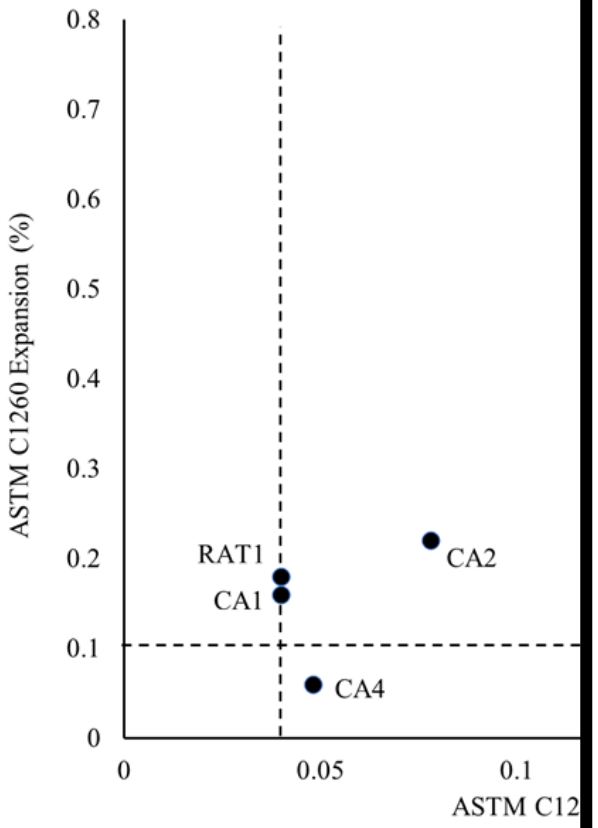
University of New Brunswick Concrete Cylinder Test (UNBCCT)

- 145 x 280 mm cylinders cast, stored in 150 x 300 mm. mold
- Matched pore solution fills area between mold and cylinder
- 60C (140F) temperature



Project Aggregates: Aggregate Reactivity – Test Method Comparison





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Project Agg … revention Following A … ive Levels

TAB…

Type of SCM[A]	Alkali Conter… (% Na_2…
Fly ash[B] (CaO ≤ 18 %)	<3.0
	3.0 – …
Slag Cement	<1.0
Silica Fume[C] (SiO_2 > 85 %)	<1.0

[A] The SCM may be added directly to the c… cement should meet the specifications … requirements of Specification C595/C595…
[B] Fly ashes with greater than 18 % CaO ca… in 8.2 and 8.3.
[C] The minimum level of silica fume (as a p… (KGA) or lb/yd^3 (LBA). Regardless of the…
[D] Note—the use of high levels of SCM in … and cured.

…n s)	
Level Z	Level ZZ
35	Table 8
40	
65	
4.0 × KGA or 2.5 × LBA	

…uirements of Specification C618, slag …. Blended cements should meet the …

…he performance-based testing outlined …

…rete expressed in either units of kg/m^3 …he only method of prevention. …is not properly proportioned, finished,

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C295/C295M Guide for Petrographic Examination of Aggregates for Concrete
C311/C311M Test Methods for Sampling and Testing Fly Ash or Natural Pozzolans for Use in Portland-Cement Concrete
C586 Test Method for Potential Alkali Reactivity of Carbonate Rocks as Concrete Aggregates (Rock-Cylinder Method)
C595/C595M Specification for Blended Hydraulic Cements
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C1157/C1157M Performance Specification for Hydraulic Cement
C1240 Specification for Silica Fume Used in Cementitious Mixtures
C1260 Test Method for Potential Alkali Reactivity of Aggregates (Mortar-Bar Method)

[1] This guide is under the jurisdiction of ASTM Committee C09 on Concrete and Concrete Aggregates and is the direct responsibility of Subcommittee C09.50 on Aggregate Reactions in Concrete.
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*A Summary of Changes section appears at the end of this standard

