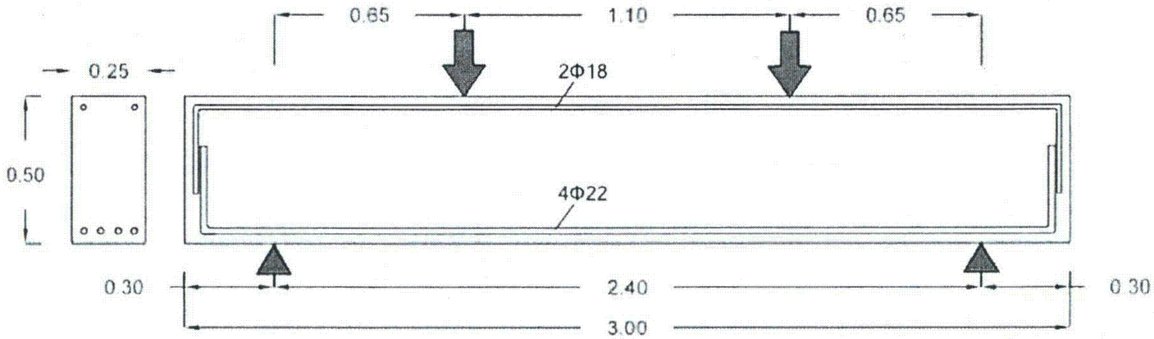
Shear Test

- The effect of ASR on the shear performance of reinforced concrete structures can be investigated through shear tests on six non-reactive beams (NR) – three with (S) and three without (W) transversal reinforcement -, six reactive beams without transversal reinforcement (W) and six reactive beams with transversal reinforcement (S). The twelve reactive beams should be tested at two different level of ASR development (R1 and R2).

Shear Test

S-NR-W, S-R1-W, S-R2-W: BEAMS WITHOUT TRANSVERSAL REINFORCEMENT

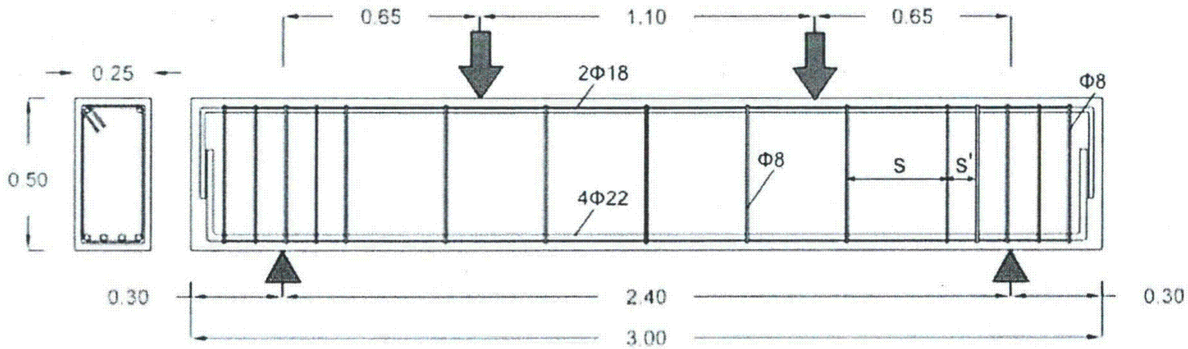
Applied load



The measures of the beam are in meters

S-NR-S, S-R1-S, S-R2-S: BEAMS WITH TRANSVERSAL REINFORCEMENT

Applied load



The measures of the beam are in meters

Shear Test

Beam	Number of beams	Concrete	Upper reinforcement φ=diameter (mm)	Lower reinforcement φ=diameter (mm)	Stirrups s=0.35 m s'=0.10 m	ASR linear expansion
S-NR-W	3	Non-reactive	2φ18	4φ22	None	None
S-NR-S	3	Non-reactive	2φ18	4φ22	Φ8	None
S-R1-W	3	Reactive	2φ18	4φ22	None	0.0011÷0.0018
S-R2-W	3	Reactive	2φ18	4φ22	None	0.0020÷0.0025
S-R1-S	3	Reactive	2φ18	4φ22	Φ8	0.0011÷0.0018
S-R2-S	3	Reactive	2φ18	4φ22	Φ8	0.0020÷0.0025

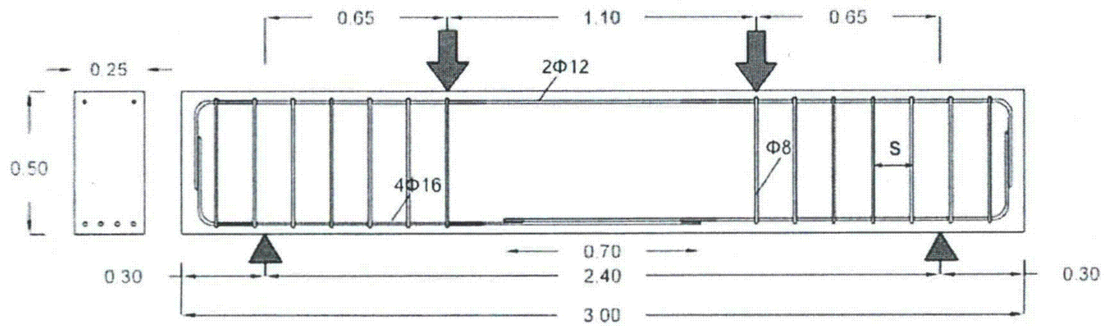
Lap splice test program

- The effect of ASR on the lap splice performance of reinforced concrete structures can be investigated through lap splice tests on six non-reactive beams (NR) – three with (S) and three without (W) transversal reinforcement -, six reactive beams without transversal reinforcement (W) and six reactive beams with transversal reinforcement (S). The twelve reactive beams should be tested at two different level of ASR development (R1 and R2).

Lap splice test program

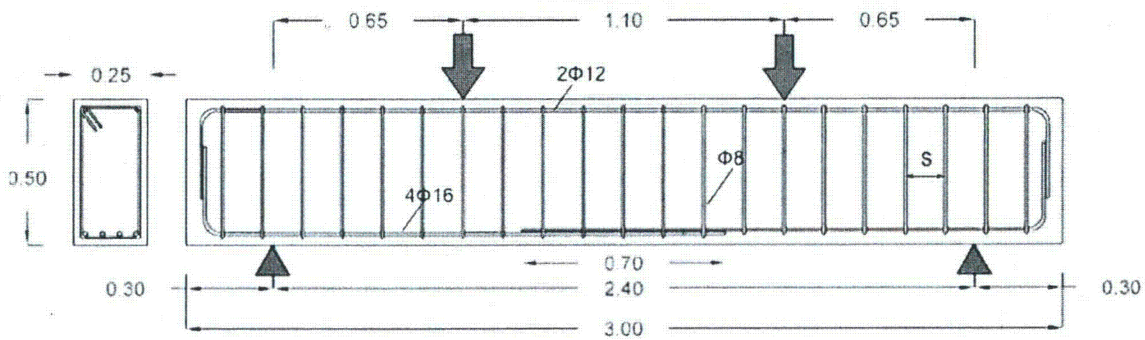
L-NR-W, L-R1-W, L-R2-W: BEAMS WITHOUT TRANSVERSAL REINFORCEMENT

Applied load



L-NR-S, L-R1-S, L-R2-S: BEAMS WITH TRANSVERSAL REINFORCEMENT

Applied load



The measures of the beam are in meters

Lap splice test program

Beam	Number of beams	Concrete	Upper reinforcement φ=diameter (mm)	Lower reinforcement φ=diameter (mm)	Stirrups s=0.14 m	ASR linear expansion
L-NR-W	3	Nonreactive	2φ12	4φ16	Φ8 None in lap splice zone	None
L-NR-S	3	Nonreactive	2φ12	4φ16	Φ8	None
L-R1-W	3	Reactive	2φ12	4φ16	Φ8 None in lap splice zone	0.0011÷0.0018
L-R2-W	3	Reactive	2φ12	4φ16	Φ8 None in lap splice zone	0.0020÷0.0025
L-R1-S	3	Reactive	2φ12	4φ16	Φ8	0.0011÷0.0018
L-R2-S	3	Reactive	2φ12	4φ16	Φ8	0.0020÷0.0025

Seismic response

- I. Generate Response Spectra for the specific location, including soil type.
- II. Conduct Response Spectrum Analyses using *Generalized Modal Analysis* to obtain peak responses for different levels of damage caused by ASR and subsequent decrease in stiffness.
- III. Obtain Floor Spectra for various locations in the model using the *Generalized Modal Analysis* to further identify the impact on equipment on various levels of ASR damage.

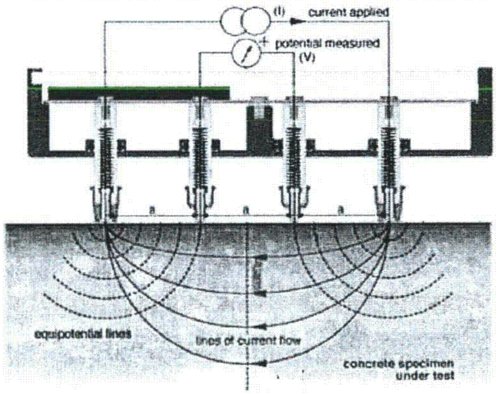
Recommendation

- At UC. Berkeley, Prof. Mahin and his group are conducting research for many nuclear power plants.
- Their approach could be used to model an analysis of the structure affected by ASR.

