MITIGATING ALKALI SILICA REACTIVITY (ASR) WITH FLY ASH

Concrete Design Using Performance Testing with Readily Available Materials vs. Prescriptive Specification Limits

Presentation Topics

- Causation of alkali-silica reactivity.
- The mechanism of ASR expansion.
- Identifying and mitigating ASR.
- The pessimism effect.
- Prescribed specifications.
- Performance testing.

Alkali Silica Reaction (ASR)

- Alkali-Silica Reaction – the reaction between the alkalis (sodium and potassium) in Portland cement and certain siliceous rocks or minerals, such as opal, chert, strained quartz and acidic volcanic glass, present in some aggregates; the products of the reaction may cause abnormal expansion and cracking of concrete in service.

- American Concrete Institute, Manual of Concrete Practice (MCP)

ACI MCP 201 Durability Table 5

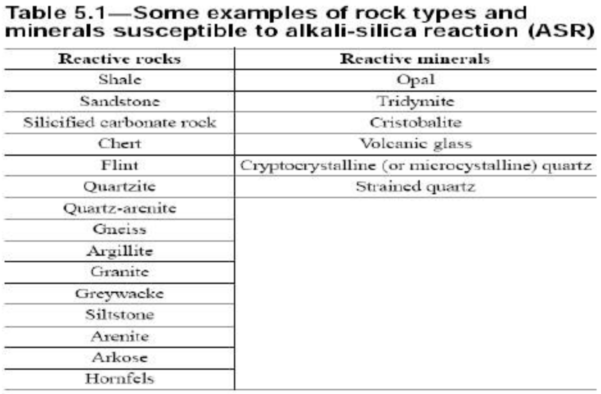
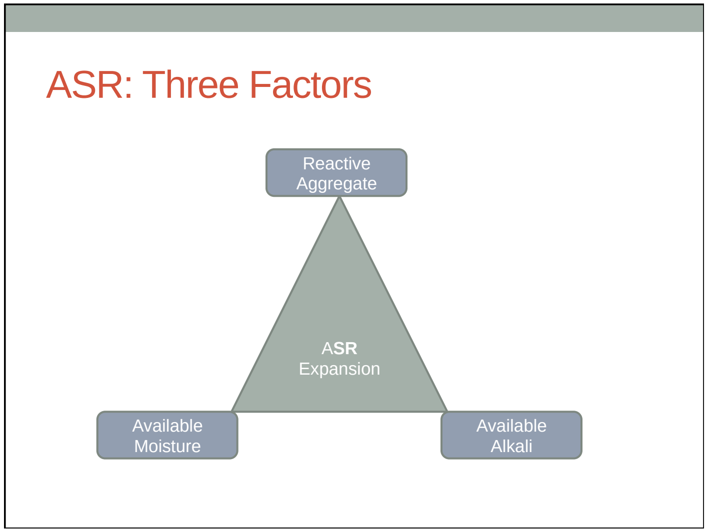


Table 5.1—Some examples of rock types and minerals susceptible to alkali-silica reaction (ASR)

Reactive rocks	Reactive minerals
Shale	Opal
Sandstone	Tridymite
Silicified carbonate rock	Cristobalite
Chert	Volcanic glass
Flint	Cryptocrystalline (or microcrystalline) quartz
Quartzite	Strained quartz
Quartz-arenite	
Gneiss	
Argillite	
Granite	
Greywacke	
Siltstone	
Arenite	
Arkose	
Hornfels	



