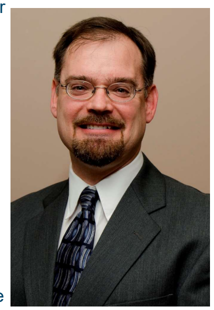
PCA America's Cement Manufacturers™

About the Presenter

NATIONAL CONCRETE CONSORTIUM

- **Paul Tennis** is the Director of Product Standards and Technology for the Portland Cement Association (PCA).
- Paul has been with PCA in various capacities for 24 years, focused on cement and concrete standards development, including ASTM and AASHTO cement specifications and concrete durability-related standards.
- He holds a Bachelor of Science degree in Ceramic Engineering from Clemson University, and an MS and PhD in Materials Science and Civil Engineering both from Northwestern University.
- He is a fellow of ACI, an ASTM Bryant Mather award recipient, past chairman of ASTM Committee C01, and 'friend' of several AASHTO and TRB committees.
- Fun fact: Paul attended the inaugural meeting of the Midwest Concrete Consortium in 1997 and has participated periodically in the MC2 and NC2 meetings ever since.



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What is ASR?

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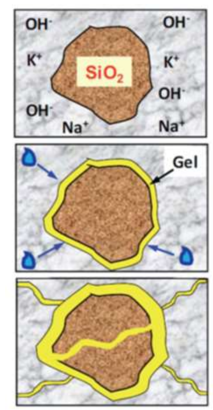
A little more on ASR…

- **Aggregates react with soluble alkalies in pore solution with silica in aggregate**
- **Alkali-Silica gel forms.**
- **AS Gel fills pores**
- **Reaction continues**



Courtesy of N Popoff VCNA

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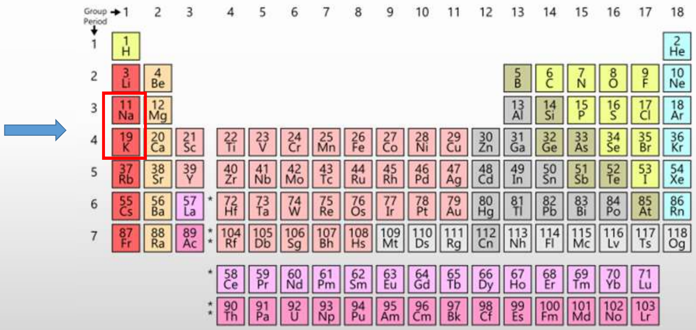
What are alkalies?



Wikipedia

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What is Equivalent Alkali?

- Definition

  Na_2Oeq = % Na_2O + 0.658 % K_2O

  0.658 is the molecular weight ratio
  Provides a convenient single value

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What is "Equivalent Alkali"?

Oxide	OPC
SiO_2	20.55
Al_2O_3	5.07
Fe_2O_3	3.10
CaO	64.51
MgO	1.53
Na_2Oeq	0.63
SO_3	2.53
LOI	1.58

+ IR and trace elements

alkalies (sodium & potassium) represent a small proportion of the cement

$K_2O + H_2O \rightarrow 2K^+ + 2OH^-$

$Na_2O + H_2O \rightarrow 2Na^+ + 2OH^-$

Most of the alkalies end up in the pore solution and the associated OH concentration is sufficient to produce a pH around 13

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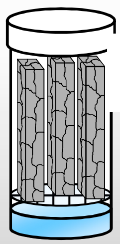
Impacts of Alkalies

- Increase pH of pore solution
- Improves steel reinforcement protection
- Stabilizes C-S-H
- Activates pozzolans and slag cement
- Can improve AEA effectiveness

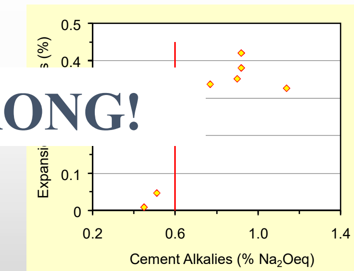
- Can contribute to ASR with susceptible aggregates

Results of Stanton's Mortar Bar Tests (Stanton, 1940 & 1952)

~~Expansion unlikely if cement alkalies < 0.60% Na_2Oeq~~



WRONG!



