Pennsylvania Outdoor Exposure Site for Monitoring Concrete Durability against ASR

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Collaborators: *PSU, OSU, UT Austin, UNB, RJ Lee Group,*
PACA, FAA stakeholders

PennState College of Engineering

PACA Pennsylvania Aggregates and Concrete Association

ACPTP Airport Concrete Pavement Technology Program

Motivation

- **ASR:** a leading durability issue in many concrete structures.
- **Problem:** Many standard tests exist; however, it often disagree on whether a given combination is "safe". decisions are risky without field truth.
- **Approach**: create a large materials matrix, represented in 200 outdoor blocks! Which will serve as benchmark for lab predictions
- **Impact**: Our program aims at understanding the mechanisms and create a long-term benchmarks.

Du Vallon-Charest Highway - Quebec

[1] Trottier, C. et al. (2025). Enhancing Efficiency in Evaluating ASR Damage. In Advancing the Use of the DRI for ISR, p. 241.

ASR mitigation is costly

Du Vallon-Charest Highway - Quebec

	Service life
Major bridges Dams tunnels	>75 years
Pavements Foundations	40-74 years
Side walks	<40 years
Non-load-bearing elements	<5 years

↑↑ ↑

Cost

Risk prevention levels

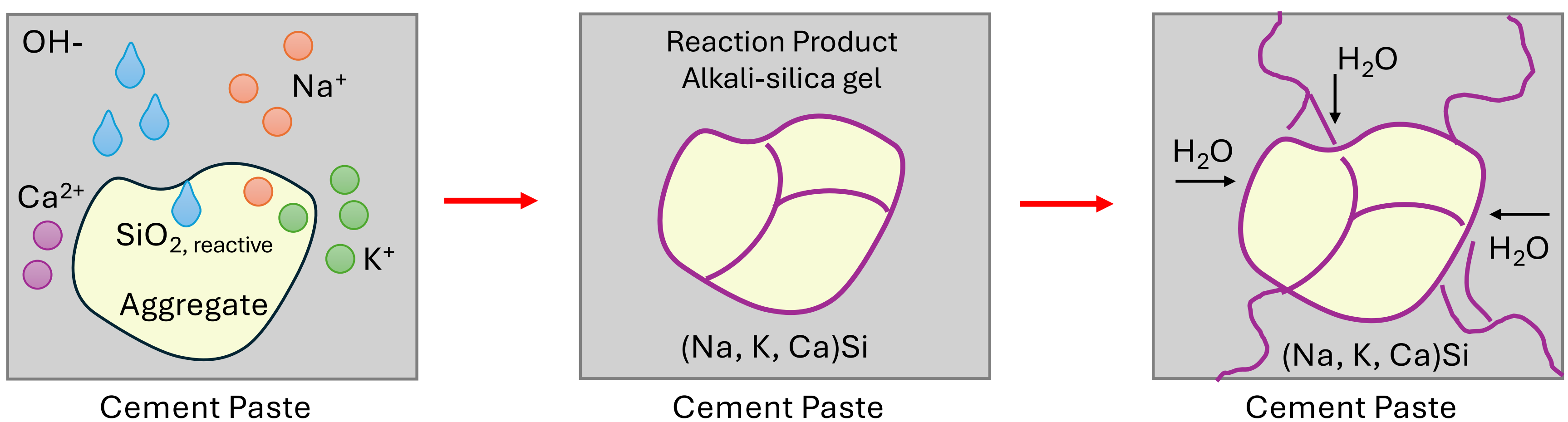
↓↓ ↓

[1] Trottier, C. et al. (2025). Enhancing Efficiency in Evaluating ASR Damage. In Advancing the Use of the DRI for ISR, p. 241.

What ASR is and why it happens ?

ASR: 3 Constituents:

1) Reactivity source of silica in aggregate
2) Alkalis (such as: Na+ and K+)
3) Presence of Moisture



[2] Rajabipour, F. et al. (2015). Alkali–Silica Reaction: Current Understanding and Knowledge Gaps. Cement and Concrete Research, 76, 130.

What ASR is and why it happens ?

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1) Reactivity source of silica in aggregate
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Aggregate

Reactivity

Pessimum Size: Max expansion

Alkali Budget

Internal
Cement & SCMs
Some Aggregates

External (Salts)

Calcium Dual Role

At surface divert towards C-S-H

Aid form ASR gel

Water content

Control ASR

Magnitude & Rate

[2] Rajabipour, F. et al. (2015). Alkali–Silica Reaction: Current Understanding and Knowledge Gaps. Cement and Concrete Research, 76, 130.

How to Reduce the risk of ASR ?

1 Risk Evaluation

Define the level of risk that is acceptable

- Aggregate reactivity
- Structure's type and Service life
- Structure condition & Exposure

2 Performance Based Approach

Criteria of testing

- ASTM & AASHTO tests

3 Prescriptive Approach

Control

ASTM C1778/AASHTO R80

- Max. loading alkali
- SCMs levels
- Admixture

[3] ASTM C1778 (2023). Guide for Reducing Risk of Deleterious Alkali–Aggregate Reaction in Concrete. ASTM Int.
[4] AASHTO R80-17(2025). *Practice for Determining Reactivity of Concrete Aggregates & ASR Mitigation Measures*. AASHTO.

State of the practice in the U.S.

ASTM C1260/1567

Accelerated mortar bar test

25x25x285 mm
80°C, 1N NaOH, 14 days

AASHTO T 380

Miniature concrete prism test

50x50x285 mm
60°C, 1N NaOH, 56-84 days

ASTM C 1293

Concrete prism test

75x75x285 mm
38°C, 100% RH
1 year aggregate reactivity
2 years preventive options

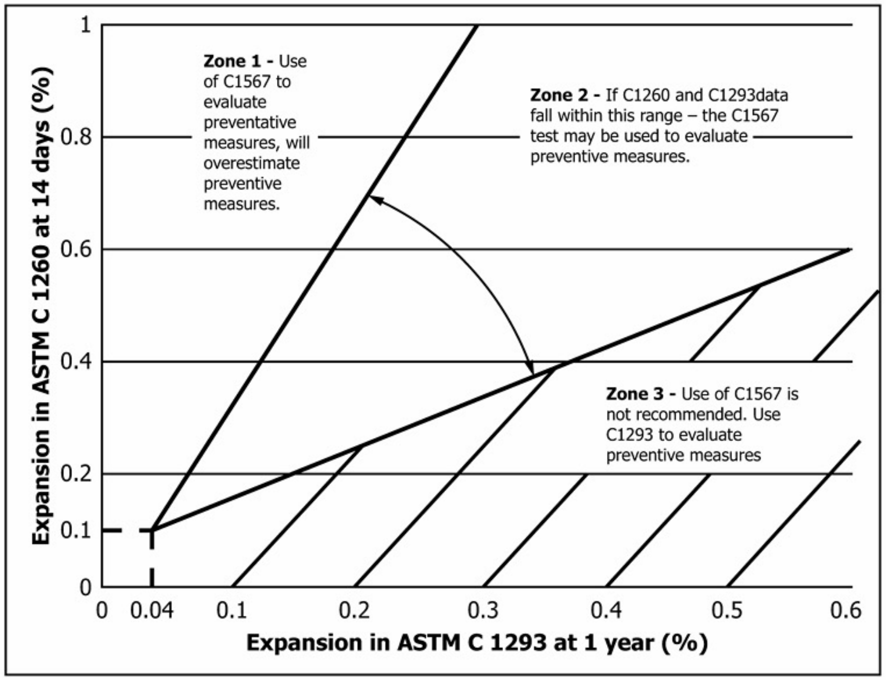
These tests show somewhat conflicting results.

[5] ASTM C1260 (2023). Test Method for Potential Alkali Reactivity of Aggregates (Mortar Bar). ASTM Int.
[6] ASTM C1293 (2023a). Test Method for Length Change of Concrete Due to ASR. ASTM Int.
[7] AASHTO T380 (2022). Test Method for Potential Alkali Reactivity & Effectiveness of ASR Mitigation (MCPT). AASHTO.

Why test results conflict across methods?

