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How Do We Specify Concrete that is Resistant to ASR?

Jason H. Ideker

Professor

School of Civil and Construction Engineering
Oregon State University, Corvallis, United States

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Jason H. Ideker Background

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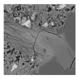

Professor at Oregon State University

2008-Present

Fundamental cement-based materials research

Alkali-silica reaction, test methods, prevention, mitigation in structures

Early-age properties of cement-based materials, calcium aluminate cements

Translating laboratory and field experience into standardization

Working in the area of ASR since 2001 as an undergraduate at Georgia Tech

Co-Author of ACI 201.2R-16 – Guide to Durable Concrete

Secretary of Subcommittee ASTM C 09.50 "Risk Management for Alkali-Aggregate Reactivity

Chair – RILEM TC ASR

Risk assessment of concrete mixture designs with alkali-silica reactive (ASR) aggregates

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Overview

- ASR Basics
- Specifying ASR resistant concrete
- Proper test methods are critical: A Case Study
- Current research

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Alkali-Aggregate Reaction (AAR)
- Alkali-Carbonate Reaction (ACR) <1% of cases
- Alkali-Silica Reaction (ASR) > 99% of cases

Alkali-Carbonate Reaction (ACR) – ACR occurs between alkali hydroxides and certain argillaceous dolomitic limestones. This reaction is characterized by rapid expansion and extensive cracking of the affected concrete. ACR is a serious, but fortunately rare, variety of AAR.

Alkali-Silica Reaction (ASR) – is associated with the dissolution of silica (SiO_2) in the aggregate and the subsequent formation of alkali-silica gel in the aggregate and concrete.

We will only be dealing with **ASR** today

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History of ASR

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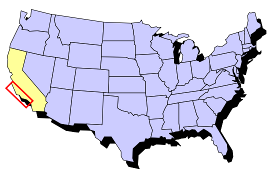

- First discovered in the late 1930's
- In Monterey County & Los Angeles County
- Thomas Stanton of California State Division of Highways

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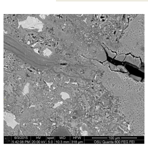
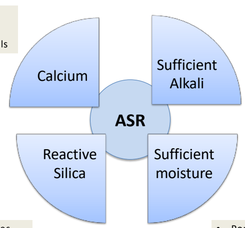
Alkali-silica reaction (ASR)

- Cement
- Supplementary cementitious materials





- Cement
- Supplementary cementitious materials
- Aggregates
- External sources (deicers)
- Chemical admixtures

Reactive aggregates
- Fine aggregates
- Coarse aggregates

- Pore solution in concrete
- Concrete exposed to moist environment (RH ≥ 60%)

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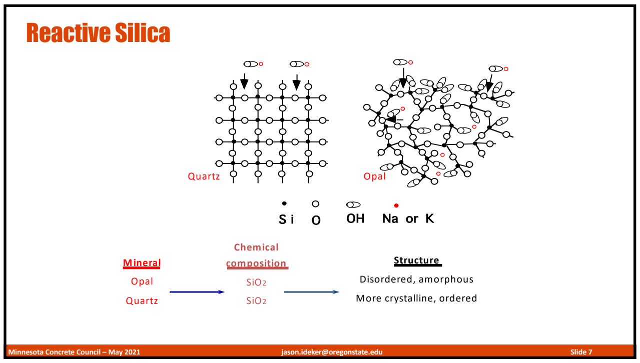
Reactive Silica
Quartz
Opal
Si O OH Na or K
Mineral
Opal
Quartz
Chemical composition
SiO2
SiO2
Structure
Disordered, amorphous
More crystalline, ordered
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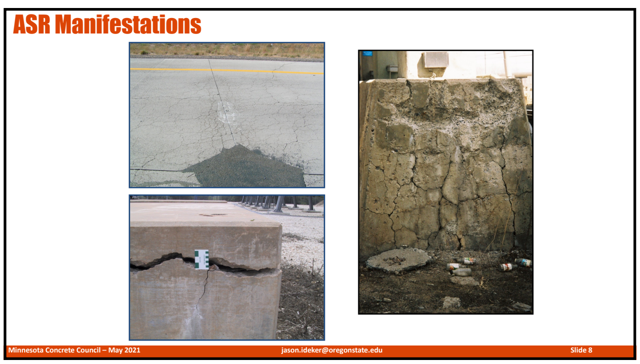
ASR Manifestations
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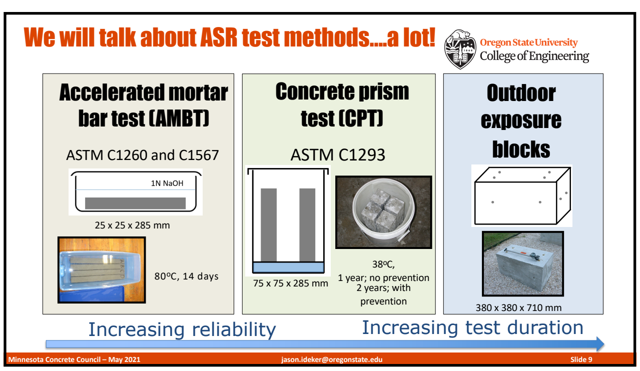
We will talk about ASR test methods....a lot!
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College of Engineering
Accelerated mortar bar test (AMBT)
ASTM C1260 and C1567
1N NaOH
25 x 25 x 285 mm
80ºC, 14 days
Concrete prism test (CPT)
ASTM C1293
75 x 75 x 285 mm
38ºC,
1 year; no prevention
2 years; with prevention
Outdoor exposure blocks
380 x 380 x 710 mm
Increasing reliability
Increasing test duration
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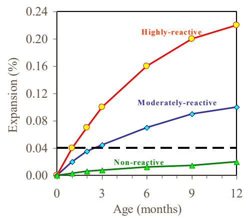
Example Concrete Prism Test Results

