Alkali-Silica Reactivity Mitigation Using Alternative Supplementary Cementitious Materials

Somayeh Nassiri

UNIVERSITY of CALIFORNIA PAVEMENT RESEARCH CENTER

Funded by

Caltrans
CALIFORNIA DEPARTMENT OF TRANSPORTATION

Spring 2026 National Concrete Consortium
April 7-9, 2026
Westin San Diego Bayview Hotel

Historical Perspective on ASR in California

- Early studies (Stanton, 1940) documented measurable expansion in concrete
- Expansion linked to high-alkali cement and reactive aggregates

AMERICAN SOCIETY OF CIVIL ENGINEERS

Founded November 5, 1852

TRANSACTIONS

Paper No. 2129

EXPANSION OF CONCRETE THROUGH REACTION BETWEEN CEMENT AND AGGREGATE

BY THOMAS E. STANTON,[1] M. AM. SOC. C. E.

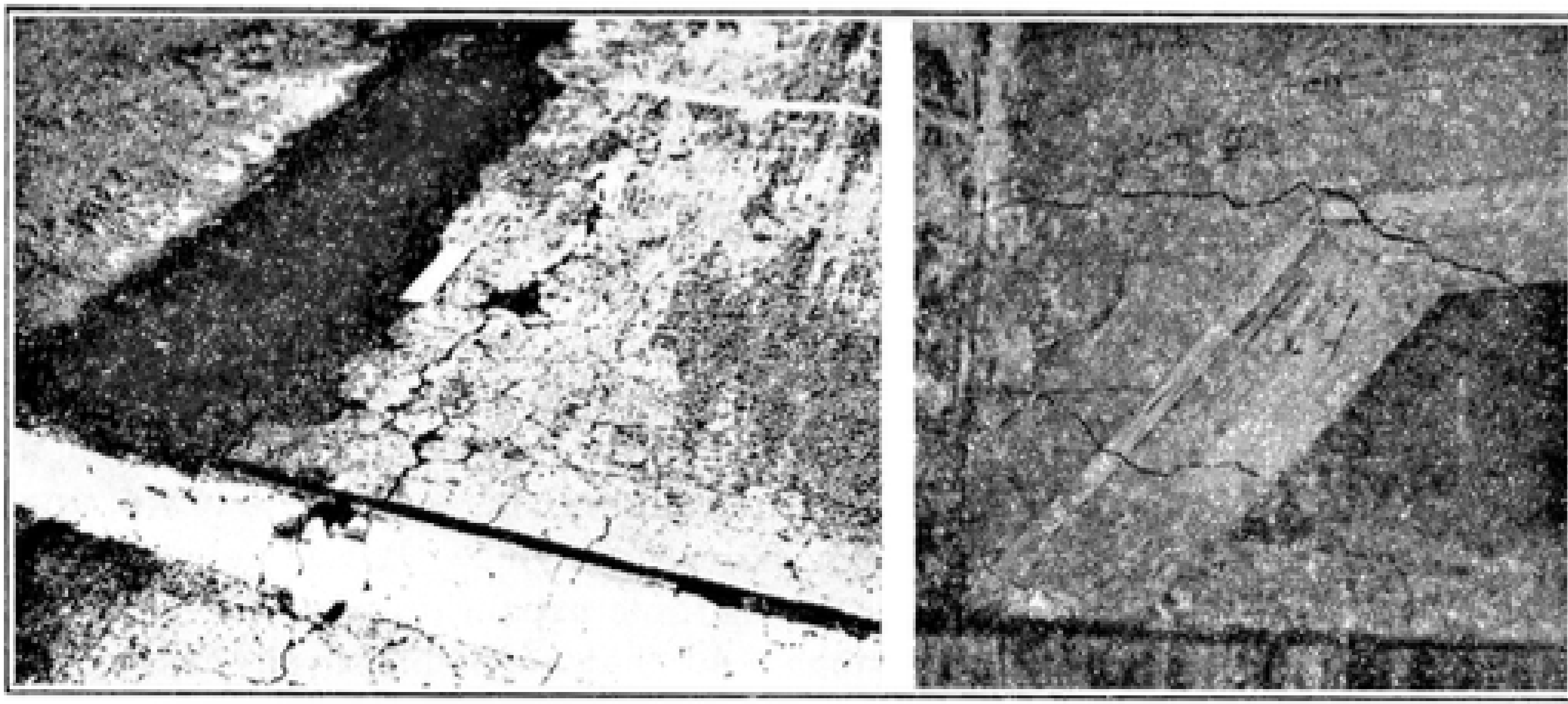
WITH DISCUSSION BY MESSRS. R. W. CARLSON, BAILEY TREMPER, HUBERT WOODS, N. T. STADTFELD, W. C. HANNA, J. C. WITT, R. F. BLANKS, J. MACNEIL TURNBULL, ROBERT A. KINZIE, JR., AND THOMAS E. STANTON.

SYNOPSIS

Tests have demonstrated that excessive expansion of concrete may occur through chemical reactions between cements of relatively high alkali content and certain mineral constituents in some aggregates, such as certain types of shales, cherts, and impure limestones found along the coast of California between Monterey Bay on the north and Los Angeles County on the south. A new test procedure is described in this paper through which it is possible, in a comparatively short time, to develop the deleterious characteristics of cement-aggregate combinations similar to those reported in the California study. The procedure consists of curing the specimens in sealed containers at normal temperatures.

Stanton (1940)'s Field Observations

- 938 pavement failures (Salinas Valley, California)
  - Distress appeared after about **2 years of service**
  - Buckling at expansion joints and **severe slab cracking**
- Investigations linked failures to **reactive aggregate from a local source (Oro Fino)**
- Sections built with imported fine aggregate (Coyote, near San Jose) no expansion

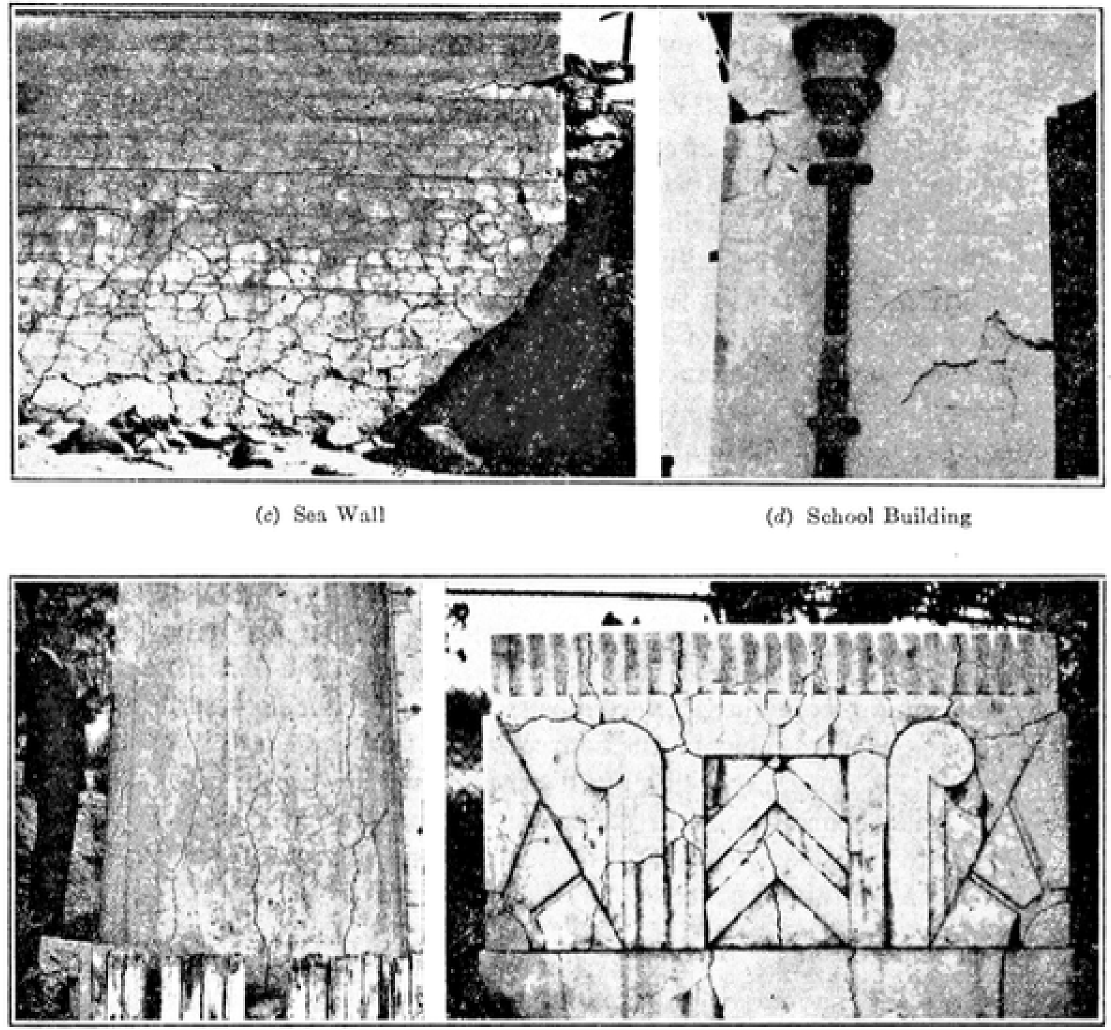


(a) Pavement (b) Bridge Girder

Stanton, T. E. (1940). "Expansion of concrete through reaction between cement and aggregate." *Transactions of the American Society of Civil Engineers*, 107(1), 54–84.

