Alkali-Aggregate Reactivity

Michael Thomas
University of New Brunswick

Jason H. Ideker
Oregon State University

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Chapter 5 Alkali-Aggregate Reaction

5.1 Introduction

5.2 Types of Reactions

5.3 Evaluating Aggregates

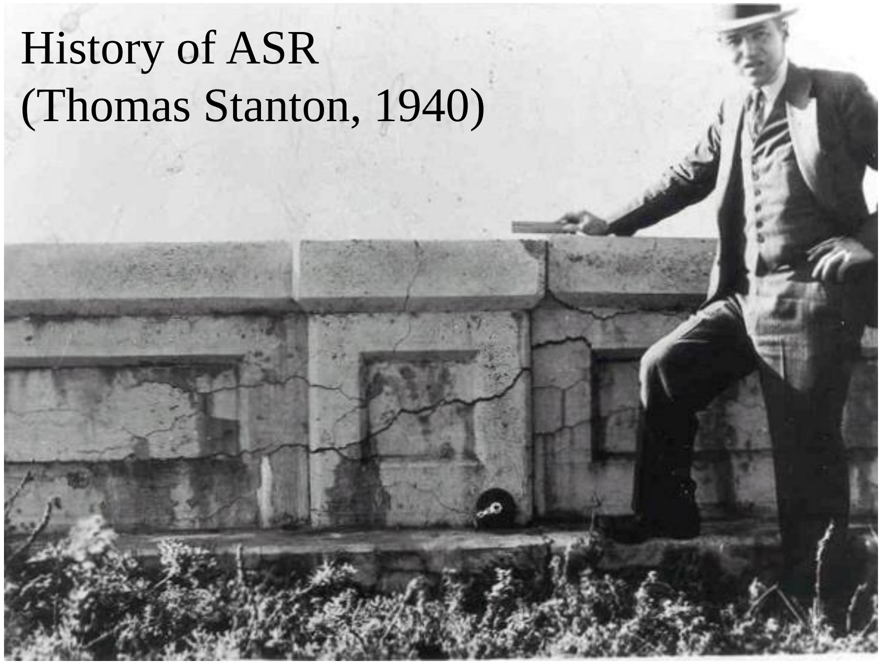
5.4 Preventive Measures

5.5 Tests for Evaluating Preventive Measures

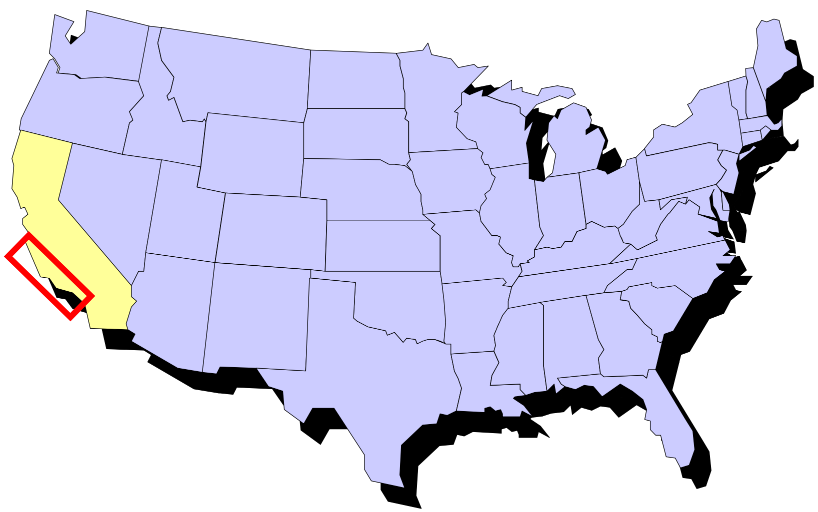
5.6 Protocols for Minimizing the Risk of AAR

5.1 Introduction

History of ASR
(Thomas Stanton, 1940)



History of ACR
(Ed Swenson, 1957)



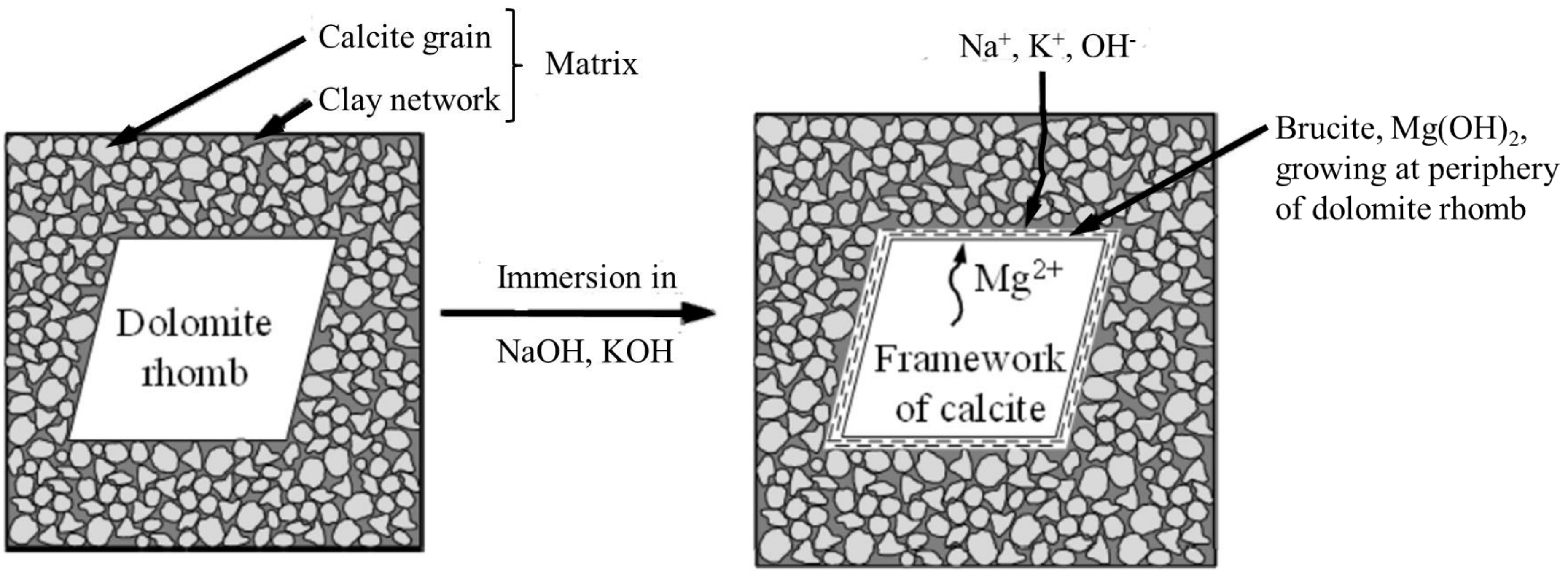
(Rogers, MTO, 1995)


5.2 Types of Reaction (AAR = ACR + ASR)

5.2.1 Alkali-Carbonate Reaction (ACR)

Dedolomitization: $$CaMg(CO_3)_2 + 2NaOH \rightarrow Mg(OH)_2 + CaCO_3 + Na_2CO_3$$

Dolomite	Alkali Hydroxide	Brucite	Calcite	Alkali Carbonate



modified from Tang et al. (1987)

