Recent Advances in ASR Test Methods and Understanding Mitigation Mechanisms, Part 2

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R. Doug Hooton is an ACI Fellow, the 2011 Arthur R. Anderson Award winner, and a member of numerous ACI committees including C232 on fly ash and C201 on durability. He is also a Fellow of ASTM, and the Engineering Institute of Canada. He is a professor and NSERC/Cement Association of Canada Senior Industrial Research Chair in Concrete Durability and Sustainability in the Department of Civil Engineering at the University of Toronto. His research over the last 38 years has focused on the durability performance of cementitious materials in concrete.

The Kingston Outdoor Exposure Site for Mitigating ASR After 20 Years

ACI Dallas, March 2012

R. D. Hooton &
T. Ramlochan
University of Toronto
Department of Civil Engineering

C.A. Rogers &
C. A. MacDonald
Ontario
Ontario Ministry of Transportation

Site Established in Kingston, Ontario in 1991

6 different concrete mixtures
reinforced and non reinforced
blocks and slab for each mix
Spratt coarse aggregate and local non-reactive fine aggregate

Sept. 1991 Kingston Site

Binder		Mix 1 50% Slag 50% HAPC	Mix 2 18% Fly Ash 82% HAPC	Mix 3 25% Slag 75% HAPC	Mix 4 25% Slag+3.8% SF 71% HAPC	Mix 5 100% LAPC 0.46% Alkali	Mix 6 100% HAPC 0.79% Alkali
w/cm		**0.4**	**0.39**	**0.39**	**0.38**	**0.37**	**0.34**
Alkali Loading (of PC)	kg/m^3 Na_2O equiv.	1.64	2.67	2.46	2.34	1.91	3.28

All mixes had total CM = 415 kg/m3

All made with ASR Spratt Reactive Coarse Aggregate (siliceous Limestone)

Aggregates

- The alkali-silica reactive coarse aggregate (5-20mm) was the Spratt aggregate from a quarry near Ottawa, Ontario.
- The aggregate had been crushed in 1985 and placed in a 120-tonne stockpile.
- **Spratt aggregate** is a Middle Ordovician, medium-grey, fine crystalline limestone. The material is slightly siliceous (9% SiO2) and has been used as a convenient alkali-silica reactive aggregate for investigating alkali-silica reaction expansion tests
- The fine aggregate was local non-reactive natural sand composed of igneous and high-grade metamorphic rocks and derived minerals with a long history of satisfactory performance in concrete made with high-alkali cement.

Concrete was batched in Ready Mix Plant, truck mixed and discharged within 0.5 to 1 hour of mixing

Compressive Strengths (MPa) and Alkali Loading

Mix	50% Slag	18% F-Ash	25% Slag	25% slag +3.8%SF	LAPC	HAPC
w/cm	0.38	0.37	0.39	0.34	0.40	0.39
28 d	40.0	39.0	41.8	47.9	39.6	35.6
82 d	44.9	50.0	42.7	52.8	46.2	44.3
1y	49.7	52.4	50.9	63.2	54.9	49.2
7.25y	58.5	60.4	59.0	61.8	62.2	57.9
Alkali Loading (kg/m3)	1.64	2.67	2.46	2.34	1.91	3.28

Accelerated Mortar Bar Test

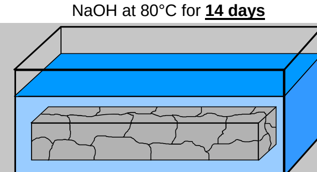
CSA A23.2-25A *ASTM C 1260*

Aggregate/cementitious material = 2.25

W/CM = 0.5

Portland cement = 0.8 to 1.0% Na_2O_e

Mortar bars, 25 x 25 x 250 mm, stored in 1M NaOH at 80°C for **14 days**



80°C Mortar Bar Expansions

Mix #	Binder Type and Proportions	Mortar Bar Expansion in Per Cent: 14 Day	21 Day	28 Day	14 Day Duplicate
1	HAPC, 50% + GGBFS, 50%	0.059	-	-	-
2	HAPC, 82% + fly ash, 18%	0.111	0.171	0.249	0.118
3	HAPC, 75% + GGBFS, 25%	0.187	-	-	-
4	HAPC, 25% + silica fume cement, 75% + GGBFS, 25%	0.041	0.089	0.153	-
5	LAPC, 100%	0.435	0.484	0.553	0.471
6	HAPC, 100%	0.315	0.378	0.480	0.330