Stanton (1940)'s Field Observations

- Similar distress reported in:
  - Los Angeles, Ventura, Santa Barbara, San Luis Obispo, Monterey counties



(c) Sea Wall (d) School Building

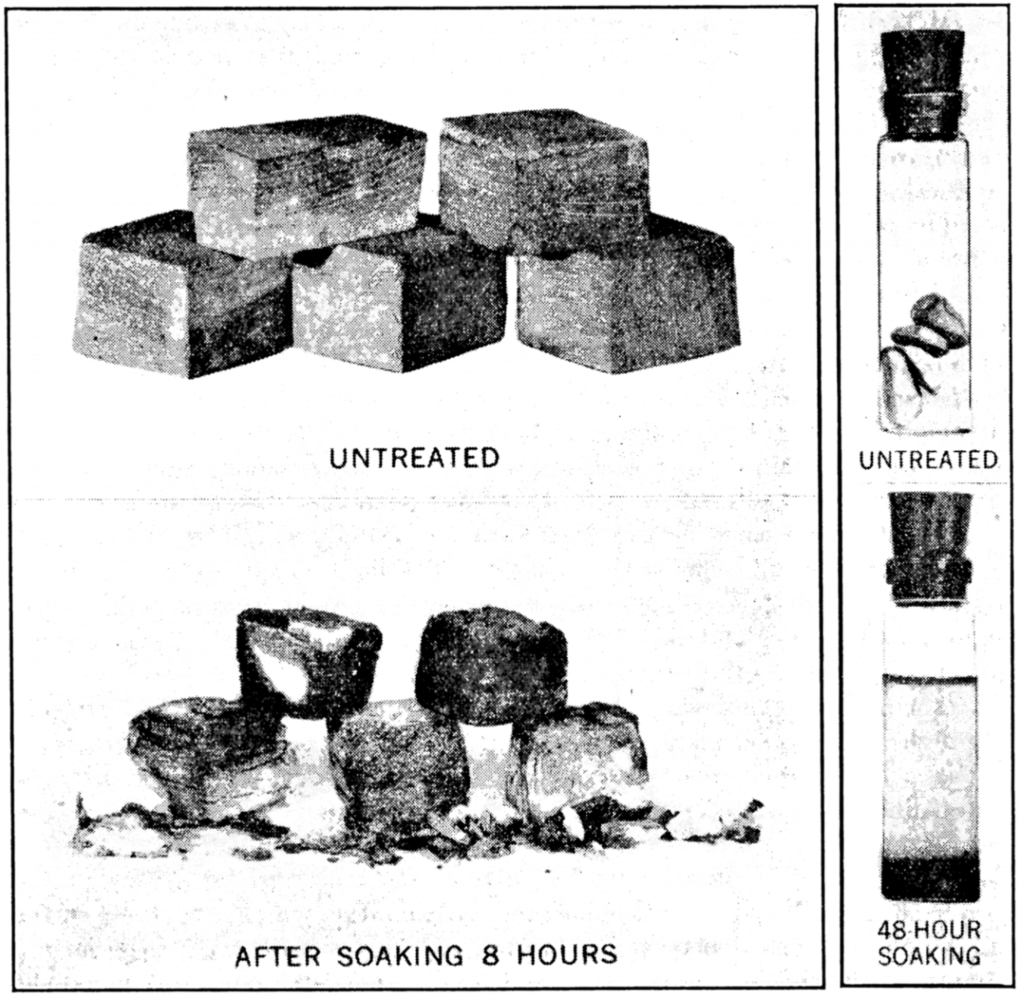
(e) Bridge Pier (f) Bridge Pylon

FIG. 1.—TYPICAL CONCRETE FAILURES RESULTING FROM COMBINATIONS OF CERTAIN AGGREGATES AND HIGH-ALKALI CEMENTS

Stanton, T. E. (1940). "Expansion of concrete through reaction between cement and aggregate." *Transactions of the American Society of Civil Engineers*, 107(1), 54–84.

Stanton (1950)'s Findings: Nature of Reactive Aggregates

- Early laboratory evidence:
- Reactive aggregates contained
  - **Hydrous silica (opaline silica)** dissolves in 10% NaOH solution
  - **4–15% shale, cherty shale, and chert**
- Found along California coast
  - Common in **Miocene marine sedimentary formations along the California coast (e.g., Monterey Shale)**



(a) Specimens Cut from Ledge Rock (b) Stream-Bed Gravel

Fig. 9.—Effect of a 10% Sodium Hydroxide Solution (at 70° F) on Some Types of Siliceous (Cherty) Shale and Chert from the California Miocene Formations

Stanton, T. E. (1940). "Expansion of concrete through reaction between cement and aggregate." *Transactions of the American Society of Civil Engineers*, 107(1), 54–84.

Stanton (1950s) – Early Solutions to ASR

- USBR (1948): Pyrex glass sand (lump cullet No. 774) as a highly reactive material for ASR lab testing.
- Tests were conducted to evaluate:
  - Ability of pozzolans (ground siliceous admixtures) to mitigate expansion in reactive mixtures.
- ASR reaction can be controlled with ~20% pozzolan (fine ground) and some calcined
- Effectiveness related to the ability to consume reactive silica soluble in NaOH

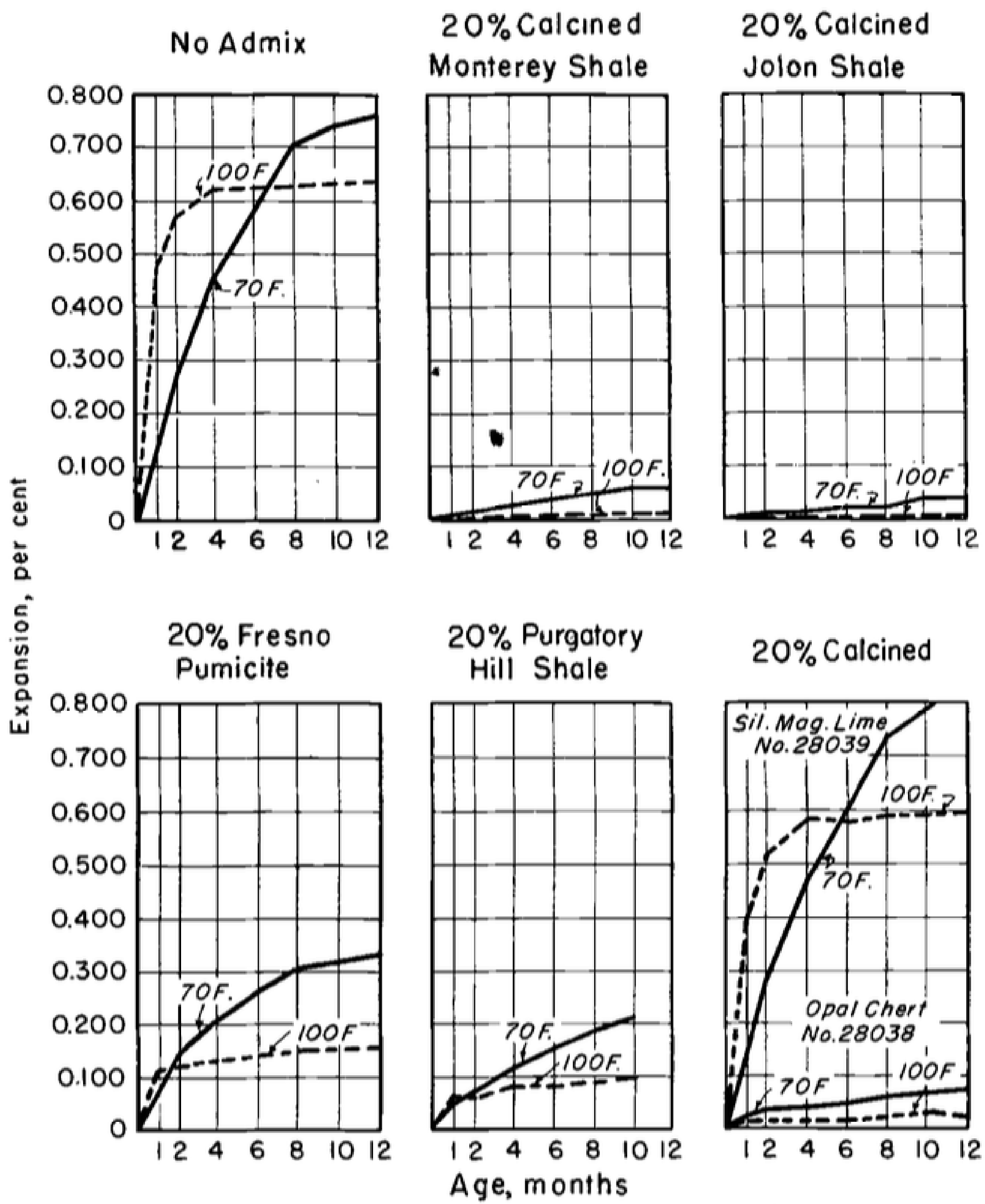
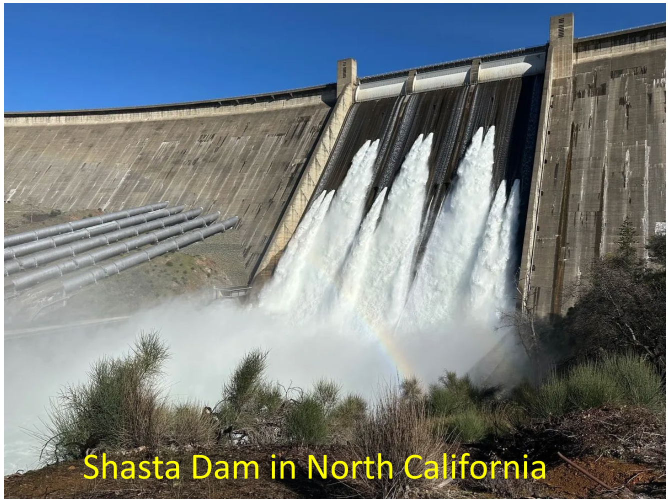


Fig. 5.—Relative Corrective Properties of Several Potential Pozzolans.

Stanton (1950), Pozzolans for ASR Mitigation, ASTM STP 99

Pozzolans and ASR Mitigation

- Research on pozzolans for concrete started in 1908
- By the 1950s, well known that pozzolans can reduce or prevent ASR expansion
    - As cement replacement (~15–20%)
    - Effectiveness depends on material type and reactivity; not all pozzolans perform equally
    - Calcination of certain materials (e.g., clays, shales) can improve their effectiveness


Shasta Dam in North California

- In the U.S.:
    - Los Angeles Aqueduct (1910-1912)
    - Metropolitan Water District Aqueduct (San Jacinto, CA – Mt. Tunnel, 1937)
    - Friant Dam (1935)
    - Golden Gate Bridge (1937)
    - Bonneville Dam (1942)
    - San Francisco–Oakland Bay Bridge (1936)
    - Shasta Dam, Hoover Dam, Davis Dam