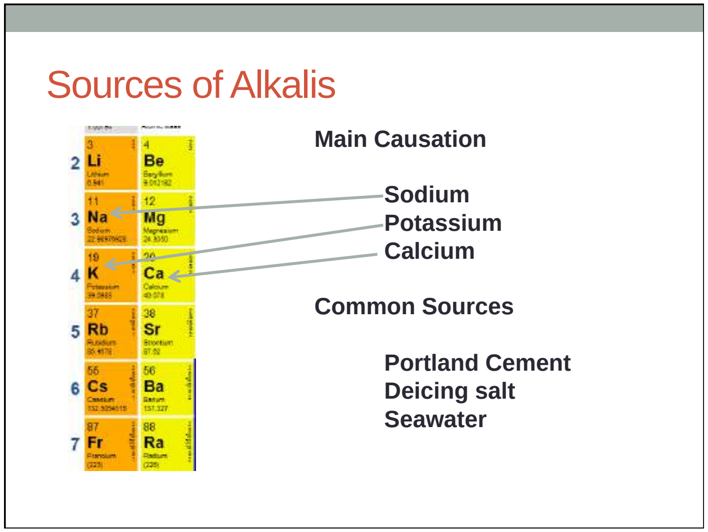
ASR: Three Factors

Reactive Aggregate

ASR Expansion

Available Moisture

Available Alkali



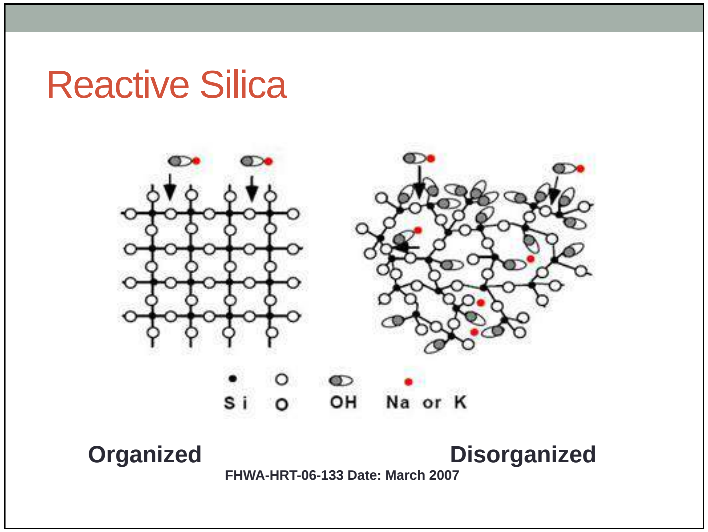
Sources of Alkalis

Main Causation

Sodium
Potassium
Calcium

Common Sources

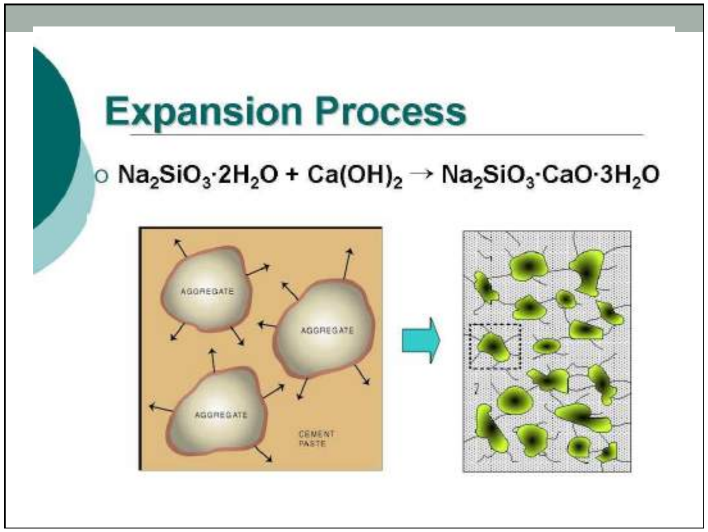
Portland Cement
Deicing salt
Seawater



Reactive Silica

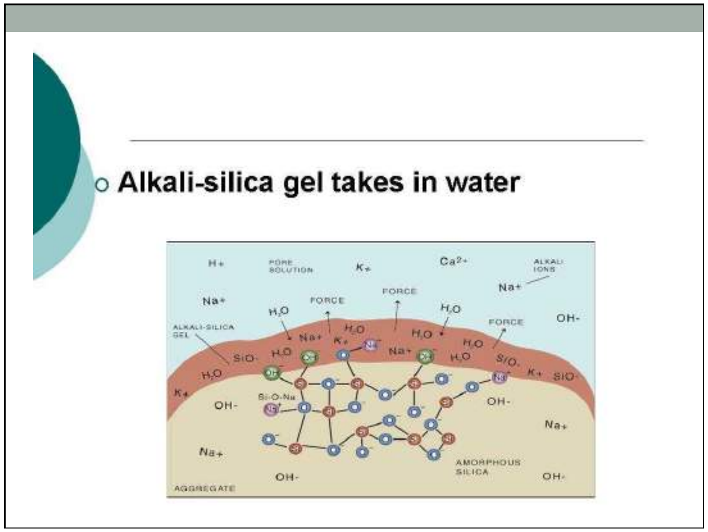
Organized **Disorganized**

FHWA-HRT-06-133 Date: March 2007

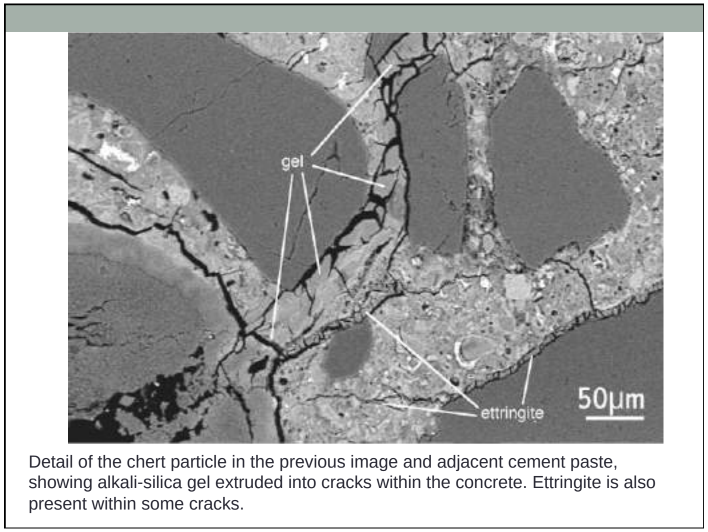


Expansion Process

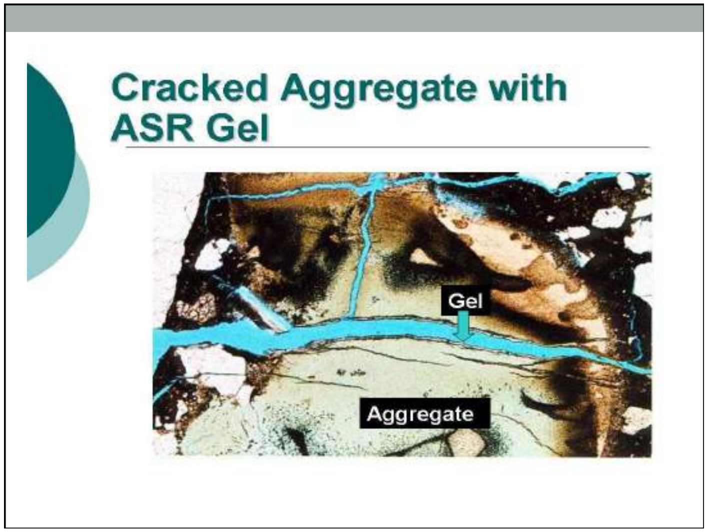
- $Na_2SiO_3 \cdot 2H_2O + Ca(OH)_2 \rightarrow Na_2SiO_3 \cdot CaO \cdot 3H_2O$