Corrosion caused by ASR cracking

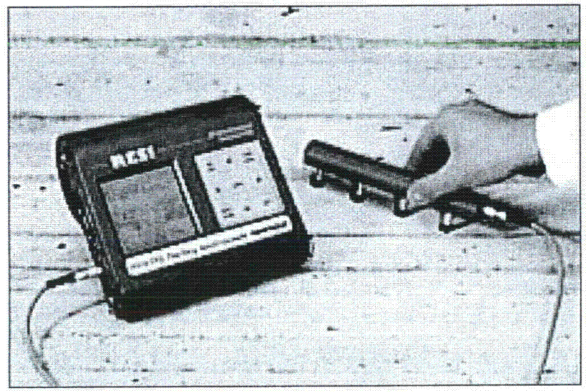
- Resistivity
- Corrosion Potential
- Polarization Resistance

Resistivity of concrete



http://www.resipodmeter.com/

CTS Electrical Resistivity Testing Using Proceq Resi

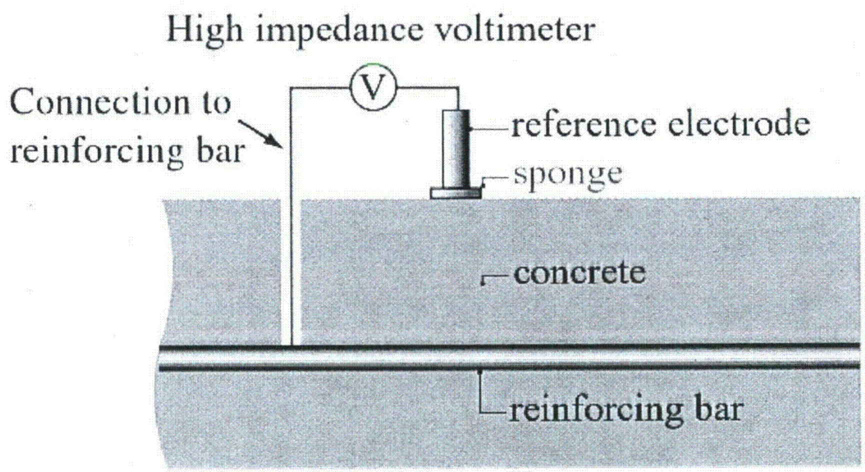


http://www.pcts.com.au/concrete-ndt/electrical-resistivity-test.htm

Concrete Resistivity (Ω_m)	Likely Corrosion rate
> 200	Negligible
100 to 200	Low
50 to 100	High
<50	Very high

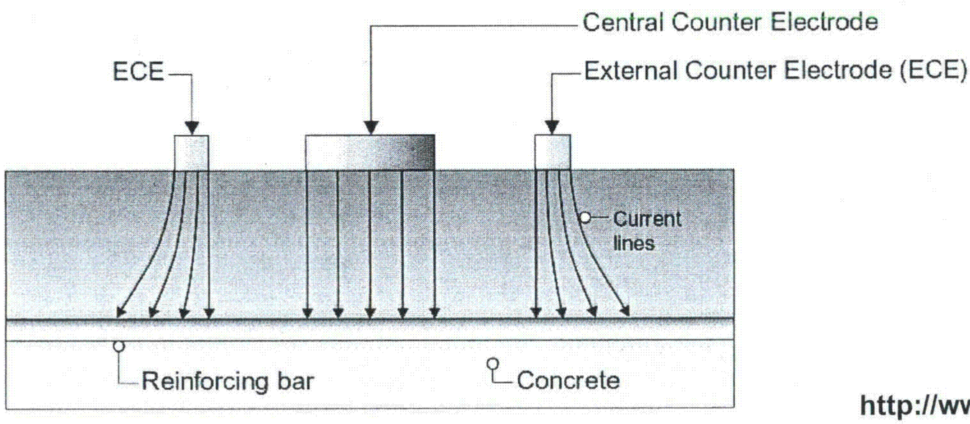
CEB-192 recommendation based on concrete resistivity to estimate the likely corrosion rate

Corrosion Potential



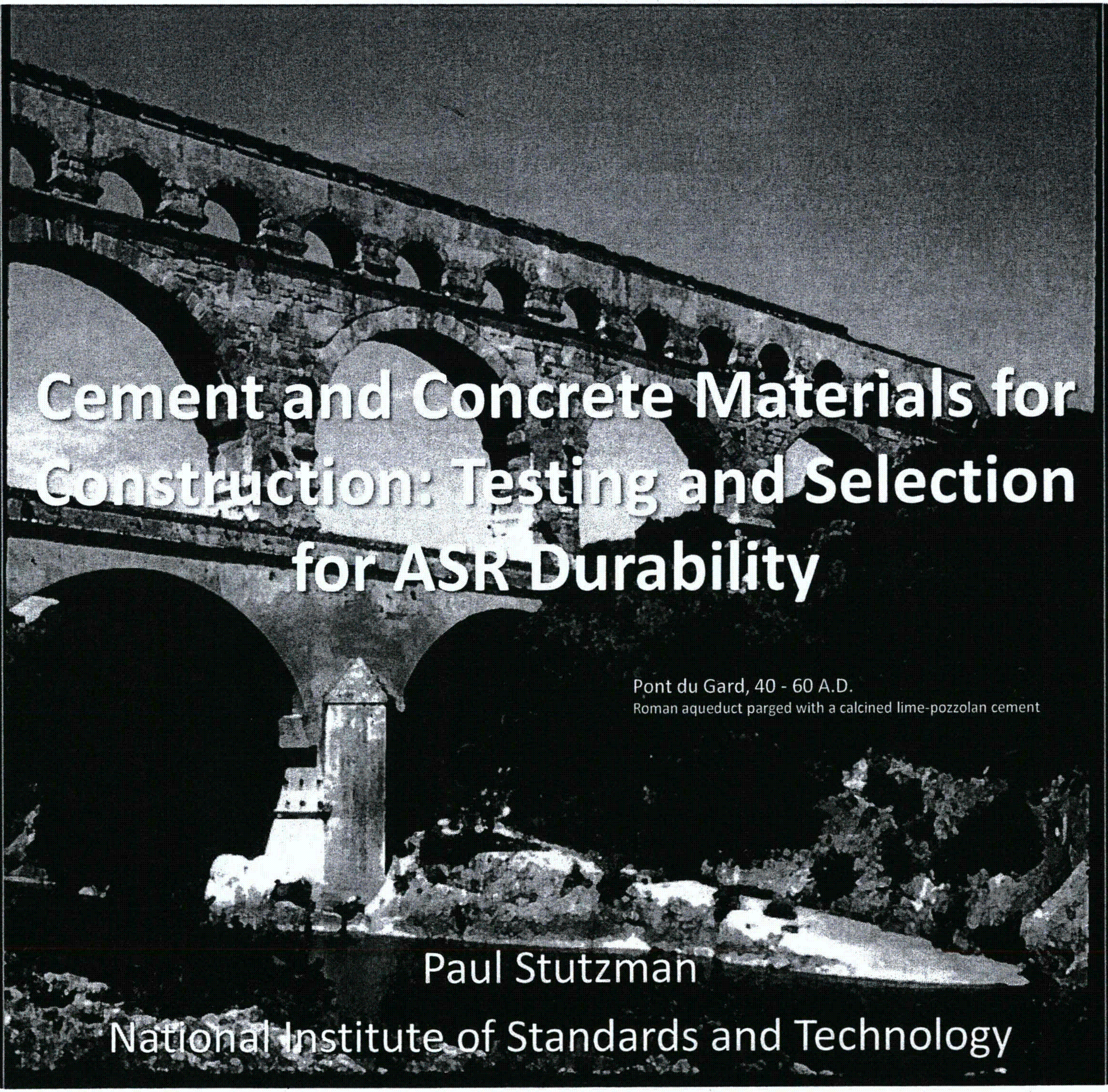
Measured potential (mV vs. CSE)	Corrosion probability
>-200	Low, less than10% probability of corrosion
-200 ~ -350	Uncertain
<-350	High, greater than 90% probability of corrosion

Polarization Resistance



http://www.ndtjames.com/Gecor-6-p/c-cs-5000.htm

Rate of corrosion	Polarization resistance, R_p (kΩ.cm^2)	Corrosion penetration, p (μm/year)
Very high	$0.25 < R_p < 2.5$	$100 < p < 1000$
High	$2.5 < R_p < 25$	$10 < p < 100$
Low/moderate	$25 < R_p < 250$	$1 < p < 10$
Passive	$250 < R_p$	$p < 1$



Cement and Concrete Materials for Construction: Testing and Selection for ASR Durability

Pont du Gard, 40 - 60 A.D.
Roman aqueduct parged with a calcined lime-pozzolan cement

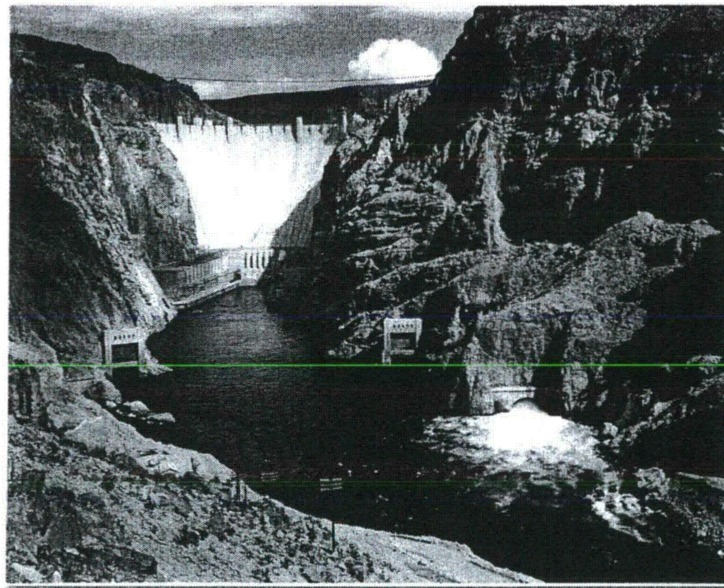
Paul Stutzman
National Institute of Standards and Technology

Outline

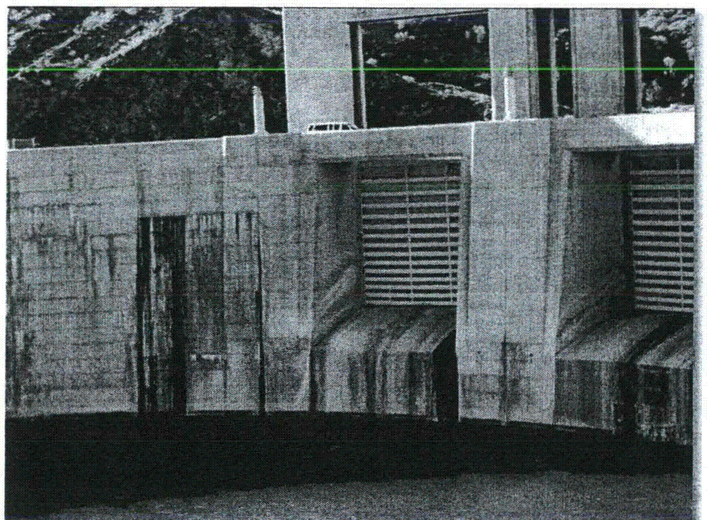
- Concrete Durability Issues
- Concrete Constituents
- Cement Specifications
- Microstructure of concrete
- Screening materials for ASR Susceptibility

Concrete Durability Issues

- Corrosion of Reinforcing Steel
  - Carbonation (drop in pH), chloride transport (breakdown of passive film)
  - Both permeate through exposed surfaces and depend upon supply, RH, and temperature
  - Carbonation stems from CO_2 dissolving in the pore solution producing CO^{2-}_3 and reacting with Ca^{2+} to produce $CaCO_3$; the $Ca2^+$ and OH^- coming from dissolution of CH and C-S-H
- Carbonation
- Alkali-Aggregate Reaction
- Sulfate Attack
- Delayed Ettringite Formation
- Leaching
- Sea Water
- Bacterial
- Fire