Image Source: https://www.globalgilson.com/length-comparator



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Prevention of ASR in Fresh Concrete

Most Supplementary Cementing Materials (SCMs) can be used to control ASR

- SCM composition (CaO, SiO_2, $\mathbf{Al_2O_3}$, Na_2O_e)
- Dosage rate
- Nature and level of aggregate reactivity
- Alkali content supplied by the portland cement (and other sources also important)

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Prevention of ASR in Fresh Concrete

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- **Most SCMs can be used to control ASR**
  - SCM composition (CaO, SiO_2, Al_2O_3, Na_2O_e)
  - Dosage rate
  - Nature and level of aggregate reactivity
  - Alkali content supplied by the portland cement (and other sources also important)
- **Lithium can also be used to control ASR in fresh concrete, and may be used in combination with SCMs**
  - Provided Li / (Na+K) is sufficient (can be determined through testing)
    - Depends on aggregate reactivity level
- **Restricting alkali contribution**
  - Alkali loading is key, not just alkali content of portland cement
  - Low alkali cement – energy intensive
- **Avoid reactive aggregates**
  - Usually not an option
  - Highly critical structures

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SCM Prevention Mechanisms for ASR

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1. Reduce CH (lower pH)
   – Reduce pore solution alkalinity
2. We produce more C-S-H and/or C-A-S-H (pozzolanic reaction)
   – Better mechanical properties (e.g. strength)
   – Refine pore network (e.g. higher tortuosity, lower permeability)
   – Reduces CH (lower pH)
3. Alumina in pore solution protects silica from dissolution (aggregate protection)
4. We use less OPC (dilution, reduce alkalis)
   – But what about SCMs with alkalis?

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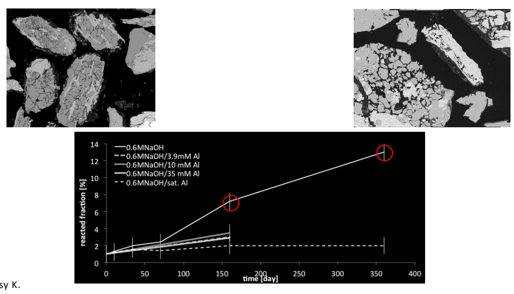

Slide: Courtesy K. Scrivener/T. Chappex

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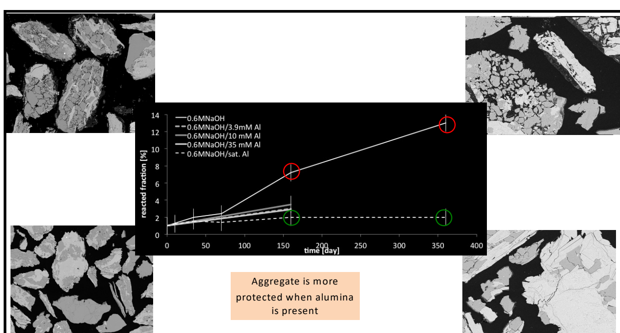

Slide: Courtesy K. Scrivener/T. Chappex

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How do we design concrete mixtures that are resistant to ASR?