- Alkali-silica gel takes in water

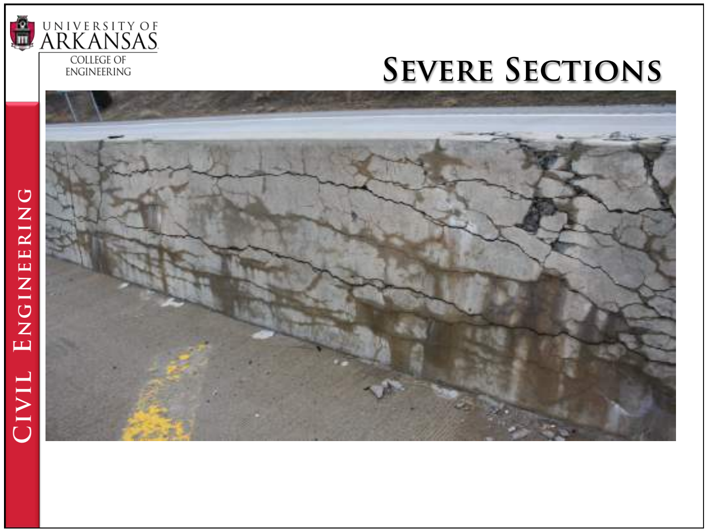


Detail of the chert particle in the previous image and adjacent cement paste, showing alkali-silica gel extruded into cracks within the concrete. Ettringite is also present within some cracks.



Cracked Aggregate with ASR Gel

Severe ASR Attack



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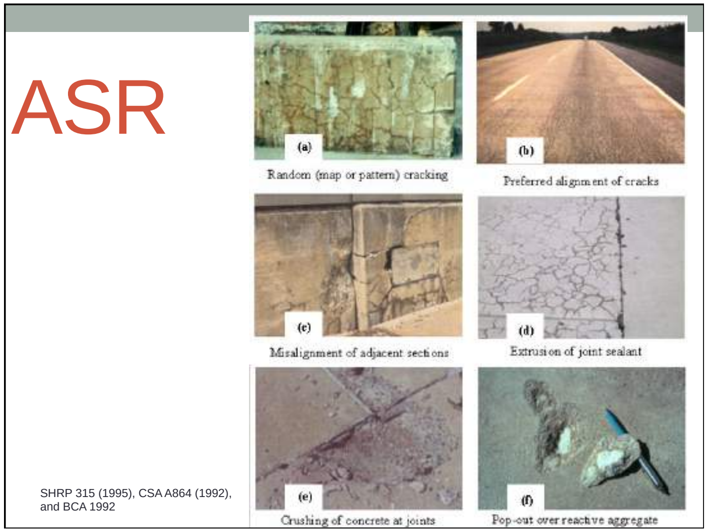
SEVERE SECTIONS



ASR

(a) Random (map or pattern) cracking

(b) Preferred alignment of cracks

(c) Misalignment of adjacent sections

(d) Extrusion of joint sealant

(e) Crushing of concrete at joints

(f) Pop-out over reactive aggregate

SHRP 315 (1995), CSA A864 (1992), and BCA 1992

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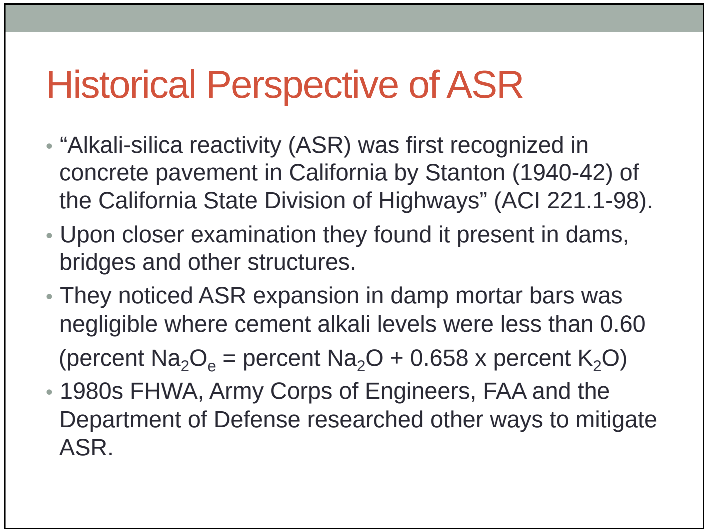
ASR BACKGROUND

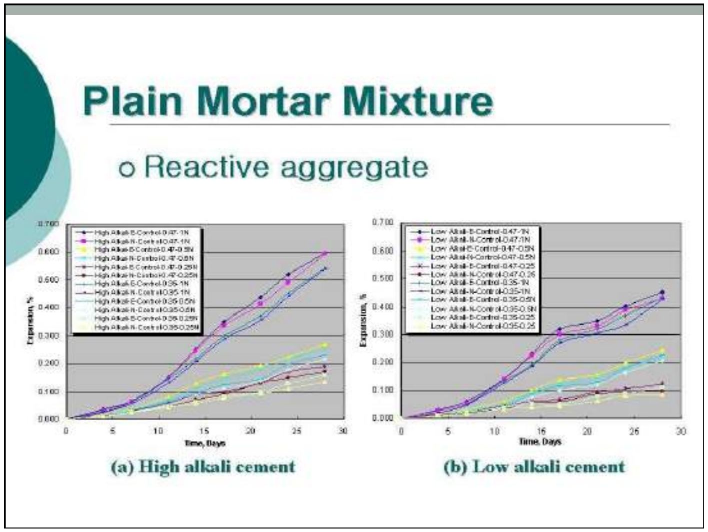


Historical Perspective of ASR

- “Alkali-silica reactivity (ASR) was first recognized in concrete pavement in California by Stanton (1940-42) of the California State Division of Highways” (ACI 221.1-98).
- Upon closer examination they found it present in dams, bridges and other structures.
- They noticed ASR expansion in damp mortar bars was negligible where cement alkali levels were less than 0.60 (percent Na_2O_e = percent Na_2O + 0.658 x percent K_2O)
- 1980s FHWA, Army Corps of Engineers, FAA and the Department of Defense researched other ways to mitigate ASR.