- Different specimen sizes, temperatures, alkali environments, and durations probe different parts of the mechanism

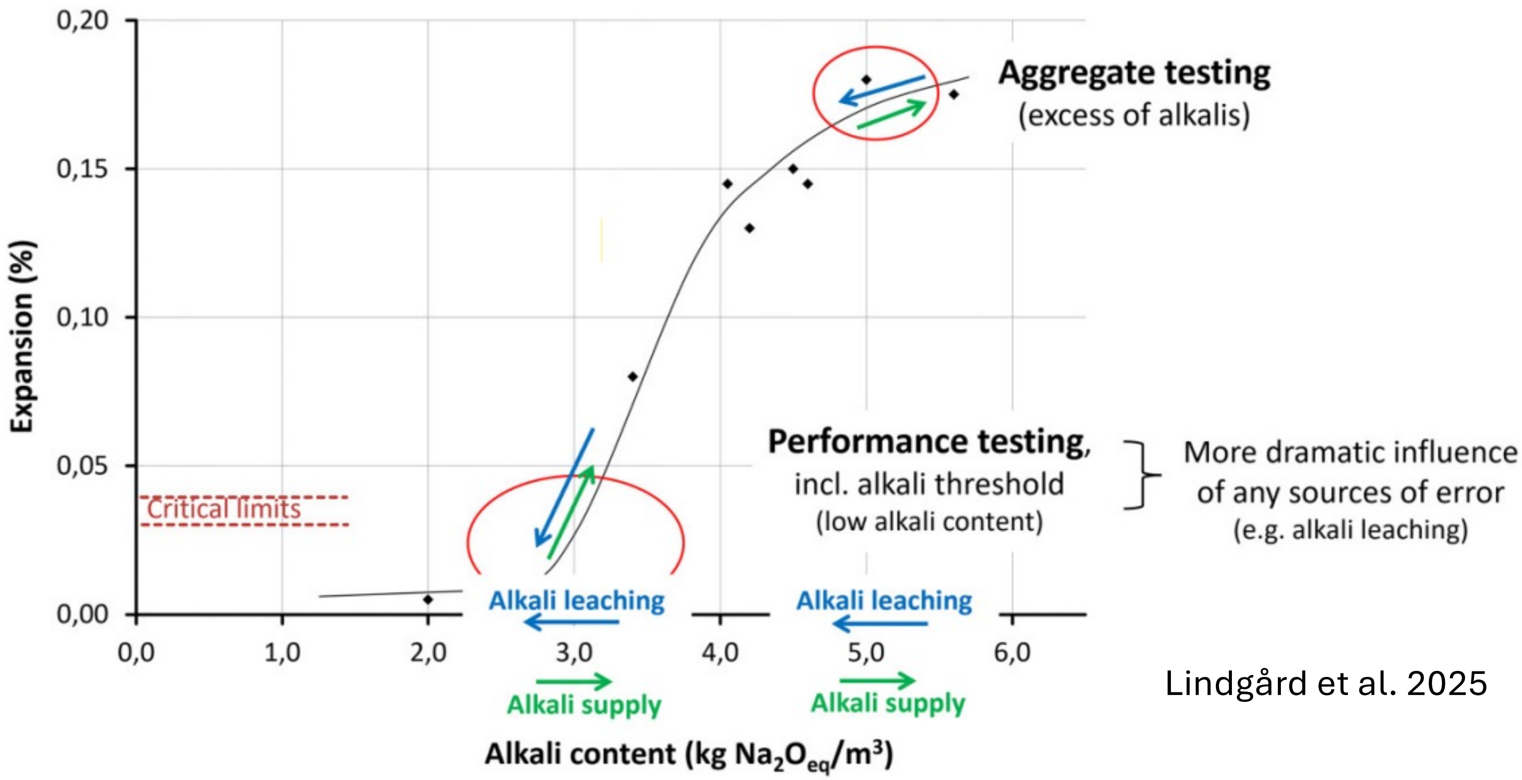
- Accelerated tests can over- or under-predict field behavior for specific SCMs or admixtures



ASTM C1778

[3] ASTM C1778 (2023). Guide for Reducing Risk of Deleterious Alkali–Aggregate Reaction in Concrete. ASTM Int.

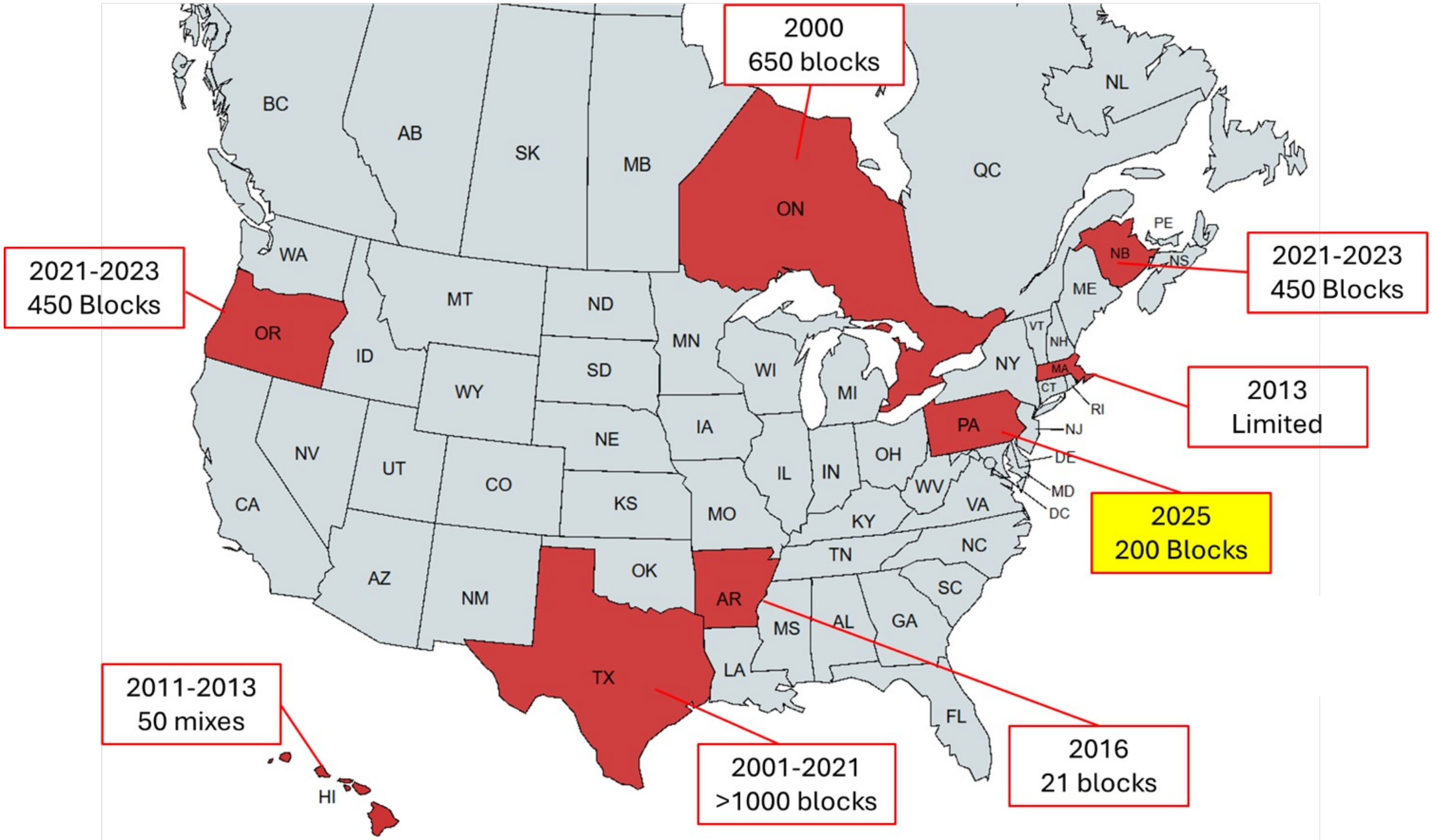
common issue with the existing tests



Lindgård et al. 2025

[8] Lindgård, J., & Drimalas, T. (2025). *Lab vs. Field Performance of ASR-Affected Concrete. Can. J. Civ. Eng.*, 00, 1–15.