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ASR Standards

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Two main approaches:

- Prescriptive specifications
- Performance-based specifications

North American Standards Associations:

- CSA, ASTM, AASHTO, FHWA – use a combination of these approaches
- ACI 201-2R-16 gives general recommendations

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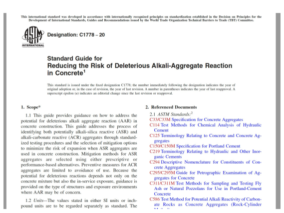
ASTM C 1778 - Risk Minimization for AAR


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 – 20

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

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

Adopted from:

Determining The Reactivity Of Concrete Aggregates And Selecting Appropriate Measures For Preventing Deleterious Expansion In New Concrete Construction
Thomas, Fournier & Folliard, 2008, Federal Highways Administration, FHWA-HIF-09-001

Standard Practice for Determining the Reactivity of Concrete Aggregates and Selecting Appropriate Measures for Preventing Deleterious Expansion in New Concrete Construction
AASHTO – PP65-11

One of the most comprehensive and progressive specifications in existence, aligns with AASHTO, FHWA and CSA.

Prescriptive & performance alternatives

Allows the use of reactive aggregates with the following preventive measures:

- Limiting the alkali content of the concrete
- Use of fly ash
- Use of slag
- Use of silica fume

The actual level of prevention varies with "risk" as defined by:

- Reactivity of the aggregate
- Nature of the structure (includes. design life)
- Exposure condition

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ASTM C 1778 - Prescriptive Approach

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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

Select the structure size and exposure category

Which defines the level of prevention needed

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

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

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-bearing 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

Select your Structure Classification

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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]

Determine the level of prevention

Select SCM replacement levels

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

Type of SCM[A]	Alkali Content of SCM (% Na_2O_e)	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	
	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	Table 8

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Performance Based Approach

- **ASTM C 295** - Standard Guide for Petrographic Examination of Aggregates for Concrete
- ASTM C 227 - Standard Test Method for Potential Alkali Reactivity of Cement-Aggregate Combinations (Mortar-Bar Method)
- **ASTM C 441** - Standard Test Method for Effectiveness of Mineral Admixtures or Ground Blast-Furnace Slag in Preventing Excessive Expansion of Concrete Due to the Alkali-Silica Reaction – Not recommended for ASR prevention evaluation
- **ASTM C 1260** - Standard Test Method for Potential Alkali-Silica Reactivity of Aggregates (Accelerated Mortar-Bar Method)
- **ASTM C 1567** Standard Test Method for Determining the Potential Alkali-Silica Reactivity of Combinations of Cementitious Materials and Aggregate (Accelerated Mortar-Bar Method)
- **ASTM C 1293** - Standard Test Method for Concrete Aggregates by Determination of Length Change of Concrete Due to Alkali-Silica Reaction (Concrete Prism Test)

Aggregate Tests

Mortar Tests

Concrete Test

Recommended Tests

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Proper Test Methods are Critical

Case Study Example

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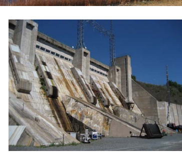
Mactaquac Generation Station

Aggregate: Greywacke

Testing methods ASTM C 227
mortar prisms over 38C water

at the time showed it was "non-reactive"



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Proper Test Methods are Critical
Mactaquac Generation Station

Significant expansion due to ASR

~$7 million per year spent on efforts to reduce the ill-effects of ASR

Intake Structure

Grown vertically by ~23 cm (~1 foot!)

Removed 63.5 cm (~2.5 feet) of concrete by slot cutting

~120 to 150 microstrain/year of unrestrained expansion

Service Life - ~150 years

How long will this last? ***~2030 – Complete replacement***

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Dealing with ASR at Mactaquac

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Slot Cutting to accommodate expansion

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Mactaquac Generation Status

Reconstruction – 2030 ??