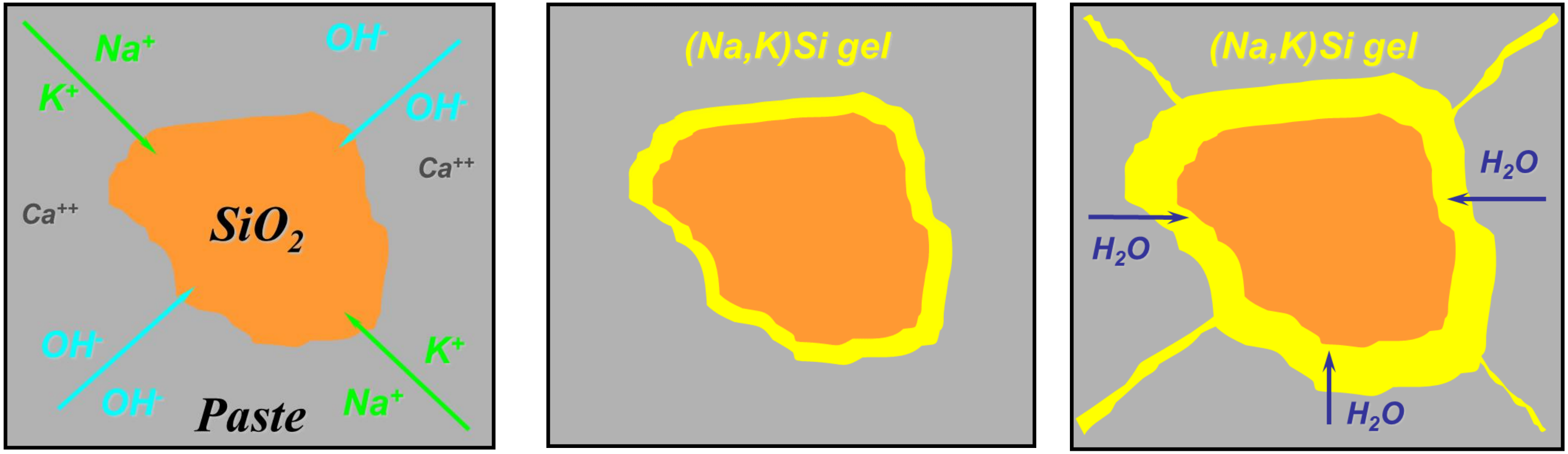
5.2 Types of Reaction (AAR = ACR + ASR)

5.2.2 Alkali Silica Reaction (ASR)

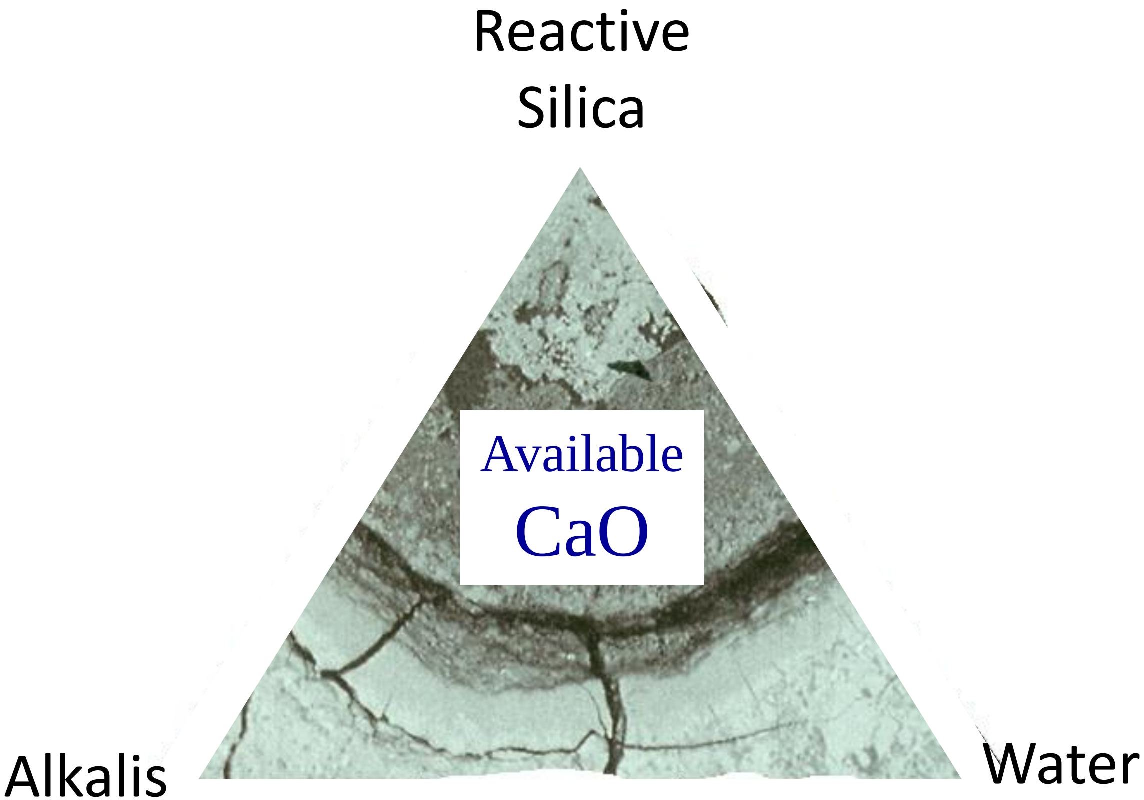
In the presence of a high concentration of hydroxyl ions (OH^-) silica tends towards dissolution (modified from *Dent Glasser & Kataoka*, *1981*):

first by neutralization of the silanol groups $\equiv Si\text{-}OH + OH^- \rightarrow Si\text{-}O^- + H_2O$

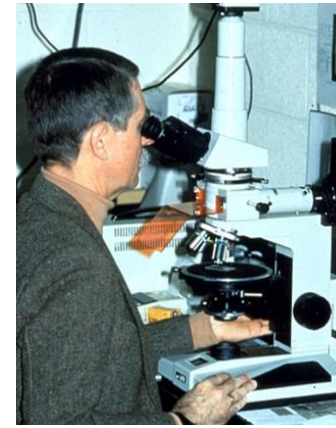
and then by attack on the siloxane groups $\equiv Si\text{-}O\text{-}Si\equiv + 2OH^- \rightarrow 2Si\text{-}O^- + H_2O$



“~~Three~~ Four Necessities for Damaging ASR”



5.3 Evaluating Aggregates for Potential Alkali-Aggregate Reactivity



5.3.1 Field Performance

5.3.2 Petrographic Examination

5.3.3 Laboratory Tests to Identify Alkali-Silica Reactive Aggregates

5.3.3.1 Mortar-Bar Test (ASTM C227)

5.3.3.2 Quick Chemical Test (ASTM C289)

5.3.3.3 Accelerated Mortar Bar Test (ASTM C1260)

5.3.3.4 Concrete Prism Test (ASTM C1293)

5.3.3.5 Accelerated Concrete Prism Test (RILEM AAR-4)

5.3.3.6 Chinese Accelerated Concrete Microbar Test

5.3.4 Laboratory Tests to Identify Alkali-Silica Reactive Aggregates

5.3.4.1 Rock Cylinder Method (ASTM C586)

5.3.4.2 Chemical Composition (CSA A23.2-26A)

5.3.4.3 Concrete Prism Test (ASTM C1105)

5.3.4.4 Chinese Accelerated Concrete Microbar Test

5.4 Preventive Measures

5.4.1 Use of Non-Reactive Aggregate

5.4.2 Limiting the Alkali Content of Concrete

5.3.3 Use of SCMs

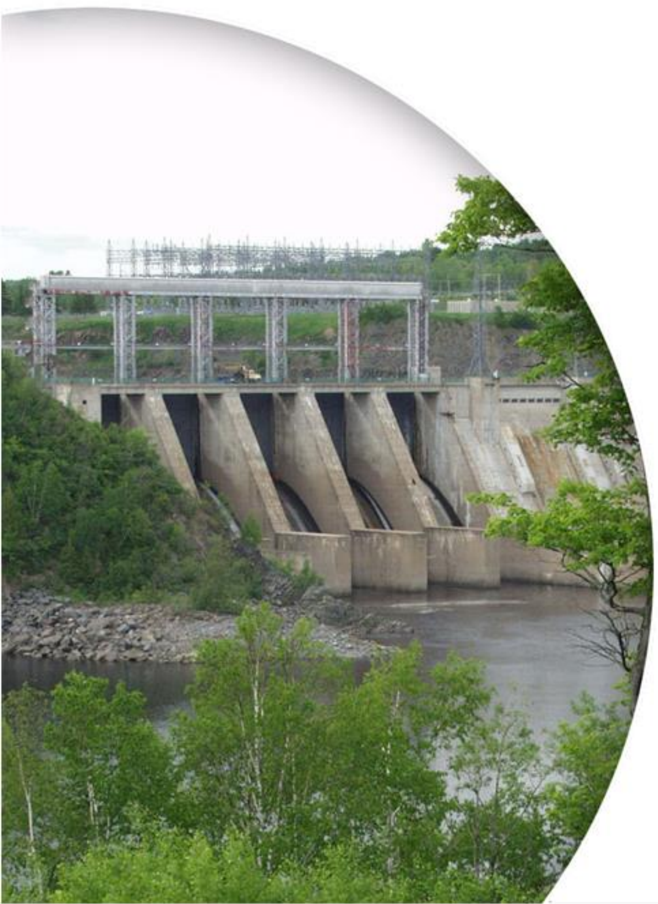
5.4.4 Use of Chemical Admixtures

5.4.4.1 Lithium Salts

5.4.4.2 Other Chemical Admixtures

5.4.1 Use of Non-Reactive Aggregate

- Most obvious and certain (?) way of preventing deleterious AAR.
- Nonreactive aggregates are not available in many locations
- AAR has occurred with aggregates that test to be “non-reactive”
- It may be prudent to take further precautions even with “non-reactive” aggregates