Field Truth: Long-term outdoor exposure sites



Pennsylvania Context

Expand testing protocol	Verification of MDAT/MDARC	Long Term Outcomes
1 To field exposure testing to local *PA aggregates*	1 *Validate* (MDAT*) & *(MDAR*) for PA aggregates*	1 Develop prescriptive approach for PA DOT.
2 towards more SCMs, cement types, and salt inhibitors.	2 Support the tests standardization	2 Modify and refine current test methods.
3 towards new climate: (Subjected to freeze-thaw).	3 Build long-term dataset to benchmark lab and field correlation.	3 Define alkali thresholds for field durability.

**MDAT: "Minimum Detrimental Alkali Threshold"*
**MDAR: "Minimum Determination of Alkali Release"*

Research Questions

Question 1

Field Performance benchmarking

How do Pennsylvania aggregates perform under real climatic exposure compared to predictions from ASTM C1260 and C1293 laboratory tests?

Question 2

Mitigation and Material Optimization

Which SCMs or ASR inhibitors most effectively limit expansion below desired threshold in PA's freeze–thaw climate?

Question 3

Integration of Emerging Test Methods

How can MDAT and MDARC be applied to PA materials to establish field-validated alkali thresholds and improve accuracy of lab–field correlations?

Question 4

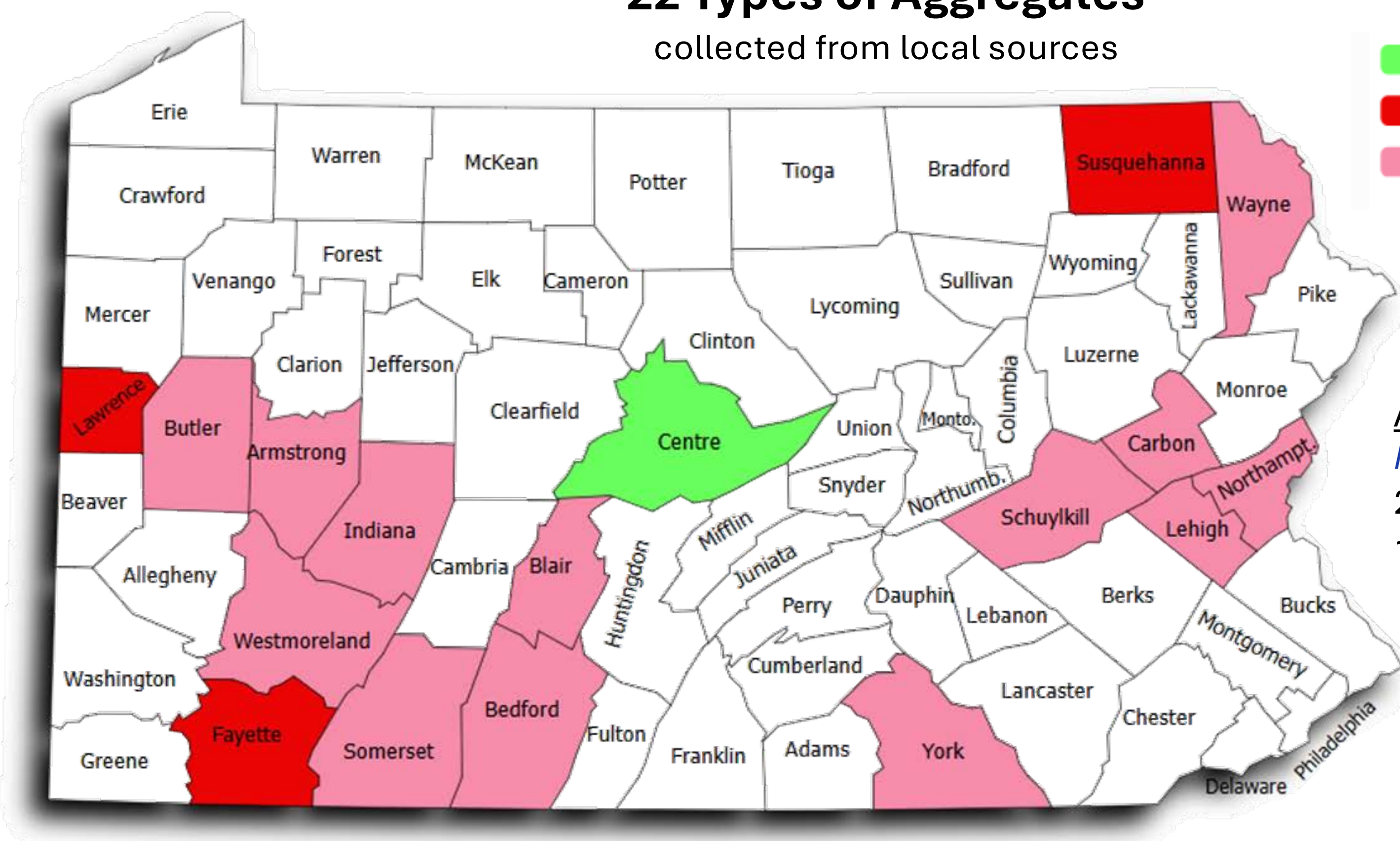
Framework Development

How can findings from lab and field data guide a prescriptive specification for PA DOT and future ASTM adoption?

Materials matrix: Aggregate Sources

22 Types of Aggregates

collected from local sources



<u>Additional Sources:</u>

From Nearby States

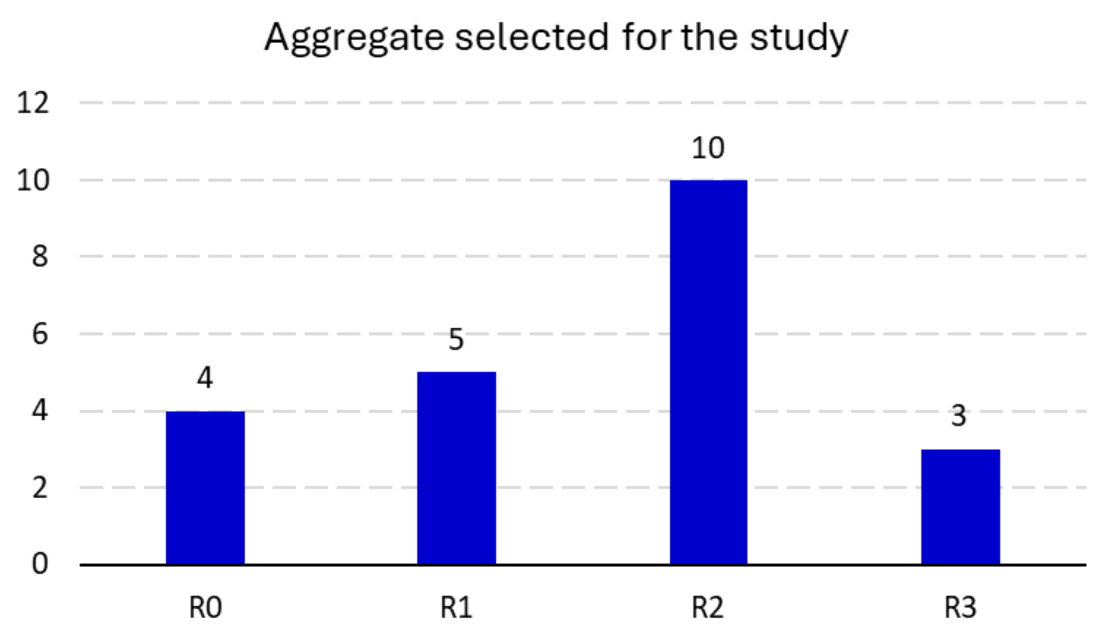
2 Sources: Morgantown, WV

1 Source: Collins, NY

Materials matrix: Aggregate Sources

22 Types of Aggregates

Reactivity based on ASTM C1293



Materials matrix: Cementitious Materials

Cement types: (5)

Type 1L (3)

	Low alkali	Mid. alkali	High alkali
Alkali content	0.49%	0.78%	1.08%
Loading Alkali	3.0 lb./yd^3	4.8 lb./yd^3	6.6 lb./yd^3
50% slag	1.5 lb./yd^3	2.4 lb./yd^3	3.3 lb./yd^3