Concrete Prism Test

CSA A23.2-14A *ASTM C 1293*

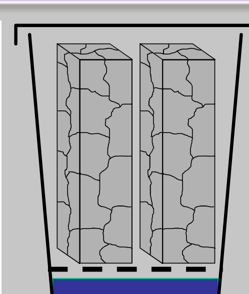
420 kg/m³ cementitious material

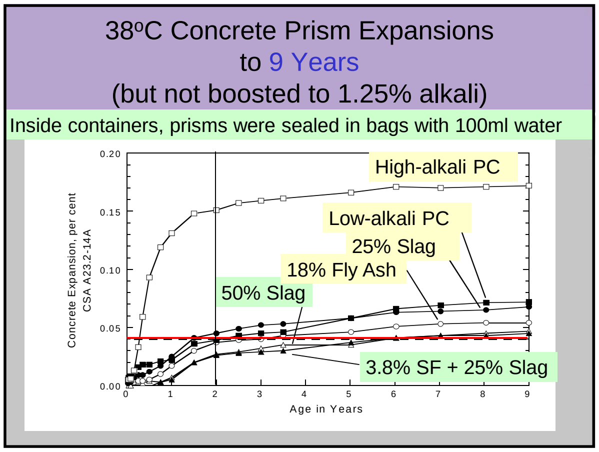
NaOH added to yield 1.25% Na_2O_e by mass of Portland cement

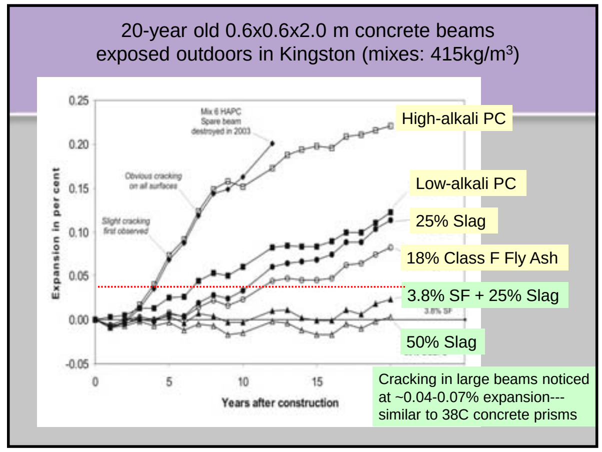
0.42 ≤ W/CM ≤ 0.45

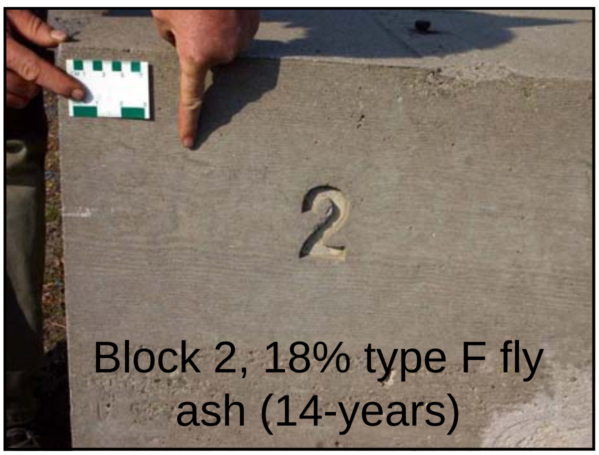
Concrete prisms
75 x 75 x 250 mm (min)

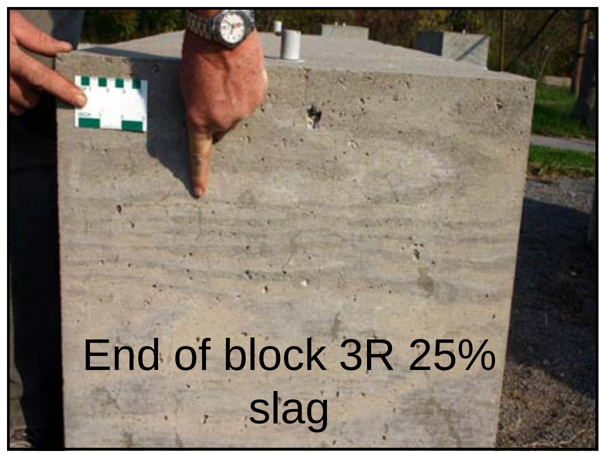
Stored over water at 38°C
(and nominally 100% RH)
for 2 years

