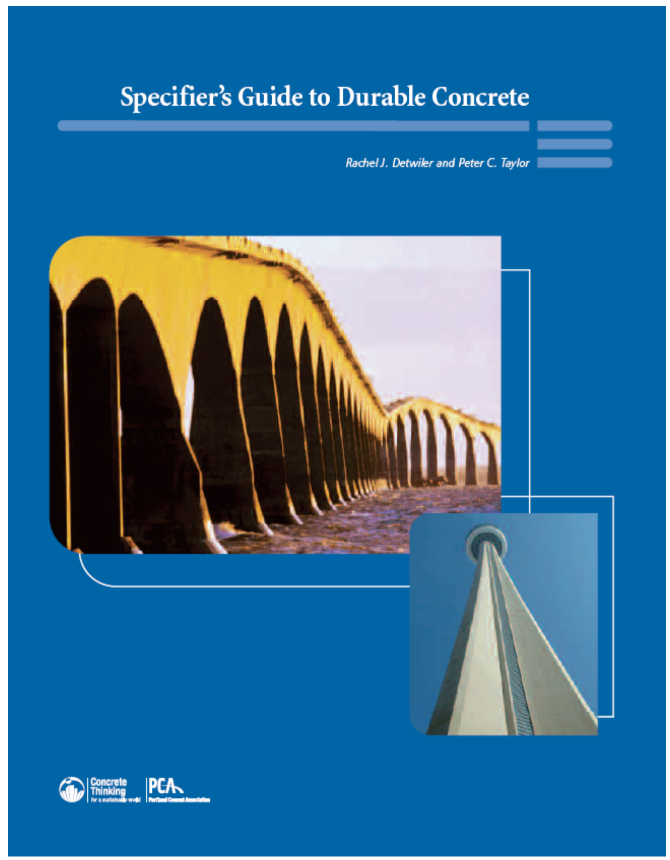
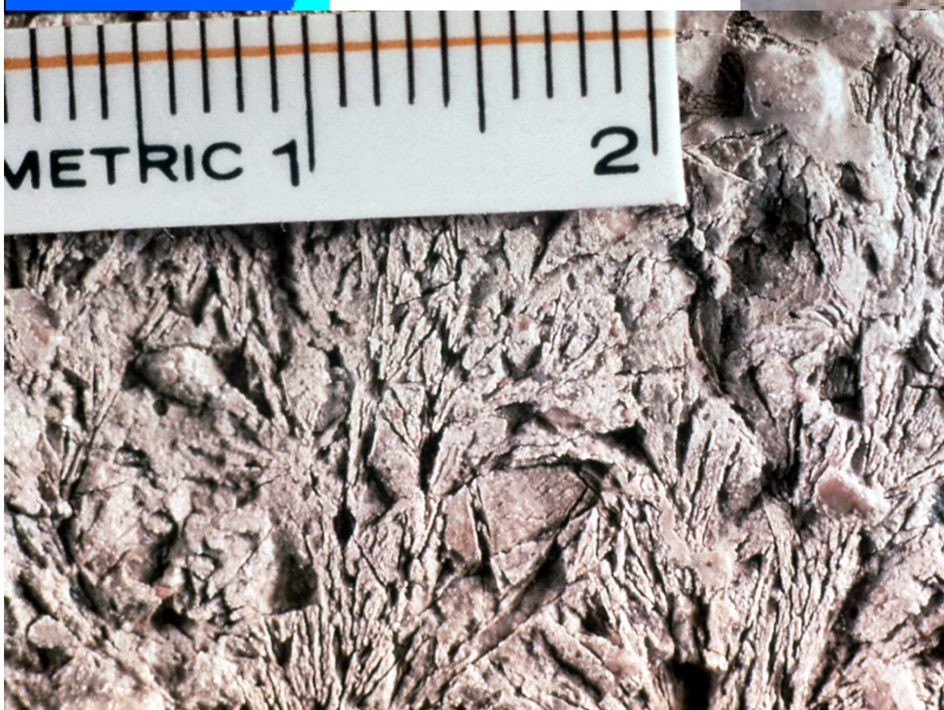
PCA