Mactaquac Dam, Fredericton, NB, Canada

- Construction 1964 – 1968
- Aggregate passed expansion criteria of ASTM C 227
  - ASTM C 33: 0.05% at 3m; 0.10 % at 6m
  - USBR: 0.10% at 12m
- Dam has grown in height by 9 inches in just under 50 years (~ 100 feet high)
- If reconstructed, consideration is being given to using the same aggregate (excavation rock)

5.4.1 Use of Non-Reactive Aggregate

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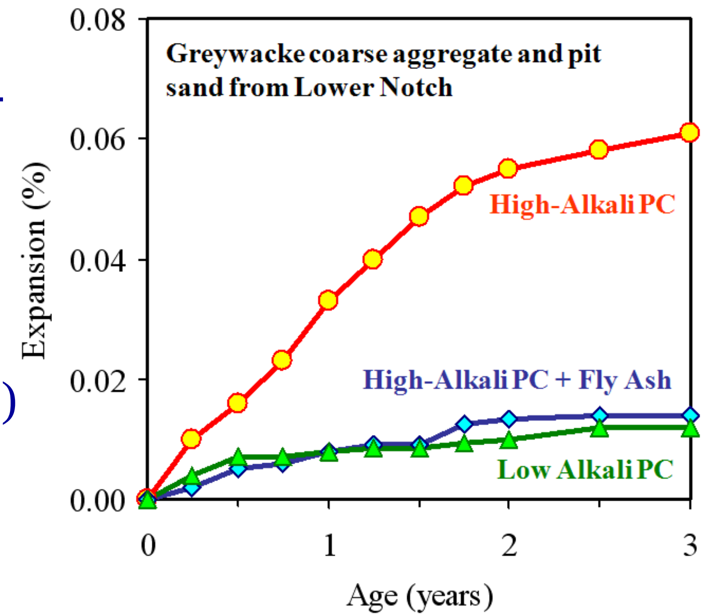
Lower Notch Dam, Ontario, Canada

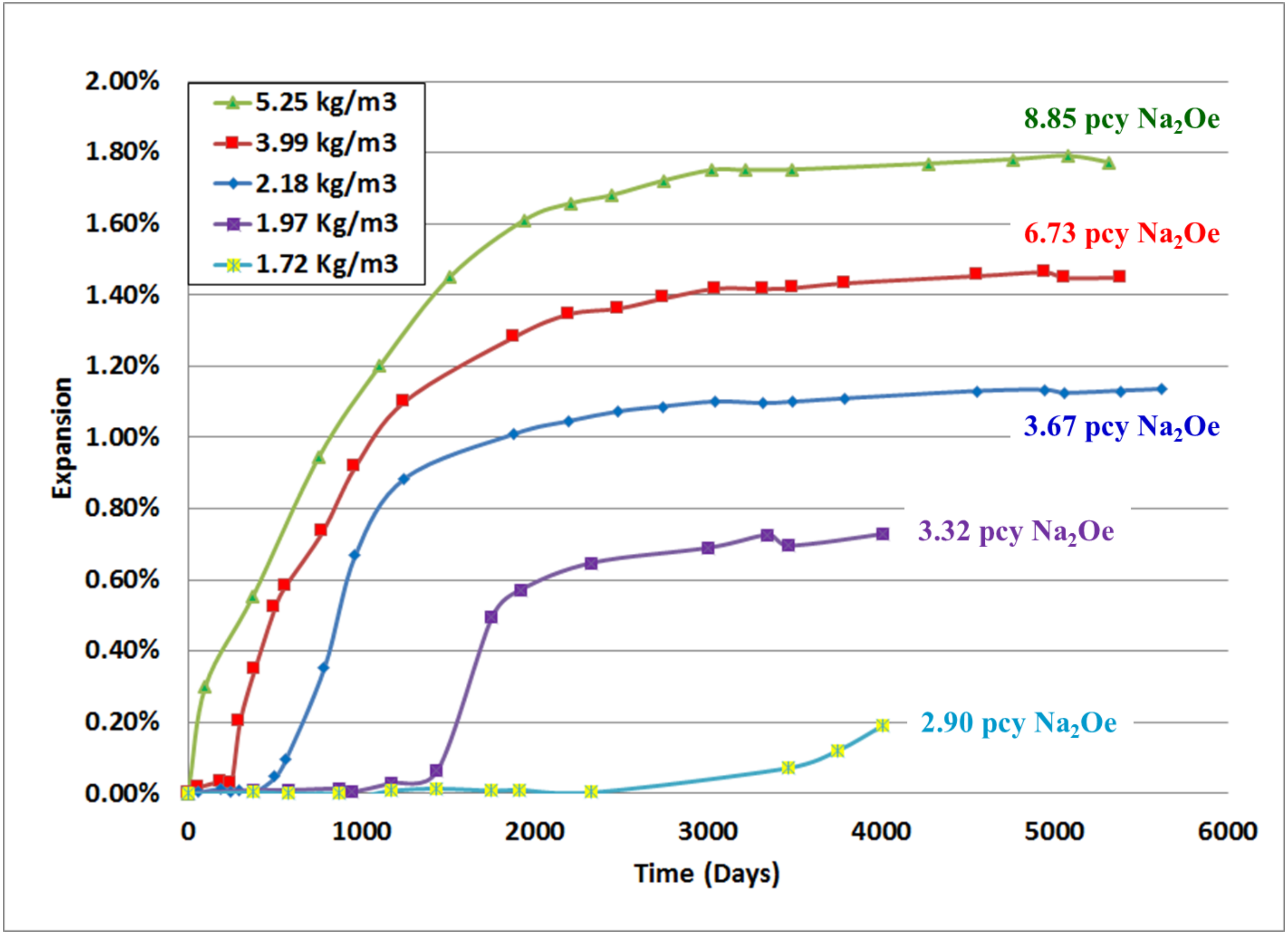
- Completed 1969
- **Aggregate** from head-pond excavation known to be reactive
- 20-30% fly ash used with high-alkali cement (1.08% Na_2Oe)
- No evidence of expansion at 40 years