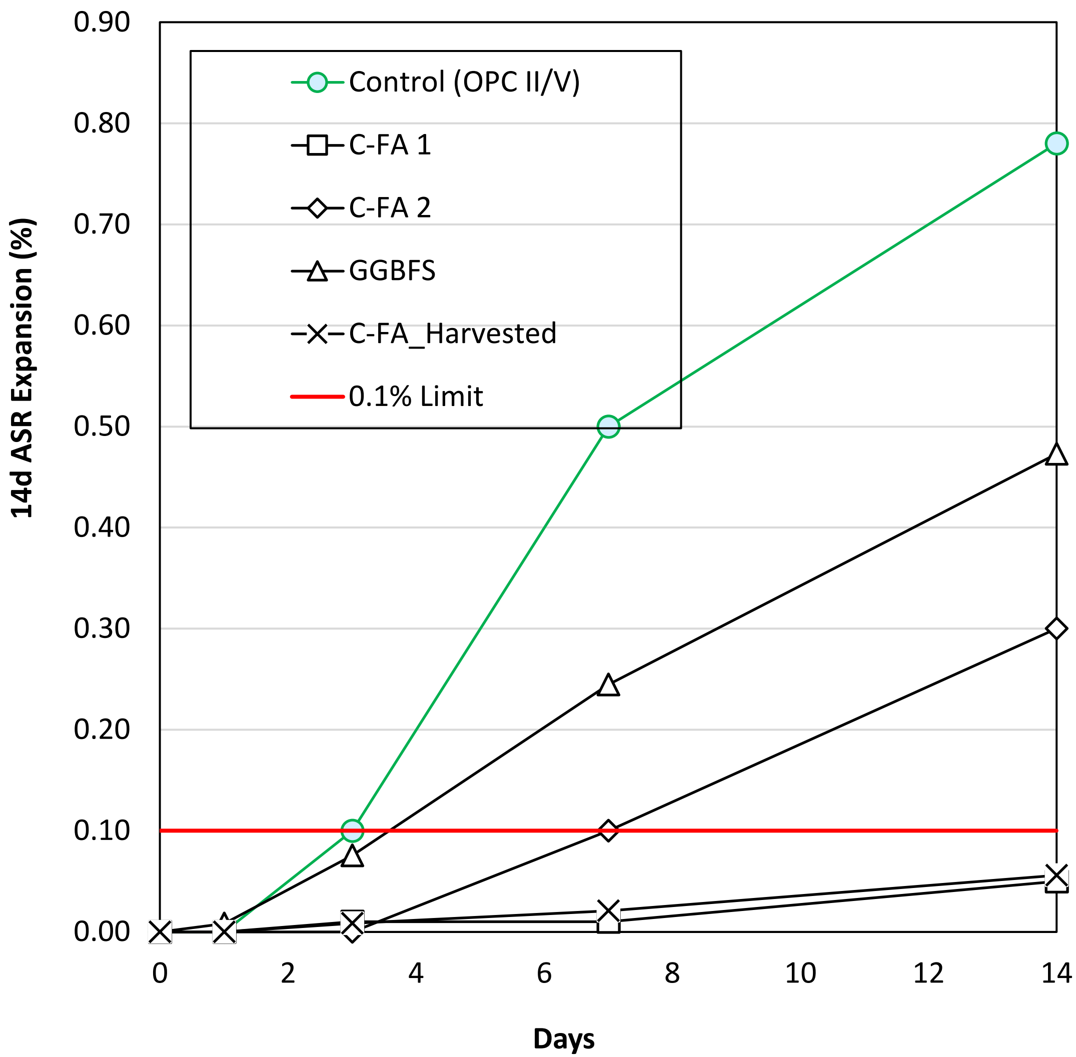
Davis, R. E. (1950). *A review of pozzolanic materials and their use in concretes*. In Symposium on Use of Pozzolanic Materials in Mortars and Concretes (ASTM STP 99). ASTM International.

Traditional SCMs & Opportunity for Domestic SCMs

- **Coal Fly Ash (C-FA)**
  - Used since the 1930s; widely adopted by the 1960s (ASTM C618)
  - Improves workability, durability, and cost efficiency
  - Limited domestic production as coal plants phase out
  - Increasing reliance on imports and reclaimed ash (impoundments/stockpiles)
- **Slag (GGBFS)**
  - Provides durability and carbon reduction benefits
  - Declining domestic steel production
  - Heavily reliant on imports, especially in California
- California is the 2nd largest cement user in the U.S. (~10–12 million tonnes/year; USGS 2021)
  - Is the market opening up to local opportunities?

ASR Mitigation- Traditional SCMs

- **About our test procedure:**
  - ASTM C1567 using R3 (highly reactive) sand
  - Control expansion: ~0.75% at 14 days
- Performance varies significantly by SCM type and source
- Fly ash (C-FA 1, harvested FA) effectively reduces expansion (<0.1%)
  - SCMs with high SiO_2 to CaO are more effective for ASR mitigation (Thomas 2011)



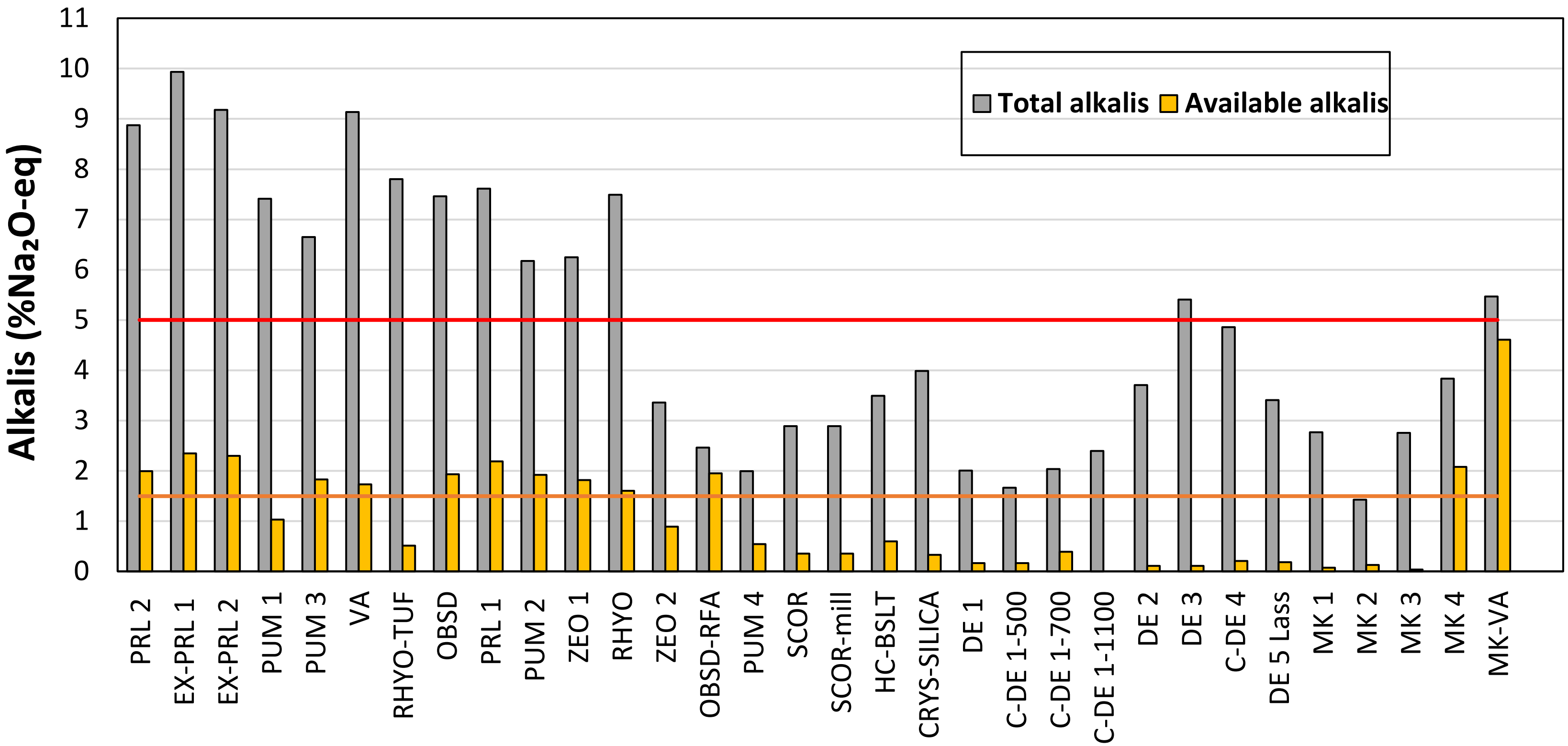
Thomas, M. 2011. "The Effect of Supplementary Cementing Materials on Alkali-Silica Reaction: A Review." *Cement and Concrete Research* 41, no. 12: 1224–1231.

Alternative SCMs

- Natural pozzolans
- others

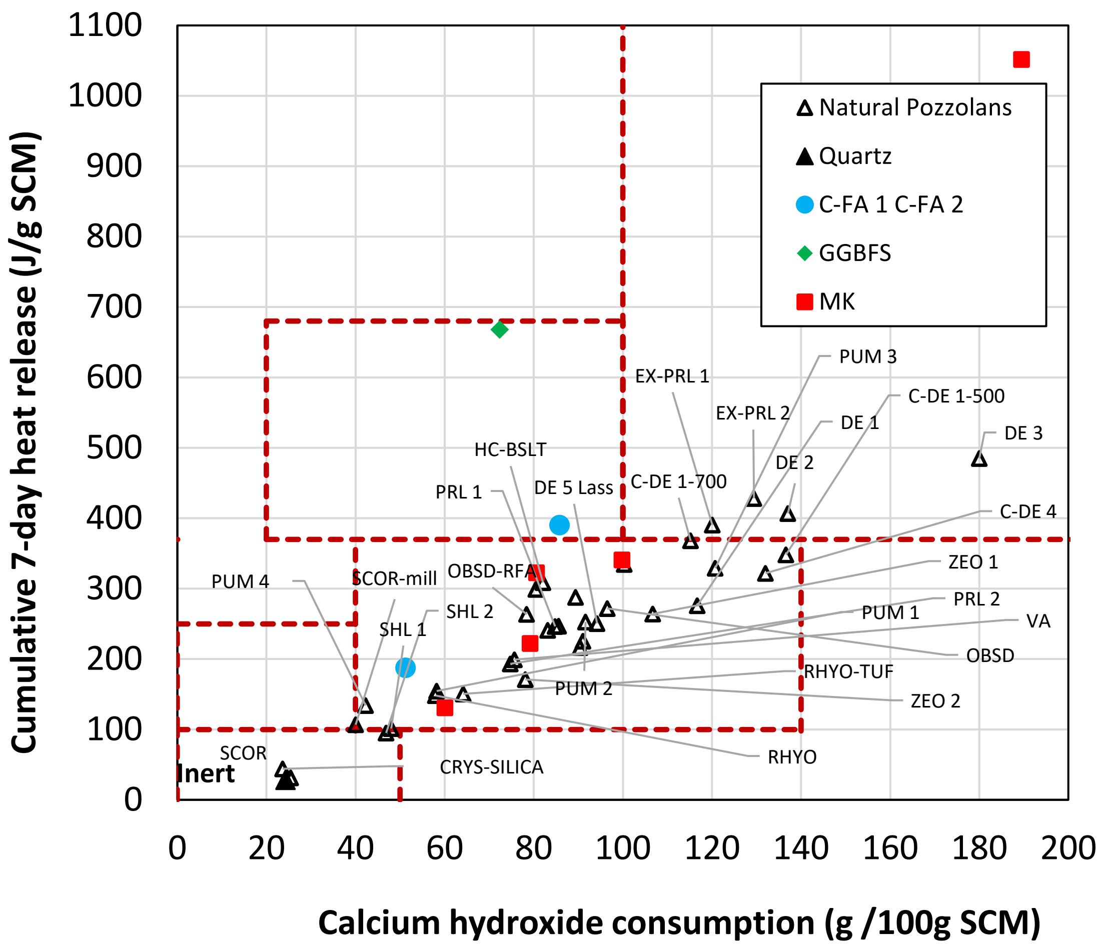
Alkalis- Natural Pozzolans

- **Total** alkalis (XRF) vary widely across natural pozzolans
  - Some exceed typical **alkali limit (~5% Na_2O_{eq})**
- **Available** alkalis (ASTM C311) are significantly lower than total alkalis
  - Most pozzolans still exceed typical limit **(1.5% Na_2O_{eq})**
- Do low available alkalis indicate ASR mitigation?
  - ASR result will show that this is not the case