Type 1T (13L) (10P)

LC3

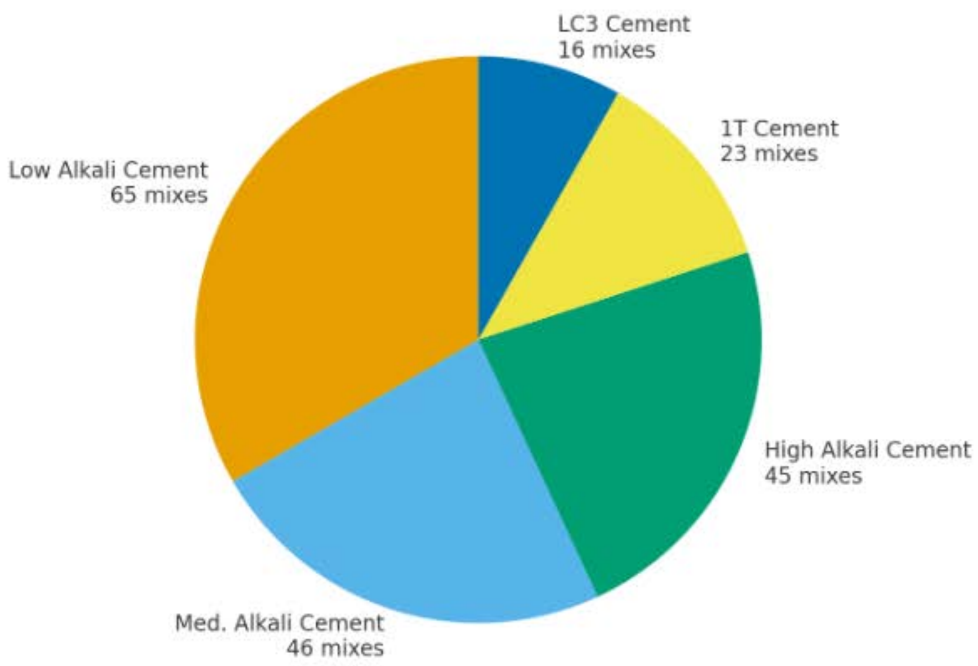
SCMs types: (3)

Slag Grade 120	Fly ash Class - F	Natural Pozzolan
35 - 50%	15-35%	TBD%

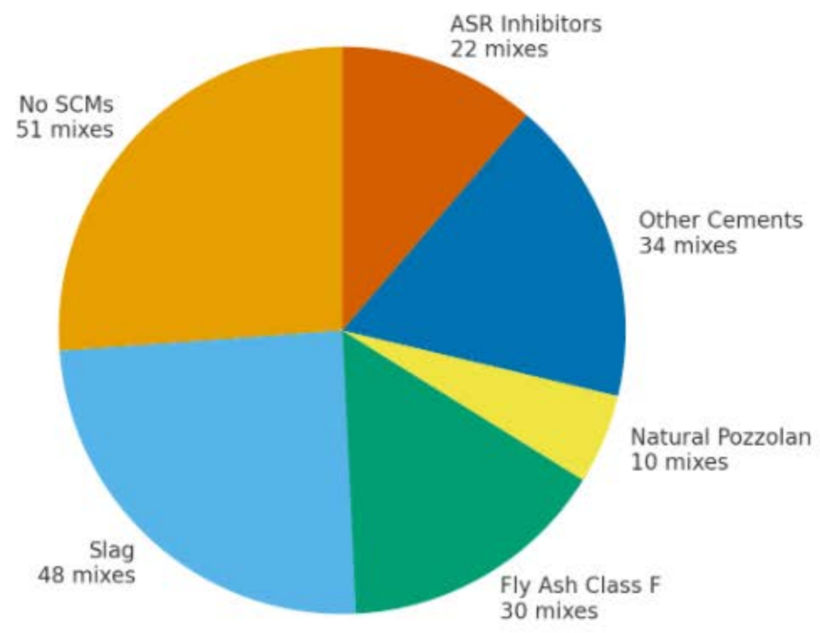
% Replacement

Materials matrix: Cementitious Materials

Distribution: Cement Types



Distribution: SCMs & Inhibitors



Materials matrix: ASR Inhibitors

Certain soluble salts + hydroxyl ions from pore solution ⟶ Precipitating Calcium hydroxide & Dropping pH of concrete

ASR Inhibitors

In a study developed by **Penn State,** salts were suggested based on following 7 criterion. Their effectiveness was subsequently assessed in concrete prisms tested **under ASTM C1293** conditions, **using reactive aggregate and high-alkali cement**, with comparisons made against a control specimen.

$Ca(CH_3COO)_2 \cdot H_2O$	***(Calcium acetate monohydrate)***
$Mg(CH_3COO)_2 \cdot 4H_2O$	*(Magnesium acetate tetrahydrate)*
$Ca(HCOO)_2$	*(Calcium formate)*
$CaBr_2 \cdot 2H_2O$	*(Calcium bromide dihydrate)*
$MgBr_2 \cdot 6H_2O$	*(Magnesium bromide hexahydrate)*
$Ca(NO_3)_2 \cdot 4H_2O$	***(Calcium nitrate tetrahydrate)***
$Mg(NO_3)_2 \cdot 6H_2O$	*(Magnesium nitrate hexahydrate)*

[6] ASTM C1293 (2023a). Test Method for Length Change of Concrete Due to ASR. ASTM Int.
[9]Kaladharan, G. *et al.* (2021). *Novel Admixtures for Mitigation of Alkali–Silica Reaction in Concrete. Cement and Concrete Composites.*

Materials matrix: ASR Inhibitors

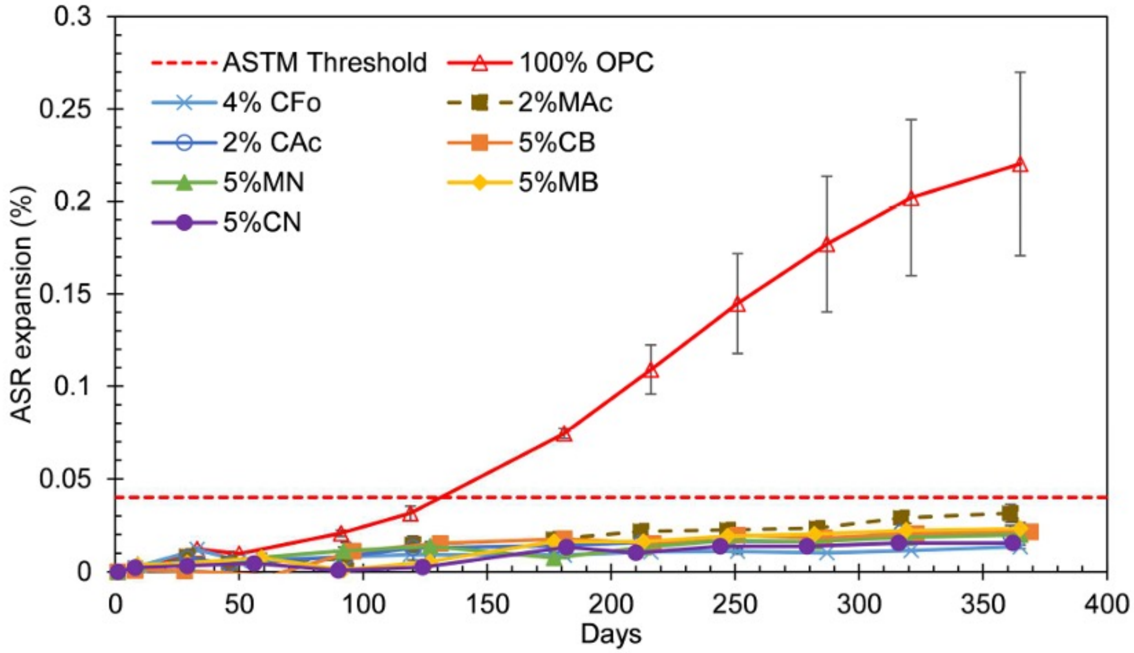


Figure 7 – ASTM C1293 results of concrete with highly reactive aggregate show the effectiveness of the promising salts in mitigating ASR (error bars represent ±1 st. dev.)