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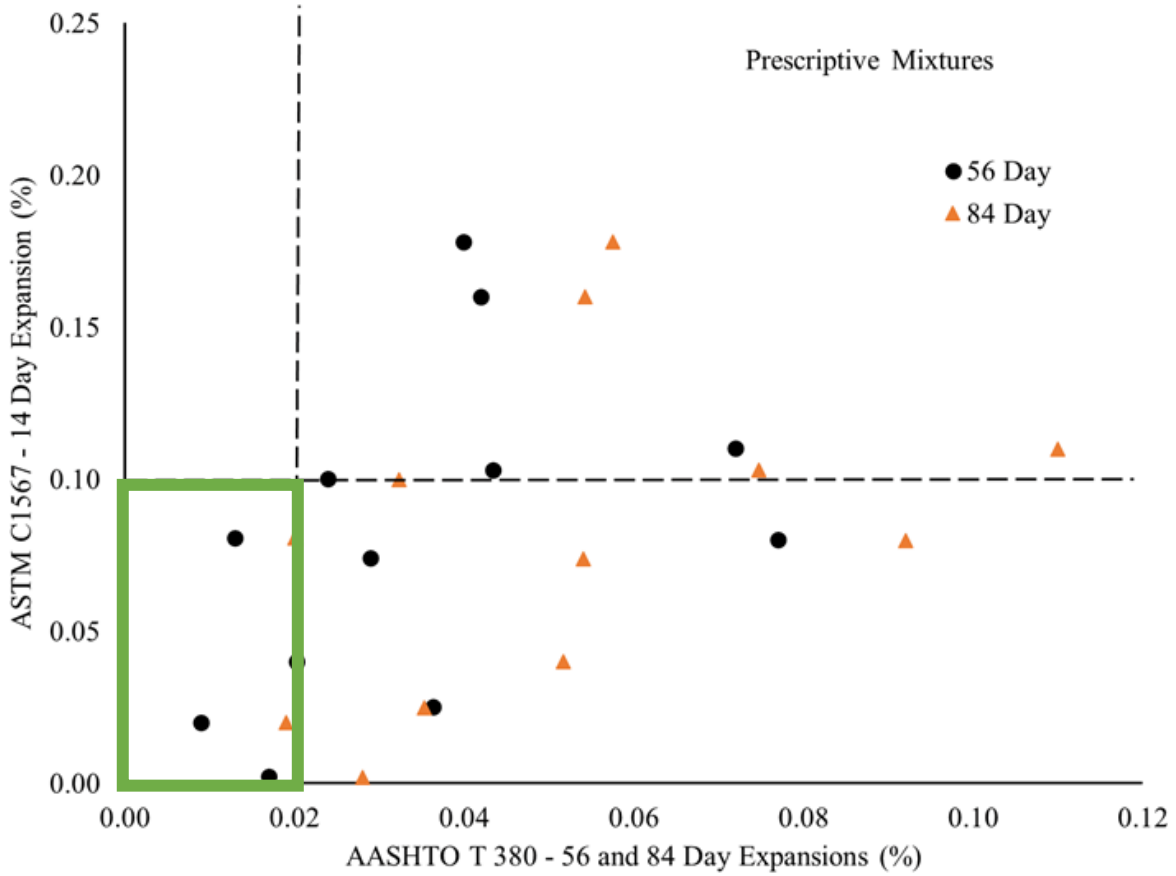
Project Aggregates: Aggregate Prevention Following ASTM C1778 Prescriptive Levels