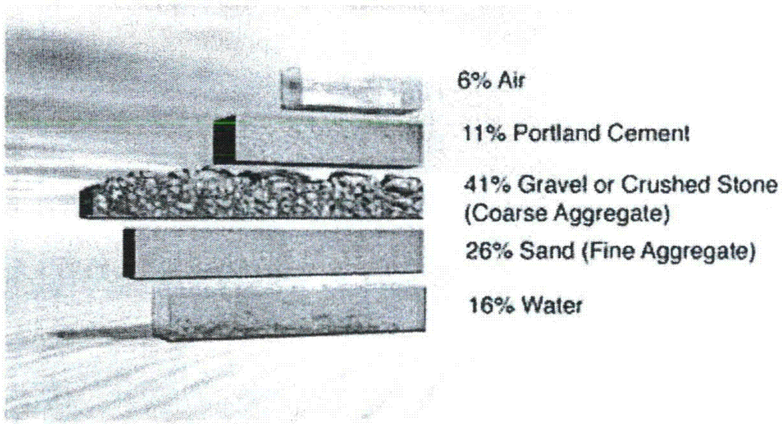


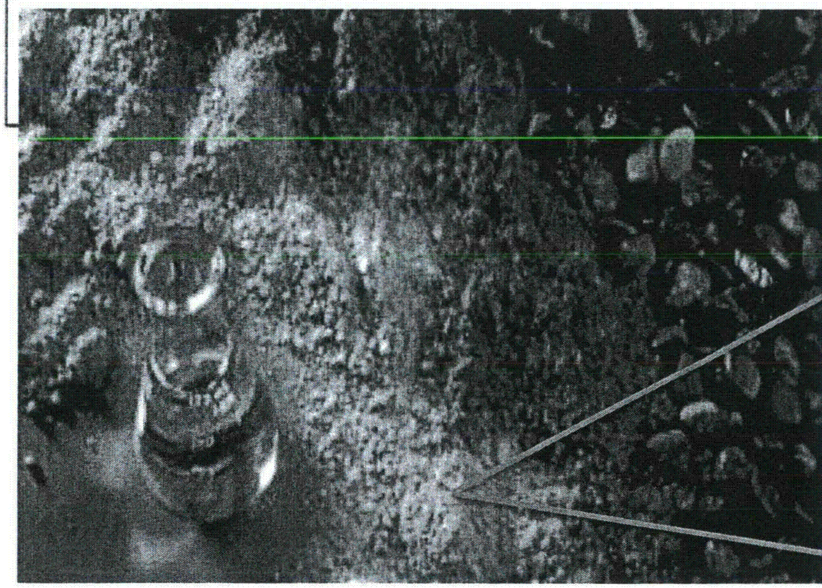
Hoover Dam, 1931-6, Bureau Rec.



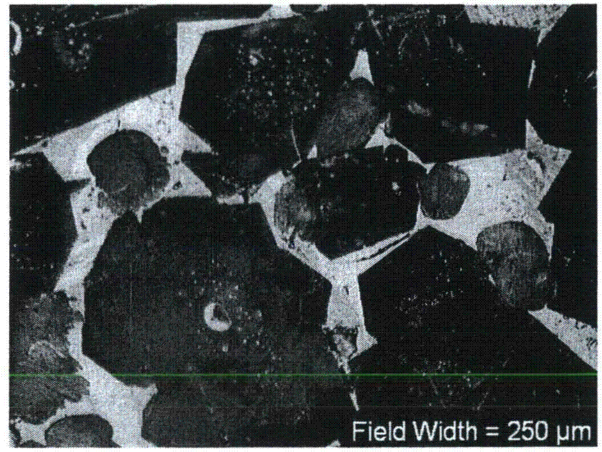
Parker Dam 1934-8

Concrete Constituents

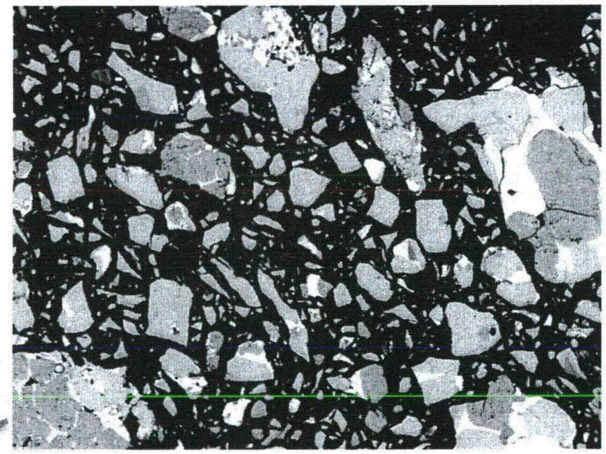




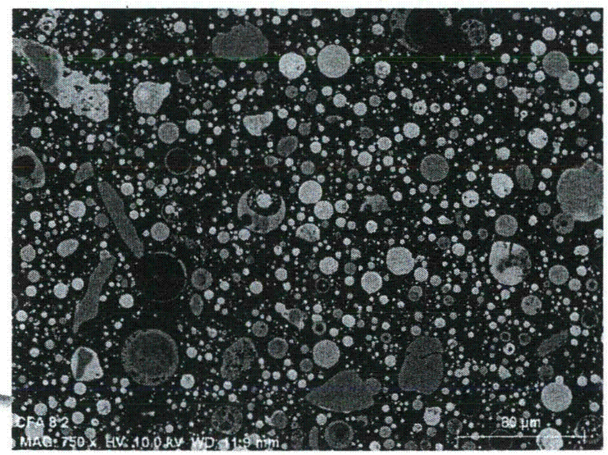
Portland Cement Association



clinker



cement



fly ash

Cement Constituents

Tricalcium silicate (Ca_3SiO_5, C_3S, alite) 40 % to 75 % of the bulk (by mass), responsible for the bulk of the early age (< 28 d) strength of hardened concrete.

Dicalcium silicate (Ca_2SiO_4, C_2S, belite) is the second most abundant phase in clinker and later-age strength

Tricalcium aluminate ($Ca_3Al_2O_6$, C_3A, aluminate) comprises from 1 % to 18 % by mass

Tetracalcium aluminoferrite (Ca_2AlFeO_5, C_4AF, ferrite) 5 % to 15 % by mass

Periclase (MgO)

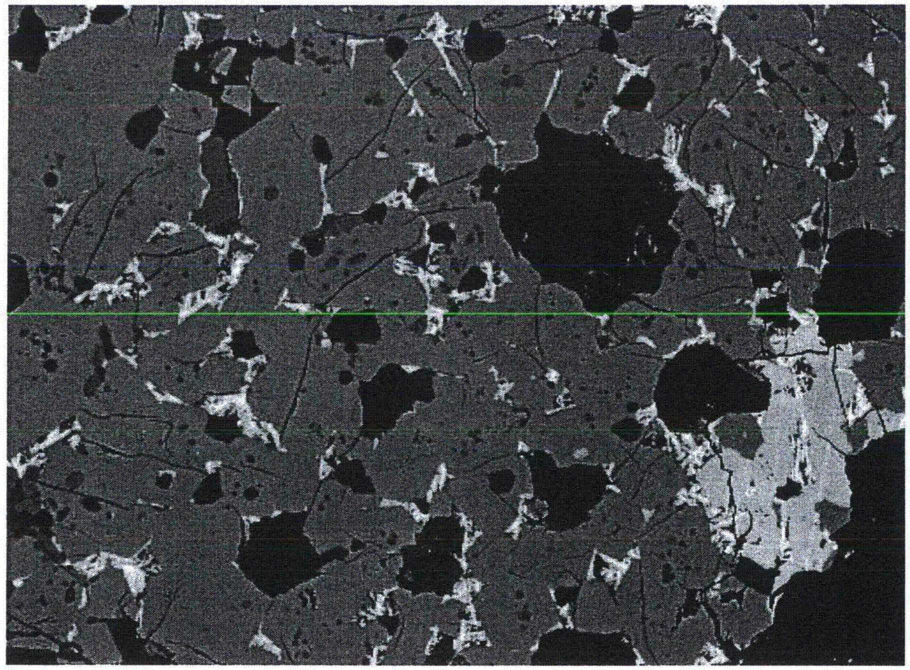
Free Lime (CaO)

The alkali sulfates: different mineral forms

- arcanite (K_2SO_4)
- aphthitalite ($(K,Na)_3Na(SO_4)_2$)
- calcium langbeinite ($K_2Ca_2(SO_4)_3$)
- thenardite ($(Na,K)SO_4$)
- anhydrite ($CaSO_4$)

Calcium Sulfates:

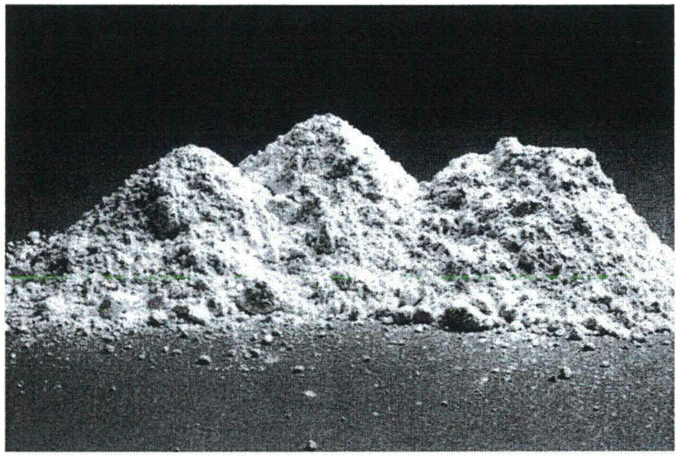
- gypsum ($CaSO_4 \cdot 2H_2O$)
- bassanite ($CaSO_4 \cdot \frac{1}{2}H_2O$, hemihydrate, plaster)
- anhydrite ($CaSO_4$)



The cement chemist's shorthand: C = CaO, S = SiO_2, A = Al_2O_3, F = Fe_2O_3, M = MgO, K = K_2O, $\bar{S} = SO_3$, N = Na_2O, T = TiO_2, P = P_2O_5, H = H_2O, and $\bar{C} = CO_2$

Cements

- ASTM C 150, Specification for Portland Cement
  - Type I General Purpose
  - Type II Moderate Sulfate Resistance
  - Type III High Early Strength (like Type 1, finer grind)
  - Type IV Low Heat
  - Type V High Sulfate Resistance
    - Additional constituents in cements may include 5.0 % limestone, 5.0 % inorganic processing addition, and 1.0 % organic processing addition
    - Canadian Specification: portland-limestone cement (15 % limestone)
- ASTM C 595 Specification for Blended Hydraulic Cements
  - Type IS (X) Portland Blast Furnace Slag Cement (up to 95 % slag)
  - Type IP (X) Portland-Pozzolan Cement (up to 40 % pozzolans)
  - Type IT (AX, BY) Ternary Blend (s=slag, p=pozzolan)