$Ca(CH_3COO)_2 \cdot H_2O$
$Mg(CH_3COO)_2 \cdot 4H_2O$
$Ca(HCOO)_2$
$CaBr_2 \cdot 2H_2O$
$MgBr_2 \cdot 6H_2O$
$Ca(NO_3)_2 \cdot 4H_2O$
$Mg(NO_3)_2 \cdot 6H_2O$

[9]Kaladharan, G. *et al.* (2021). *Novel Admixtures for Mitigation of Alkali–Silica Reaction in Concrete. Cement and Concrete Composites.*

Specimen types and instrumentation

- **200** Concrete cubes built have the same structure, dimensions and test logic.
- Long-gage length strain measurement to track expansion.

Mix	CA#	FA#	CM type	SCMs	Dosage	TCM	CM	SCM	Water	CA	FA	AEA	WRA
B009	31	17	IL (3.0)	0	-	611	611	0	275	1770	1207	0.51	2.5
B010	31	17	IL (3.0)	slag	35%	611	397.15	213.85	275	1770	1195	0.51	2.5
B011	31	17	1H (6.6)	0	-	611	611	0	275	1770	1197	0.51	3.5
B012	31	17	1H (6.6)	slag	50%	611	305.5	305.5	275	1770	1218	0.51	3.5
B013	31	17	1M (4.8)	0	-	611	611	0	275	1770	1236	0.51	3.0
B014	31	17	1M (4.8)	slag	50%	611	305.5	305.5	275	1770	1220	0.51	3.0
B015	31	17	IL (3.0)	Fly ash	25%	611	458.25	152.75	275	1770	1209	0.51	2.5
B016	35	17	IL (3.0)	0	-	611	611	0	275	1777	1113	0.51	2.5

[10] ACI 211.1-91 (R2009) - *Design and Control of Concrete Mixtures (17th Ed., 2021).*

Specimen types and instrumentation

- **200** Concrete cubes built have the same structure, dimensions and test logic.
- Long-gage length strain measurement to track expansion.

[11] ASTM C31 (2021). *Standard Practice for Making and Curing Concrete Test Specimens in the Field*. ASTM International.
[12] ASTM C94 (2023). *Standard Specification for Ready-Mixed Concrete.* ASTM International.
[13] ASTM C192 (2019). *Standard Practice for Making and Curing Concrete Test Specimens in the Laboratory.* ASTM International.

Storage of Concrete cubes

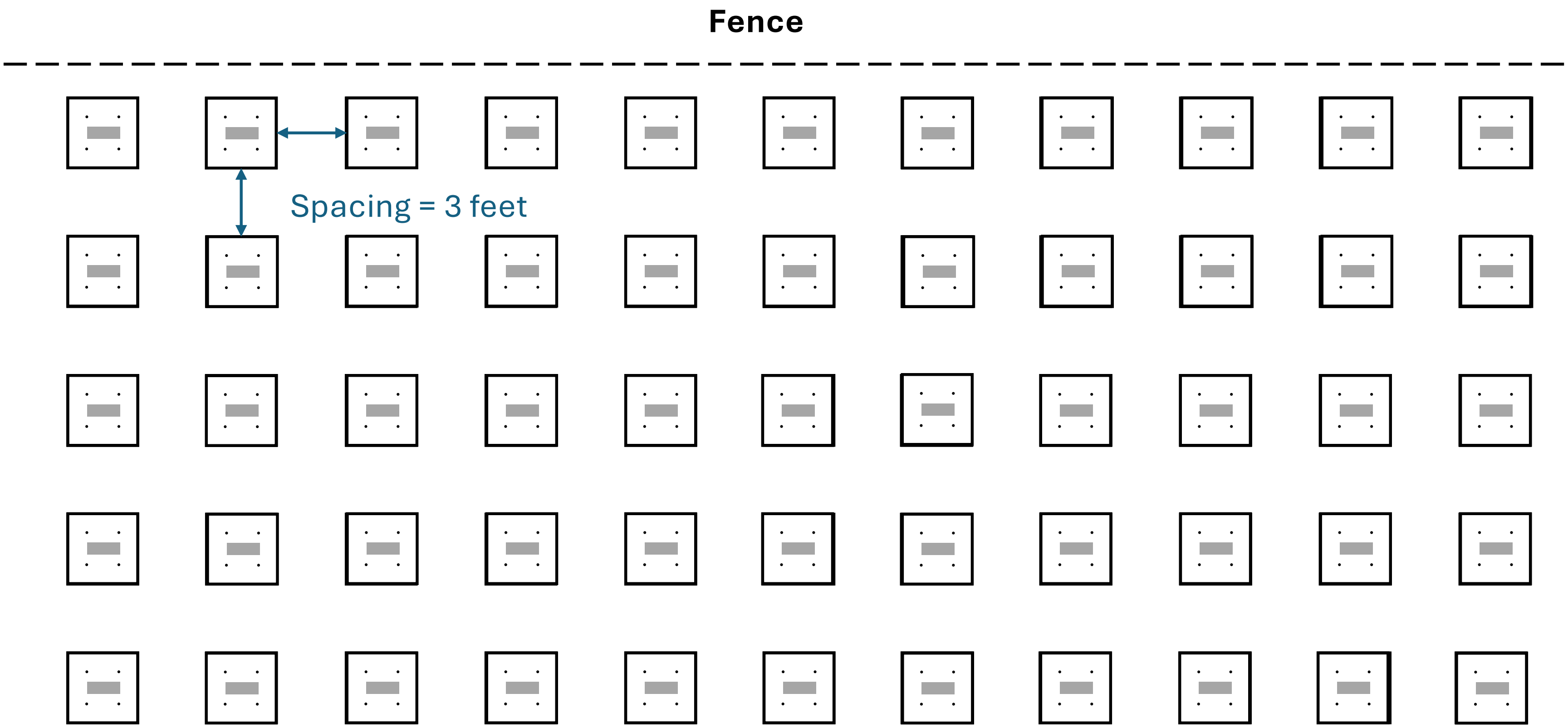
Timeline: (5 Stages)

Stages	Duration	Location	System
1	First 24 hours:	within the molds.	Controlled **T & RH**
2	1 to 7 days:	placed inside moist room	Controlled **T & RH**
3	7 to 28 days:	within PSU lab.	Controlled **T** only
4	28 to 56 days:	Outside PSU lab	Uncontrolled **T & RH**
5	>56 days:	Designated outdoor site	Uncontrolled **T & RH**

Storage of Concrete cubes: Designate site

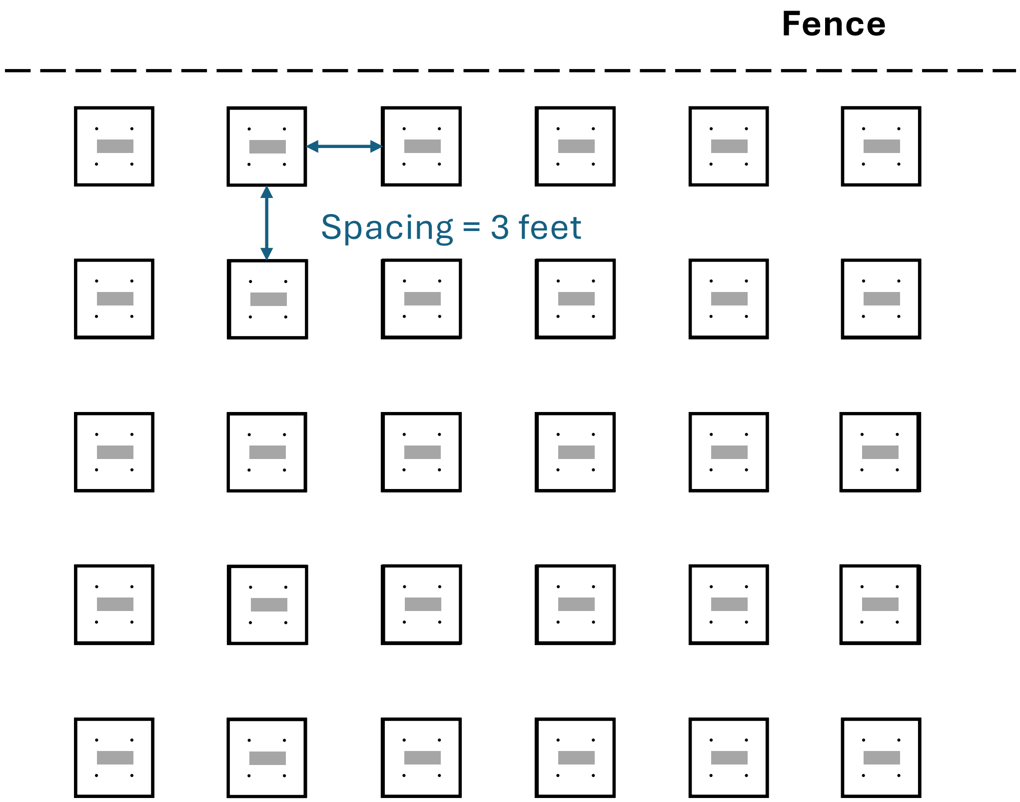
Location: 1556 Clearfield St, West Decatur, PA 16878