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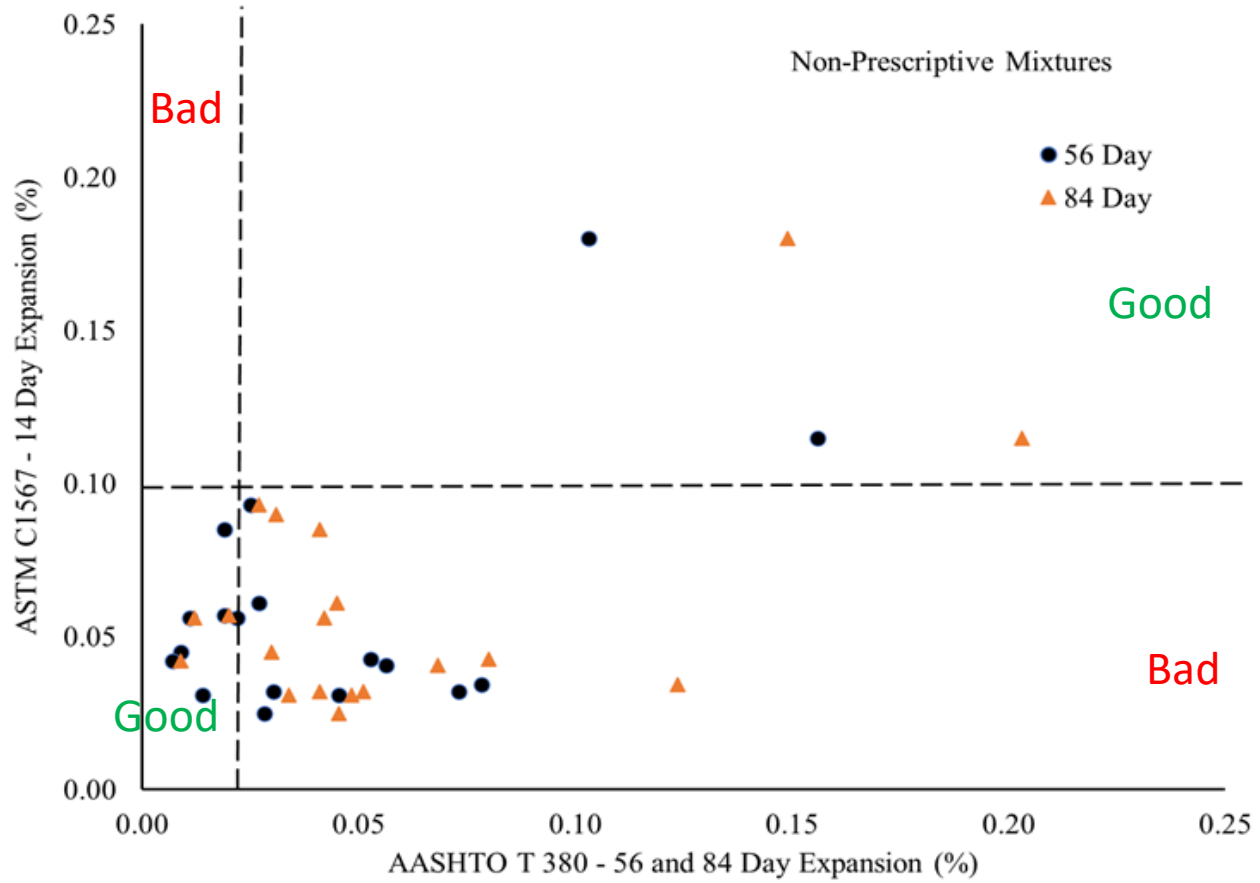
Project Aggregates: Aggregate Prevention Following ASTM C1778 Non-Prescriptive Levels

Non-Prescriptive SCMs

- Blended Ash
- Metakaolin
- Reclaimed Ash
- High Calcium Fly Ash (Class C)
- Natural Pozzolans