Cement Alkali *Content* vs. Concrete Alkali *Loading*

$$\text{Concrete alkali loading (lb/yd}^3) = \text{Portland cement content (lb/yd}^3) \times \text{Portland cement alkalies (\% Na}_2\text{Oeq)} \times \frac{1}{100}$$

Example:

If a concrete contains 564 lb/yd³ of portland cement and the cement has an alkali content of 0.78% Na_2Oeq then the **alkali loading** of the concrete is:

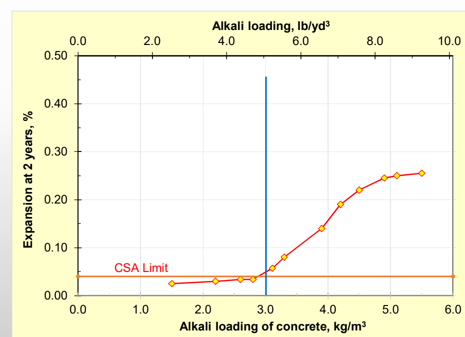
$$= \frac{564 \times 0.78}{100} = 4.40 \text{ lb/yd}^3 \qquad (= 2.61 \text{ kg/m}^3)$$

Cement Alkali *Content* vs. Concrete Alkali *Loading*

$$\text{Concrete alkali loading (lb/yd}^3\text{ Na}_2\text{Oeq)} = \text{Cement content (lb/yd}^3) \times \text{Cement alkalies (\% Na}_2\text{Oeq)} \times \frac{1}{100}$$

Na_2Oeq %	Cement Content lb/yd³	Alkali Loading lb/yd³
0.50	500	2.5
0.50	**700**	**3.5**
0.70	**500**	**3.5**
0.70	700	4.9

Effect of Concrete Alkali Loading



Data courtesy of M. Thomas

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What changed in the Specs?

- C150/M 85 no longer include the optional low-alkali limit of 0.60%
- Manufacturers are required to report Na_2Oeq on all portland cement mill test reports
- Note references ASTM C1778/AASHTO R 80 for guidance on ASR
- Reference to the historical optional limit is included in a non-mandatory note

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Why the Spec Change?

- A 0.60% limit on *cement* is not protective in all cases
  - False sense of security
  - Aggregate reactivity
  - Concrete mix design
- Alkali loading of *concrete* is more relevant/effective
  - Reporting equivalent alkalies allows alkali loading to be readily calculated
- SCMs are most common solution
- C1778 and R 80 provide state-of-the-art guidance

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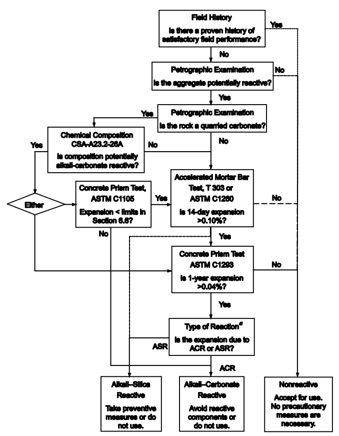
Approach

- Classify aggregate reactivity
- Level of risk (size and exposure conditions)
- Criticality of structure
- Level of prevention needed



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AASHTO R 80 (PP 65)/ASTM C1778: Data Needed

- Prescriptive approach
  - Portland cement: Na_2Oeq
  - Slag cement: $Na_2Oeq < 1.0\%$
  - Fly ash: $CaO \leq 18\%$ and $Na_2Oeq \leq 4.5\%$
  - Silica fume: $SiO_2 > 85\%$ and $Na_2Oeq < 1.0\%$
- Performance approach
  - Portland cement: Na_2Oeq

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Figure 3

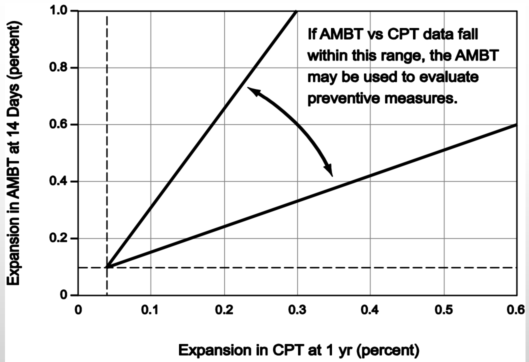

Figure 3

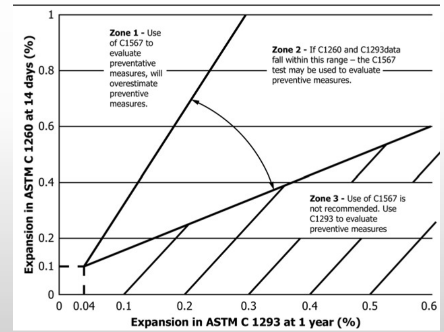

Table 1. Classification of Aggregate

Aggregate-Reactivity Class	Description of Aggregate Reactivity	1-Year Expansion in CPT, %	14-Day Expansion in AMBT, %
R0	Nonreactive	≤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

Table 2. Level of ASR Risk

	Aggregate-Reactivity Class			
Size and Exposure Conditions	R0	R1	R2	R3
Nonmassive concrete[a] in a dry environment	Level 1	Level 1	Level 2	Level 3
Massive elements[a] in a dry 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

[a] A massive element has a least dimension >0.9 m (3 ft).