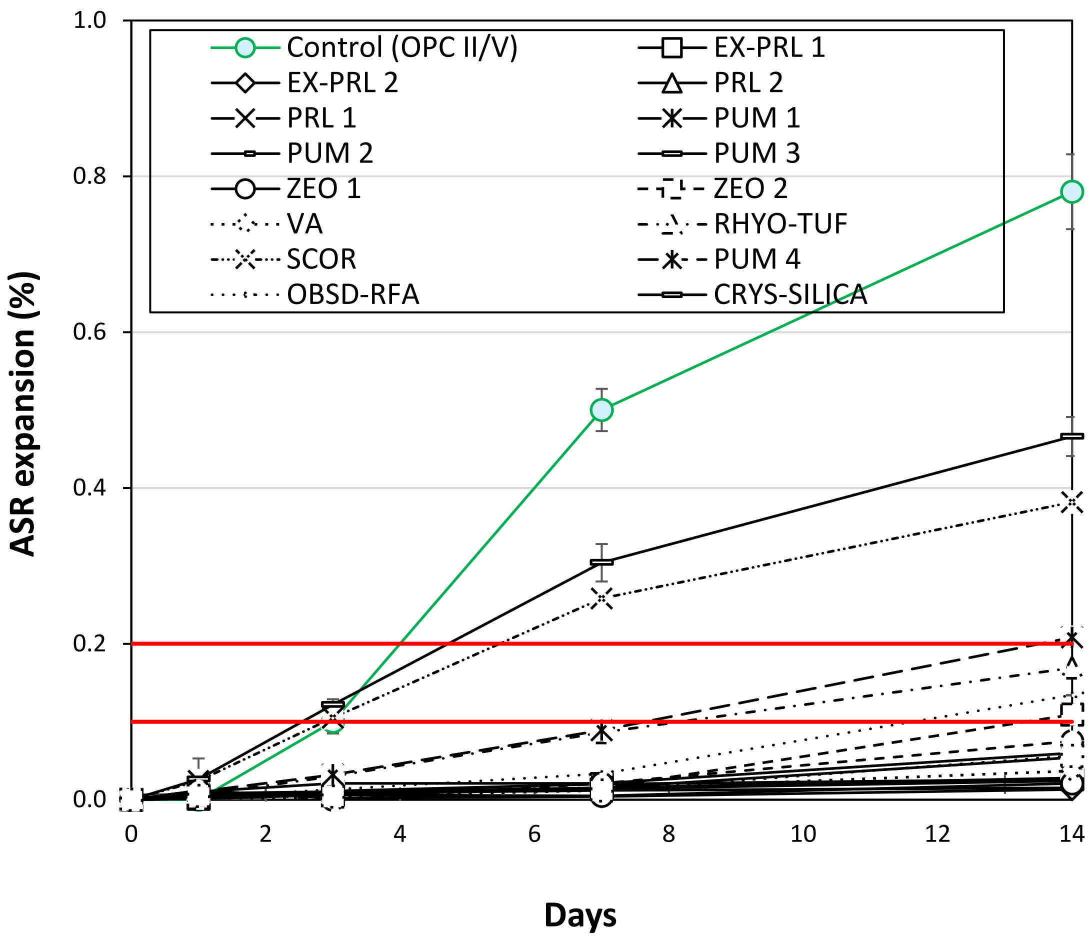
Pozzolanic Reactivity Performance- Natural Pozzolans

- ASTM C1897: R3 reactivity (calorimetry + calcium hydroxide consumption)



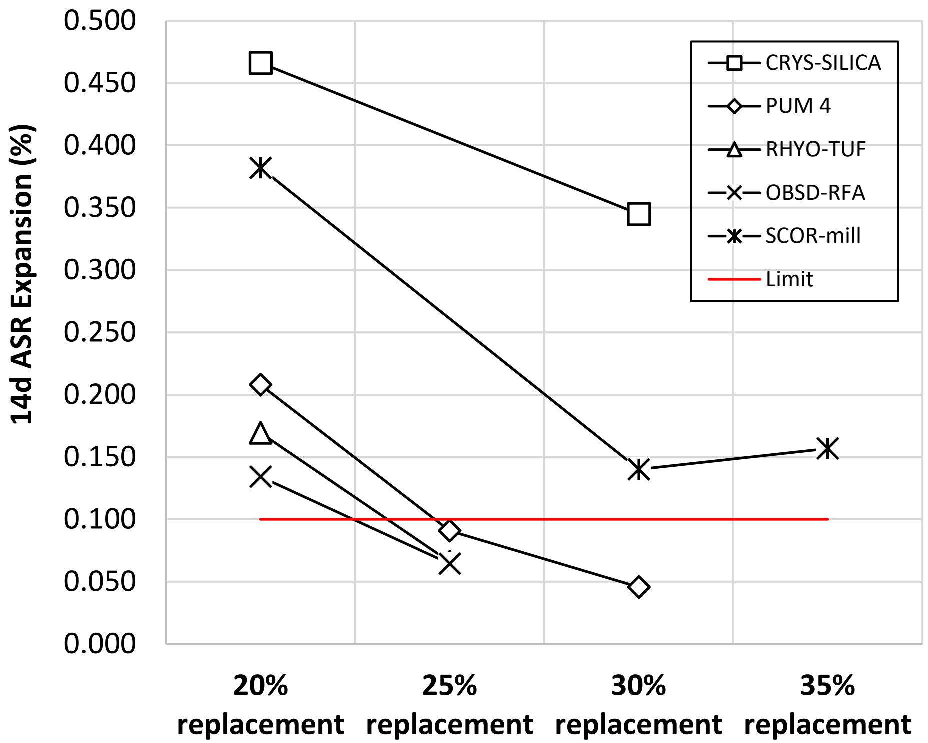
ASR Mitigation- Natural Pozzolans

- Most other pozzolans provide **effective mitigation (<0.1%)**
- These samples exceed **0.1% limit**, including:
  - CRYS-SILICA (~0.46%); MK4 (~0.43%); SCOR-mill (~0.38%); PUM 4 (~0.21%)
- Let's see if we can make them pass by using a higher replacement rate



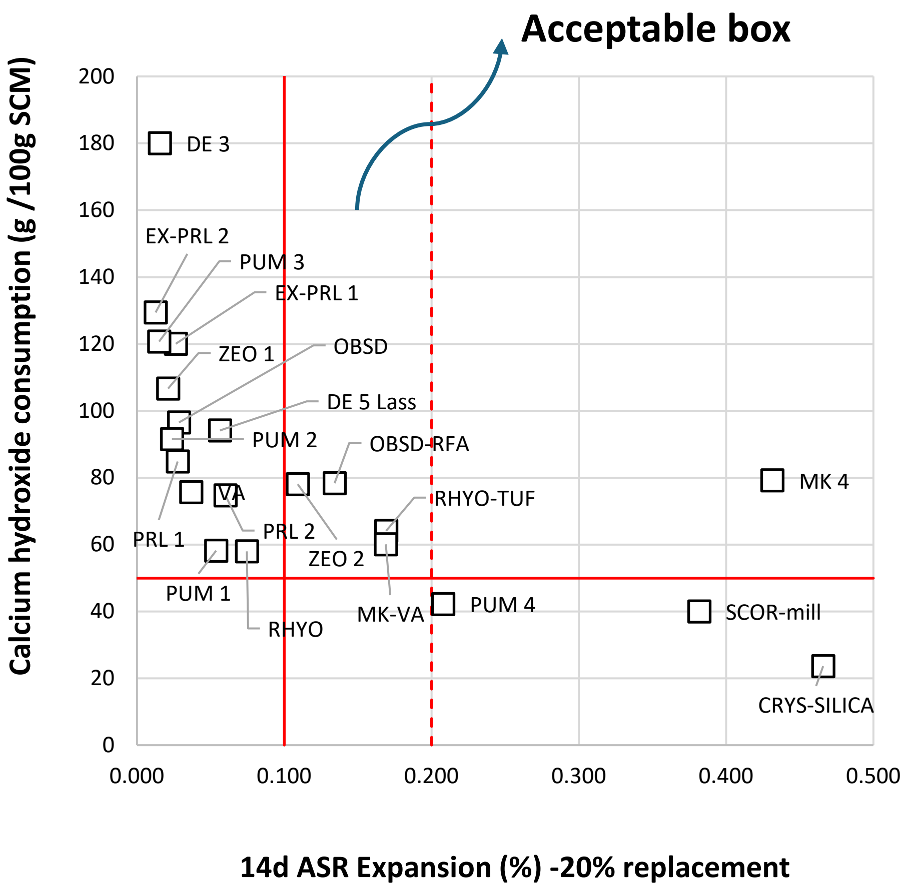
ASR Mitigation- Effect of Replacement Rates

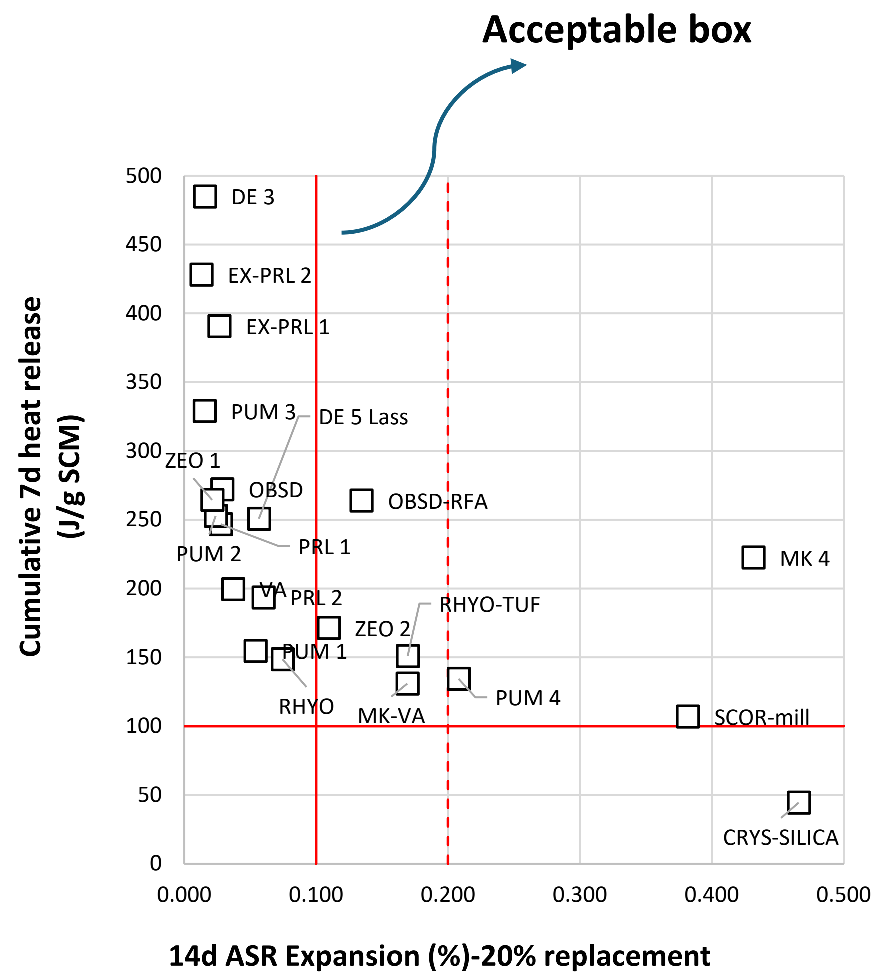
- Increasing the replacement level **reduces expansion but only for some**
- **CRYS-SILICA and SCOR-mill:**
  - Show reduction with higher dosage but still fail
  - Let's see why