- Number of alternatives investigated
- Construction of a similar powerhouse, intake and 10-bay spillway
- 500,000 m3 of concrete (654,000 yds^3)
- Same aggregate from excavation will be used
- Extensive study started in 2005 to determine most effective and economic means for preventing future AAR

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MACTAQUAC LIFE ACHIEVEMENT PROJECT

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The Mactaquac Generating Station is a run of the river hydro facility with an installed generation capacity of 660 MW, supplying about 12 per cent of New Brunswick homes and businesses with clean, low-cost power.

The facility began generating electricity in 1968. Since the 1980s, concrete portions of the hydro station have been affected by a chemical reaction called alkali-aggregate reaction. The reaction causes the concrete to swell and crack and has required substantial annual maintenance and repairs.

NB Power is proposing a project to ensure the station can operate to its intended 100-year lifespan with a modified approach to maintenance and adjusting and replacing equipment over time. This recommendation follows three years of expert research, including input from science, engineers, the public and First Nations.

This approach will meet all safety and environmental requirements. It will allow NB Power to take into account changes in cost, technology and electricity demand while ensuring a steady supply of clean, renewable power for New Brunswickers.

https://www.nbpower.com/en/about-us/projects/mactaquac-project

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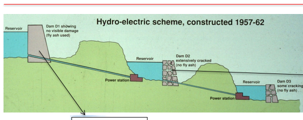
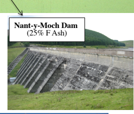
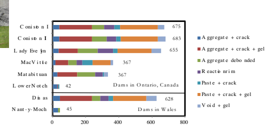
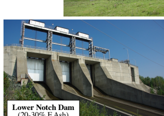
Use of Fly Ash









15th ICAAR – São Paulo, Brazil

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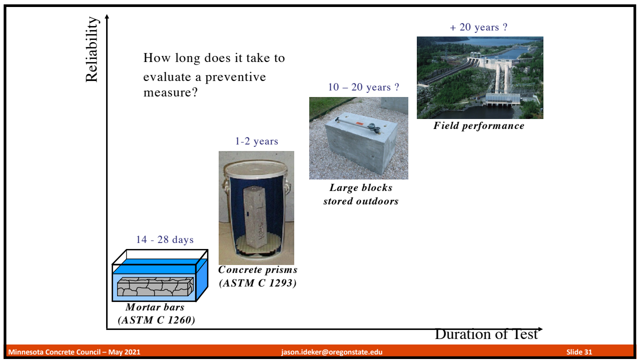
Reliability
How long does it take to evaluate a preventive measure?
+ 20 years ?
Field performance
10 – 20 years ?
Large blocks stored outdoors
1-2 years
Concrete prisms (ASTM C 1293)
14 - 28 days
Mortar bars (ASTM C 1260)
Duration of Test
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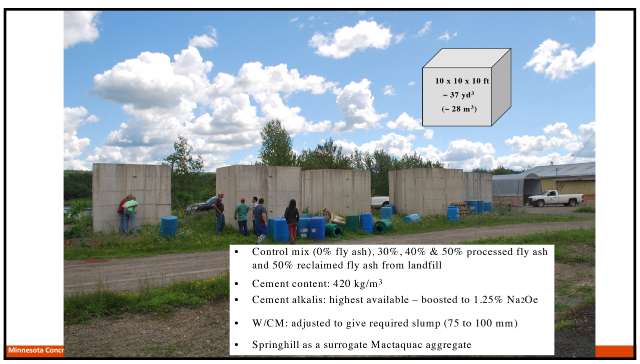
10 x 10 x 10 ft
~ 37 yd³
(~ 28 m³)
Control mix (0% fly ash), 30%, 40% & 50% processed fly ash and 50% reclaimed fly ash from landfill
Cement content: 420 kg/m³
Cement alkalis: highest available – boosted to 1.25% Na2Oe
W/CM: adjusted to give required slump (75 to 100 mm)
Springhill as a surrogate Mactaquac aggregate

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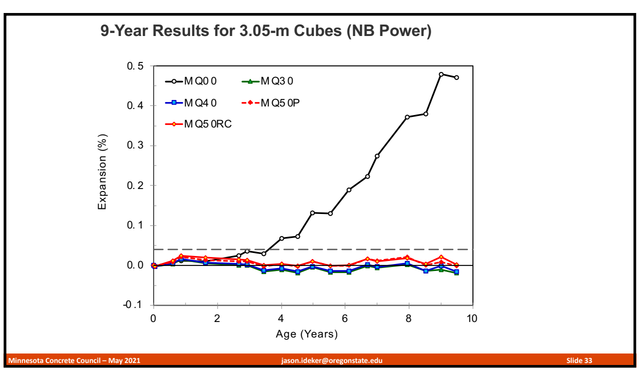
9-Year Results for 3.05-m Cubes (NB Power)
MQ00
MQ30
MQ40
MQ50P
MQ50RC
Expansion (%)
Age (Years)
0.5
0.4
0.3
0.2
0.1
0.0
-0.1
0
2
4
6
8
10
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Our biggest practical challenge:

The reliability of current laboratory (accelerated) test methods

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ASR test methods (third reminder)

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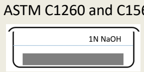
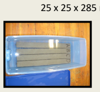
Accelerated mortar bar test (AMBT)

ASTM C1260 and C1567



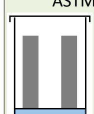
25 x 25 x 285 mm



80°C, 14 days

Concrete prism test (CPT)

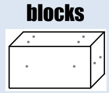
ASTM C1293

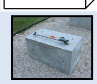


75 x 75 x 285 mm

38°C,
1 year; no prevention
2 years; with prevention

Outdoor exposure blocks





380 x 380 x 710 mm

Increasing reliability Increasing test duration

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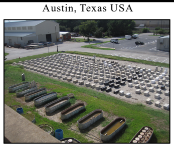
Austin, Texas USA



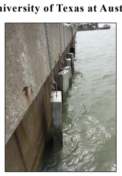
University of Texas at Austin

Fredericton, New Brunswick, Canada

University of New Brunswick

Corvallis, Oregon USA

Oregon State University



Port Aransas, Texas USA

Treat Island, Maine USA

Newport, Oregon USA

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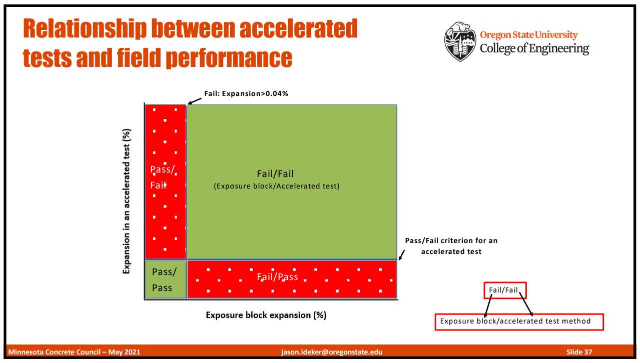
Relationship between accelerated tests and field performance
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Fail: Expansion>0.04%
Pass/ Fail
Fail/Fail
(Exposure block/Accelerated test)
Pass/Fail criterion for an accelerated test
Pass/ Pass
Fail/Pass
Fail/Fail
Exposure block/accelerated test method
Expansion in an accelerated test (%)
Exposure block expansion (%)
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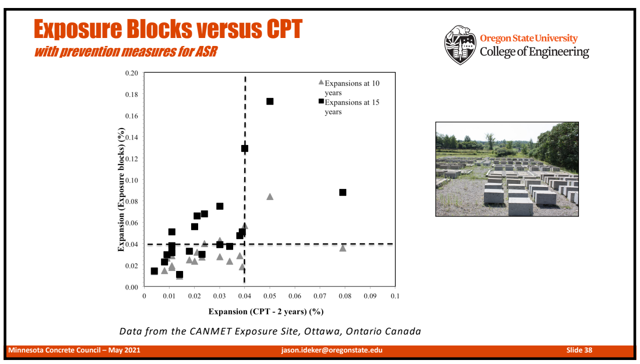
Exposure Blocks versus CPT
with prevention measures for ASR
Oregon State University College of Engineering
Expansions at 10 years
Expansions at 15 years
Expansion (Exposure blocks) (%)
Expansion (CPT - 2 years) (%)
Data from the CANMET Exposure Site, Ottawa, Ontario Canada
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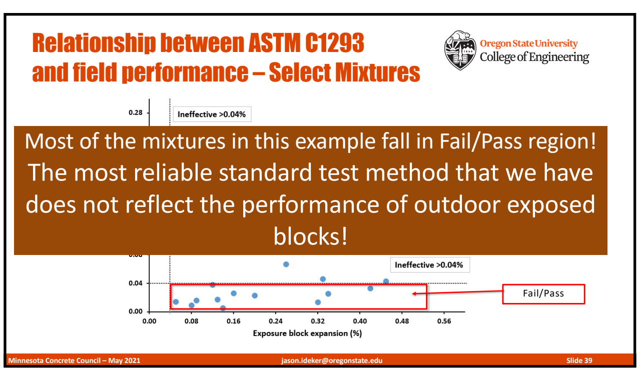
Relationship between ASTM C1293 and field performance – Select Mixtures
Oregon State University College of Engineering
Ineffective >0.04%
Most of the mixtures in this example fall in Fail/Pass region! The most reliable standard test method that we have does not reflect the performance of outdoor exposed blocks!
Ineffective >0.04%
Fail/Pass
Exposure block expansion (%)
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Recent research