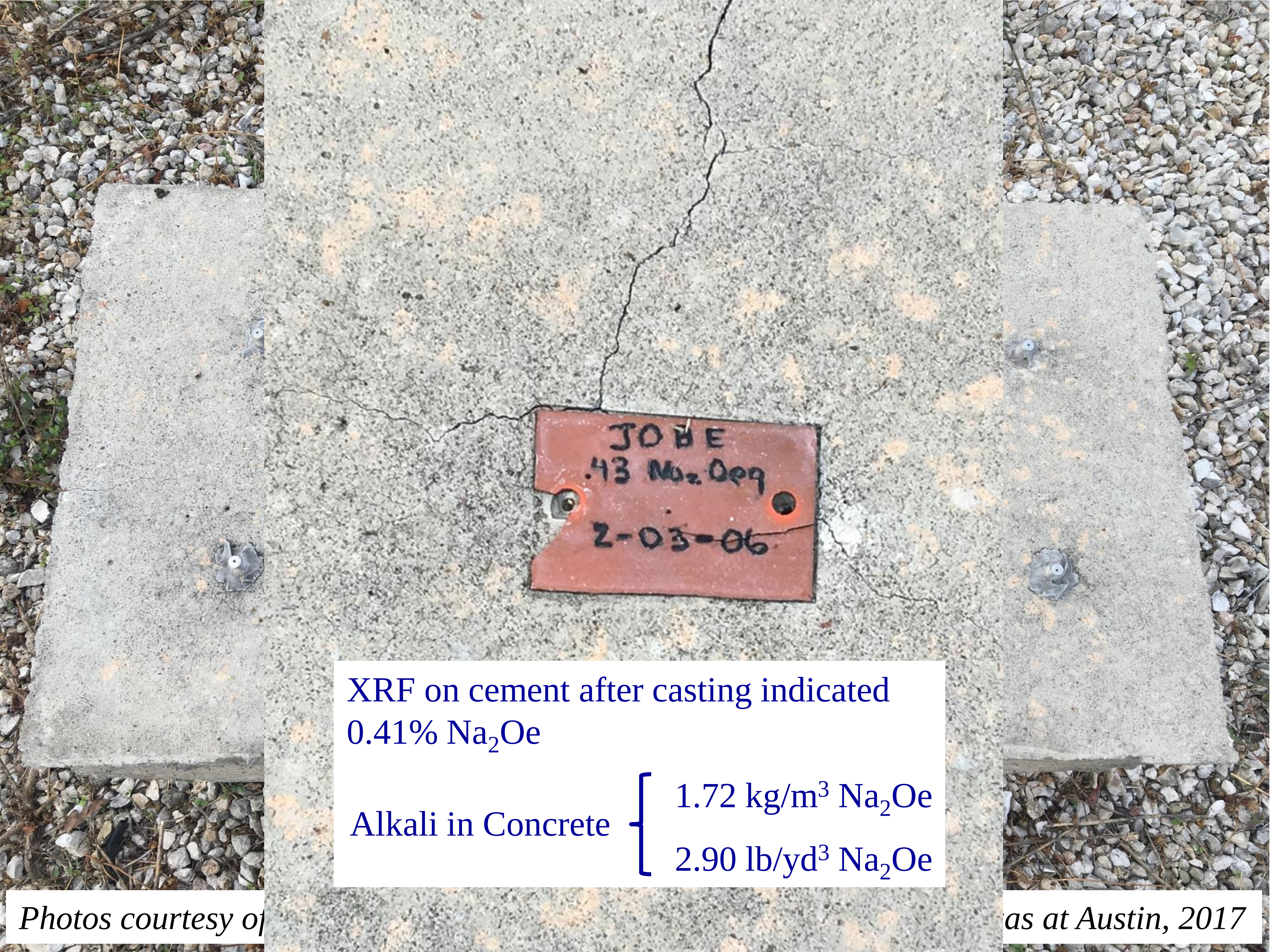
5.4.2 Limiting the Alkali Content of Concrete

- Specifying low-alkali cement ($\leq$ 0.60% Na_2Oe) not sufficient remedy
- Need to limit alkali content of concrete
  - In Canada (CSA A23.2-27A): limit ranges between 1.2 to 3.0 kg/m^3 (2 to 5 lb/yd^3) Na_2O_e.
  - AASHTO & ASTM practices: limit ranges between 1.8 to 3.0 kg/m^3 (3 to 5 lb/yd^3) Na_2O_e.
- Penetration of external alkalis and/or migration of internal alkalis may increase alkali content locally

How Low is Low Enough?



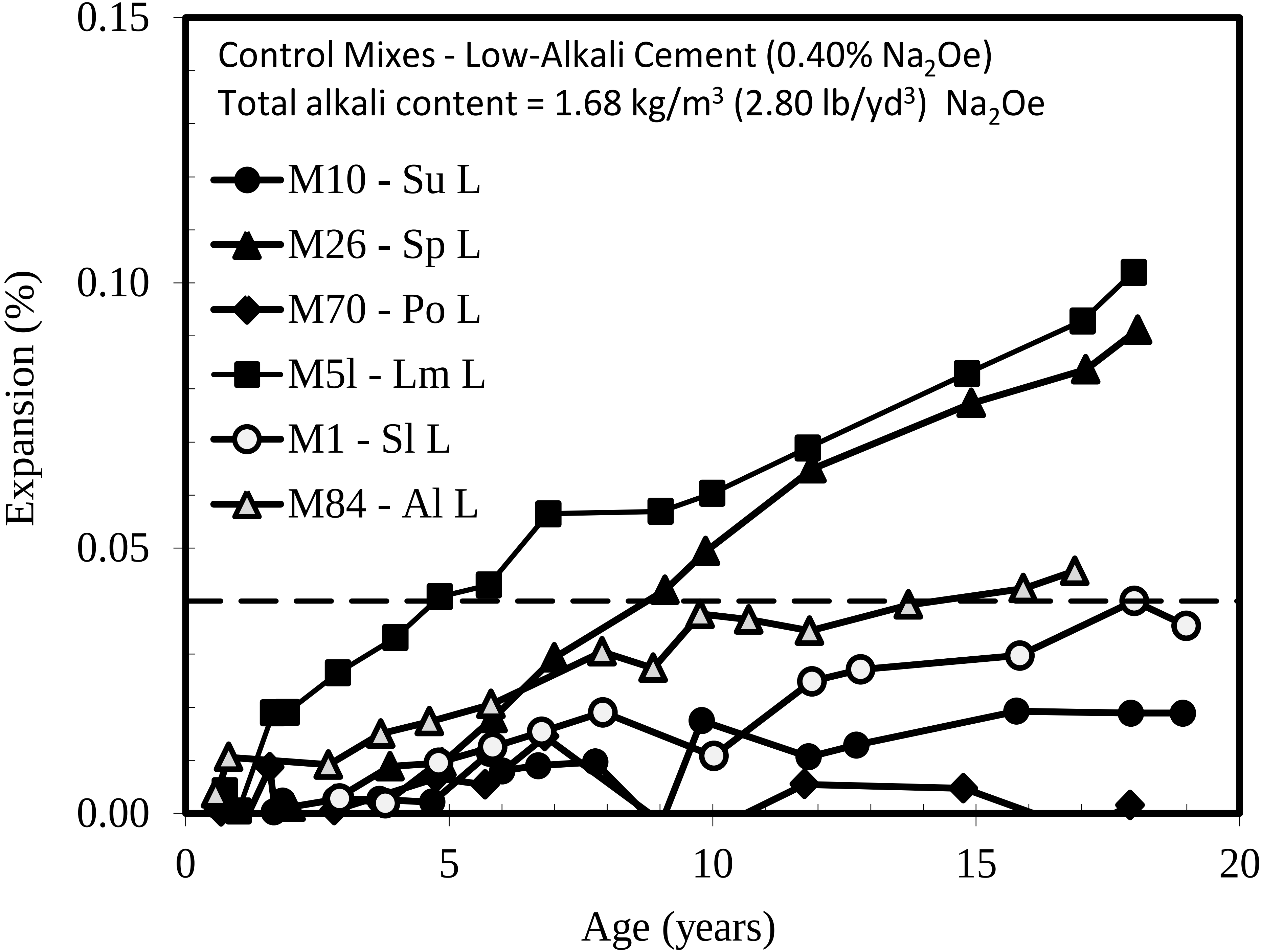
Data courtesy of Kevin Folliard and Thano Drimalas, University of Texas at Austin, 2017