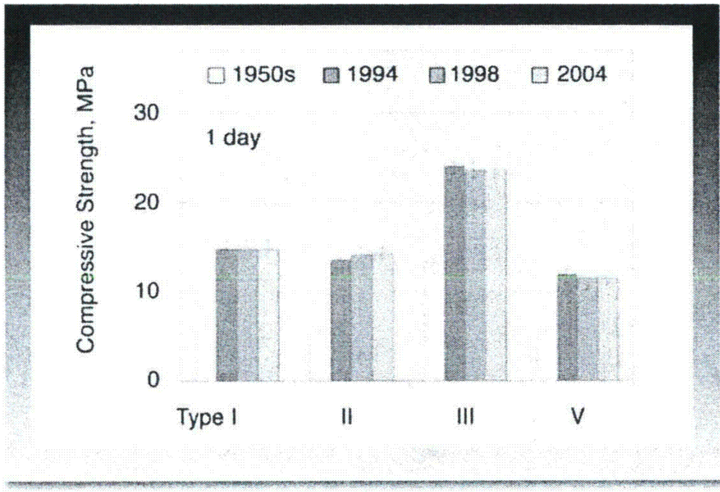
Portland Cement Association

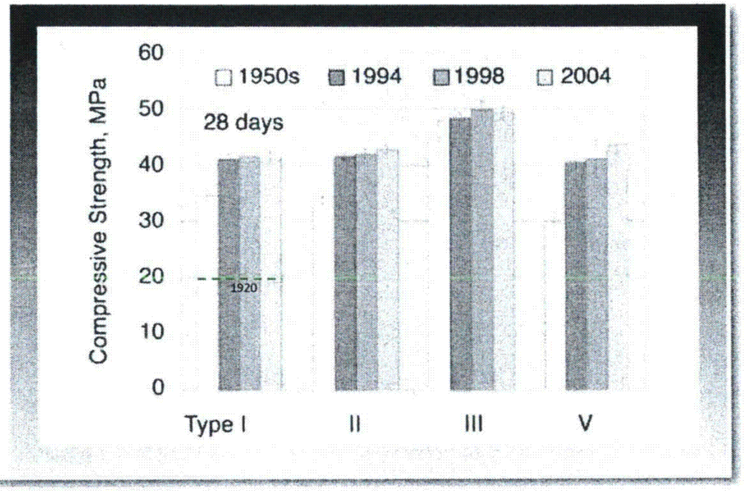
- ASTM C 1157 Performance Specification for Hydraulic Cements

  Performance-based cement classification: specific requirements for general use, high early strength, sulfate resistance, and heat of hydration. Low reactivity with alkali-silica-reactive aggregates as an option
  - GU General Construction
  - HE High Early-Strength
  - MS Moderate Sulfate Resistance
  - HS High Sulfate Resistance
  - MH Moderate Heat of Hydration
  - LH Low Heat of Hydration

- Optional expansion limits when using a reactive aggregate – but this is not necessarily the job aggregate.
  - ASTM C 311, Standard Test Methods for Sampling and Testing Fly Ash or Natural Pozzolans for Use in Portland-Cement Concrete
  - Comparative testing of fly ash or pozzolan with test cement against a low alkali cement following ASTM C441
    - *But*, it uses constant flow rather than constant water and uses Pyrex glass
  - Also have an evaluation of the effectiveness of fly ash or pozzolan for sulfate resistance
    - Follows C 1012 test. Compares job cement and fly ash to a control cement, can use different amounts of fly ash to assess effectiveness. Uses a constant flow, though they attempt to limit the range that it might vary from a 0.485 W/S

Cements of Today vs. Yesterday





Type I General Purpose
Type II Moderate Sulfate Resistance
Type III High Early Strength
Type IV Low Heat
Type V High Sulfate Resistance

Finer grinding to enhance early age strength development

- Decreases air content, bleeding, setting time, and workability
- Increases heat of hydration, shrinkage, slump loss and water requirement

Narrower Particle Size Distribution

- Increases strength and water requirements
- decreases setting time

Increase in CaO index, resulting in more alite (the principal phase)

- Increases heat of hydration, reactivity with SCM, and strength
- Decreases setting time

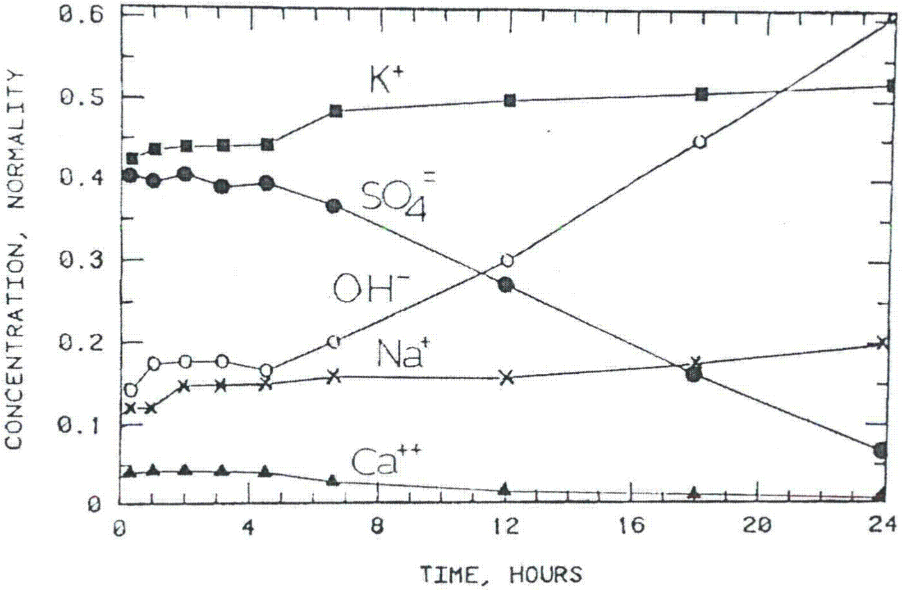
Increase in alkali sulfate phases

- Increases air content, heat of hydration, reactivity with SCMs, ASR risk, water requirements, early age strength
- Decreases bleeding, shrinkage, workability, and late-age strength, changes setting times

Increase in sulfate content

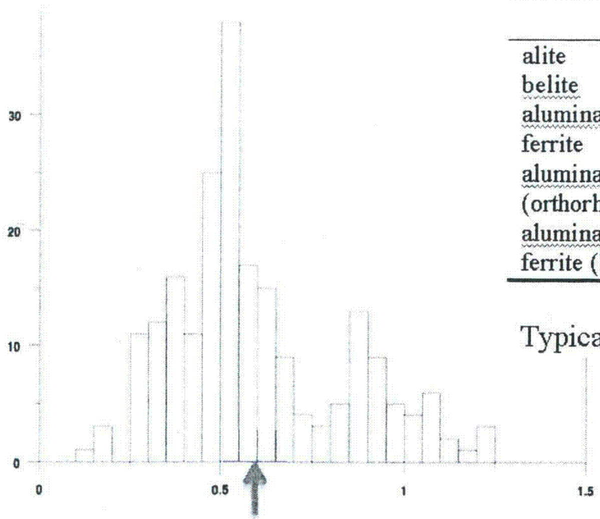
- Increases water requirement
- Decreases shrinkage and slump loss

Pore Solution Chemistry



M. Penko, Some Early Hydration Processes in Cement Paste as Monitored by Liquid Phase Composition Measurements, Ph. D. Thesis, Purdue University, 1983, 124 pp.

Age (d)	Ca^{++}	Na^+	K^+	OH^-
15	0.001	0.22	0.55	0.73
49	0.002	0.24	0.59	0.77
70	0.000	0.22	0.57	0.75
149	0.002	0.23	0.60	0.80
585	0.000	0.24	0.58	0.78



	Na_2O	MgO	Al_2O_3	SiO_2	P_2O_5	SO_3	K_2O	CaO	TiO_2	Mn_2O_3	Fe_2O_3
alite	0.1	1.1	1.0	25.2	0.1	0.1	0.1	71.6	0.0	0.0	0.7
belite	0.1	0.5	2.1	31.5	0.1	0.2	0.9	63.5	0.2	0.0	0.9
aluminate (cubic.)	1.0	1.4	31.3	3.7	0.0	0.0	0.7	56.6	0.2	0.0	5.1
ferrite	0.1	3.0	21.9	3.6	0.0	0.0	0.2	47.5	1.6	0.7	21.4
aluminate (orthorhombic)	0.6	1.2	28.9	4.3	0.0	0.0	4.0	53.9	0.5	0.0	6.6
aluminate (low Fe)	0.4	1.0	33.8	4.6	0.0	0.0	0.5	58.1	0.6	0.0	1.0
ferrite (low Al)	0.4	3.7	16.2	5.0	0.0	0.3	0.2	47.8	0.6	1.0	25.4

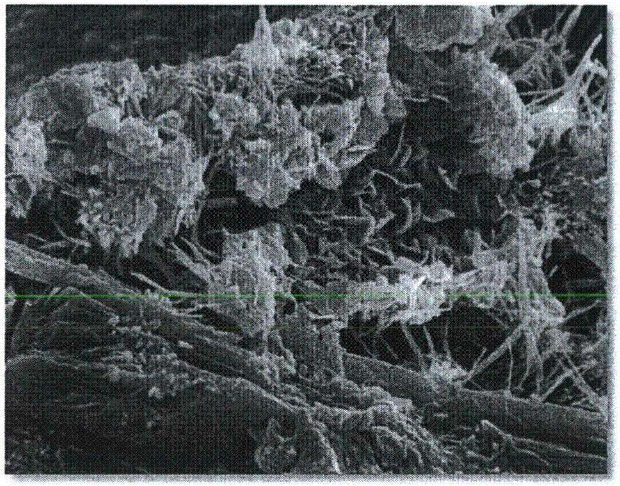
Typical chemical compositions for the primary phases in cement clinkers. Taylor, 1997

ACI recommends 3 kg/M^3 total alkali

Concrete Microstructure

Silicates hydrate to produce calcium silicate hydrate (C-S-H) and calcium hydroxide (CH)

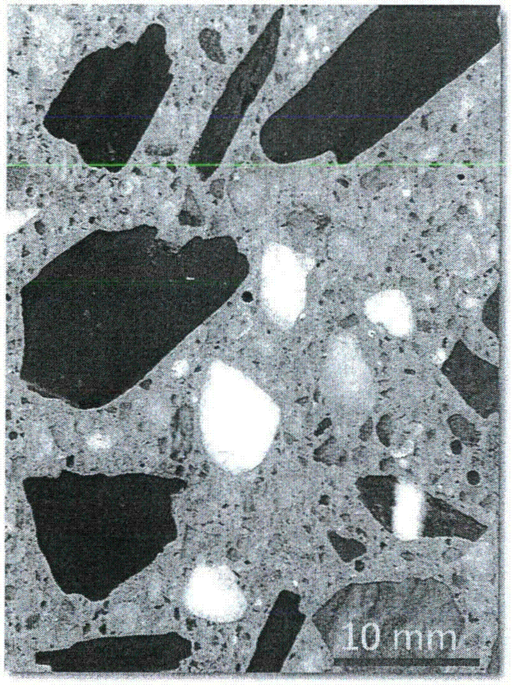
- C-S-H: poorly-crystallized, fibrous, honeycomb, massive equant grains
- CH: well-crystallized, hexagonal plates