First Instances of fly ash mitigation Practices

- Starting in the 60s most of the theories to mitigate ASR seem to focus on the pozzolans, primarily fly ash used to mitigate ASR rather than addressing the use of high alkali cement and reactive coarse and fine aggregates. This was the standard practice at least through 2004.

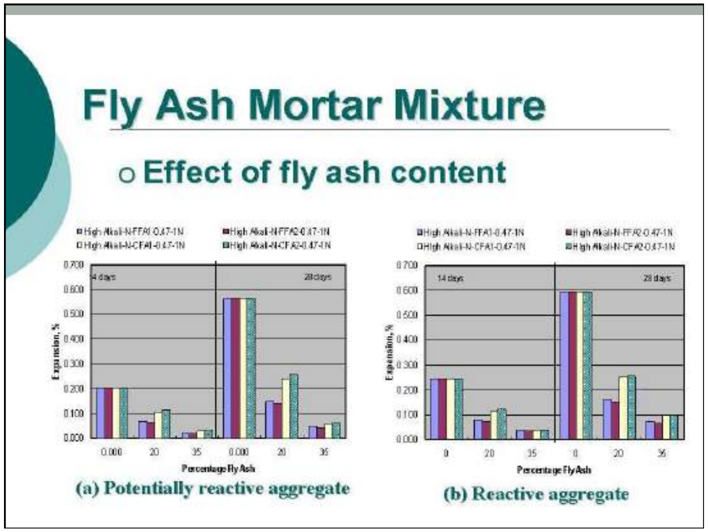


Plain Mortar Mixture

- Reactive aggregate

(a) High alkali cement

(b) Low alkali cement

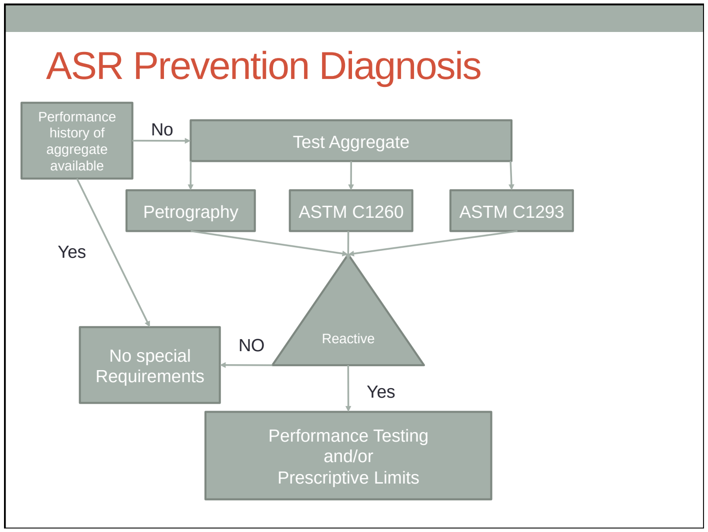


Fly Ash Mortar Mixture

- Effect of fly ash content

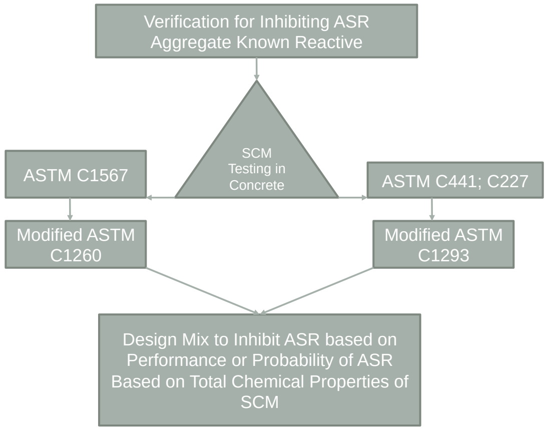
(a) Potentially reactive aggregate

(b) Reactive aggregate



ASR Prevention Diagnosis

Performance Testing


Verification for Inhibiting ASR Aggregate Known Reactive

ASTM C1567

SCM Testing in Concrete

ASTM C441; C227

Modified ASTM C1260

Modified ASTM C1293

Design Mix to Inhibit ASR based on Performance or Probability of ASR Based on Total Chemical Properties of SCM

Prescriptive Specifications for Fly Ash

- Require minimum 25% fly ash for cement replacement,.
- Limit fly ash Available Alkali < 1.5%
- Limit Alkali Equivalent 3 or 4% ($Na_2Oe = Na_2O + .0658\ K_2O$)
- Limit Fly Ash CaO 10% max.
- Require .45 max w/c ratio.
- **Must be Class F fly ash.**

Prescriptive Mitigation of ASR

- Often excludes SCMs that mitigate ASR when used in combination with various cements and aggregates.
- Does not take into consideration the degree of aggregate reactivity.
- Often increases the cost of materials when more economical materials are proven to mitigate ASR.
- Most of all, Prescriptive Mitigation Specifications do not guarantee ASR will not occur.

Performance Testing

- ASTM C1293 “Concrete Aggregates by Determination of Length Change of Concrete Due to ASR.”

This test method is intended to evaluate the potential of an aggregate to expand deleteriously due to any form of ASR in an alkaline environment. When the aggregate is known reactive, C1293 can be modified to evaluate the mitigation effectiveness of SCMs by replacing cement.

The intent is to develop information on a particular aggregate at a specific alkali level of 5.25 kg/m^3 (8.85 lb/yd^3)

ASTM requirement is 1-year. Researchers generally expose aggregates to the alkaline solution 2 to 3-years.