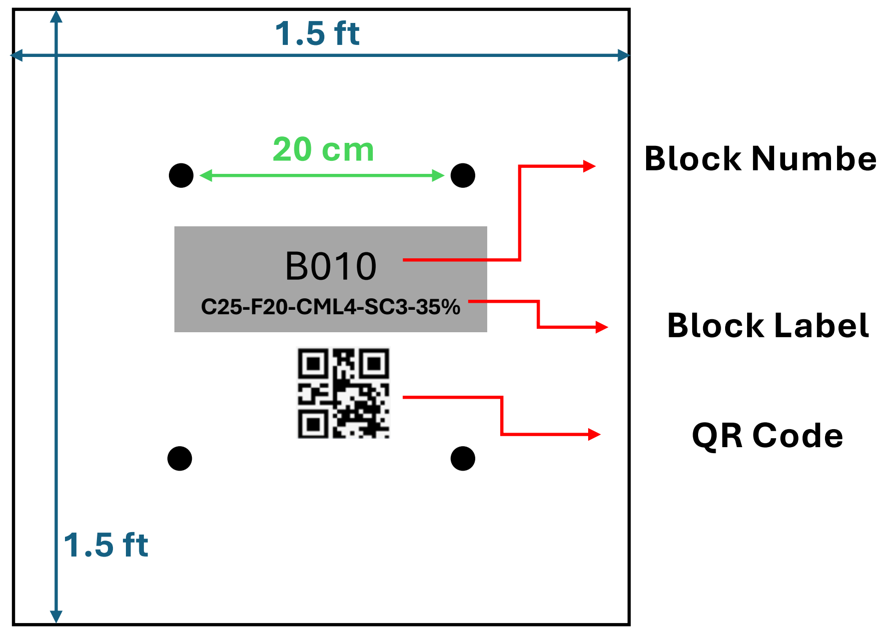
Storage of Concrete cubes



Location: 1556 Clearfield St, West Decatur, PA 16878

Storage of Concrete cubes





B010:	Block number
C25:	Coarse Aggregate -PACA # 1
F20:	Fine Aggregate – PACA#17
CML4 :	Type IL (LA cement)
SC3:	Slag
% repl.:	35%

Location: 1556 Clearfield St

Fresh and hardened properties recorded

Slump Test	Air Content	Compressive Strength	Strain Estimation
			
2.0 – 6.0”	4.5 – 7.5%	> 3500 psi Test At 28 Days for all samples Tested At 56 Days for SCMs samples.	Disp. Measured Over a span of 20 years

[14] ASTM C143 (2020). *Standard Test Method for Slump of Hydraulic-Cement Concrete.* ASTM International.

[15] ASTM C231(2024). *Standard Test Method for Air Content of Freshly Mixed Concrete by the Pressure Method.* ASTM International.

[16] ASTM C39(2024). *Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens.* ASTM International.