[b] A dry environment corresponds to an average ambient relative humidity lower than 60 percent, normally found only in buildings.

[c] Examples of structures exposed to alkalies (sodium and potassium) in service include marine structures exposed to seawater and highway structures exposed to deicing salts (e.g., NaCl) or anti-icing salts (e.g., potassium acetate, potassium formate, sodium acetate, sodium formate, etc.).

Table 4. Structure Classification based on Severity of Consequences of ASR

Class	Consequences of ASR	Acceptability of ASR	Examples[b]
S1	Safety, economic, or environmental consequences small or negligible	Some deterioration from ASR may be tolerated.	Non–load-bearing elements inside buildings Temporary structures (e.g., <5 years)
S2	Some safety, economic, or environmental consequences if major deterioration	Moderate risk of ASR is acceptable.	Sidewalks, curbs, and gutters Service life <40 years
S3	Significant safety, economic, or environmental consequences if minor damage	Minor risk of ASR acceptable.	Pavements Culverts Highway barriers Rural, low-volume bridges Large numbers of precast elements where economic costs of replacement are severe Service life normally 40 to 75 years
S4	Serious safety, economic, or environmental consequences if minor damage	ASR cannot be tolerated.	Major bridges Tunnels Critical elements that are very difficult to inspect or repair Service life normally >75 years

Table 3. Level of Prevention

Level of ASR Risk (Table 2)	Classification of Structure (Table 4)			
	S1	S2	S3	S4
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]

[a] It is not permitted to construct a Class S4 structure (see Table 4) when the risk of ASR is Level 6. Measures must be taken to reduce the level of risk in these circumstances. The levels of prevention V, W, X, Y, Z, and ZZ are used in Tables 5 to 8.

Table 5. Maximum Alkali Contents in Portland Cement Concrete

	Maximum Alkali Loading of Concrete (Na_2Oeq)	
Prevention Level	kg/m^3	lb/yd^3
V	No limit	No limit
W	3.0	5.0
X	2.4	4.0
Y	1.8	3.0
Z[a]	Table 8	Table 8
ZZ[a]	Table 8	Table 8

[a] SCMs must be used in prevention levels Z and ZZ.

Table 6. Minimum SCM Levels

Type of SCM[a]	Alkali Level of SCM, (% Na_2Oeq)	Minimum Replacement Level[b] (% by Mass of Cementitious Material)				
		Level W	Level X	Level Y	Level Z	Level ZZ
Fly ash (CaO ≤18%)	≤3.0	15	20	25	35	Table 8
	>3.0, ≤4.5	20	25	30	40	
Slag	≤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 2.4 × LBA	

Table 7. Adjustment for Alkali Level of Portland Cement

Cement alkalies (% Na_2Oeq)	Level of SCM
≤0.70	Reduce the minimum amount of SCM given in Table 6 by one prevention level.[a]
>0.70, ≤1.00	Use the minimum levels of SCM given in Table 6.
>1.00, ≤1.25	Increase the minimum amount of SCM given in Table 6 by one prevention level.
>1.25	No guidance is given.

[a] The replacement levels should not be below those given in Table 6 for prevention level W, regardless of the alkali content of the portland cement.

Table 8. Using SCM and Limiting Alkali Content to Provide Exceptional Levels of Prevention

Prevention Level	SCM as Sole Prevention	Limiting Concrete Alkali Loading Plus SCM	
	Minimum SCM Level	Maximum Alkali Loading, kg/m^3 (lb/yd^3)	Minimum SCM Level
Z	SCM level shown for Level Z in Table 6	1.8 (3.0)	SCM level shown for Level Y in Table 6
ZZ	Not permitted	1.8 (3.0)	SCM level shown for Level Z in Table 6

Prescriptive Approach

- Options for mitigation
  - Limit concrete alkali loading
  - Use of SCMs
  - Both

Performance Approach

- Uses testing to assure performance
  - ASTM C1567 or C1293
  - <0.10% or <0.04%

Performance approach: Data Needed

- C1293: Adjusts mix water alkali content based on portland cement
- Equivalent alkali content of portland cement or portland cement portion of blended cement

Conclusion

- Alkali-Silica Reactivity (ASR)
- Alkalies in Cement and Concrete
  - Cement equivalent alkali content
  - Concrete alkali loading
  - Benefits of alkalies in concrete
- ASTM C1778/AASHTO R 80 for best guidance now and for the future
- http://mdot.mse.mtu.edu/dotspecs/