Oregon State University College of Engineering

- AASHTO T380 - Miniature Concrete Prism Test – developed by Rangaraju and Latifee in 2010's.
- Validated for a wide range of aggregates for reactivity testing, only minor work done with SCMs (fly ash was the focus)
- Benchmark the MCPT against outdoor exposure blocks for efficacy of a wide range of prevention measures.

Tanesi, J., Drimalas, T., Chopperla, K.S.T., Beyene, M., Ideker, J.H., Kim, H., Montanari, L. and Ardani, A., "Divergence between Performance in the Field and Laboratory Test Results for Alkali-Silica Reaction," Transportation Research Record, April 16, 2020, https://doi.org/10.1177/0361198120913288.

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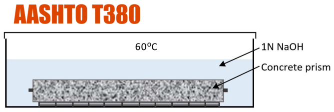
Miniature-Concrete Prism Test (MCPT) AASHTO T380

Oregon State University College of Engineering



- 50 x 50 x 285 mm bars
- w/cm = 0.45
- 60ºC, immersed in 1N NaOH solution
- 56 to 84 days

AASHTO T380 (MCPT)

Efficiency of prevention	% Expansion limits at 56 days
Effective	< 0.020%
Uncertain*	0.020% - 0.025%
Not effective	> 0.025%

*Recommend retest with MCPT using a higher dosage of prevention

- MCPT provided reliable aggregate reactivity characterization in a shorter duration (56/84 days) (Rangaraju et al. 2016)
  - 33 different reactive and nonreactive aggregates
  - Compared to CPT and AMBT results
- Needs validation for mixtures with wide range of preventive measures
- Needs benchmarking to the outdoor exposure blocks

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Materials and Test Matrix

Oregon State University College of Engineering

MCPT and CCT: Alkali boosted mixtures HRC, UT Austin

Mixtures	Reactive Coarse aggregate		Reactive Fine aggregate	
	Spratt	Placitas	Wright	Jobe
OPC	✓	✓	✓	✓
20% F fly ash		✓	✓	
30% F fly ash				✓
40% C fly ash	✓	✓	✓	
40% Slag			✓	
50% Slag				✓
100% Lithium		✓		✓
35% Slag + 5% Silica fume			✓	

prevention options

Spratt- Highly reactive; Siliceous limestone

Placitas- Highly reactive; Mixed mineralogy gravel with volcanics

Springhill - Highly reactive; Greywacke

Wright- Highly reactive; Natural river sand with chert

Jobe- Very highly reactive; Mixed quartz/chert/feldspar

Note: Used ASTM C1778 classification of aggregate reactivity

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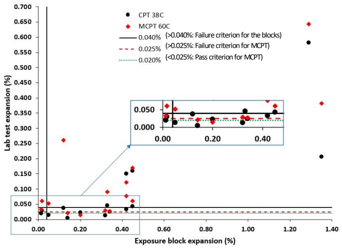
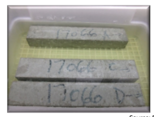
MCPT results





Source: FHWA

50 x 50 x 285 mm

	False-positive	False-negative	Uncertain
CPT 38C	0	7	0
MCPT 60C	0	1	1

❑The age of the MCPT specimens expansion data used for the plot: 56 d

❑The expansion limit for the CPT method and the exposure blocks was considered as 0.04%.