Performance Testing

- ASTM C227 “Potential Alkali Reactivity of Cement-Aggregate Combinations (Mortar-Bar Method).”

Test is used as the basis for conclusions and recommendations concerning the use of cement-aggregate combinations in concrete.

Modified ASTM C227 evaluates the performance of cementitious systems of various alkali contents. Work has also focused on developing this test method to quantify the available alkali (actually contributed to expansion) from fly ash and slag.

ASTM requires 12-months. Researchers often take measurements @ 12-months and every 6-months after.

Performance Testing

- ASTM C1260 “Potential Alkali Reactivity of Aggregates (Mortar-Bar Method)

This test method provides a means of detecting potential of an aggregate intended for use in concrete for undergoing ASR resulting in potentially deleterious internal expansion. It does not evaluate combinations of aggregates with cementitious materials . . . .

If the aggregate is found reactive, the modified C1260 can be used to evaluate mitigative measures, i.e., low alkali cement and SCMs.

ASTM requires 16-days to evaluate results. Researchers often take measurements at 16 and 28-days.

Performance Testing

- ASTM C1567 “Determining the Potential Alkali-Silica Reactivity of Combinations of Cementitious Materials and Aggregate (Accelerated Mortar-Bar Method).”

Test method provides a means for evaluating the ability of SCMs to control deleterious internal expansion due to ASR when used with an aggregate intended for use in concrete.

ASTM requires 14-days. Measurements at 28-days can provide additional information.

Beneficial Admixtures

- The following admixtures have been shown to mitigate ASR to various degrees:
  - Fly Ash Classes F, N, C
  - GGBFS
  - Lithium
  - Silica Fume
- Each of these admixtures has to be added within specific minimum amounts, otherwise they may create problems, including ***worse*** ASR

Improper admixture dosage or usage can exacerbate the ASR problem !

Last Comments: Performance Testing

- ASR performance testing is better than prescriptive methods to mitigate expansion. Performance testing, even with its faults allows for more economical use of indigenous aggregates and fly ashes and because the accelerated tests are conservative, reliable verification the potential for ASR expansion is mitigated.
- Writing a prescriptive specification can have several unintended consequences.

AASHTO Designation PP 65-11

"Determining the Reactivity of Concrete Aggregates and Selecting Appropriate Measures for Preventing Deleterious Expansion in New Concrete Construction".

AASHTO Designation PP 65-11

Classification of Aggregate Reactivity	
R0	Non Reactive
R1	Moderately Reactive
R2	Highly Reactive
R3	Very Highly Reactive

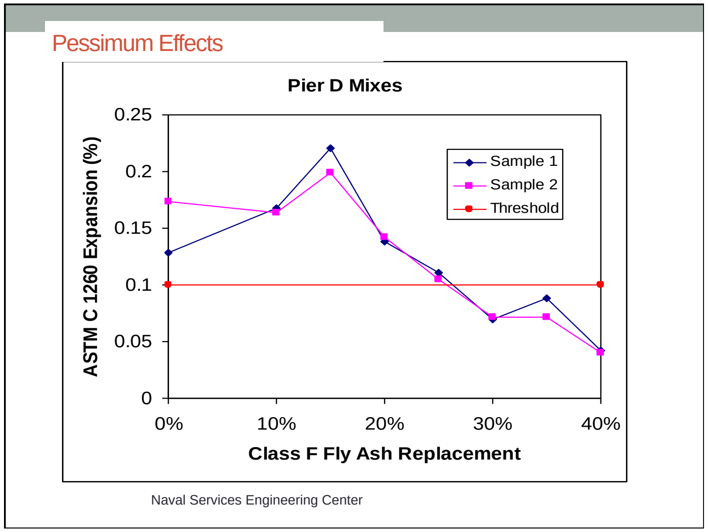
Determining the Level of ASR Risk

	RO	R1	R2	R3
Non-massive concrete in dry environment	Level 1	Level 1	Level 2	Level 3
Massive delements in dry environment	Level 2	Level 2	Level 3	Level 4
All concrete exposed to humid air, buried or immersed	Level 3	Level 3	Level 4	Level 5
All concrete exposed to alkalis in service	Level 4	Level 4	Level 5	Level 6

AASHTO Designation PP 65-11

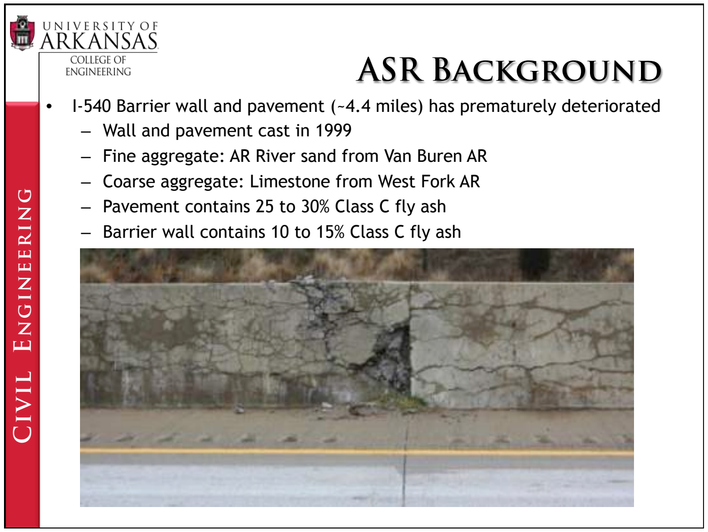
In the AASHTO PP 65 Standard Practice prescriptive limits for fly ash are the following: CaO < 18% and Na_2O_e < 4.5

For ashes greater than 18% CaO, they do not have prescriptive recommendations; rather, they require performance specifications that allow for ASTM C1567 testing.