XRF on cement after casting indicated 0.41% Na_2Oe

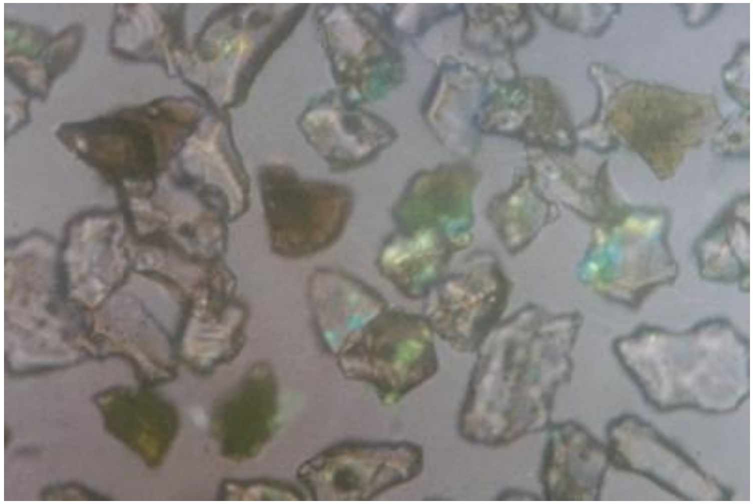
Alkali in Concrete
- 1.72 kg/m^3 Na_2Oe
- 2.90 lb/yd^3 Na_2Oe

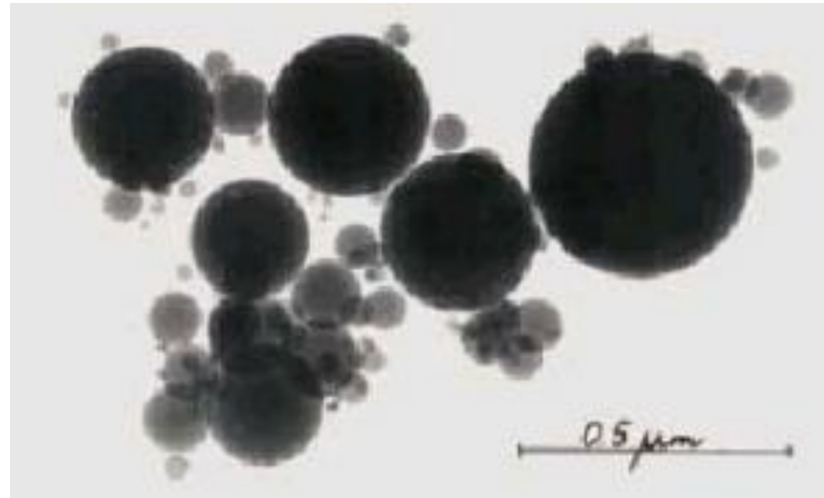
Photos courtesy of ... as at Austin, 2017

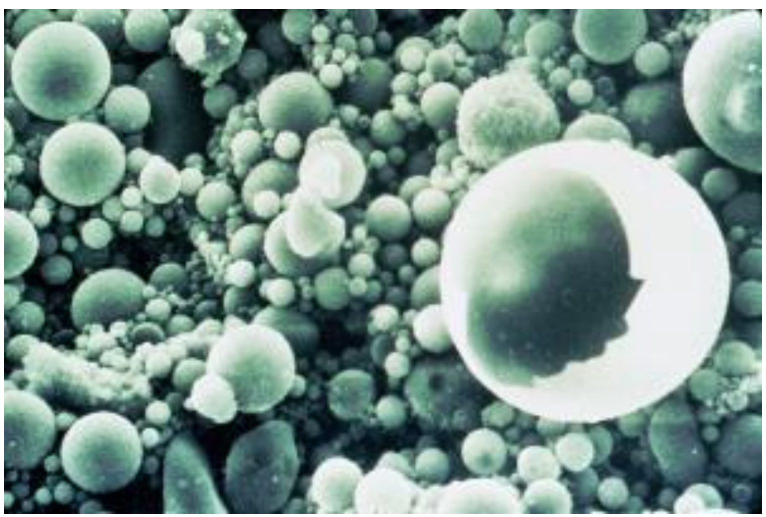


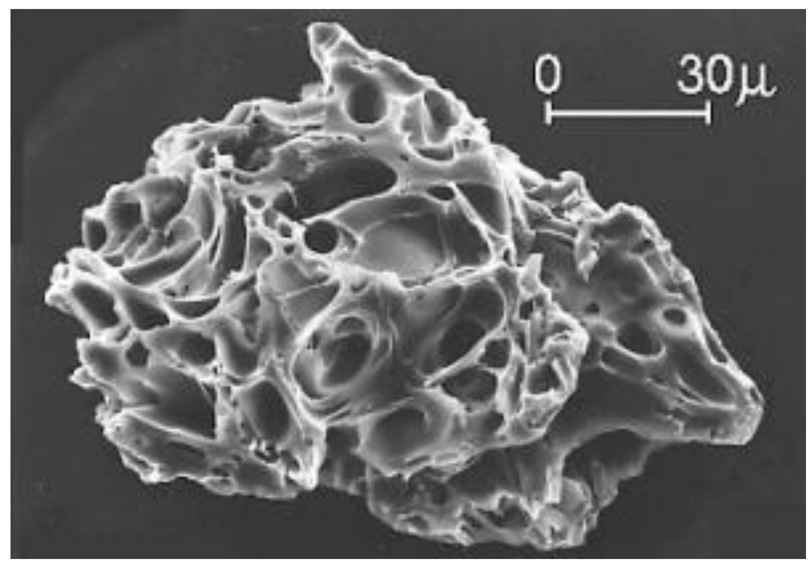
Control Mixes - Low-Alkali Cement (0.40% Na_2Oe)
Total alkali content = 1.68 kg/m³ (2.80 lb/yd³) Na_2Oe
M10 - Su L
M26 - Sp L
M70 - Po L
M5l - Lm L
M1 - Sl L
M84 - Al L
Expansion (%)
0.15
0.10
0.05
0.00
0
5
10
15
20
Age (years)

5.3.3 Use of SCMs









Field Performance of Fly Ash & ASR

No fly ash | **With fly ash**

Field-exposure-site studies

Site in UK shown: fly ash effective in controlling ASR after 18 y

Other sites …

Dams in Ontario (Greywacke)

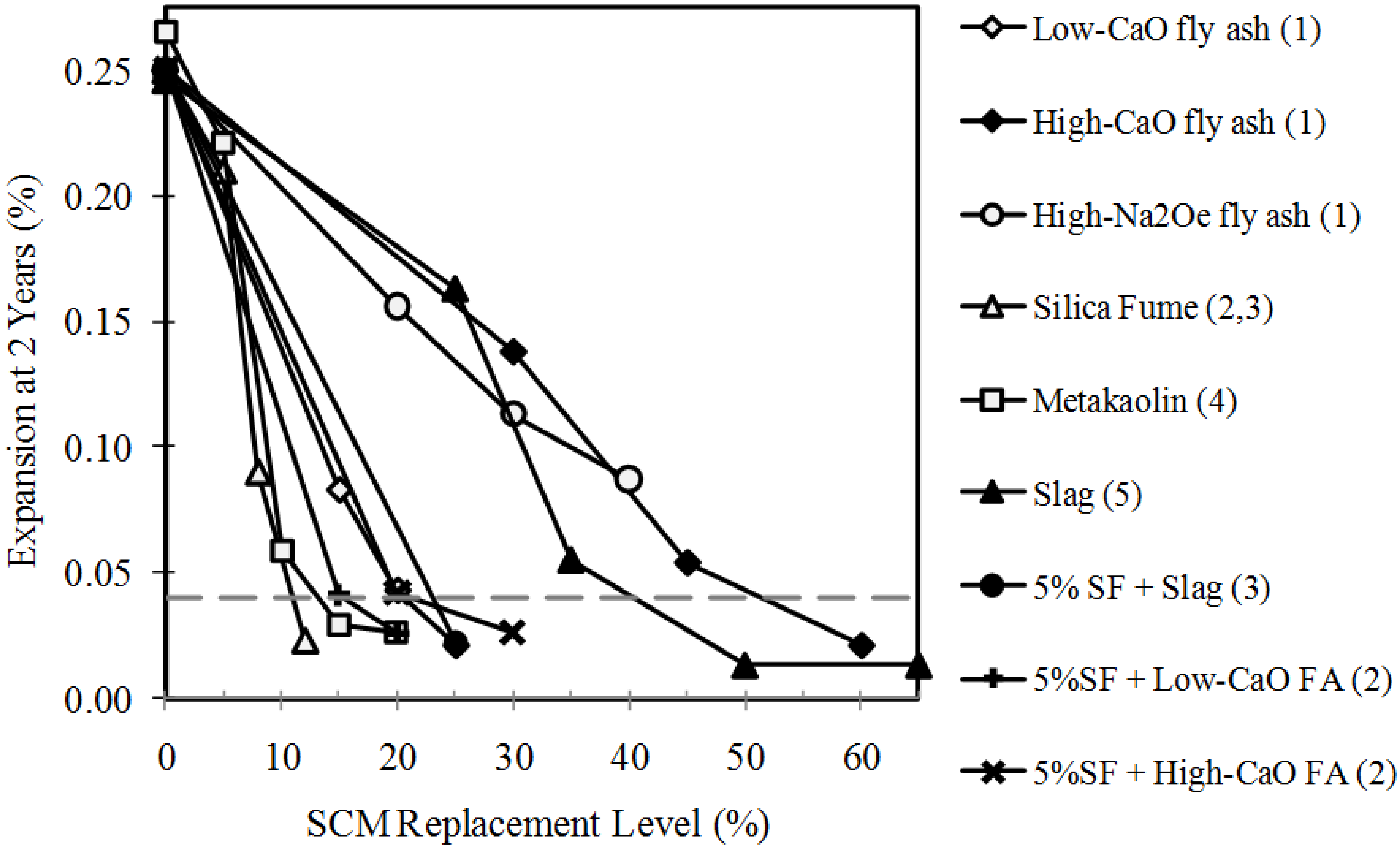
Many structures with same highly reactive aggregate have ASR