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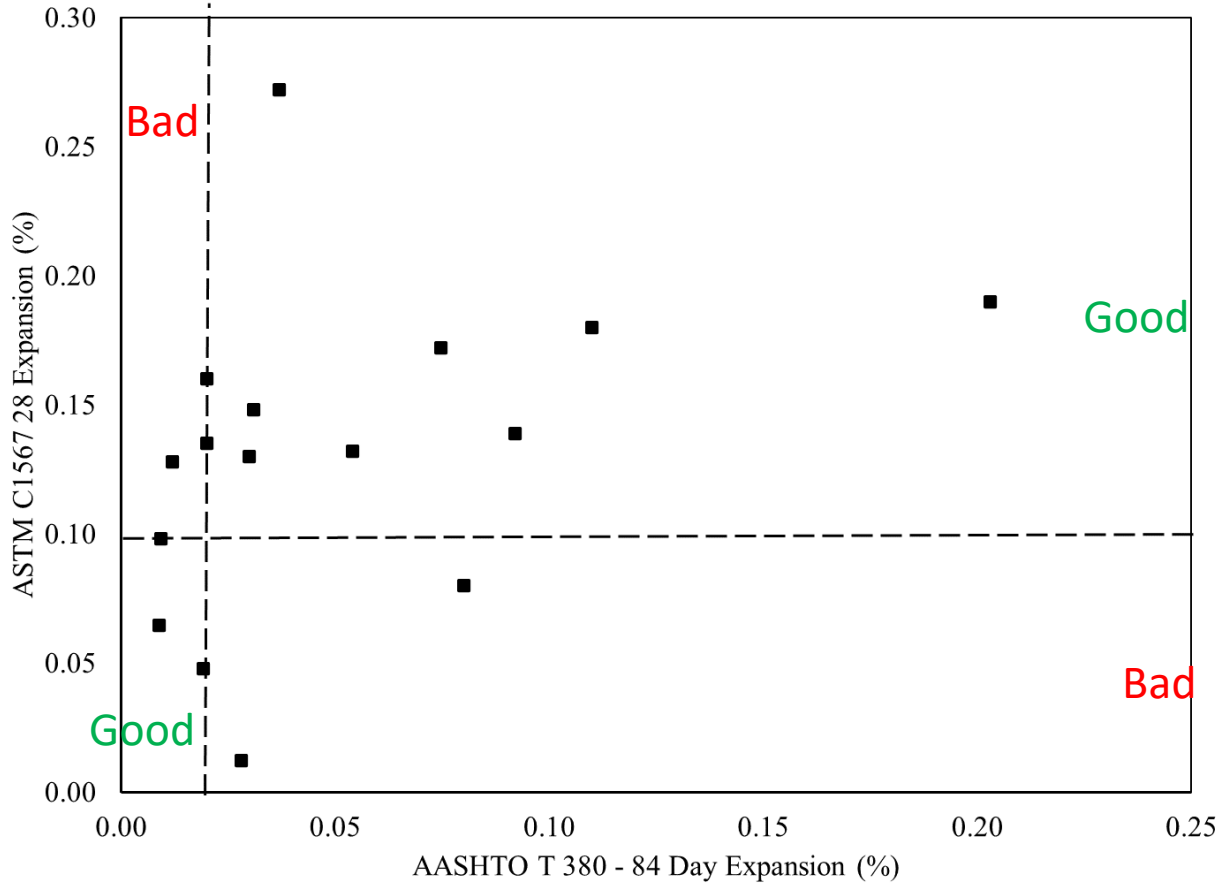