Pessimum Effects

Naval Services Engineering Center

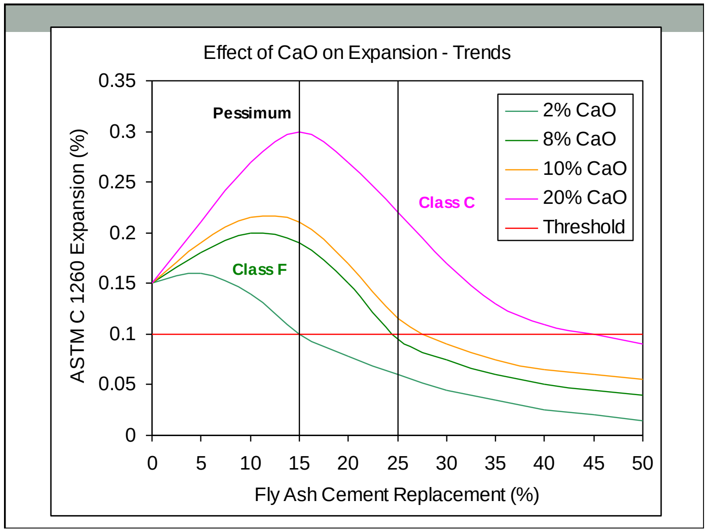


ASR BACKGROUND

- I-540 Barrier wall and pavement (~4.4 miles) has prematurely deteriorated
  - Wall and pavement cast in 1999
  - Fine aggregate: AR River sand from Van Buren AR
  - Coarse aggregate: Limestone from West Fork AR
  - Pavement contains 25 to 30% Class C fly ash
  - Barrier wall contains 10 to 15% Class C fly ash

Chemistry of Fly Ash

- Si + Al + Fe oxides sum determines if the ash is a Class F or C. Sum > 70 are F ash and Sum > 50 < 70 are C ash.
- CaO in a F ash is generally < 16%
- CaO in a C ash is generally > 18%



Malvar et al. (2002) Effect of CaO

Because of the pessimism effect due to CaO content

- Class C fly ash should not be used
- Class F or N fly ash with CaO < 8% should be used at minimum replacements of 25%
- Class F or N fly ash with 8% < CaO < 10% can be allowed at minimum replacements of 30%
- Unless the CaO < 2%, a strong pessimism effect may be found for replacements below 25% - this is a problem for current practice which often uses 15%.

Previous Class F 15% cement replacements may have resulted in WORSE expansion !

Malvar et al. (2002) "Alkali-silica reaction mitigation: State of the art and recommendations.

"These guidelines, however, are somewhat conservative, allowing only the use of ASTM C618 Class F fly ash with additional restrictions. Hence, various ashes very close to, but not meeting, that specification cannot be used, in some cases increasing concrete costs . . . ."

Malvar and Lenke (2006) "Efficiency of fly ash in mitigating alkali-silica reaction based on chemical composition

"The objective of this paper is to refine the fly ash requirements using their chemical composition, and to provide an alternate classification to ASTM C618 that would allow ash assessment as well as the usage of ashes currently not meeting [Malvar, (2002)] that specification."[2]

Questions Researchers Need to Answer.

- Is CaO in ash the only parameter that dictates ASR mitigation when fly ash is used in concrete, or does CaO level only reflect the lower total silica oxides content of the ash?
- Does higher CaO content of the ash indicate impairment of ASR mitigation due to other components in that type of ash, i.e., higher alkalis.
- Can higher CaO but lower alkali content ash perform well?
- How much does accelerated testing for ASR skew the results against higher CaO or higher alkali ash?
- Should more focus be placed on cement sources vs the fly ash?

Characteristics of a fly ash that determine its efficiency in preventing ASR (Malvar)

- Fineness: “Finer pozzolans are more efficient in reducing ASR expansion.”
- Mineralogy: “. . . basic chemical components, these components can be bound differently and react differently from ash to ash.”
- Chemistry: “This approach has already been used with success (Shehata and Thomas).”

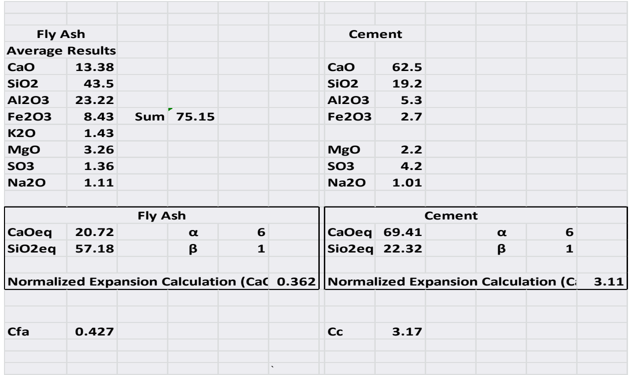
Malvar’s Conclusion

Malvar indexed fly ash (C_{fa}) that correlated well with ASTM C618 and CSA A3001 classifications.

The index was also used to assess the efficiency of other ashes that did not meet either specification.

For a given aggregate reactivity, a given cement, and a given ash, it was possible to derive the minimum cement replacement that is needed to ensure with 90: reliability that the 14-day AMBT expansion would remain below 0.8%

Fly Ash Efficiency Mitigating ASR.