Fresh and hardened properties recorded

Strain
Estimation

Disp. Measured
Over a span of
20 years

precision/resolution

0.0000 mm

4 digits

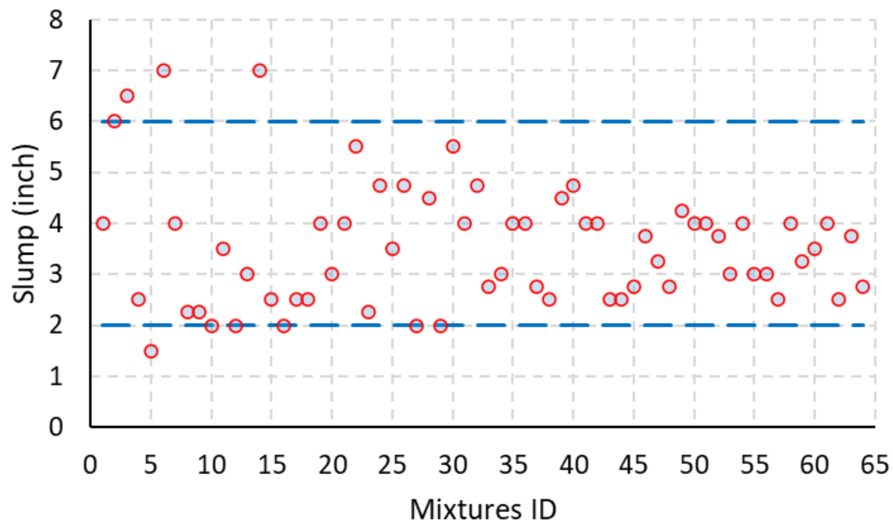
Measurements

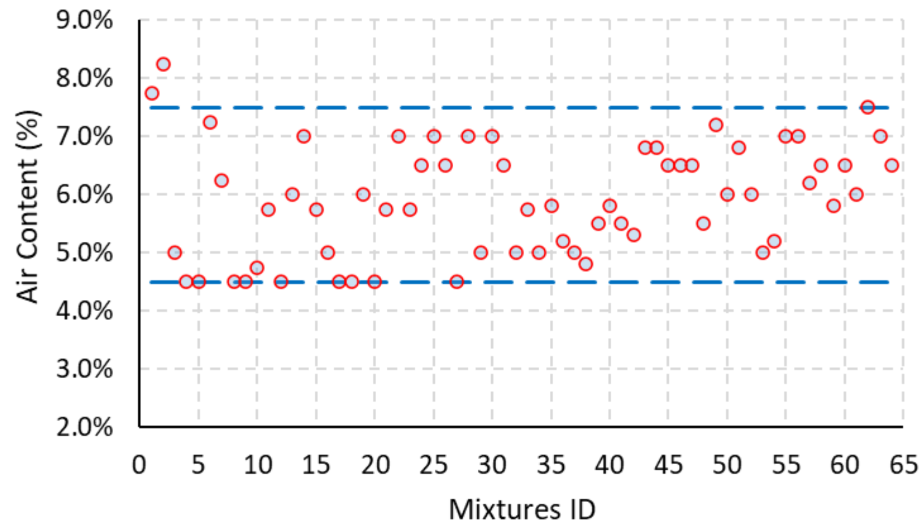
Average of 8
readings

4 readings Top face	4 readings The 4 sides

Strain is evaluated
from change in length
**with respect to 28D
reading**

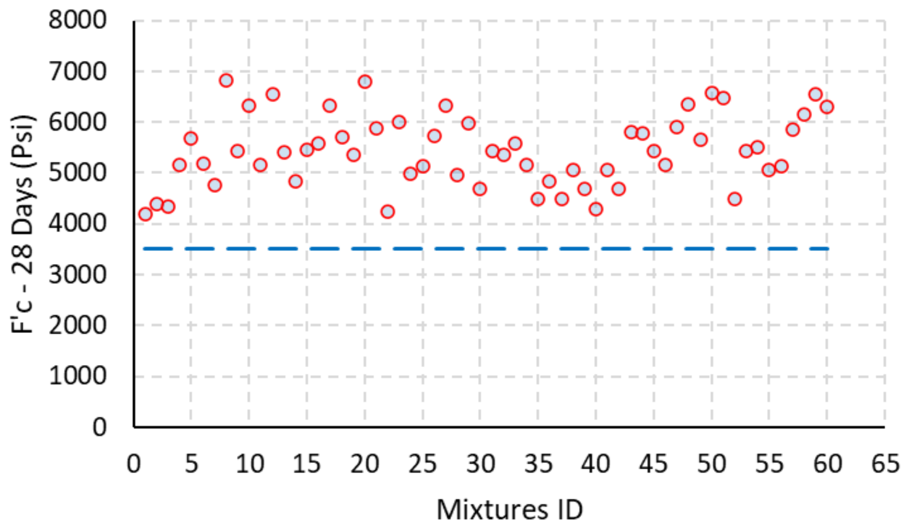
Results: Fresh properties

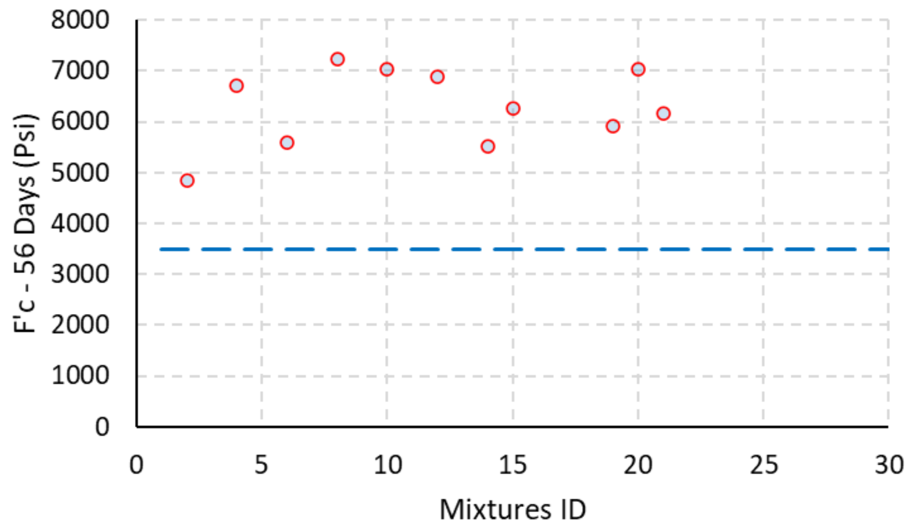




[14] ASTM C143 (2020). *Standard Test Method for Slump of Hydraulic-Cement Concrete*. ASTM International.
[15] ASTM C231(2024). *Standard Test Method for Air Content of Freshly Mixed Concrete by the Pressure Method*. ASTM International.

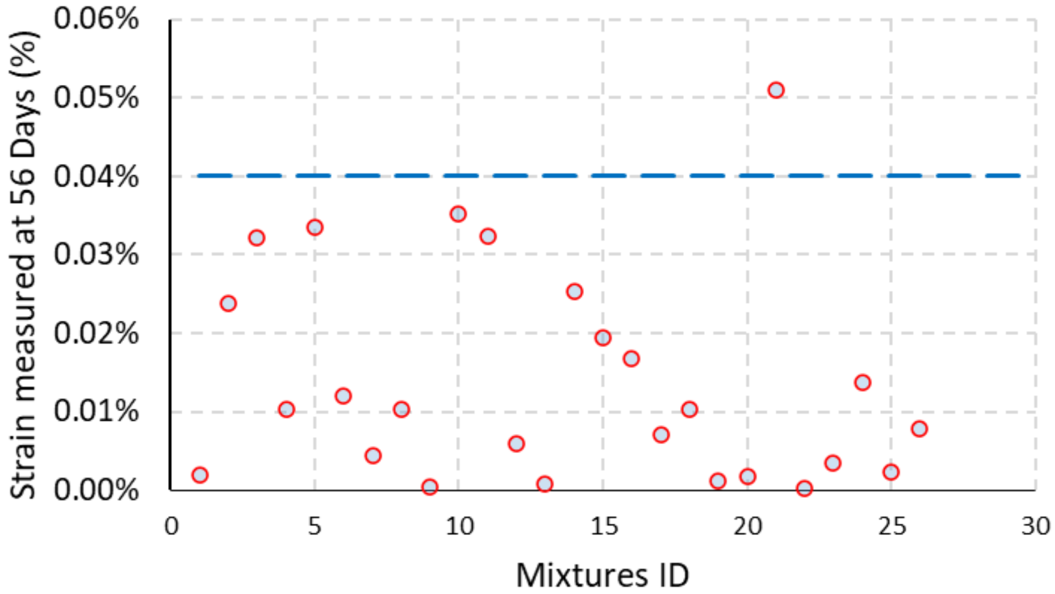
Results: Compressive Strength





[16] ASTM C39(2024). *Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens*. ASTM International.

Results: Strain at 56 Days



QR Code


ASR Expansion Tracker
PennState
Enter Block No. e.g. B001
Clear
Submit
ACPTP Phase II
Block No: B001
Block ID: C25 3.0-CML4
Ingredients
Mix Design
Important Dates
Aggregate Info
Concrete Properties
Cement Type
CML4
Alkali Loading (lb/cft)
3
Reactive Aggregate
C25
SCM Type
-
View/Add Stain Values
Block No: B001
Block ID: C25 3.0-CML4
Mix Design
Important Dates
Aggregate Info
Concrete Properties
Slump (Inch)
4
Air Content (%)
0.0775
28 Day Compressive Strength (Psi)
4202
56 Day Compressive
View/Add Stain Values
Block No: B001
Block ID: C25-3.0-CML4
Block No.
B001
Block_ID
C25-3.0-CML4
Relative Humidity
ASR Expansion Over Time
1.5
1.25
1
0.75
0.5
0.25
0
9/10/202
9/10/202
Submit New Data

Previous Land Exposure Sites: Oregon

Figure 4.2: Land exposure site at OSU.

[17] Parashar, A., Chopperla, K. S. T., Ghanizadeh, A., Lute, R., Drimalas, T., Thomas, M., Folliard, K., & Ideker, J. H. (2022). *Overview on improving the guidance of AASHTO R 80 and ASTM C1778 for ASR potential and prevention with SCMs.*

Previous Land Exposure Sites: New Brunswick

Figure 4.3: Land exposure site at UNB.

[17] Parashar, A., Chopperla, K. S. T., Ghanizadeh, A., Lute, R., Drimalas, T., Thomas, M., Folliard, K., & Ideker, J. H. (2022). *Overview on improving the guidance of AASHTO R 80 and ASTM C1778 for ASR potential and prevention with SCMs.*

Previous Land Exposure Sites: TEXAS

Figure 4.4: Land exposure site at UTA.

[17] Parashar, A., Chopperla, K. S. T., Ghanizadeh, A., Lute, R., Drimalas, T., Thomas, M., Folliard, K., & Ideker, J. H. (2022). *Overview on improving the guidance of AASHTO R 80 and ASTM C1778 for ASR potential and prevention with SCMs.*

Expected outcomes

- Within the first 2 years, cracking may begin to appear in highly aggressive, reactive aggregates.
- False positives and false negatives in ASR classification can be identified by comparing results from different ASTM test methods.
- Evaluate prescriptive methods: whether the SCM/ASR inhibitors dosages prescribed by current codes are sufficient for mitigation.
- Assess alkali threshold values (e.g., 0.04% expansion limit in ASTM C1293) to improve correlation with accelerated test results.
- Identify the most reliable test method by benchmarking existing approaches against field performance.