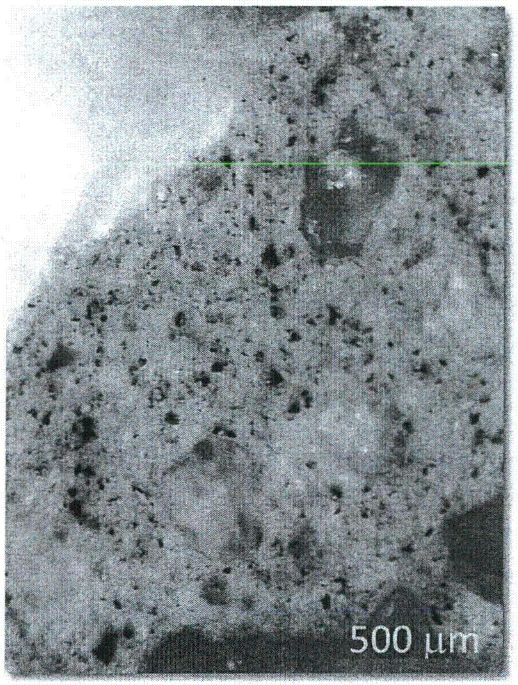


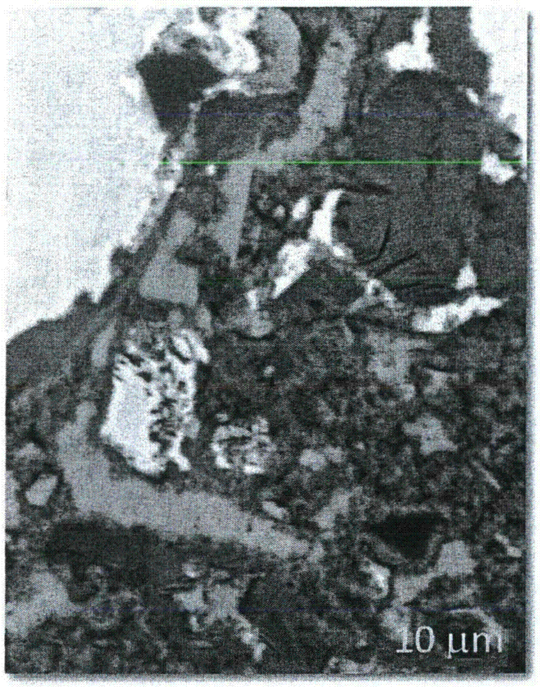
Aluminate, ferrite, and sulfate phases hydrate to produce:

- Afm ($Al_2O_3 - Fe_2O_3$-mono, or monosulfate) and
- Aft (Al_2O_3-Fe_2O_3-tri, or ettringite) phases

- Afm: platy, hexagonal crystals, layer structure
- Aft: hexagonal prismatic or acicular crystals (needles)



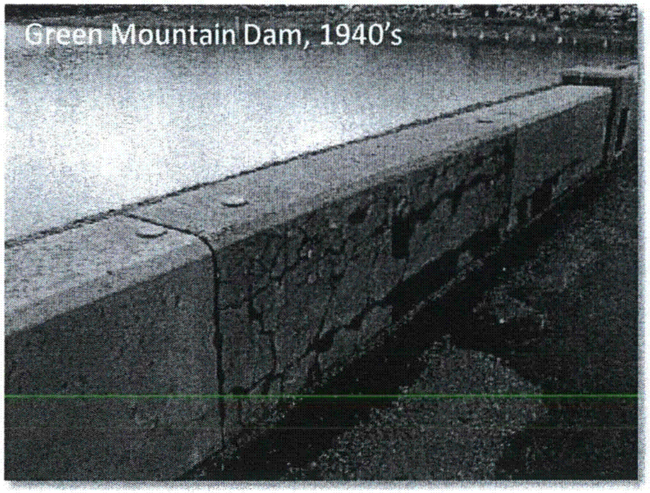


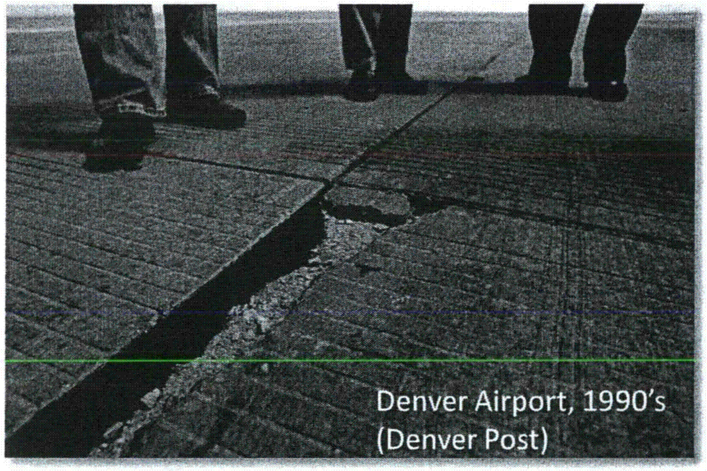


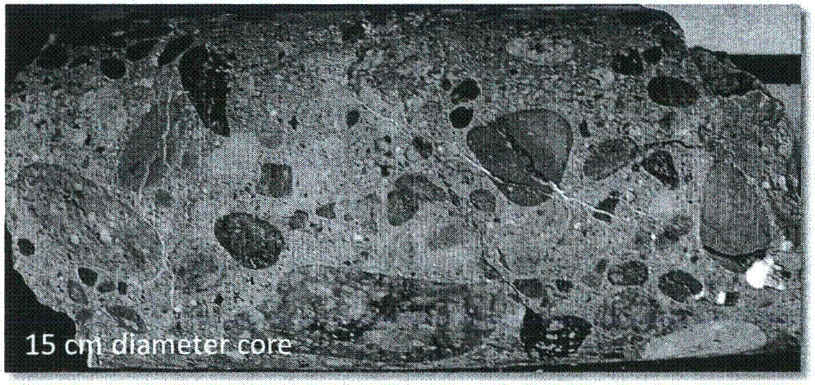
Alkali-Aggregate Reaction

- Identified in the 1940's in North America
  - A chemical reaction between aggregate and the highly alkaline pore solution (pH 12.5) in portland cement concretes
    - Aggregate constituents attacked by OH^-
    - Silanol groups (Si-OH) broken down into SiO^- molecules
    - SiO^- molecules attract alkali cations, forming an alkali-silica gel which takes on water and expands
  - Phenomena occurs in mortar bars with high-alkali cement (> 0.60 Na_2O_e), aggregate, and high RH (80 %)
  - With sufficient water, alkali, and reactive aggregate, a gel will be produced that swells, potentially creating sufficient pressure to crack the concrete
  - Typically a "map cracking" manifestation of the reaction is present (subject to restraint from reinforcement); displacement in concrete experiencing advanced stages of reaction
  - Concrete permeability: alkali concentration, alkali from water reducers or aggregate, alkali leaching, ingress of external alkali (deicing salts)
  - Concentration of the hydroxyl ion (pH) is a major factor, cement factors and alkali per unit volume may be a better measure
    - 3 kg/m^3 maximum from cement, pozzolan, slag (ACI, UK)
    - 3 kg/m^3 maximum from cement alone (CSA)
  - Consideration of the aggregate for potential reactivity
  - Consideration of the service environment: temperature, moisture, F-T

$Na_2O_e = Na_2O + 0.658\ K_2O$; the correction factor for K_2O reflects the relative difference in molecular weight


Green Mountain Dam, 1940's

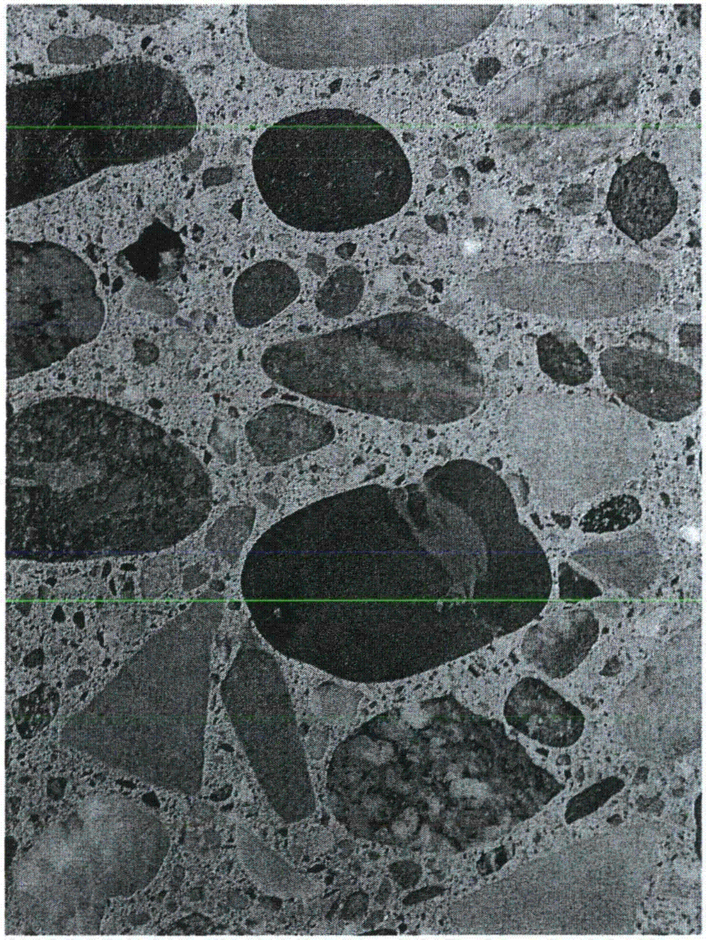

Denver Airport, 1990's (Denver Post)


15 cm diameter core

Petrography

- ASTM C 33 Specification for Concrete Aggregates

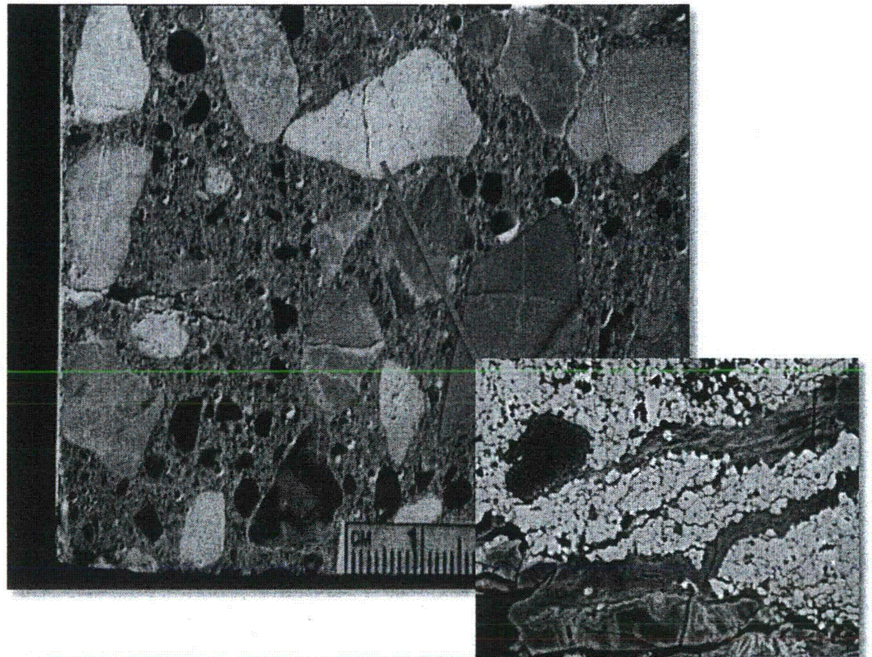
  " .. There is no general agreement on the relation between the results of these tests and the amount of expansion to be expected or tolerated in service. Therefore, evaluation of the suitability of an aggregate should be based upon judgment, interpretation of test data, and results of examinations of concrete structures containing the same aggregates and similar cementitious materials having similar levels of alkalis."