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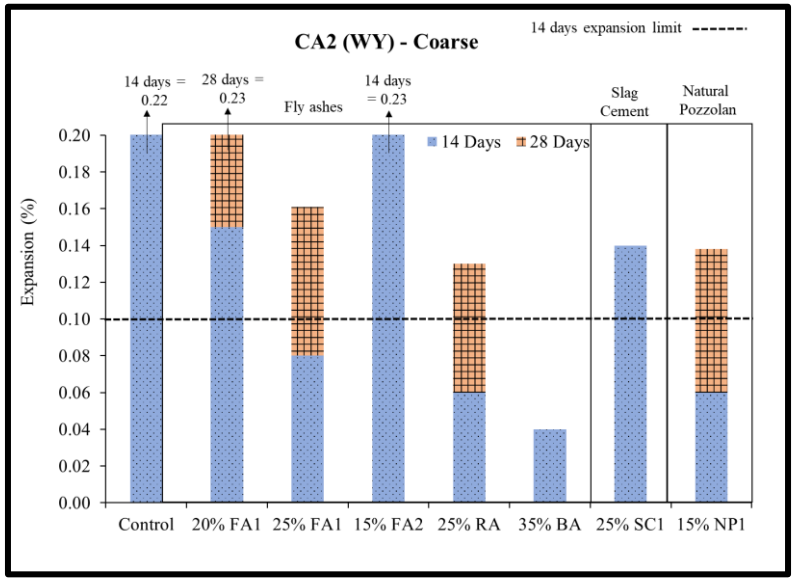
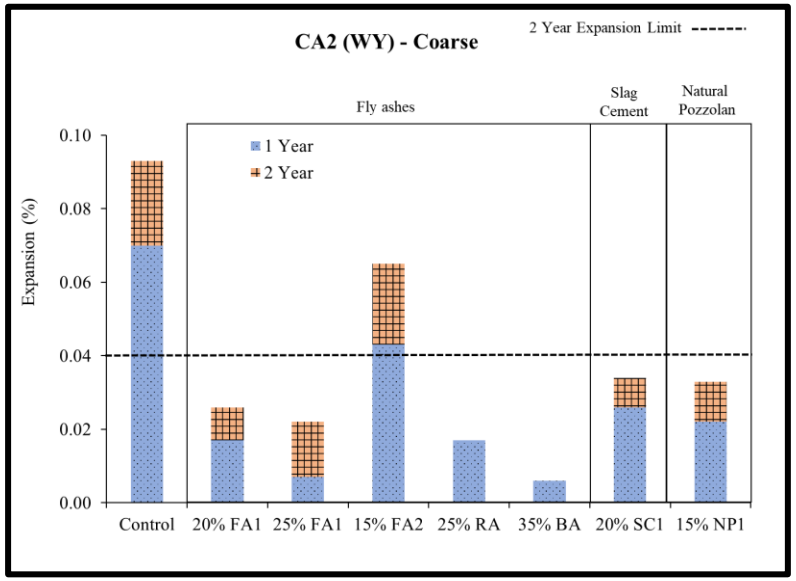
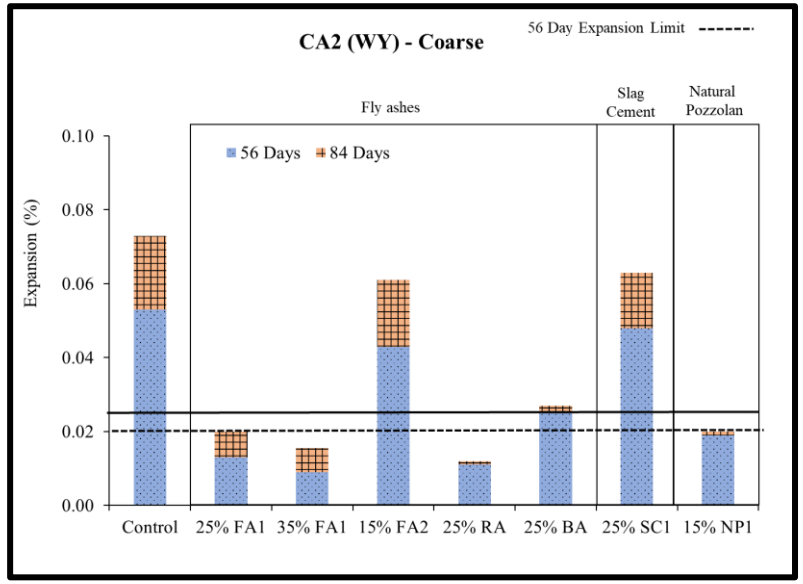
Prevention of R1 Aggregate – ASTM C1567



ASTM C1567



ASTM C1293



AASHTO T 380

More tests

- UNBCCT
- AAR-13

This data will help benchmark against the 450 concrete exposure blocks

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Project Agg … revention Following A … ive Levels

TAB…

Type of SCM[A]	Alkali Conter… (% Na_2…
Fly ash[B] (CaO ≤ 18 %)	<3.0
	3.0 – …
Slag Cement	<1.0
Silica Fume[C] (SiO_2 > 85 %)	<1.0

[A] The SCM may be added directly to the c… cement should meet the specifications … requirements of Specification C595/C595…
[B] Fly ashes with greater than 18 % CaO ca… in 8.2 and 8.3.
[C] The minimum level of silica fume (as a p… (KGA) or lb/yd^3 (LBA). Regardless of the…
[D] Note—the use of high levels of SCM in … and cured.