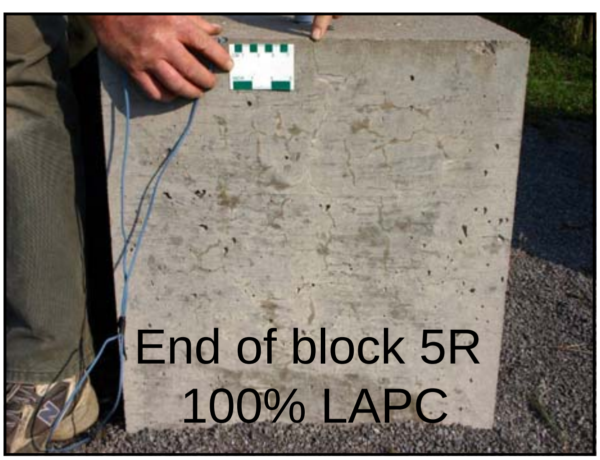



38°C Concrete Prism Expansions
to 9 Years
(but not boosted to 1.25% alkali)
Inside containers, prisms were sealed in bags with 100ml water
High-alkali PC
Low-alkali PC
25% Slag
18% Fly Ash
50% Slag
3.8% SF + 25% Slag
Concrete Expansion, per cent
CSA A23.2-14A
Age in Years


20-year old 0.6x0.6x2.0 m concrete beams
exposed outdoors in Kingston (mixes: 415kg/m³)
High-alkali PC
Low-alkali PC
25% Slag
18% Class F Fly Ash
3.8% SF + 25% Slag
50% Slag
Mix 6 HAPC Spare beam destroyed in 2003
Obvious cracking on all surfaces
Slight cracking first observed
Expansion in per cent
Years after construction
Cracking in large beams noticed
at ~0.04-0.07% expansion---
similar to 38C concrete prisms


Block 2, 18% type F fly
ash (14-years)