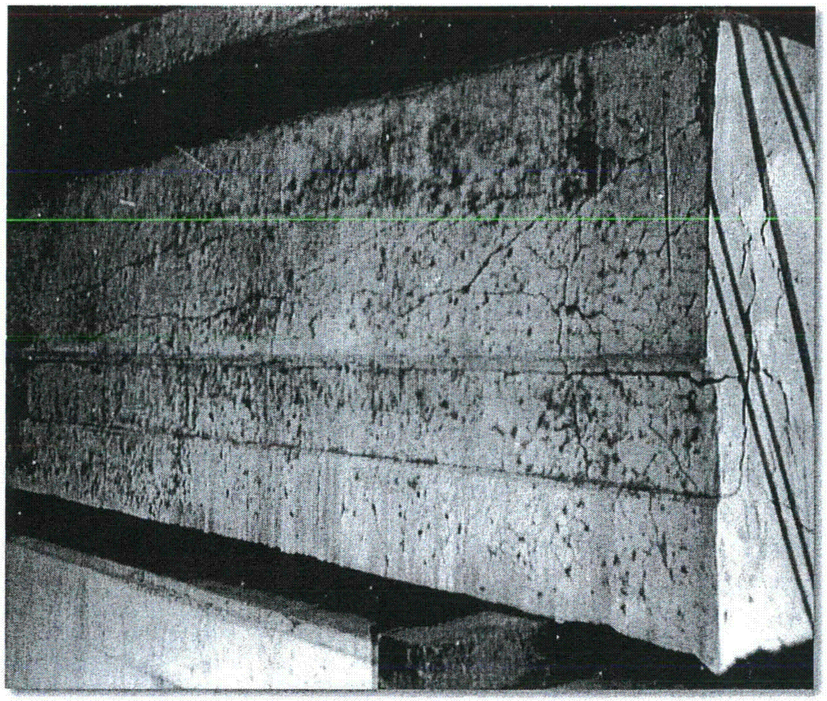


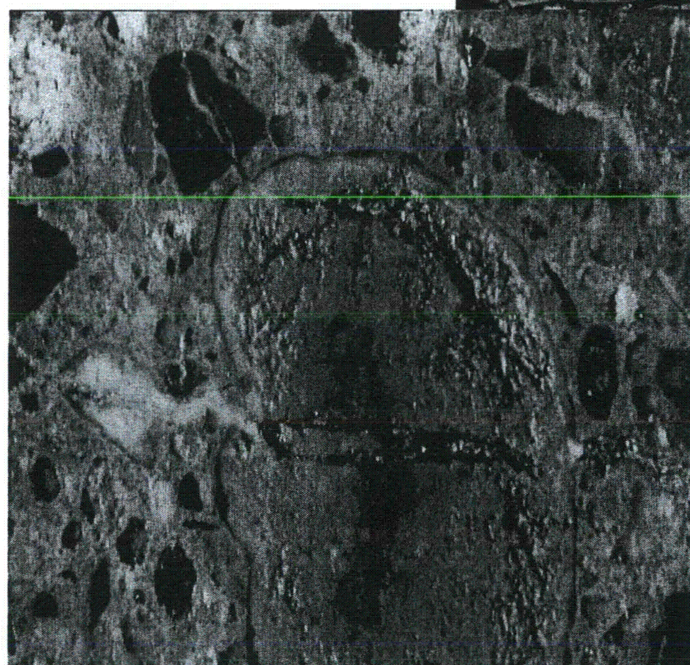
- C295 Standard Guide for Petrographic Examination of Aggregates for Concrete
  - Describe physical and mineralogical characteristics of aggregate through megascopic and microscopic evaluation, representative sampling can be an issue, does not consider specific cement or supplementary cementitious materials (SCMs)
  - Visual examination and description of aggregate (both raw materials and in hardened concrete)
  - Reactive constituents: opal, chalcedony, cristobalite, tridymite, highly strained quartz, microcrystalline quartz, volcanic glass, synthetic silicious glass. Aggregates include glassy to cryptocrystalline intermediate to acidic volcanic rocks, some argillites, phyllites, graywacke, gneiss, schist, gneissic granite, vein quartz, quartzite, sandstone, and chert
  - Reliability depends upon experience and familiarity with regional geology and aggregate use in concrete
  - Despite this, occurrence of ASR happens to this day
    - Incomplete evaluation of aggregate
    - Unanticipated exposure conditions (deicing chemicals, salt)
    - Materials incompatibilities (cement factor, alkali loading)

Texas Box Beams

Precast in SE Texas,
Fairly rapid onset of cracking,
No known history of reactive aggregate,
Limited information on concrete mix design,
Suspected mortar expansion due to cement





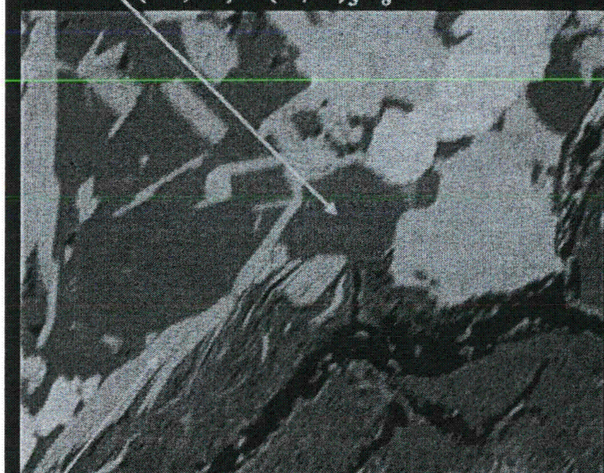


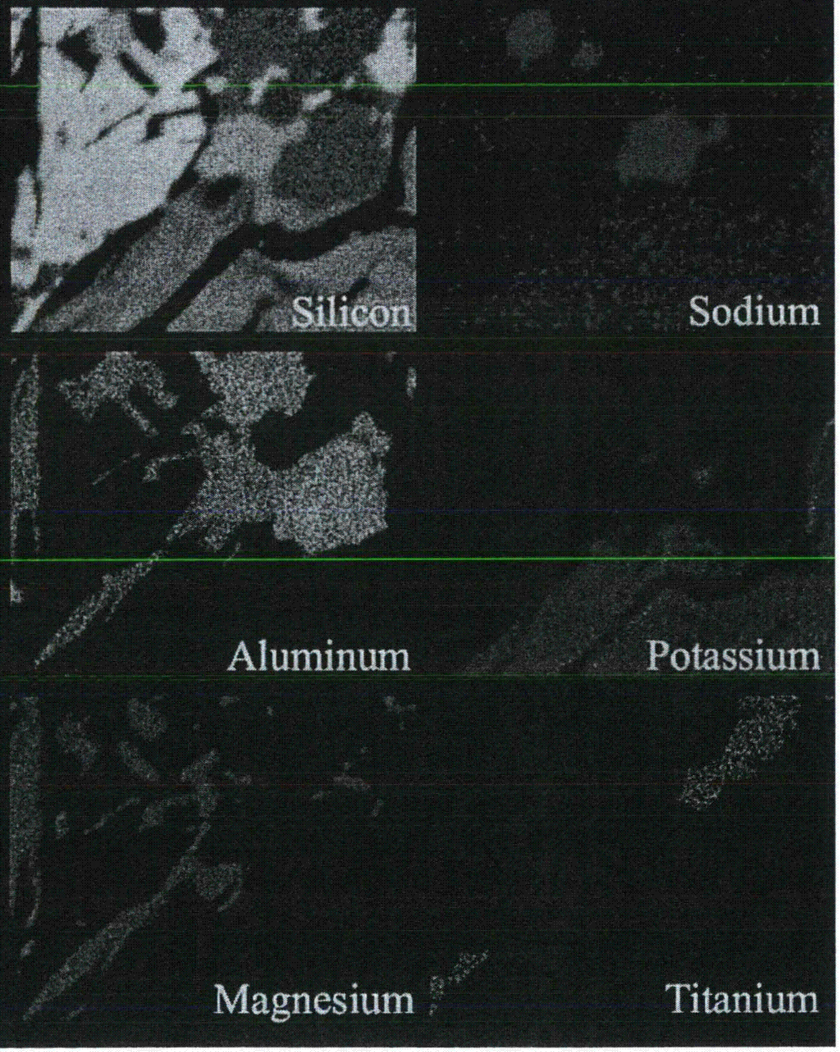
10 mm field width

Controlling Potential for ASR:

Improved Aggregate Characterization

- Identify reactive constituents
- Devise classification scheme
- Improved understanding of the potential for reactivity and pore solution / mineral interactions

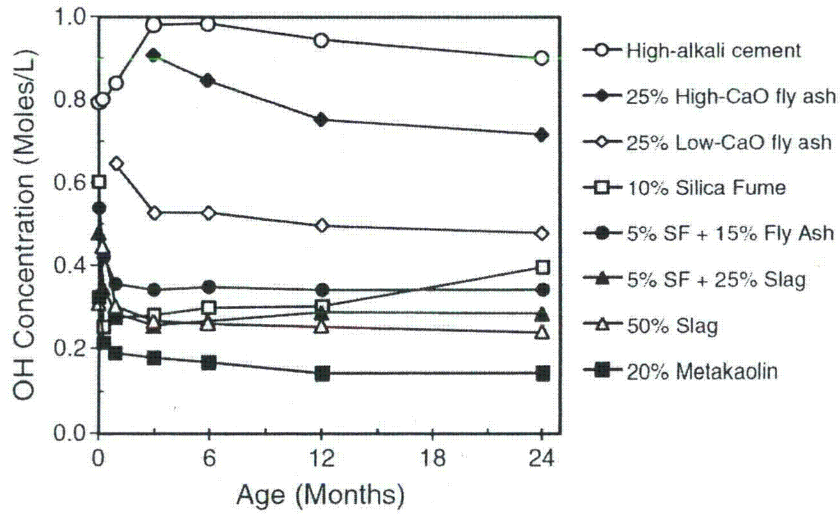




Controlling Potential for ASR

- Historical performance records are still the best predictors of future aggregate performance
- Dilution with non-reactive aggregate
- Selective quarrying
- Beneficiation –
    - washing, separation, chemical treatment