…n s)	
Level Z	Level ZZ
35	Table 8
40	
65	
4.0 × KGA or 2.5 × LBA	

…uirements of Specification C618, slag …. Blended cements should meet the …

…he performance-based testing outlined …

…rete expressed in either units of kg/m^3 …he only method of prevention. …is not properly proportioned, finished,

This International standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.

Designation: C1778 – 22

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

This standard is issued under the fixed designation C1778; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope*

1.1 This guide provides guidance on how to address the potential for deleterious alkali aggregate reaction (AAR) in concrete construction. This guide addresses the process of identifying both potentially alkali-silica reactive (ASR) and alkali-carbonate reactive (ACR) aggregates through standardized testing procedures and the selection of mitigation options to minimize the risk of expansion when ASR aggregates are used in concrete construction. Mitigation methods for ASR aggregates are selected using either prescriptive or performance-based alternatives. Preventive measures for ACR aggregates are limited to avoidance of use. Because the potential for deleterious reactions depends not only on the concrete mixture but also the in-service exposure, guidance is provided on the type of structures and exposure environments where AAR may be of concern.

1.2 *Units*—The values stated in either SI units or inch-pound units are to be regarded separately as standard. The values stated in each system may not be exact equivalents; therefore, each system shall be used independently of the other. Combining values from the two systems may result in nonconformance with the standard.

1.3 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety, health, and environmental practices and determine the applicability of regulatory limitations prior to use.*

1.4 *This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.*

2. Referenced Documents

2.1 *ASTM Standards:*[2]
C33/C33M Specification for Concrete Aggregates
C114 Test Methods for Chemical Analysis of Hydraulic Cement
C125 Terminology Relating to Concrete and Concrete Aggregates
C150/C150M Specification for Portland Cement
C219 Terminology Relating to Hydraulic and Other Inorganic Cements
C294 Descriptive Nomenclature for Constituents of Concrete Aggregates
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ASTM C1778 Recommended New Prescriptive Table

Type of SCM	Alkali Level of SCM (%Na_2O_e)	Minimum Replacement Level ** (% by mass of Cementitious Material)				
		Level W	Level X	Level Y	Level Z	Level ZZ
Fly Ash ($CaO \leq 18\%$)	$x \leq 3.0$	20	25	25	35	Table 7
	$3.0 < x \leq 4.5$	25	30	Not Permitted	Not Permitted	
Slag Cement	< 1.0	30	40	50	65	
Natural Pozzolan *(Meeting ASTM C618 Class N)*	$x \leq 8.0$	25	Assess in C1567/ T 380	Assess in C1567/ T 380	Assess in C1567/ T 380	
Silica Fume ($SiO_2 \geq 0.85$)	$\leq 1.0\%$	2.0 x KGA 1.2 x LBA	2.5 x KGA or 1.5 LBA	Not permitted as a sole preventive option	Not permitted as a sole preventive option	

- Increasing the minimum fly ash replacement level for fly ash and slag cement
- Addition of Natural pozzolans
- Not permitting higher alkali fly ash and silica fume in higher risk situations

Correlations with Historical exposure blocks

Test Method	Accuracy of Tests Matching Historical Blocks
ASTM C1567	14 Day Expansion Limit = 0.100
	44%
ASTM C1567	28 Day Expansion Limit = 0.100
	81%
ASTM C1293	2 Year Expansion Limit = 0.040
	28%
AAR-13	2 Year Expansion Limit = 0.040
	13%
AASHTO T 380	84 Day Expansion Limit = 0.030
	63%
UNBCCT	1 Year Expansion Limit = 0.040
	38%