Lower Notch Dam: high-alkali cement, 20 – 30% fly ash; no ASR after 40 y

Dams in Wales (UK)

Dinas Dam: no fly ash; severe ASR after 50 yNant-y-Moch Dam: 25% fly ash, same aggregate; no ASR after 50 y

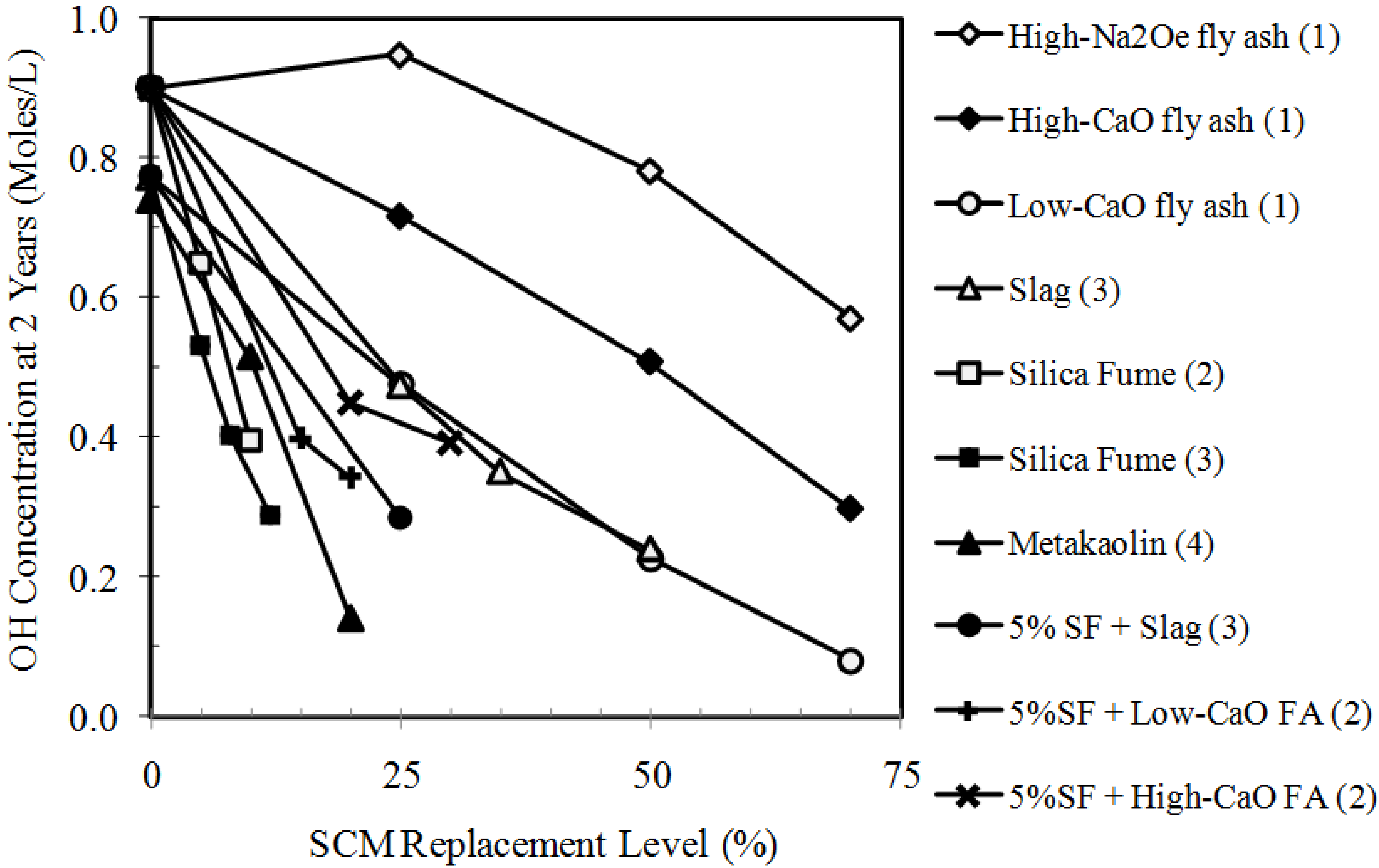
5.3.3 Use of SCMs



ACI 201.2R-16: Figure 5.4.3d

5.3.3 Use of SCMs

- Beneficial effect of SCMs attributed to alkali-binding which reduces the availability of alkalis in the pore solution for reaction with aggregate



ACI 201.2R-16: Figure 5.4.3b

5.3.3 Use of SCMs

The amount of SCM required to control ASR depends on the following (Thomas, 2011):

- The composition of the SCM – increasing amounts are required as the alkali or calcium content of the SCM increase or as the silica content decreases;
- The alkali contributed by the portland cement – generally increased amounts of SCM are required as the alkali provided by the cement increases
- The reactivity of the aggregate – the amount of SCM required increases as the the reactivity of the aggregate increases.

In most conditions, the following levels of replacement are usually sufficient to control expansion due to ASR:

- Silica fume 10 to 15%
- Metakaolin 15 to 20%
- Low-CaO fly ash 20 to 30%
- Slag 35 to 50%
- High-CaO fly ash ≥ 40%

The amount of SCM required should be determined on a case-by-case basis:

- AASHTO PP 65 (now R 80-17)
- ASTM C 1778

Both practices provide both performance-based and prescription-based methodologies for determining SCM content.

5.4.4 Use of Chemical Admixtures

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Lithium Salts

- Initial work (McCoy and Caldwell, 1951; Lawrence and Vivian, 1961) established: [Li]/[Na + K] molar ratio ≥ 0.74
- Since then others (e.g. Tremblay et al. 2007; Feng et al. (2008) have shown the amount of lithium required to control ASR expansion varies greatly and is largely dependent on the aggregate type. In some cases [Li]/[Na+K] = 1.1 may not be sufficient.
- $LiNO_3$ generally considered to most effective salt (e.g. compared with LiOH or $LiCO_3$)
- Several documents provide more detailed review material and guidance for the use of lithium-based admixtures to control ASR (e.g. AASHTO & FHWA).