- Use of pozzolans
    – Fly ash,
    – ground blast furnace slag,
    – silica fume,
    – rice husk ash,
    – metakaolin



MDA Thomas, The effect of supplementary cementing materials on alkali-silica reaction: A review Cement and Concrete Research 41 (2011) 1224-31

- Studies on older structures (25 yrs +) indicate that a 20 % to 30 % replacement of cement by fly ash can control potentially expansive reactions

- The reaction products have a lower CaO:SiO_2 ratio, producing a C-S-H gel that more effectively incorporates alkalis and reduces pH

- Pozzolanic reaction produces a denser paste microstructure (lower permeability), consumes CH (lowering pH) and a lower calcium environment which may have reduced swelling potential

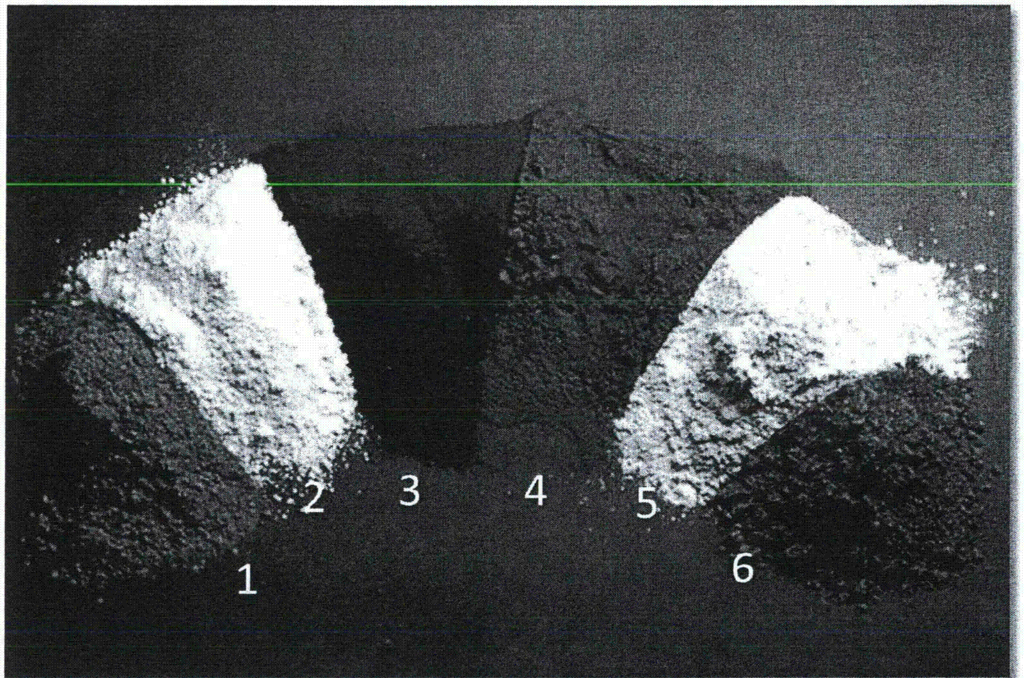
- Replacing cement can reduce total alkali of the cementitious system (portland + SCM)

Supplementary Cementing Materials, Mineral Admixtures

- ASTM C 618, Standard Specification for Coal Fly Ash or Calcined Natural Pozzolan for Use in Concrete
  - Class C and Class F fly ash
  - Class N natural pozzolans: calcined clays (metakaolin), volcanic ash, calcined shale, rice husk ash

- ASTM C 989, Standard Specification for Slag Cement for Use in Concrete and Mortars
  - Grade 80 low activity index
  - *Grade 100 moderate activity index*
  - *Grade 120 high activity index*
  - 2.5 % sulfide sulfur, 4.0 % SO_3

- ASTM C 1240, Standard Specification for Silica Fume Used in Cementitious Mixtures

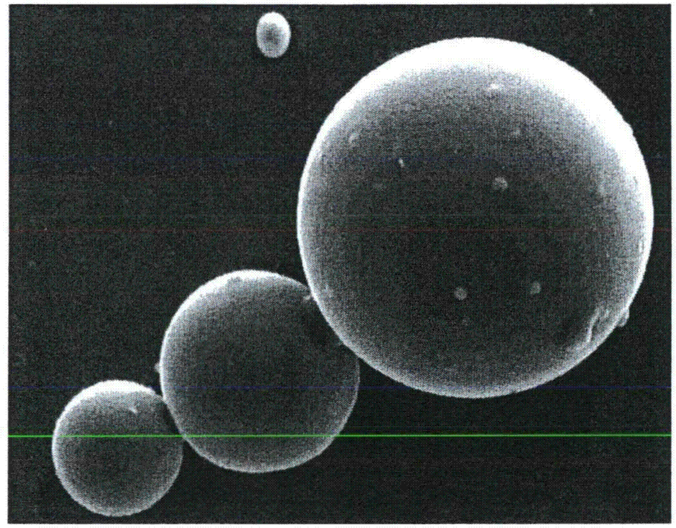


1) Class C FA 2) metakaolin 3) silica fume
4) Class F FA 5) slag 6) calcined shale

Portland Cement Association

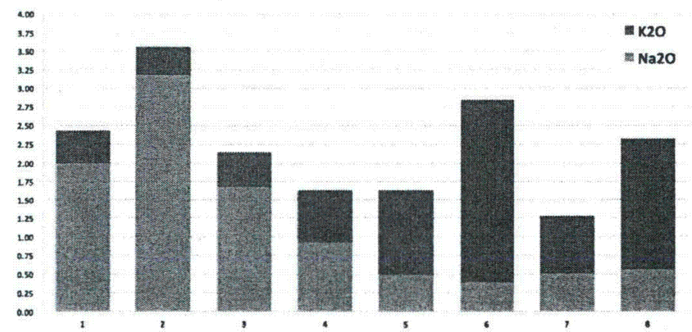
Fly Ash and Natural Pozzolans

- Fly Ash, Natural Pozzolans: ASTM C 618
  - Class C, F fly ash, Class N (calcined clays, volcanic ash)
    - Class F – pozzolanic
    - Class C – pozzolanic and cementitious (generally less efficient in controlling ASR)
      - Reduce concrete permeability
      - Mitigation of sulfate, ASR, corrosion degradation
      - CSA recommends a total alkali <4.5 % Na_2O_e, and water-soluble alkali < 0.5 % Na_2O_e



	Class		
	N	F	C
$SiO_2 + Al_2O_3 + Fe_2O_3$, min. %	70.0	70.0	50.0
SO_3 (maximum), %	4.0	5.0	5.0
Moisture Content, max. %	3.0	3.0	3.0
Loss on ignition, max. %	10.0	6.0	6.0
Fineness, max %, 325 mesh sieve	34	34	34
Strength activity index (7d, min.)	75	75	75
Strength activity index (28d, min.)	75	75	75
Water requirement (max.)	115	115	115
Soundness (autoclave, max. +-)	0.8	0.8	0.8
Density, max. variation from avg.	5	5	5
Percent retained, 325 mesh sieve	5	5	5
Optional Requirements			
Drying shrinkage (max. %)	0.03	0.03	0.03
Uniformity (air entrainment)	20	20	20
ASR, 14 d max %, low alkali cement control	100	100	100
Sulfate Resistance: Moderate sulfate, max. %	0.10	0.10	0.10
(6 month tests) High sulfate, max. %	0.05	0.05	0.05
Expansion compared to test mixture	100	100	100

Set of Class C (3) and F fly ashes



Silica Fume

- ASTM C 1240, Standard Specification for Silica Fume Used in Cementitious Mixtures

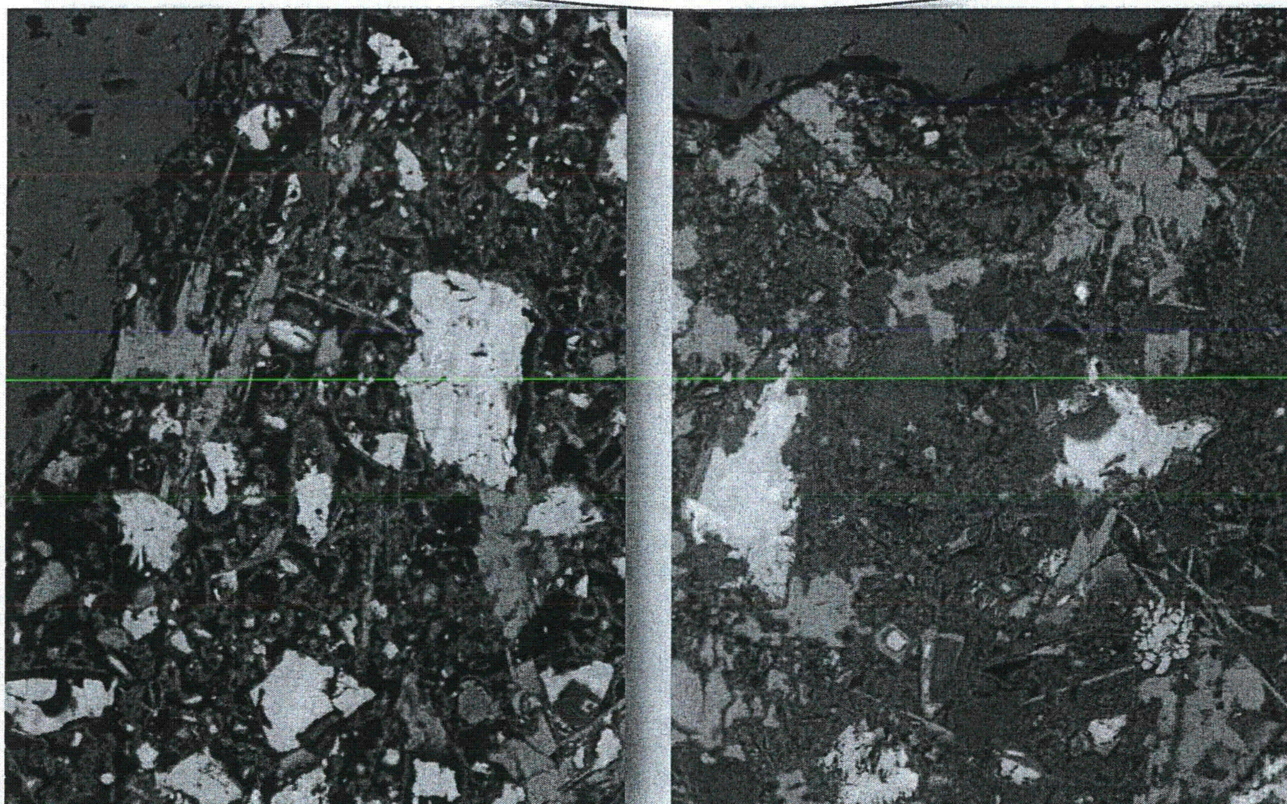
SiO_2, min. %	85.0
Moisture content max. %	3.0
Loss on ignition, max. %	6.0
Percent retained 45 μm sieve max., %	10
Accelerated pozzolanic strength activity index	105
Specific surface M^2/g	15
Optional Requirements	
Uniformity: AEA requirement variability, %	20
Cement alkali 14 d mortar expansion, min %	80
Sulfate resistance expansion, % maximum	
Moderate (6 mo.), High (6 mo.), V. High (1 yr)	0.10, 0.05, 0.05