Greater than 75% Correlation would be satisfactory

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Correlations with Historical exposure blocks

Test Method	Accuracy of Tests Matching Historical Blocks		
ASTM C1567	14 Day Expansion Limit = 0.100	14 Day Expansion Limit = 0.080	[redacted]
	44%	56%	
ASTM C1567	28 Day Expansion Limit = 0.100	28 Day Expansion Limit = 0.080	
	81%	88%	
ASTM C1293	2 Year Expansion Limit = 0.040	2 Year Expansion Limit = 0.030	
	28%	39%	
AAR-13	2 Year Expansion Limit = 0.040	2 Year Expansion Limit = 0.030	
	13%	25%	
AASHTO T 380	84 Day Expansion Limit = 0.030	84 Day Expansion Limit = 0.025	
	63%	75%	
UNBCCT	1 Year Expansion Limit = 0.040	1 Year Expansion Limit = 0.030	
	38%	77%	

Greater than 75% Correlation would be satisfactory

Correlations with Historical exposure blocks

Test Method	Accuracy of Tests Matching Historical Blocks		
ASTM C1567	14 Day Expansion Limit = 0.100	14 Day Expansion Limit = 0.080	14 Day Expansion Limit = 0.060
	44%	56%	72%
ASTM C1567	28 Day Expansion Limit = 0.100	28 Day Expansion Limit = 0.080	28 Day Expansion Limit = 0.060
	81%	88%	94%
ASTM C1293	2 Year Expansion Limit = 0.040	2 Year Expansion Limit = 0.030	2 Year Expansion Limit = 0.020
	28%	39%	56%
AAR-13	2 Year Expansion Limit = 0.040	2 Year Expansion Limit = 0.030	2 Year Expansion Limit = 0.020
	13%	25%	63%
AASHTO T 380	84 Day Expansion Limit = 0.030	84 Day Expansion Limit = 0.025	84 Day Expansion Limit = 0.020
	63%	75%	81%
UNBCCT	1 Year Expansion Limit = 0.040	1 Year Expansion Limit = 0.030	1 Year Expansion Limit = 0.020
	38%	77%	92%

Greater than 75% Correlation would be satisfactory

Lessons Learned Since Development of ASTM C1778

1. The concrete prism test has continued to be very reliable in assessing aggregate reactivity (1-yr, 0.04% expansion).
2. The 2-year concrete prism test has been found to underestimate the dosage of SCM (or lithium nitrate) needed to control ASR-induced expansion, based on correlation with high-alkali loading exposure blocks.
3. Based on the preliminary findings from NCHRP 10-103, revisions are recommended to ASTM C1778/AASHTO R80, as described next.

NCHRP 10-103 – KEY FINDINGS AND RECOMMENDATIONS

1. ASTM C1293 is still recommended for evaluating aggregate reactivity but NOT to evaluate preventive measures.
2. AASHTO T380 is recommended to evaluate aggregate reactivity or preventive measures (56 and 84 day expansion limits, respectively).
3. ASTM C1567, once properly benchmarked against ASTM C1293 or AASHTO T380 for a given aggregate, can be used to determine SCM dosage using a 28-day expansion limit of 0.10 percent.
4. Natural pozzolans should be included both in the performance and prescriptive-based approaches.
5. The SCM dosages previously recommended should be increased to better correlate with exposure blocks.
6. A combination of SCMs and cement alkali loading limits are recommended for critical structures.
7. All of these recommendations may change as the data from the 450 exposure blocks emerges.

Other Continuing ASR Research

Under funding from Airfield Pavement Technology Program (ACPTP):

- Additional materials, including Natural Pozzolans, Reclaimed or blended fly ashes, ground bottom ash, and chemical admixtures (e.g., calcium nitrite, magnesium acetate) are being evaluated.
- New test methods are being evaluated, including:
  - Alkali release tests (from SCMs or aggregates)
  - Alkali Threshold Test

Thank you!

Thano Drimalas
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Questions?

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