Efficiency of prevention	% Expansion limits at 56 days
Effective	< 0.020%
Uncertain	0.020% - 0.025%
Not effective	> 0.025%

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Summary – MCPT and CCT results

Reactive Aggregate	Mixtures	Age of the exposure blocks (years)	Average expansion (%) Exposure block
Spratt	OPC	13.0	0.420
	40% C fly ash	13.0	0.050
Placitas			
Wright			
	20% F fly ash	15.4	0.140
	40% C fly ash	15.4	0.420
	40% Slag	15.4	0.340
	35% Slag + 5% Silica fume	15.3	0.200
Jobe	OPC	14.9	1.290
	30% F fly ash	2.3	0.013
	50% Slag	2.2	0.017
	100% Lithium	14.4	0.120

MCPT showed the most reliability among CPT-38C, MCPT-60C, CCT-38C, and CCT-50C

The mixtures that failed the test method/exposure block
The mixtures that passed the test method/exposure block
Exposure blocks are just about 2.2 years old
The mixture that is uncertain if passed or failed

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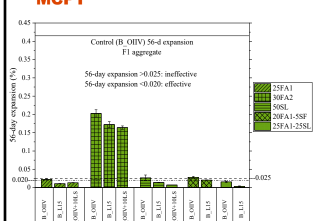
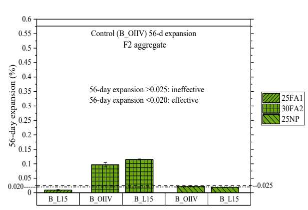
Evaluating Portland Limestone Cements MCPT

Oregon State University College of Engineering





- The mixtures with PLCs performed similar to or better than the OPC mixtures
- FA2 – high alkali fly ash (4.0 Na_2O_{eq}) and low alumina (16.0% Al_2O_3)

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NCHRP 10-103

Improving Guidance of AASHTO R 80/ASTM C 1778 for Alkali-Silica Reactivity (ASR) Potential and Mitigation

Oregon State University College of Engineering

- Cast exposure blocks with low/moderate alkali loadings
  - Focus on prevention
  - Use prescriptive approach and existing data to select help inform prevention material quantities
- Investigate "new" accelerated test methods
  - Benchmark to existing field sites
  - Allow future benchmarking to new blocks

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New Project to Address Disconnect and Alkali loading Question

UTA, UNB, OSU Sites
land and marine

~450 moderate alkali loading blocks

Will provide long-term benchmarking of highway representative concrete

Accelerated Block Curing

~30 mixtures subjected to accelerated curing at 38C and/or greenhouse type condition

Rapid link to accelerated laboratory tests in this project

Laboratory Tests

50 ASTM C1293 (reg)
50 ASTM C1293 (mod alkali)
125 ASTM C1293 (alk. Wrapped)
125 MCPT (1 N NaOH, pore soln soak)
125 UNBCCT

- **Data across accelerated tests will be compared to determine sensitivity to alkali loading/SCMs**
- **Data from accelerated block curing and laboratory tests, combined with information on existing sites will inform improvements to AASHTO R80 and ASTM C1778**

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Conclusions

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- Not all concrete is susceptible to ASR
  - Must have reactive aggregate, fine or coarse
- ASR can be prevented through proper use of supplementary cementitious materials, lithium nitrate and/or low alkali contents
  - Prescriptive or performance-based approach
- Reliable rapid test methods are still a challenge
  - Significant research thrust

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THE CORVALLIS WORKSHOPS

Concrete Fit for Purpose and Planet

June 22-24, 2022

http://thecorvallisworkshops.org/

http://blogs.oregonstate.edu/concreteshortcourse/

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- Stacey S, Folliard KJ, Drimalas T, & Thomas MDA (2016). *An Accelerated and more Accurate Test Method to ASTM C1293: The Concrete Cylinder Test*. Published as a part of proceedings of the 15th International Conference on Alkali-Aggregate Reaction (ICAAR) held in Sao Paulo, Brazil.
- Tanesi, J., Drimalas, T., Chopperla, K.S.T., Beyene, M., Ideker, J.H., Kim, H., Montanari, L. and Ardani, A., “Divergence between Performance in the Field and Laboratory Test Results for Alkali-Silica Reaction,” Transportation Research Record, April 16, 2020, https://doi.org/10.1177/0361198120913288.

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Thank you!

Questions

Infrastructure Materials Group at OSU
- https://cce.oregonstate.edu/infrastructure-materials-laboratories

Ideker Research Group Website
- https://blogs.oregonstate.edu/jasonhideker/

ICAAR Database
- https://icaarconcrete.org/

Corvallis Workshops
- https://thecorvallisworkshops.org/

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