Fly Ash					
Average Results					
CaO	13.38				
SiO2	43.5				
Al2O3	23.22				
Fe2O3	8.43	Sum	75.15		
K2O	1.43				
MgO	3.26				
SO3	1.36				
Na2O	1.11				
Fly Ash					
CaOeq	20.72		α	6	
SiO2eq	57.18		β	1	
Normalized Expansion Calculation (CaC					0.362
Cfa	0.427				

Cement					
CaO	62.5				
SiO2	19.2				
Al2O3	5.3				
Fe2O3	2.7				
MgO	2.2				
SO3	4.2				
Na2O	1.01				
Cement					
CaOeq	69.41		α	6	
Sio2eq	22.32		β	1	
Normalized Expansion Calculation (C					3.11
Cc	3.17				

Monroe Ash C_{fa} 0.42

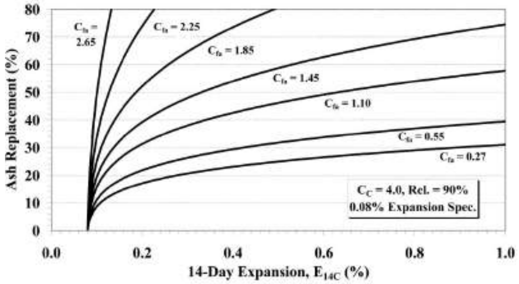
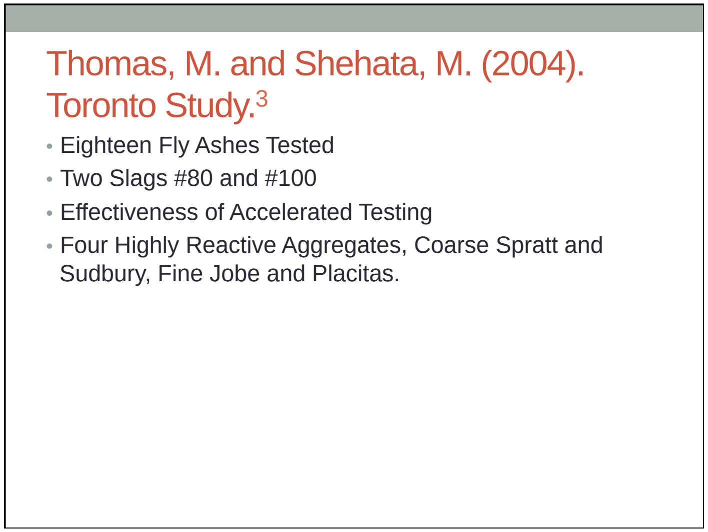
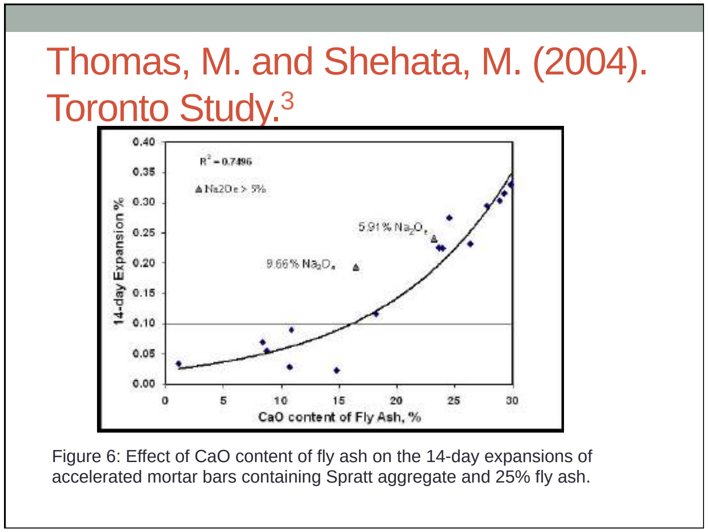


Fig. 13—Minimum fly ash replacement to mitigate alkali-silica reaction with 90% reliability.



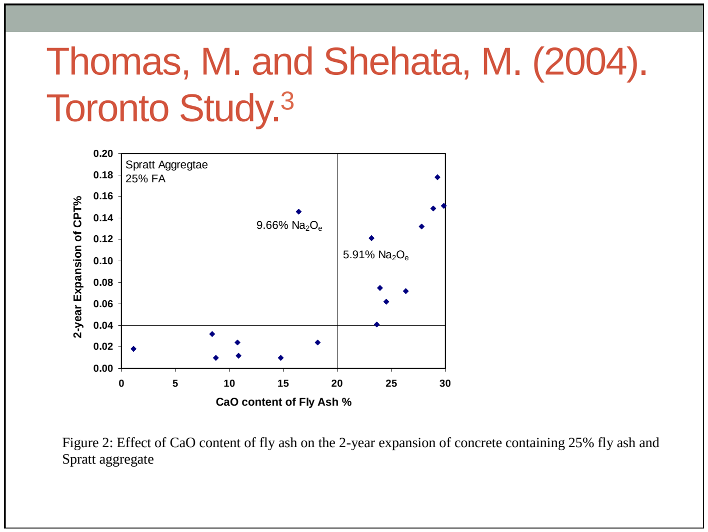
Thomas, M. and Shehata, M. (2004). Toronto Study.[3]

- Eighteen Fly Ashes Tested
- Two Slags #80 and #100
- Effectiveness of Accelerated Testing
- Four Highly Reactive Aggregates, Coarse Spratt and Sudbury, Fine Jobe and Placitas.



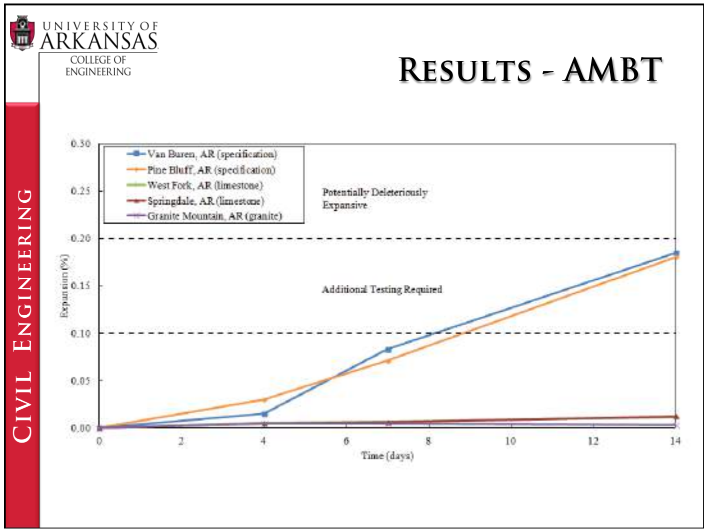
Thomas, M. and Shehata, M. (2004). Toronto Study.[3]

Figure 6: Effect of CaO content of fly ash on the 14-day expansions of accelerated mortar bars containing Spratt aggregate and 25% fly ash.