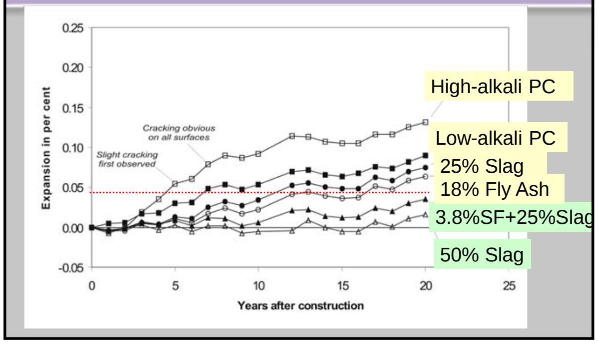

End of block 3R 25%
slag


End of block 5R
100% LAPC

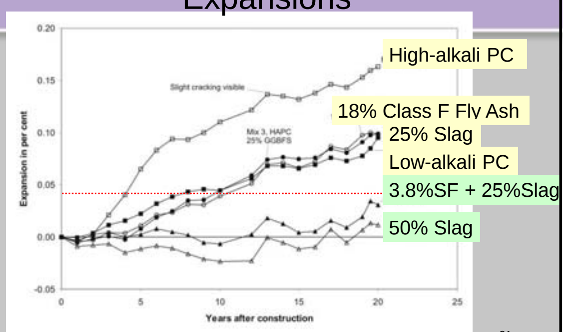

Block 6, 100% HAPC

16-year Reinforced Beam Expansions

Area of steel = 1.41%
(4-25M and 8-20M bars



20-year Pavement Slab Expansions



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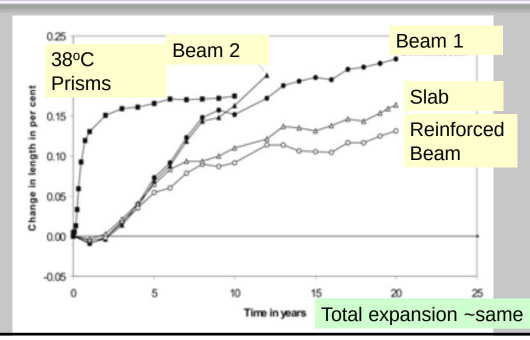
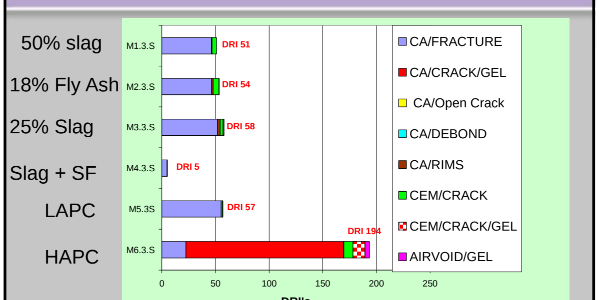
Mix 6: High-alkali Cement Concrete Lab vs 20-Year Field Exp'n

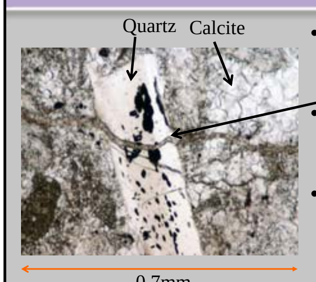


Damage Rating Index of Cores at 14-years (thanks to P. Grattan-Bellew)



Note only 50% Slag and Slag+SF Beams are uncracked

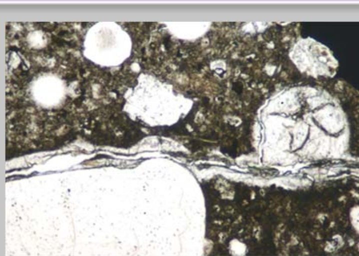
Low-Alkali Cement Concrete



- Crack in coarse aggregate filled with ASR product "Okenite"?
- Only found in aggregate not in adjacent cement paste
- First described in 1986 by Fournier /Berube /Vezina for Ordovician carbonates of St Lawrence Lowlands

Okenite ($Ca_{10}Si_{18}O_{46}\cdot 6H_2O$)

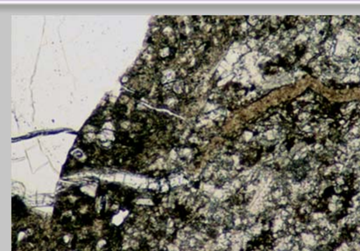
High-Alkali Cement Concrete 12-year cores



0.7mm

- ASR in air Void
- and in crack
  - Cracks ranged from about 5 µm to 200 µm in width on 30-50% of all aggregate particles

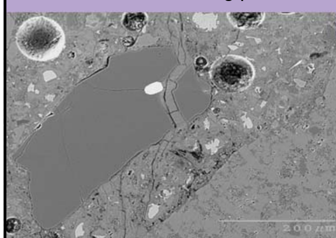
High-Alkali Cement Concrete



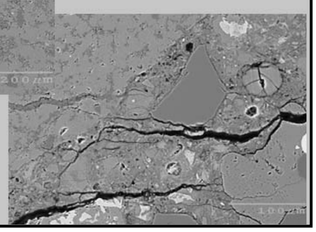
0.7mm

- ASR in crack inside limestone aggregate on right, extending into paste on left.

100% HAPC Concrete with Spratt reactive aggregate ASR cracking paste and filling cracks



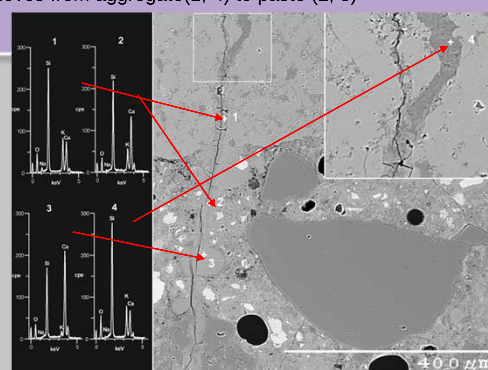
Spratt aggregate is a limestone with ~5% reactive silica.