ASR Mitigation: Screening Tool for Pozzolanic Reactivity

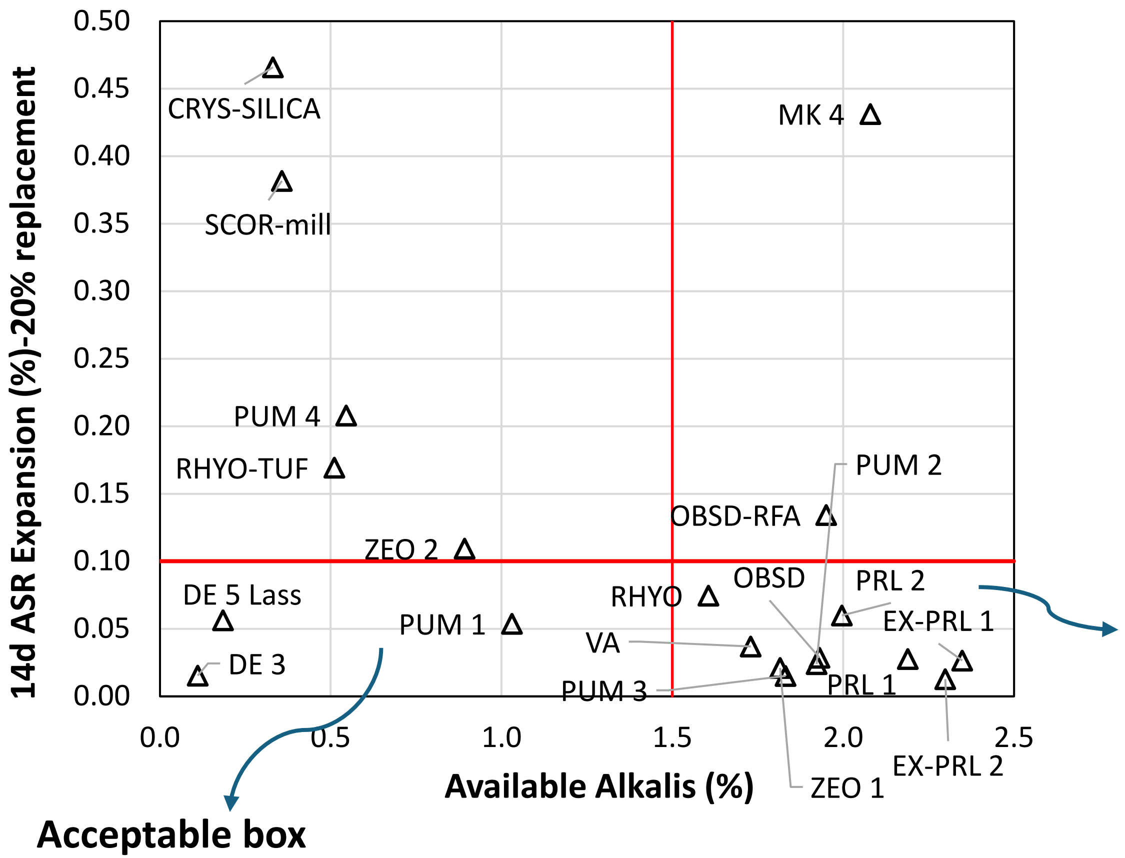
- **ASTM C1867 results correlate with ASR performance**
- The same four samples that fail ASR (**>0.1% expansion**) also fall outside pozzolanic reactivity limits:
    - CRYS-SILICA, SCOR-mill, MK 4, PUM 4





Available Alkalis is not a Good Screening Tool

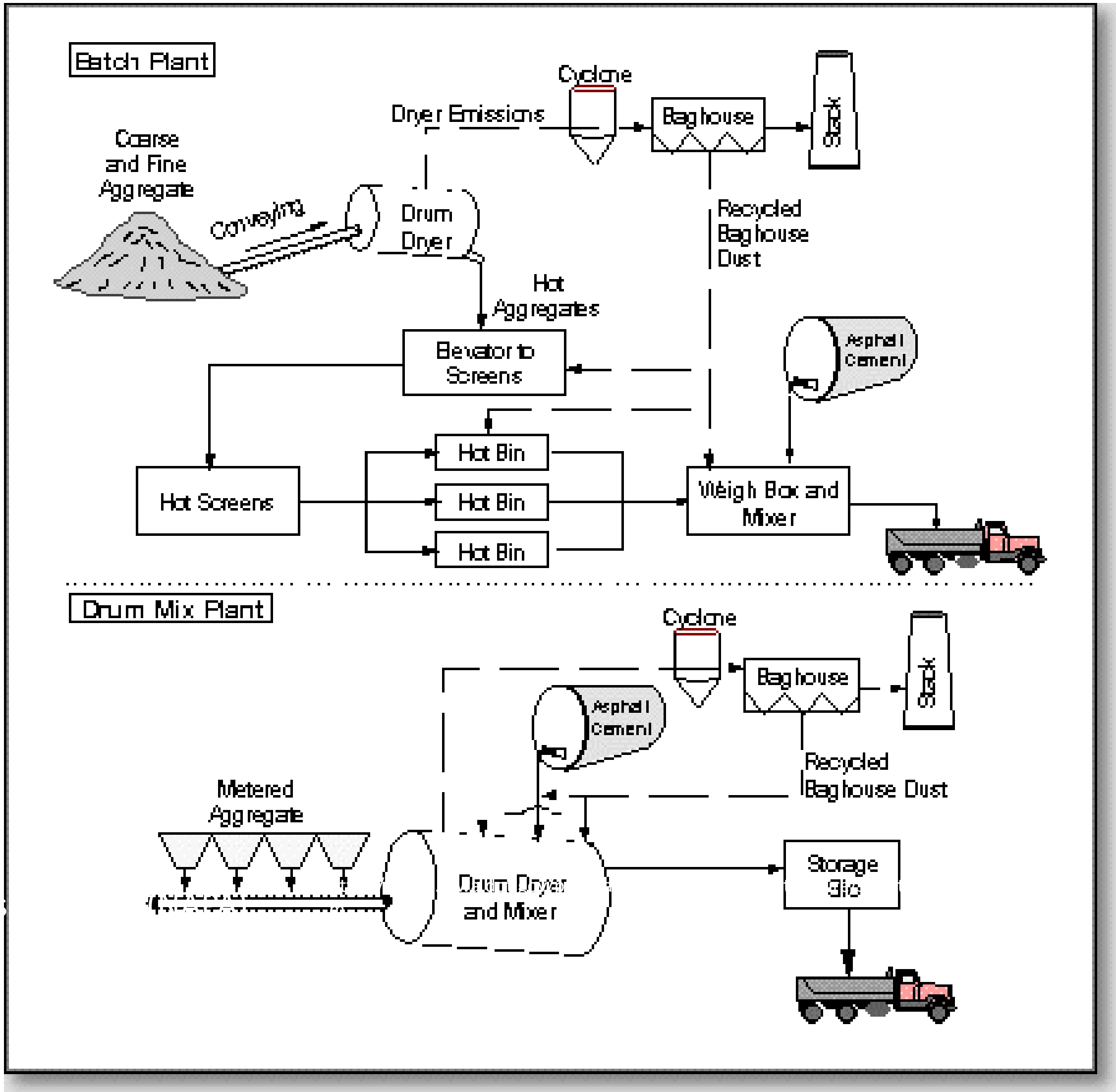
- Using available alkalis as a screening criterion **excludes many well-performing pozzolans**
  - Poor alignment between **available alkalis and ASR performance**



Several materials that meet ASR limits (<0.1%) fall outside current alkali limit

Baghouse Fines

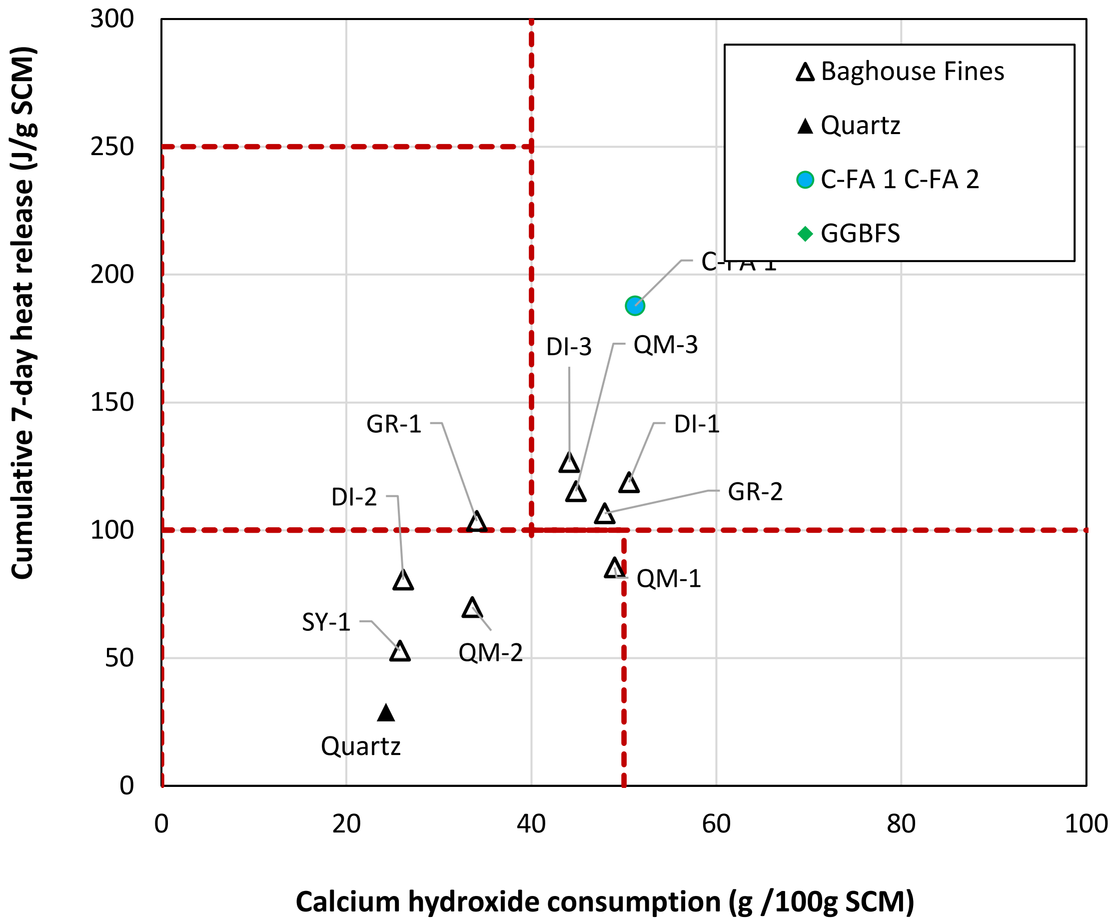
- ~ 6 to 8 million short tons of baghouse fines generated annually by U.S. asphalt production industry
- Most asphalt producers try to recycle as much of the dust back into their mixes as possible