Microstructure Effects Of silica fume:

24 h 0.45 w/s, OPC (left), 10 % silica fume (right)

Pozzolanic reaction incorporates alkali metals into the hydration products

Permeability decreased



Screening Tests

Most screening tests use either elevated alkali hydroxide levels, increased temperature or both to accelerate testing period

- C227 Standard Test Method for Potential Alkali Reactivity of Cement Aggregate Combinations (Mortar bar method)
  - Testing cement-aggregate combinations; optional use of a reference cement, 38 C temperature, high RH, measure at 14 d, 3, 6 and 12 months
  - leaching of alkali, increased surface area of aggregate; inconsistent cement alkali and addition of NaOH to mix water to 1.25 Na_2Oeq, water/cement proportions are not consistent (flow),

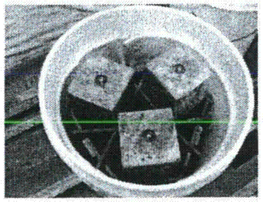
- C289 Standard Test Method for Potential Alkali-Silica Reactivity of Aggregates (chemical method)
  - 1N NaOH solution at 80 C for 24h; good for highly-reactive aggregate, slowly-reactive aggregate ranking is a problem. Some aggregate have high silica solubility, but acceptable field performance, numerous interferences and inadequate classifications, not used for carbonates

- C1105 Standard Test Method for Length Change of Concrete Due to Alkali-Carbonate Rock Reaction
  - Limestone and dolomitic limestone and job or reference cement (to evaluate aggregate); up to 1 year testing in moist storage

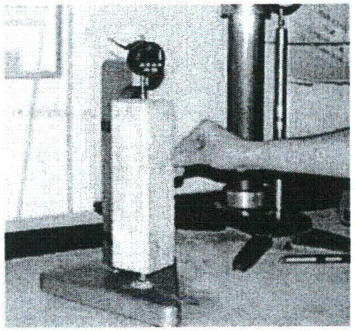
- C441 Standard Test method for Effectiveness of Mineral Admixtures or Ground Blast Furnace Slag in Preventing Excessive Expansion of Concrete Due to Alkali-Silica Reaction
  - Similar to C227 but uses Pyrex glass as a reactive aggregate. Problems include use of constant flow rather than fixed W/C, variability in Pyrex shipments, changes in aggregate shape resulting in differences in water demand, alkali content of Pyrex, reaction of Pyrex may precede that of the pozzolan, the Pyrex not being representative of the job aggregate, and conservative performance limits

- C1260 Standard Test method for Potential Alkali Reactivity of Aggregates (Mortar bar method)
  - aggregate-only screening test, partly due to severe conditions, considered inconsistent for both innocuous and slowly-reacting aggregate. 1N NaOH solution at 80 C; expansions measured at 4d, 7d, 11d, and 14d
  - At 14d <0.10% innocuous; >0.20% reactive; 0.10% - 0.20% inconclusive
  - the severity make it useful in identification of slowly-reactive aggregate not identified in C227
    - Recommendations to modify alkali concentration of the solution to match that of anticipated mix design, and to use in evaluation of mineral admixtures.
    - Suggestion that this test procedure could be modified to determine the threshold level of cement alkali required to initiate reaction and expansion
    - Adjusting soak solution alkali concentration to their best estimate of the pore solution, based upon cement equivalent alkali and water/cement ratio

- C1567 Standard Test Method for Determining the Potential Alkali-Silica Reactivity of Combinations of Cementitious Materials and Aggregate (Accelerated Mortar bar Method)
  - Following C1260 but to evaluate pozzolan effectiveness. 16 day test. Pozzolans function by lowering the alkali hydroxide concentrations so an abundance of alkali in the testing conditions would seem to make this questionable. Differences are seen so the test is used. Some attempts to use the test to assess the level of SCM necessary to change the mix susceptibility



- C1293 Standard Test Method for Concrete Aggregates by Determination of Length Change of Concrete Due to Alkali Silica Reaction
  - Cement / aggregate combinations, 1.25 % Na_2O (5.25 kg/m^3) (cement 0.90 % +- 0.1 % Na_2O plus added alkali) for aggregate or combination of aggregate/pozzolan/slag, range of W/C allowed
  - Concrete prisms are stored over water at high RH at 38 °C.
    - Expansions measured 7d, 28 d, 56 d, and 3, 6, 9, and 12 months
  - Failure criteria 0.04 % expansion
  - Considered more realistic, though is slow and susceptible to storage conditions

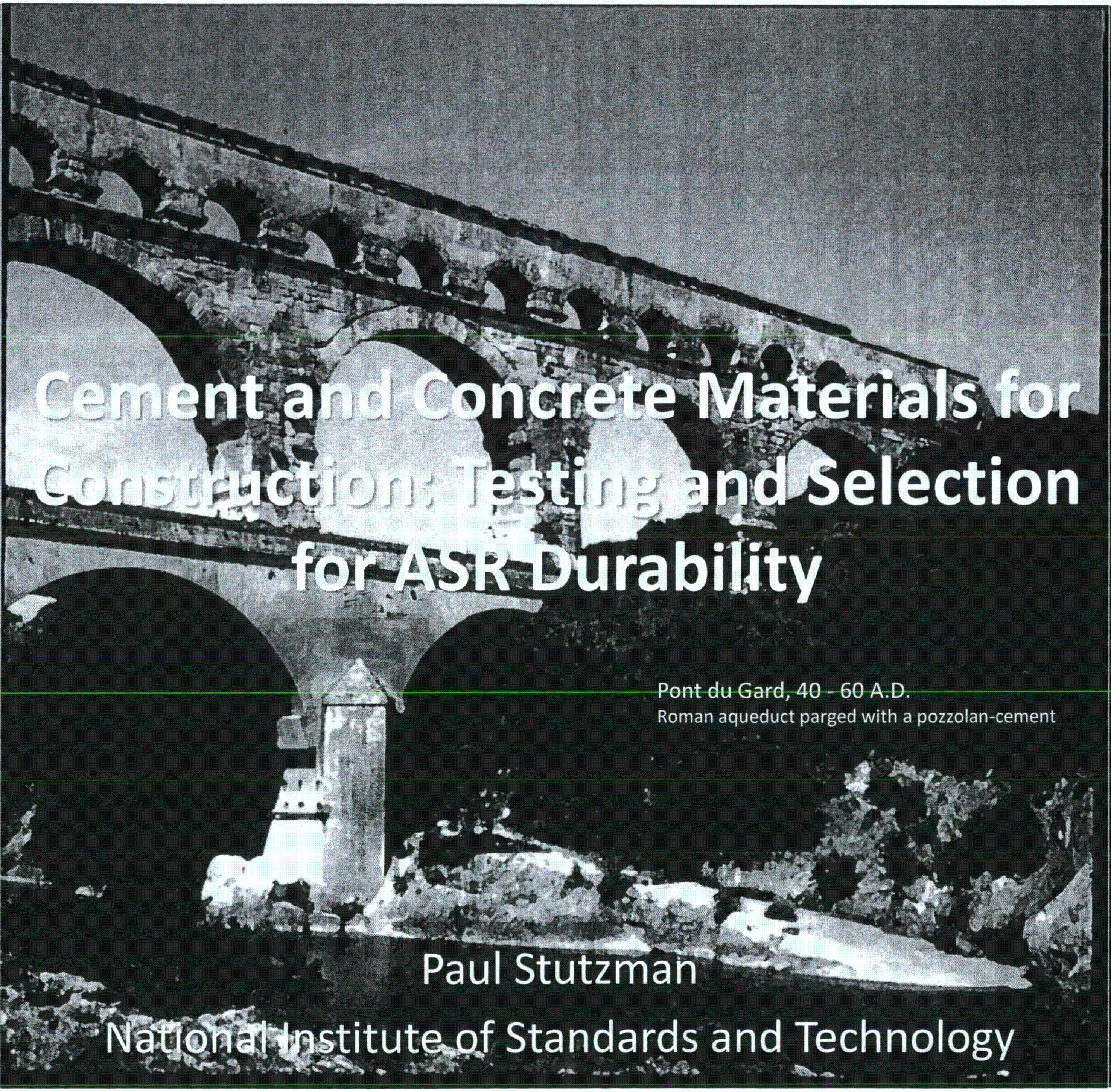


Images: FHWA

Research Needs

Develop an understanding of the processes behind alkali-aggregate reactivity and how pozzolanic and cementitious materials such as fly ash, slag, silica fume, calcined clays, and natural pozzolans affect the developing microstructure and provide improved durability for concretes. Building upon that understanding, develop practical simulation models that incorporate this knowledge into a useful predictive tool for new concrete mixtures

- Catalog mineral types and textures associated with alkali-aggregate reactivity – silicious and carbonate
- Define threshold levels of alkali hydroxides required to promote mineral reactivity – do Na^+ and K^+ differ?
- Develop a better understanding of reaction products, swelling, migration, rate of development of expansive pressures, and how these mechanisms combine to generate cracks in aggregate and concrete
- Quantitative characterization of pore solution chemistry and changes due to incorporation of mineral admixtures
- More complete characterization of fly ash for bulk chemistry, mineral and glassy constituents
- Characterization of the impact fly ash (both Class C and F) has on the development of concrete microstructure and how that microstructure impacts chemical and physical degradation processes
- Anticipate potential durability issues posed by changes to hydraulic cement systems
- Robust accelerated test methods for combinations of materials using job cement and aggregate
- Robust accelerated tests with multiple modes of chemical and physical attack, for example, freeze-thaw combined with chemical deicers
- Improved performance tests for performance-based cement specifications (C 1157, hydraulic cements)



Cement and Concrete Materials for Construction: Testing and Selection for ASR Durability

Pont du Gard, 40 - 60 A.D.
Roman aqueduct parged with a pozzolan-cement

Paul Stutzman
National Institute of Standards and Technology