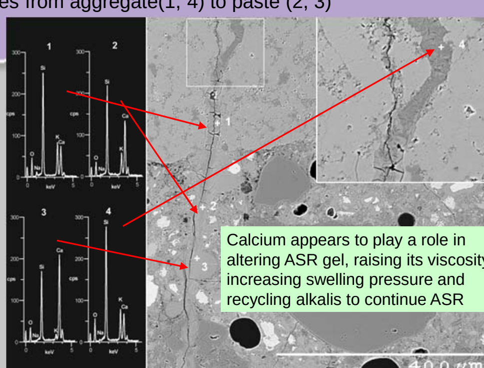
T. Ramlochan,

U. of Toronto

100% PC Concrete: K/Ca changes as ASR Gel moves from aggregate(1, 4) to paste (2, 3)

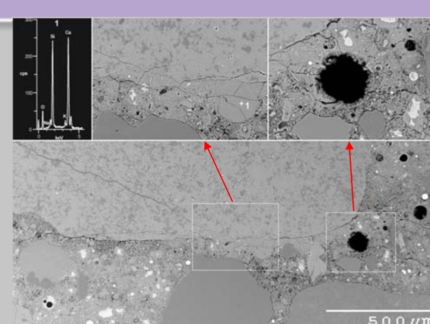


100% PC Concrete: K/Ca changes as ASR Gel moves from aggregate(1, 4) to paste (2, 3)

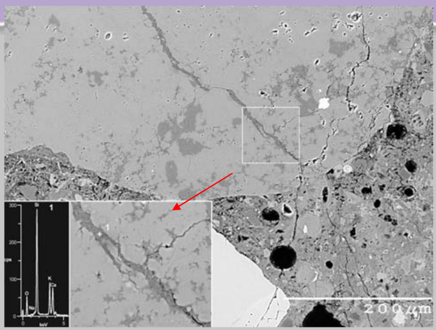


Calcium appears to play a role in altering ASR gel, raising its viscosity, increasing swelling pressure and recycling alkalis to continue ASR

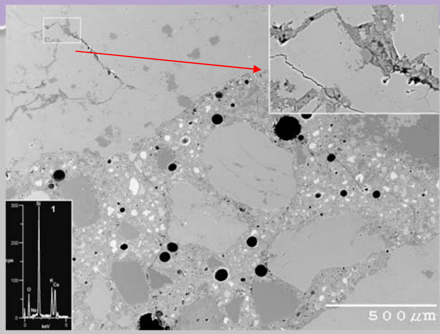
18% F Ash Concrete



25% Slag Concrete



25% Slag + 3.8% SF Concrete



Summary 1

- The concrete made with high-alkali cement and no protective measures cracked at an age of 5 years when stored outdoors in the Canadian climate.
- Low-alkali cement did not prevent cracking, it delayed it until ~ 7 years even at 1.91 kg/m^3 alkali loading
- The expansion levels at the time of cracking ranged from 0.04 to 0.07%.
- This is similar to the 0.04% limit used for the 38^{o}C Concrete prism test

Summary 2

- When the high-alkali cement was replaced with various amounts of supplementary cementing materials or low-alkali cement, expansion was considerably less and only very minor cracking occurred at 16 years.
- When sufficient SCMs were used, there was no sign of ASR or cracking at 20 years.

Summary 3

- Damage Rating Index was performed on cores at 12 years.
- DRI values of 54-58, coincided with minor visible cracking in outdoor beams and slabs
- The uncracked Slag+SF mix DRI =5
- The uncracked 50% Slag mix DRI = 51
- The severely cracked HAPC DRI = 194

Summary 4

- The data confirm the advice given in CSA standards that, when mortar bars give less than 0.10% expansion at 14 days with a reactive aggregate and a supplementary cementing material, the material in the proportion used will prevent deleterious alkali-silica reaction in concrete.

Summary 5

- The concretes with SCMs also had superior chloride resistance properties to the pure Portland cement mixtures, as measured by both bulk diffusion (ASTM C 1556) and ASTM C 1202 coulomb results.