Other Chemicals

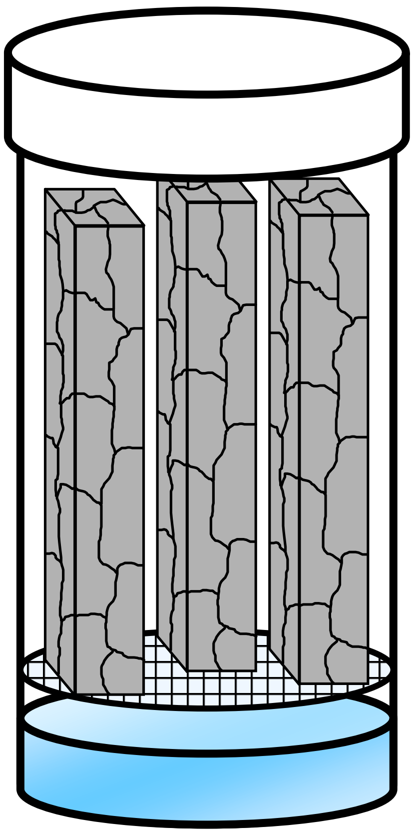
- Various barium salts (Hansen 1960), sodium silicofluoride, and alkyl alkoxy silane (Ohama et al. 1989)
- Needing more testing to confirm efficacy, dose rates and mechanisms, and to determine the impact on fresh and hardened concretes (other than ASR)

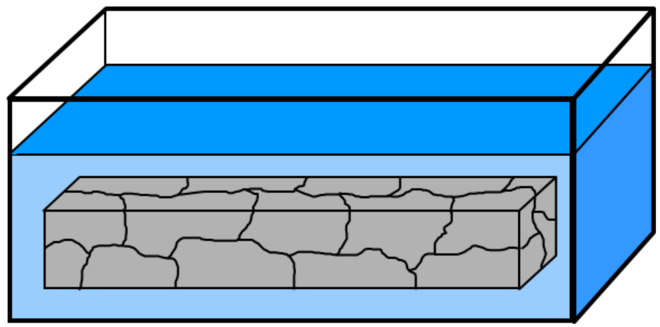
5.5 Tests for Evaluating Preventive Measures

5.5.1 ASTM C441 – Pyrex Mortar-Bar Test

5.5.2 Accelerated Mortar Bar Test (ASTM C1567)

5.5.3 Concrete-Prism Test (ASTM C1293)





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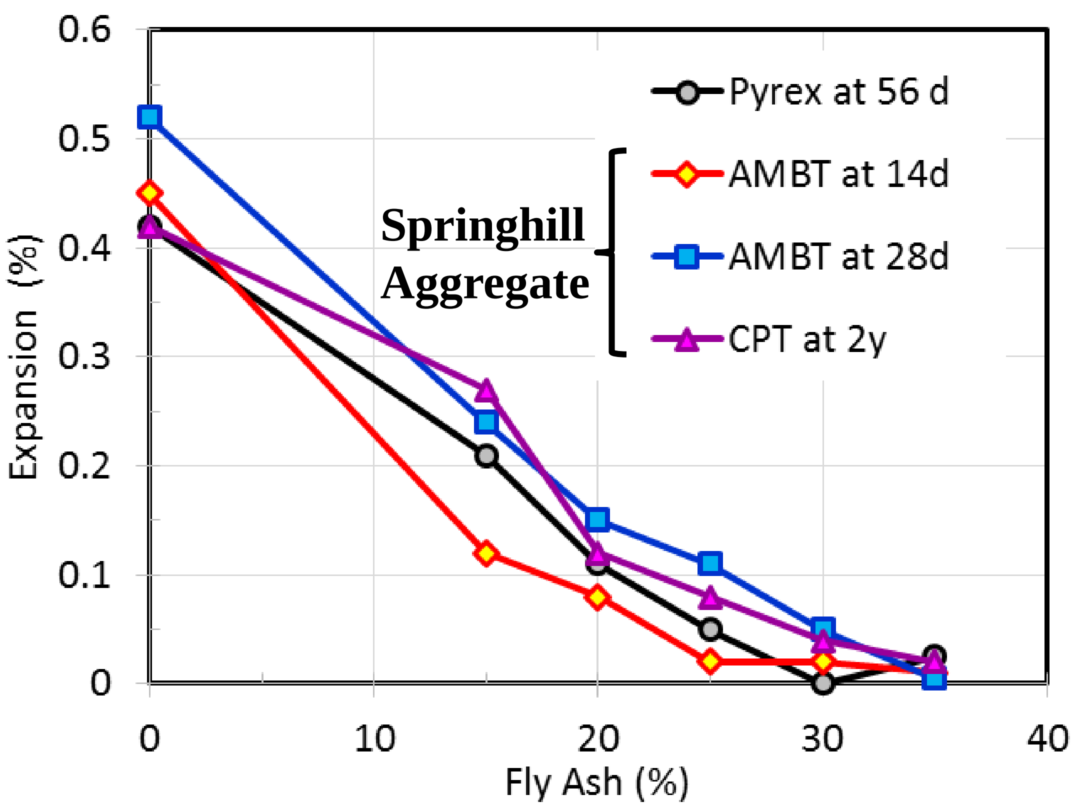
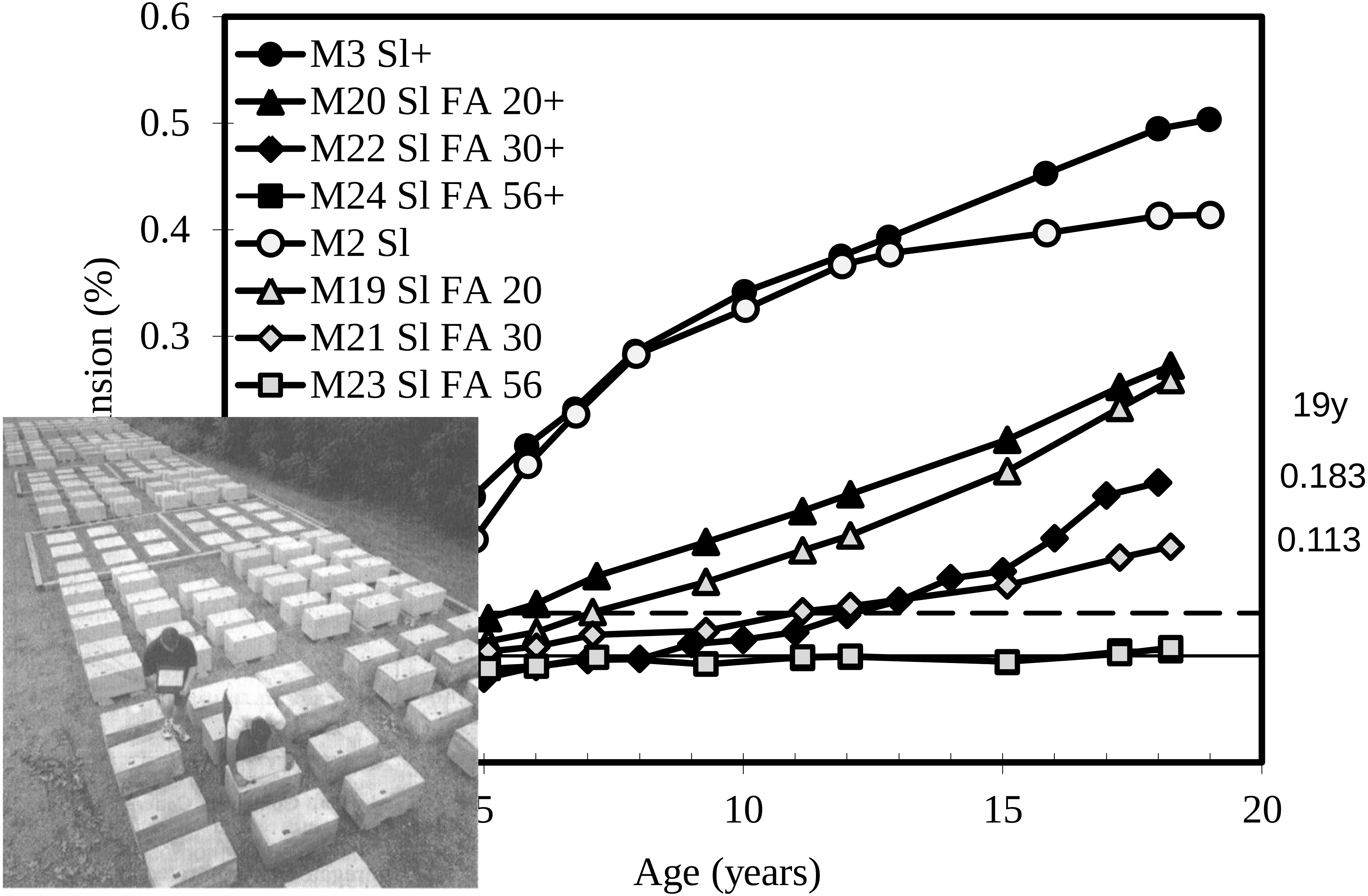