(NCHRP Synthesis No. 199)

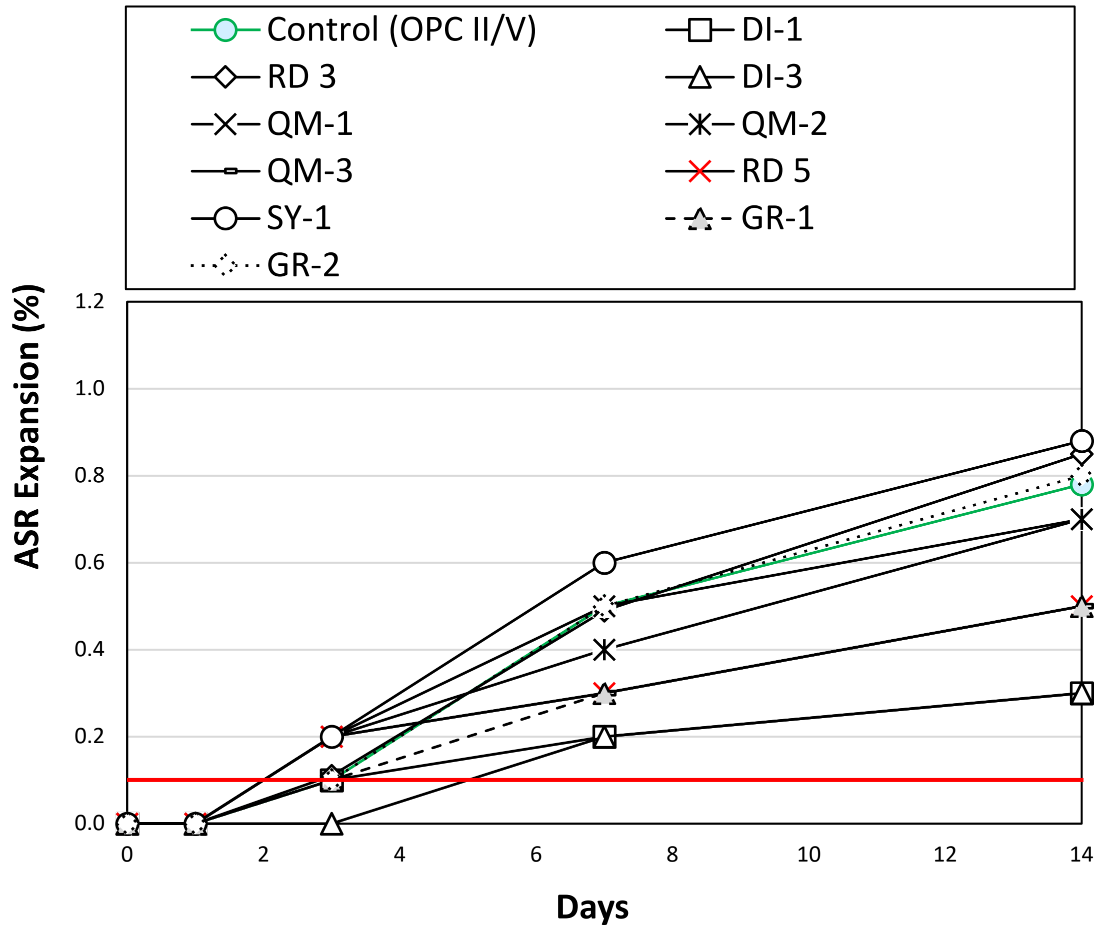
Are Baghouse Fines from Asphalt Plants Pozzolans?

- Four of the tested samples fall inside the pozzolanic box
- Others mostly inert



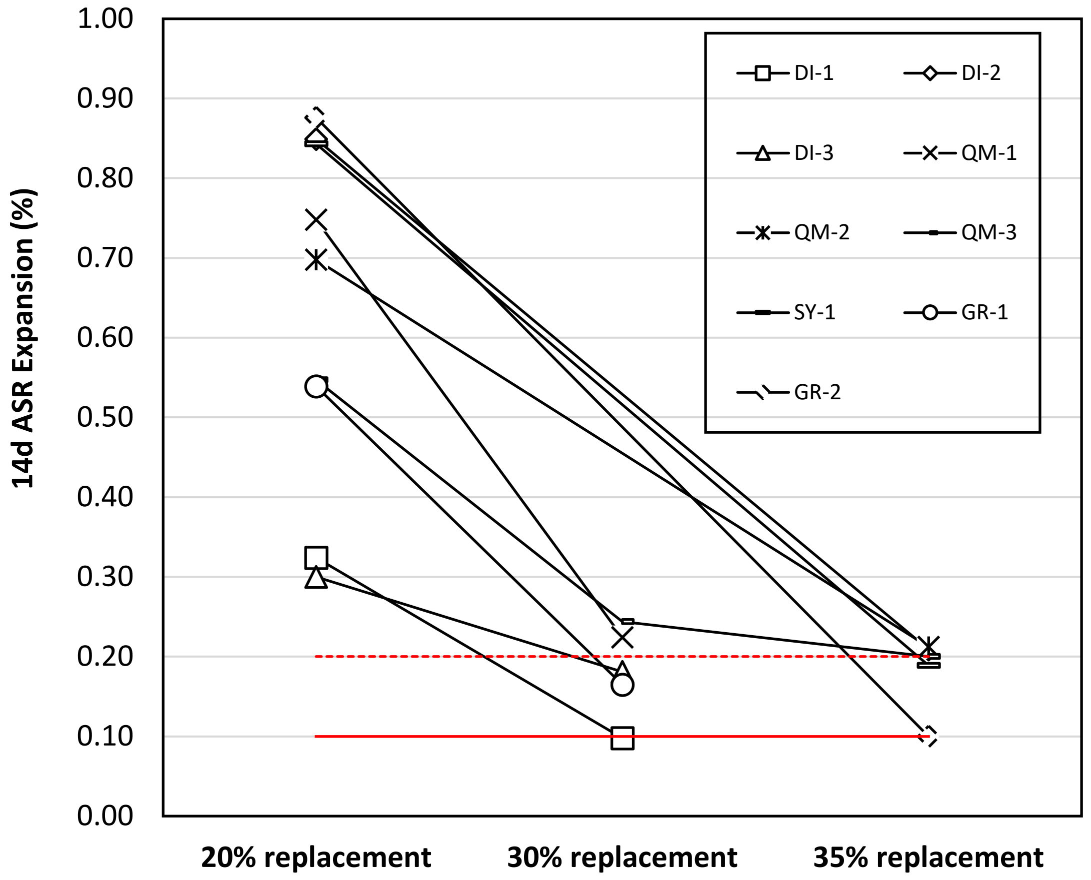
ASR Performance- Baghouse Fines

- Several materials: high expansion (>0.7–0.9%), some exceeding the control
- Some show moderate reduction, but still above acceptable limits



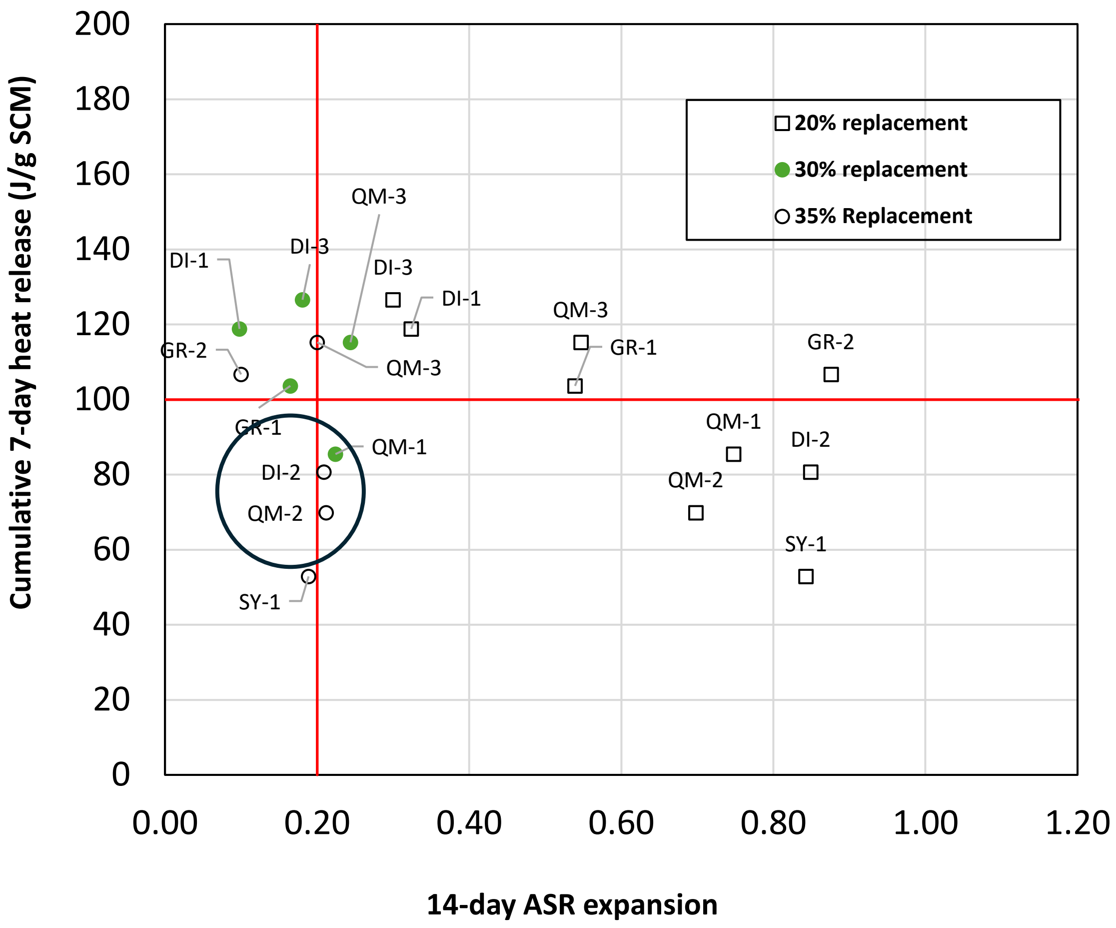
ASR Mitigation- Effect of Replacement Rate- Baghouse Fines