Thomas, M. and Shehata, M. (2004). Toronto Study.[3]

Figure 2: Effect of CaO content of fly ash on the 2-year expansion of concrete containing 25% fly ash and Spratt aggregate



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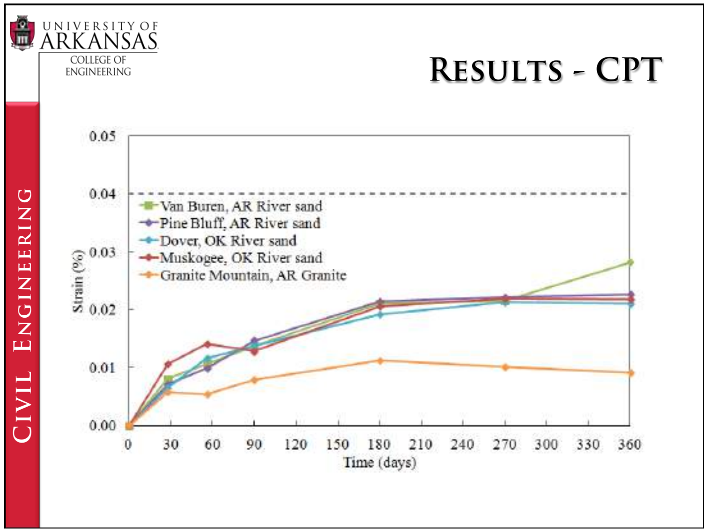
RESULTS - AMBT



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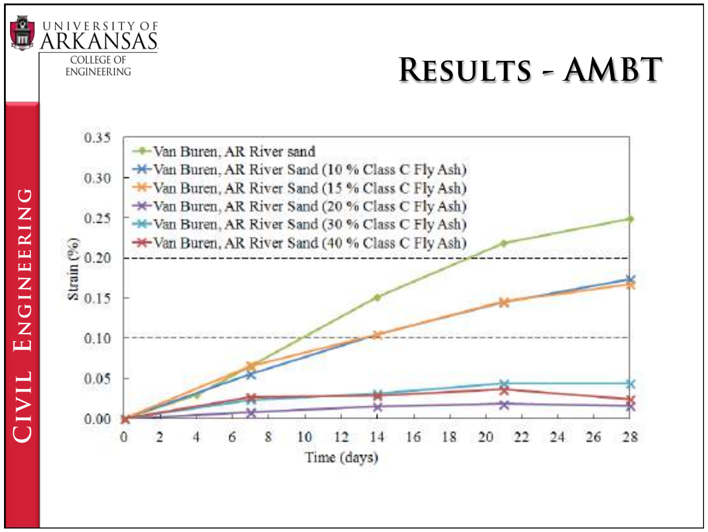
RESULTS - CPT



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RESULTS - AMBT

Conclusion

- Better understanding of ASR
- How to identify aggregate conducive to ASR expansion. Build a database and require semi-annual or annual 3rd party testing.
- Pessimism effect, don't specify a SCM maximum substitution limit.
- Performance testing for verifying ASR reductions.

HEADWATERS RESOURCES

Thank You ! Questions!

SUBTITLE C Recycle First! www.recyclingfirst.org

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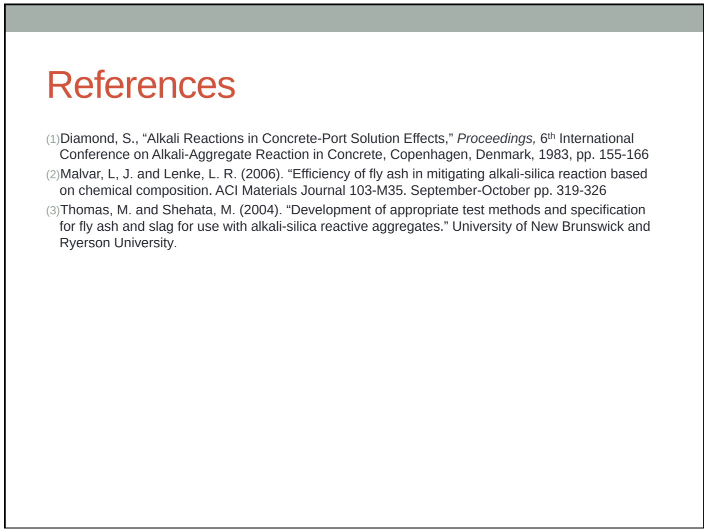

References

(1) Diamond, S., "Alkali Reactions in Concrete-Port Solution Effects," *Proceedings,* 6th International Conference on Alkali-Aggregate Reaction in Concrete, Copenhagen, Denmark, 1983, pp. 155-166

(2) Malvar, L, J. and Lenke, L. R. (2006). "Efficiency of fly ash in mitigating alkali-silica reaction based on chemical composition. ACI Materials Journal 103-M35. September-October pp. 319-326

(3) Thomas, M. and Shehata, M. (2004). "Development of appropriate test methods and specification for fly ash and slag for use with alkali-silica reactive aggregates." University of New Brunswick and Ryerson University.