Fly Ash required to reduce expansion to ≤ 0.10% in mortar and ≤ 0.04% in concrete

Pyrex at 56d	20 – 25%
AMBT at 14d	15 – 20%
AMBT at 28d	25 – 30%
CPT at 2y	30 – 35%

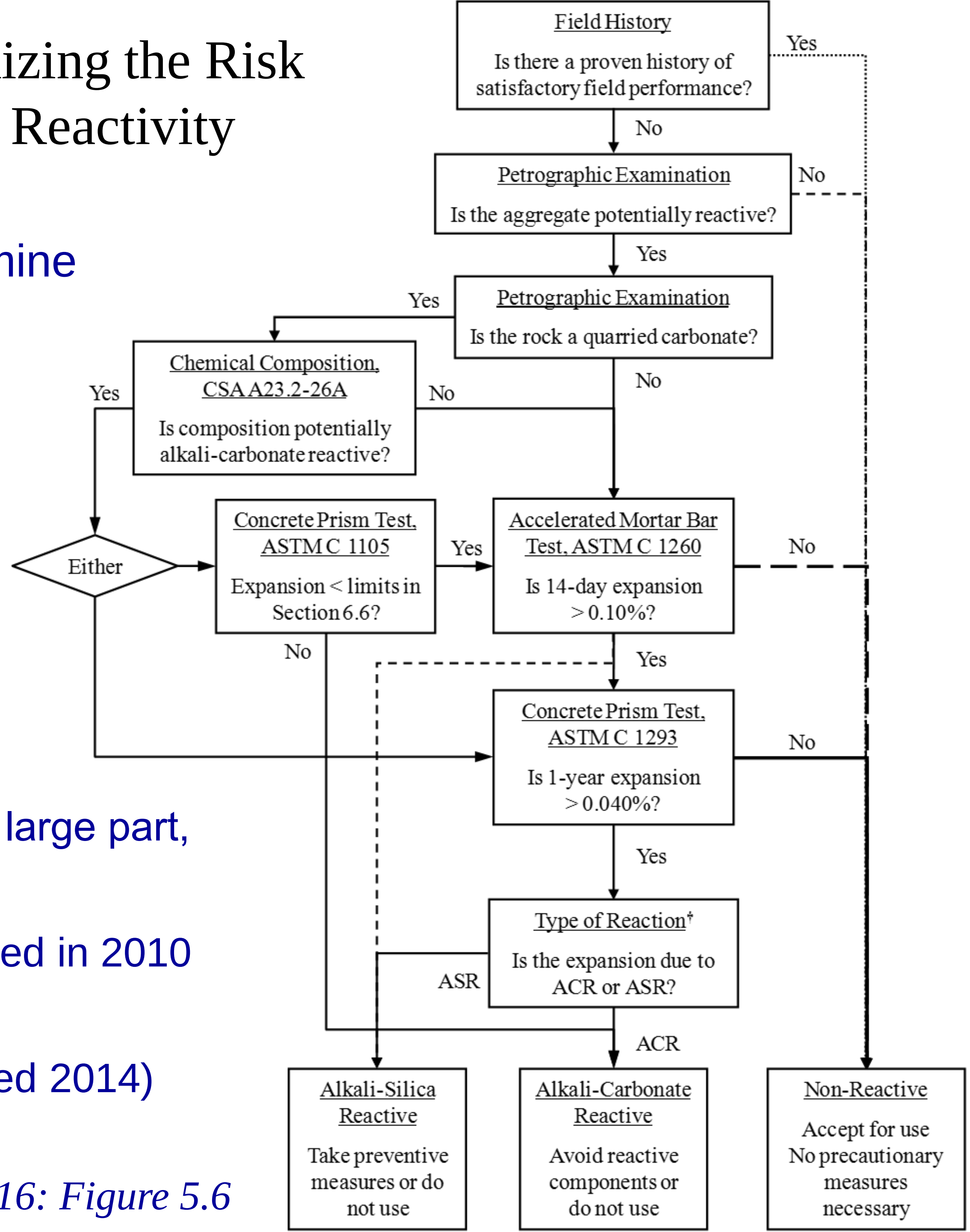
Expansion of Exposure Blocks on CANMET Site (Ottawa)
Springhill Aggregate & Class F Fly Ash



5.6 Protocols for Minimizing the Risk of Alkali-Aggregate Reactivity

Sequence of Testing to Determine Aggregate Reactivity

(modified from CSA A23.2-27A)



The “Canadian Approach” has, in large part, been adopted by:

- AASHTO R 80-17 (first published in 2010 as PP65-10)
- ASTM C 1778-16 (first published 2014)

ACI 201.2R-16: Figure 5.6

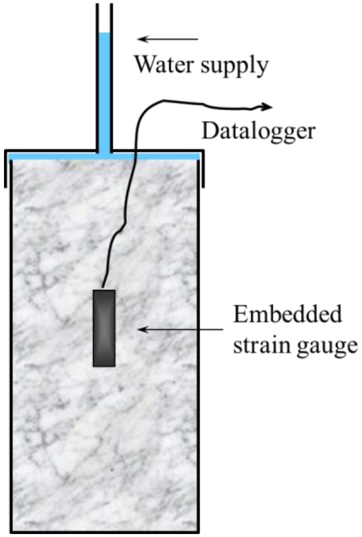
AASHTO R 80 and ASTM C1778

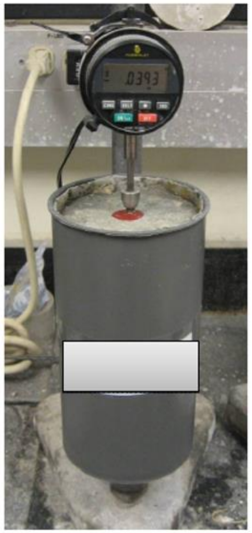
- **Testing for aggregate reactivity – sets reactivity levels**
- **Prescriptive alternative**
  - Allows the use of reactive aggregates with the following preventive measures:
    - Limiting the alkali content of the concrete
    - Use of fly ash
    - Use of slag
    - Use of silica fume
    - Use of ternary blends
  - The actual level of prevention varies with “risk” as defined by:
    - Reactivity of the aggregate
    - Nature of the structure (includes. design life)
    - Exposure condition
- **Performance alternative**
  - Determine level of prevention using concrete prism test (ASTM C 1293) or accelerated mortar bar test (ASTM C 1567)
    - Suitability of accelerated mortar bar test should first be determined by correlation with concrete prism test

What's New for the Next Edition?

ACI 201 TG3 Alkali-Aggregate Reactivity

- Change name to Aggregate Reactivity and provide advice on pyrrhotite oxidation
    - Draft Tech Note
- Reference to new standardized test methods
- Monitor progress with a number of **performance tests** currently under development
- Summarize exposure-site studies





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Standard Method of Test for

Potential Alkali Reactivity of Aggregates and Effectiveness of ASR Mitigation Measures (Miniature Concrete Prism Test, MCPT)

AASHTO Designation: TP 110-14 (2016)[1]

Technical Section: 3c, Hardened Concrete

Release: Group 1 (April 2016)

Standard Method of Test for

Nonlinear Impact Resonance Acoustic Spectroscopy (NIRAS) for Concrete Specimens with Damage from the Alkali–Silica Reaction (ASR)

AASHTO Designation: TP 109-14 (2016)[1]

Technical Section: 3c, Hardened Concrete

Release: Group 1 (April 2016)