- Significant reduction from 20% → 30% replacement
  - Most pass (≤0.2% at higher replacement)
- **Failing materials (>0.2% even at 35%):**
  - **DI-2, QM-2, QM-1**

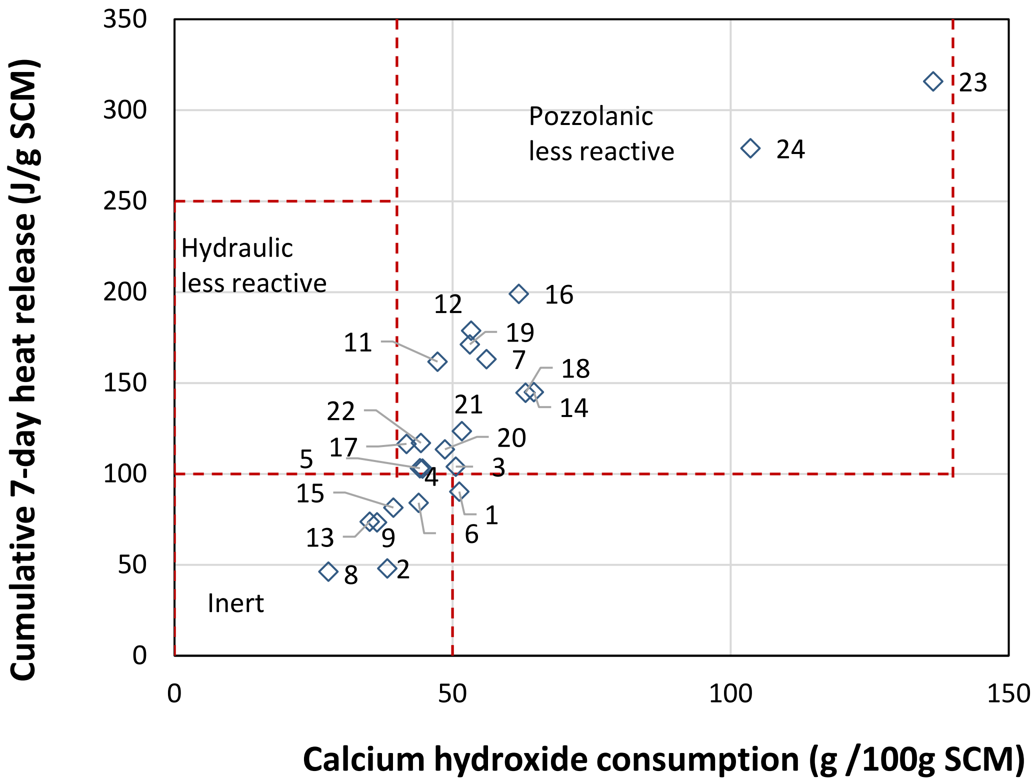


ASR Mitigation/Pozzolanic Reactivity- Baghouse Fines

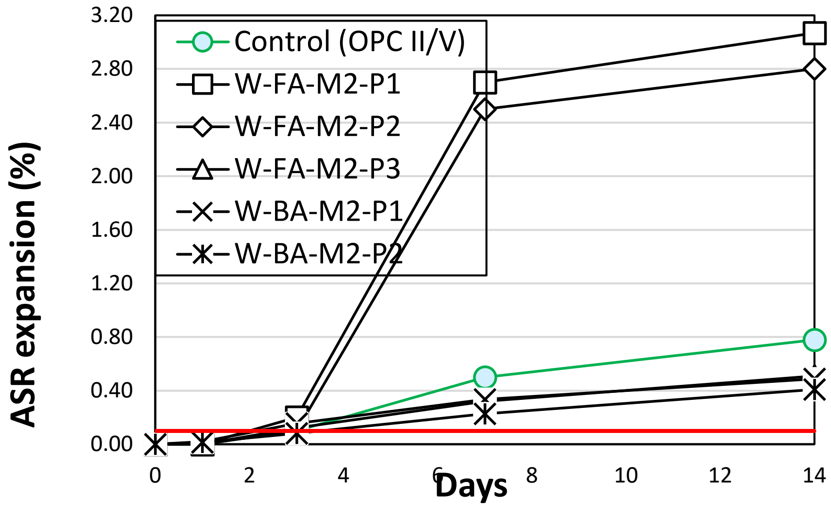
- DI-2, QM-2, and QM-1 don't pass for pozzolanic reactivity
- Consistent with ASR results

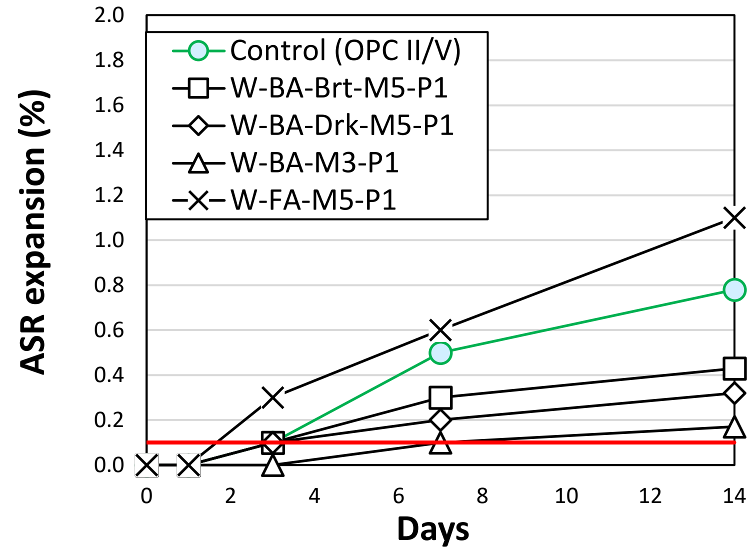


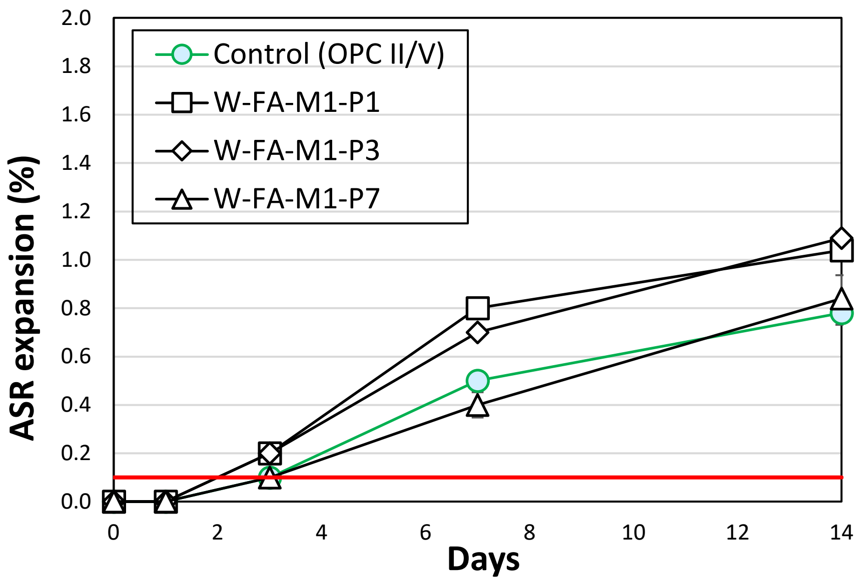
Are Wood Ashes Pozzolans?