Expectations: Development of cracks

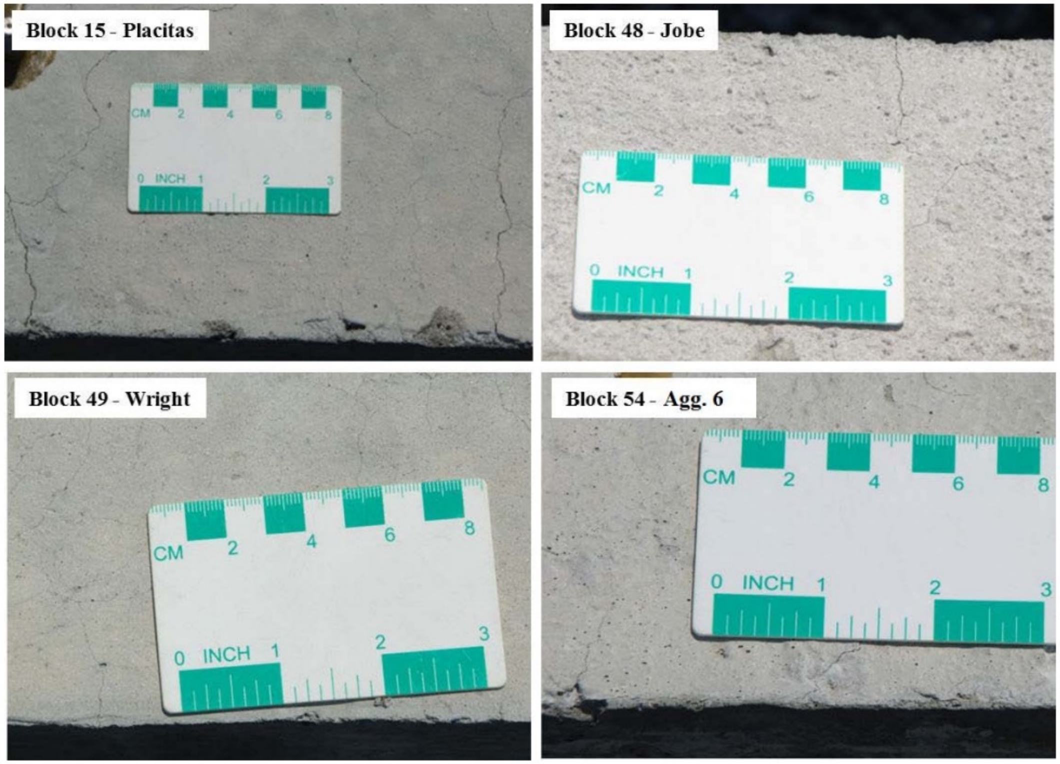
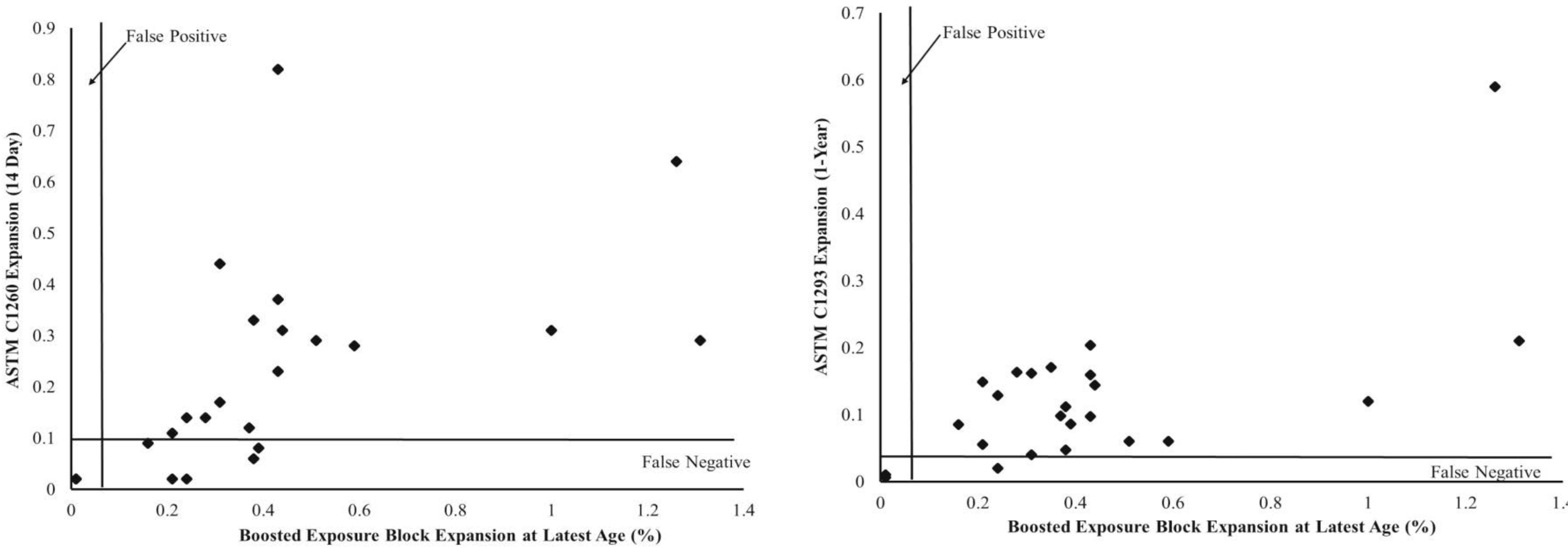


Figure 11. Cracking in Blocks on Exposure Site after One Year

[18] Thomas, M. D. A., Folliard, K. J., Fournier, B., Drimalas, T., & Garber, S. I. *Methods for Preventing ASR in New Construction: Results of Field Exposure Sites*. FHWA-HIF-14-004, 2013

Rapid tests vs long-term benchmarks

Control – No SCMs



In terms of classifications, Both tests, tends to mislabel the reactivity of some mixes.

[19] Drimalas, T.; Folliard, K. J.; Ideker, J. H. *Findings from the University of Texas at Austin: ASR Exposure Site after 20 Years.* In: Proceedings of the 17th International Conference on Alkali-Aggregate Reaction (ICAAR), 2024

Rapid tests vs long-term benchmarks

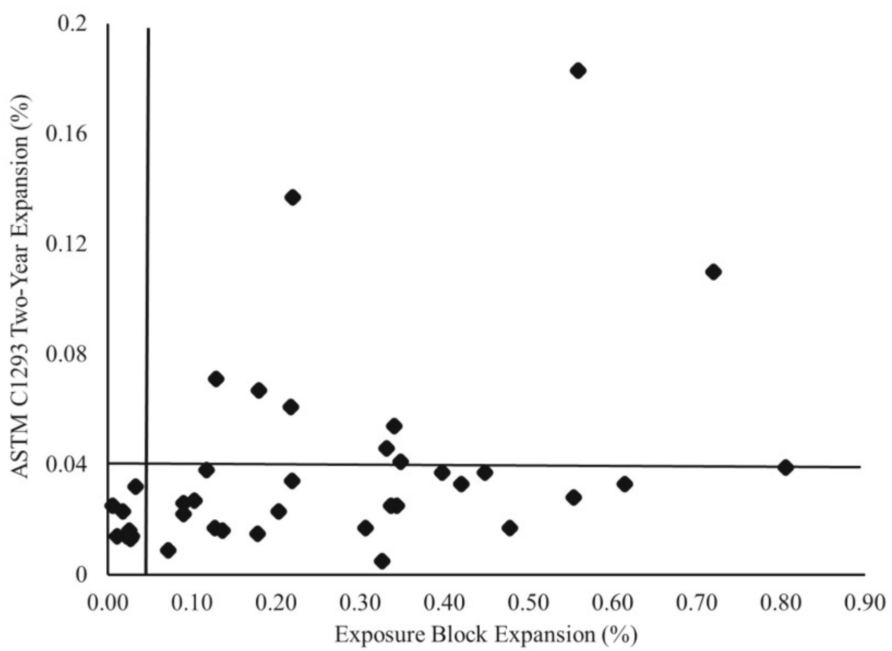


Fig. 8. Comparison between exposure block and ASTM C1293 at 2 years for prevention mixtures (fly ash, slag cement, silica fume, lithium nitrate)

When it comes to Prevention methods like addition of salts or SCMs:

It appears that expansion exist however it is not captured by the ASTM C1293 tests.

[19] Drimalas, T.; Folliard, K. J.; Ideker, J. H. *Findings from the University of Texas at Austin: ASR Exposure Site after 20 Years.* In: Proceedings of the 17th International Conference on Alkali-Aggregate Reaction (ICAAR), 2024

Summary: Importance of the study

- Expand study: test severe weather (including freeze-thaw)
- Expand study: test local aggregate sources, different cements and SCMs, and ASR inhibitors.
- Create benchmarking for the different local mixes.
- Develop a new alkali threshold improving existing tests.

Acknowledgments

Acknowledgments