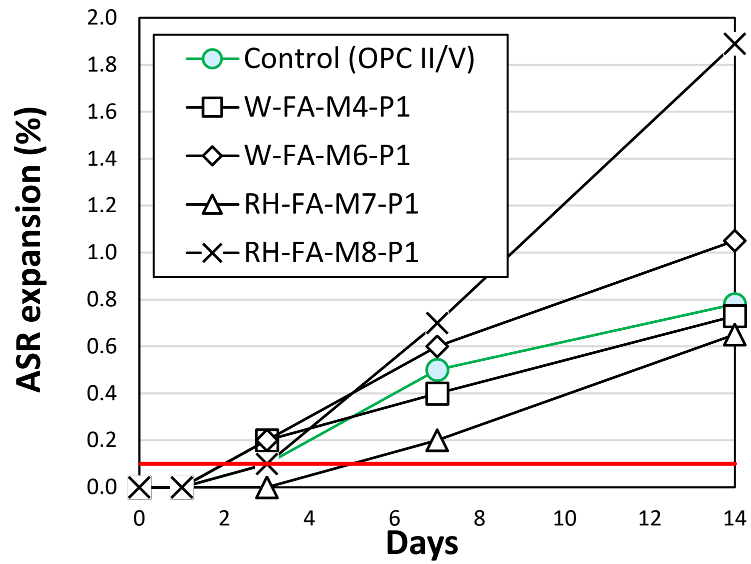


ASR Mitigation- Wood Ashes



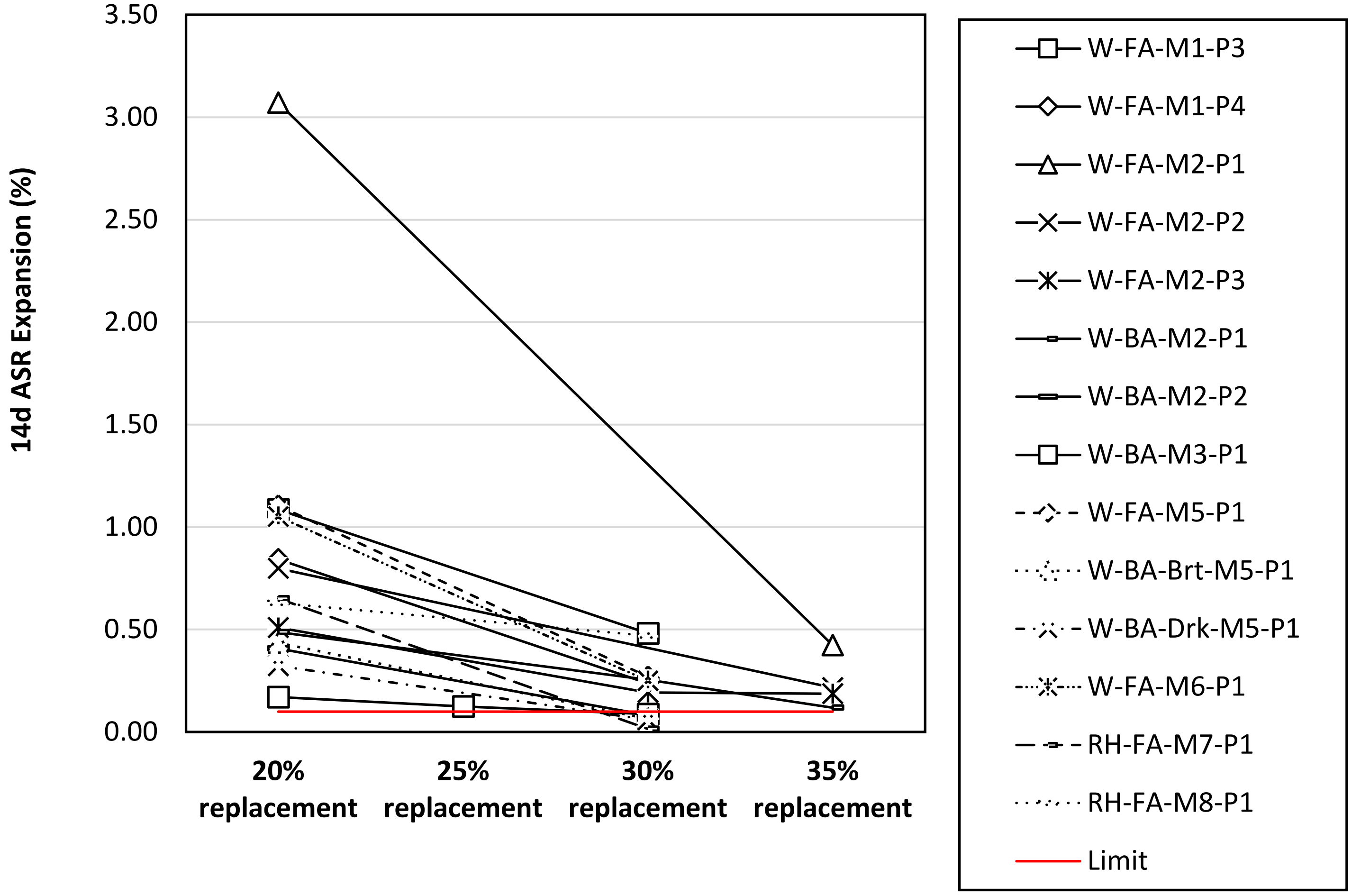






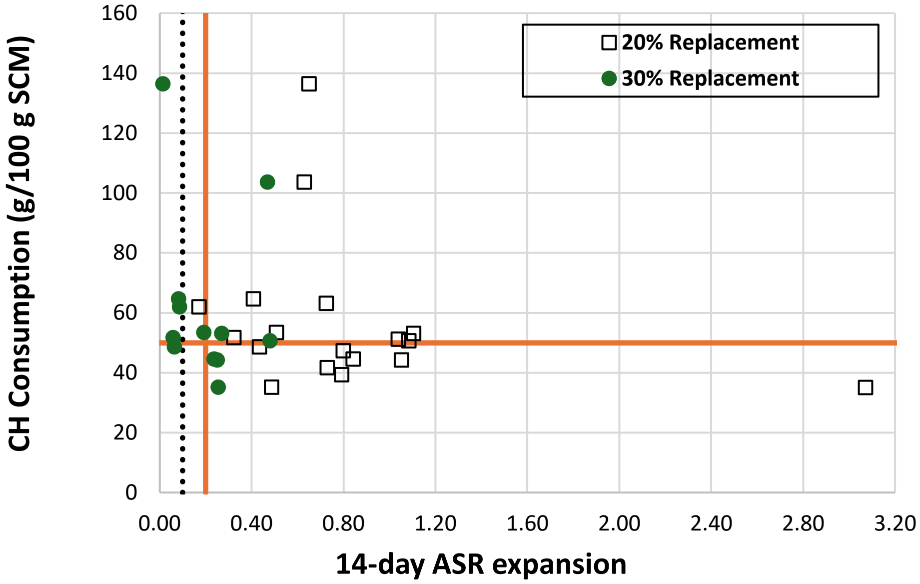
ASR Mitigation- Wood Ashes

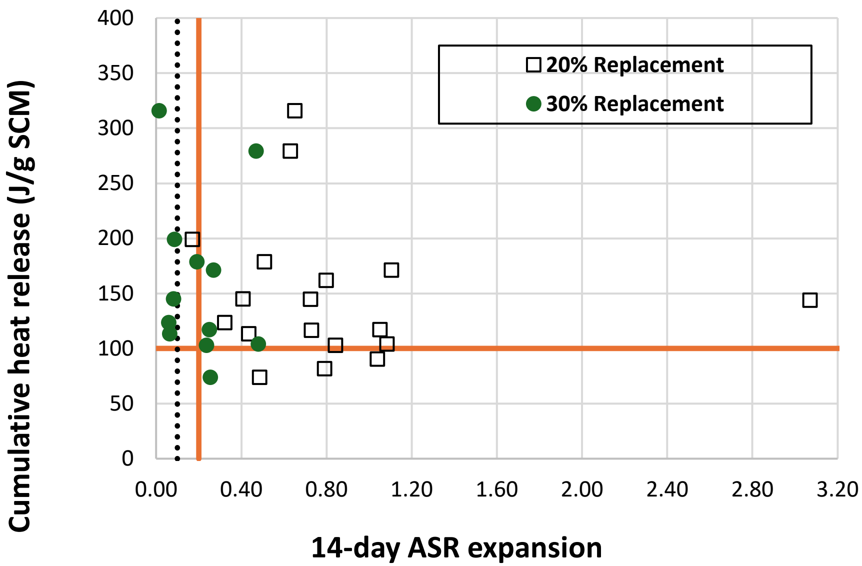
- Increasing replacement level reduces ASR expansion
- Large reduction from 20% → 30%-35% replacement most samples



ASR Mitigation/Pozzolanic Reactivity- Wood Ashes

- Many wood ashes meet pozzolanic reactivity criteria
- However, at 20% replacement:
  - Poor ASR mitigation performance
- At 30% replacement:
  - Several shift into the acceptable box



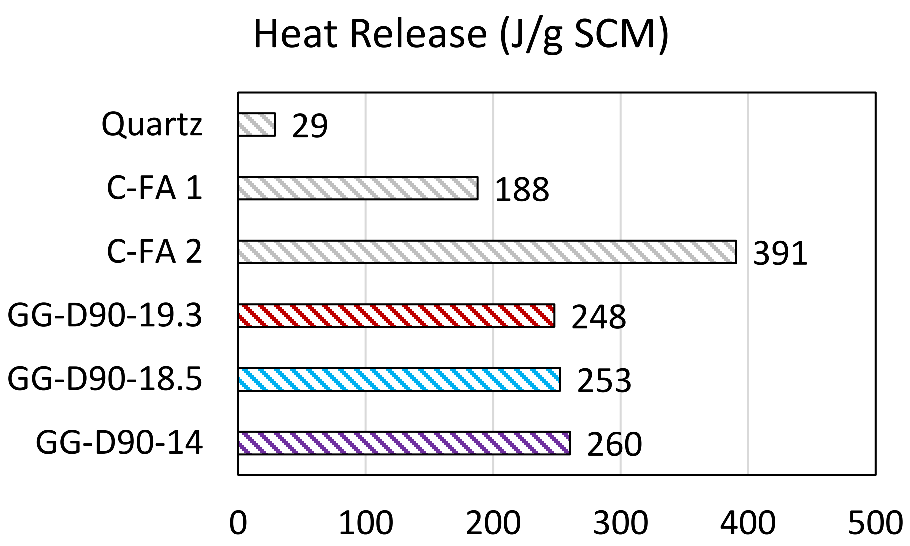


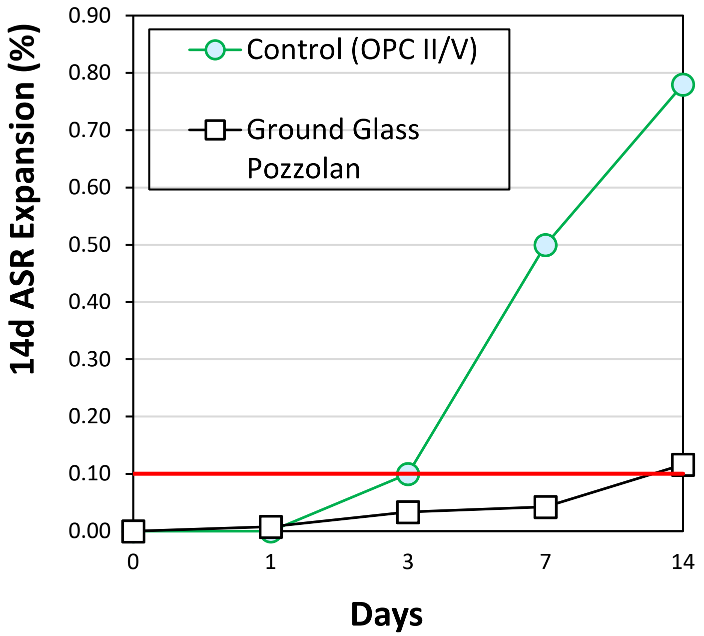
Ground Glass Pozzolan (ASTM C1866)

TABLE 1 Chemical Requirements

	Classification	
	Type GS	Type GE
Silicon dioxide (SiO_2), min %	60.0	55.0
Aluminum oxide (Al_2O_3), max %	5.0	15.0
Calcium oxide (CaO), max %	15.0	25.0
Iron oxide (Fe_2O_3), max %	1.0	1.0
Sulfur trioxide (SO_3), max %	1.0	1.0
Total equivalent alkalies, Na_2O_{eq}, max %[A]	15.0	4.0
Moisture content, max %	0.5	0.5
Loss on ignition, max %[B]	0.5	0.5

[A] Na_2O_{eq} % = Na_2O + 0.658K_2O. See Notes 1 and 2 for total equivalent alkali content ranges.
[B] Loss on ignition shall be conducted at 600° C in accordance with CSA A3003.





Summary

- Alternative SCMs can perform as well as or better than traditional SCMs (fly ash, slag)
  - Need to be properly evaluated and used at appropriate replacement levels
- Pozzolanic reactivity correlates with ASR performance
  - ASR mitigation depends on pozzolanic reactivity and replacement rate
- Screening should consider pozzolanic reactivity and ASR testing, not alkalis alone
- There are reactive pozzolans that are effective in ASR mitigation from various sources
  - Natural pozzolans
  - Wood ash
  - Ground glass
  - Baghouse fines
- Some alternative SCMs with low reactivity may still be good for use with innocuous aggregate
  - Concrete durability testing is required

Upcoming Conference at UC Davis!

- CCPC (organized by SWCP) integrates Lab2Slab construction to accelerate technology transfer
  - Next conference: April 22–23, 2026 | UC Davis
  - Register: theccpc.com

Thank You

- Questions?
- nassiri@ucdavis.edu