Concrete Technology and Codes

Considerations for Concrete Durability

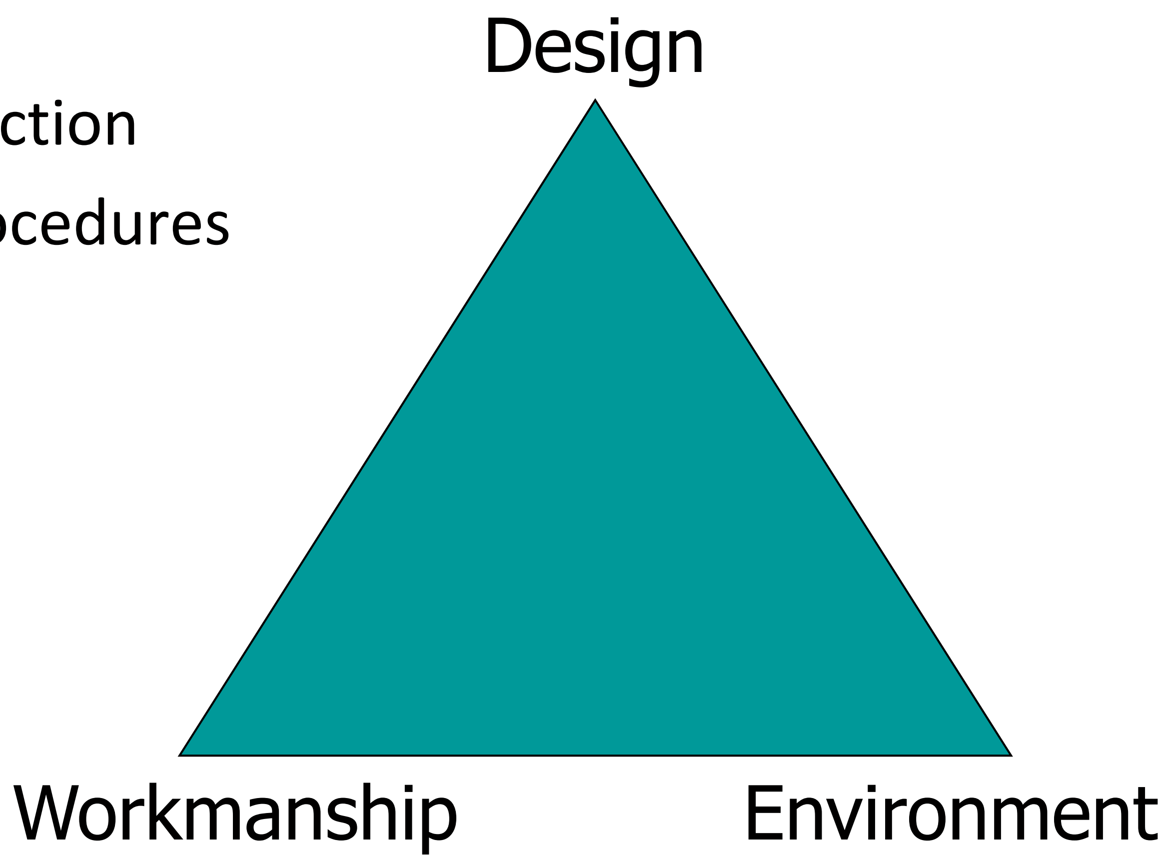


Why do concrete problems occur?



Avoiding Problems

- Design- Constructability
- Mix Design
- Materials Selection
- Placement Procedures
- Environment



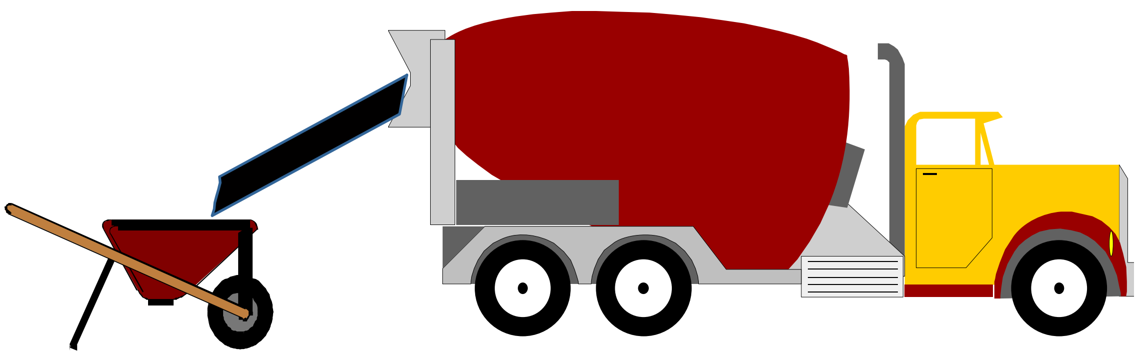
Discussion:

- Desired Durability
- Concrete Specifications
  - Mix Design Requirements
  - ACI 318-08 Updates- CH 4
- Evaluating Concrete Performance

Designing Concrete Mixtures

Objective:

To determine the most economical and practical combination of readily available materials to produce a concrete that will satisfy the performance requirements under particular conditions of use.



Concrete Durability

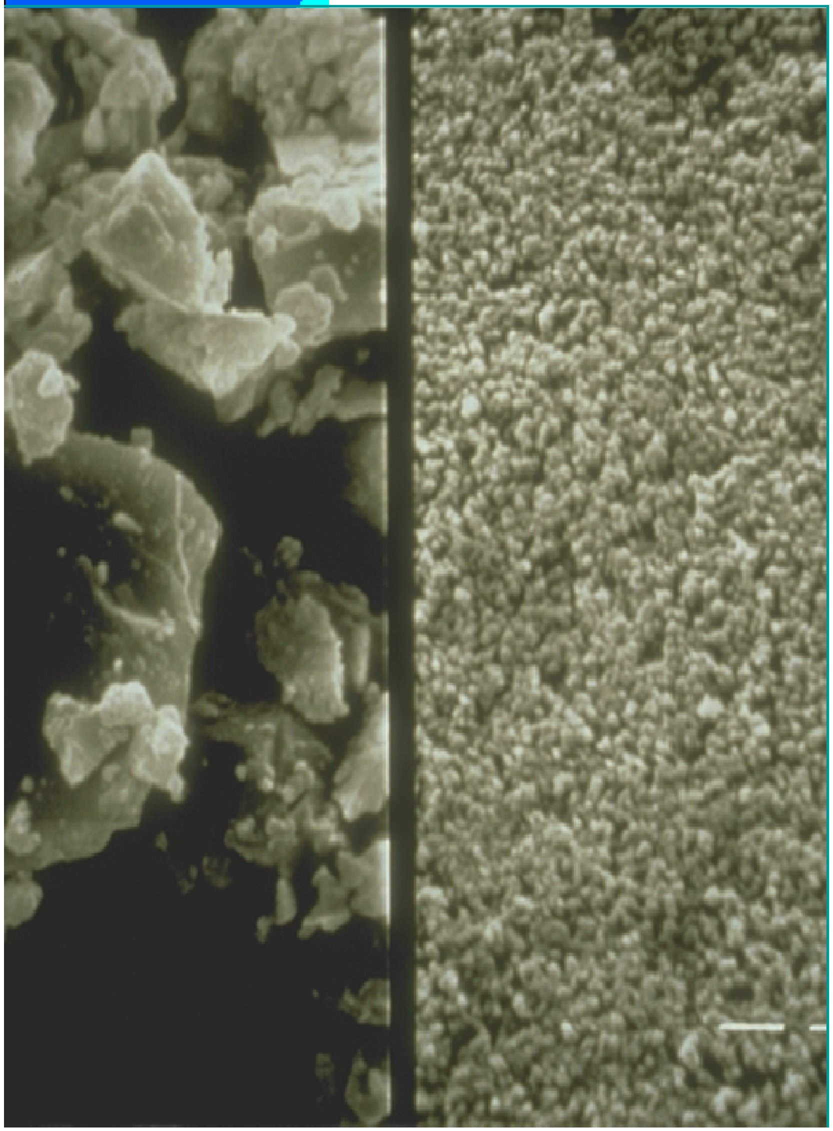
M-21 / Plaster Creek

- Ability of Concrete to Resist Weathering Action, Chemical Attack, and Abrasion While Maintaining its Desired Engineering Properties.

Durability Considerations

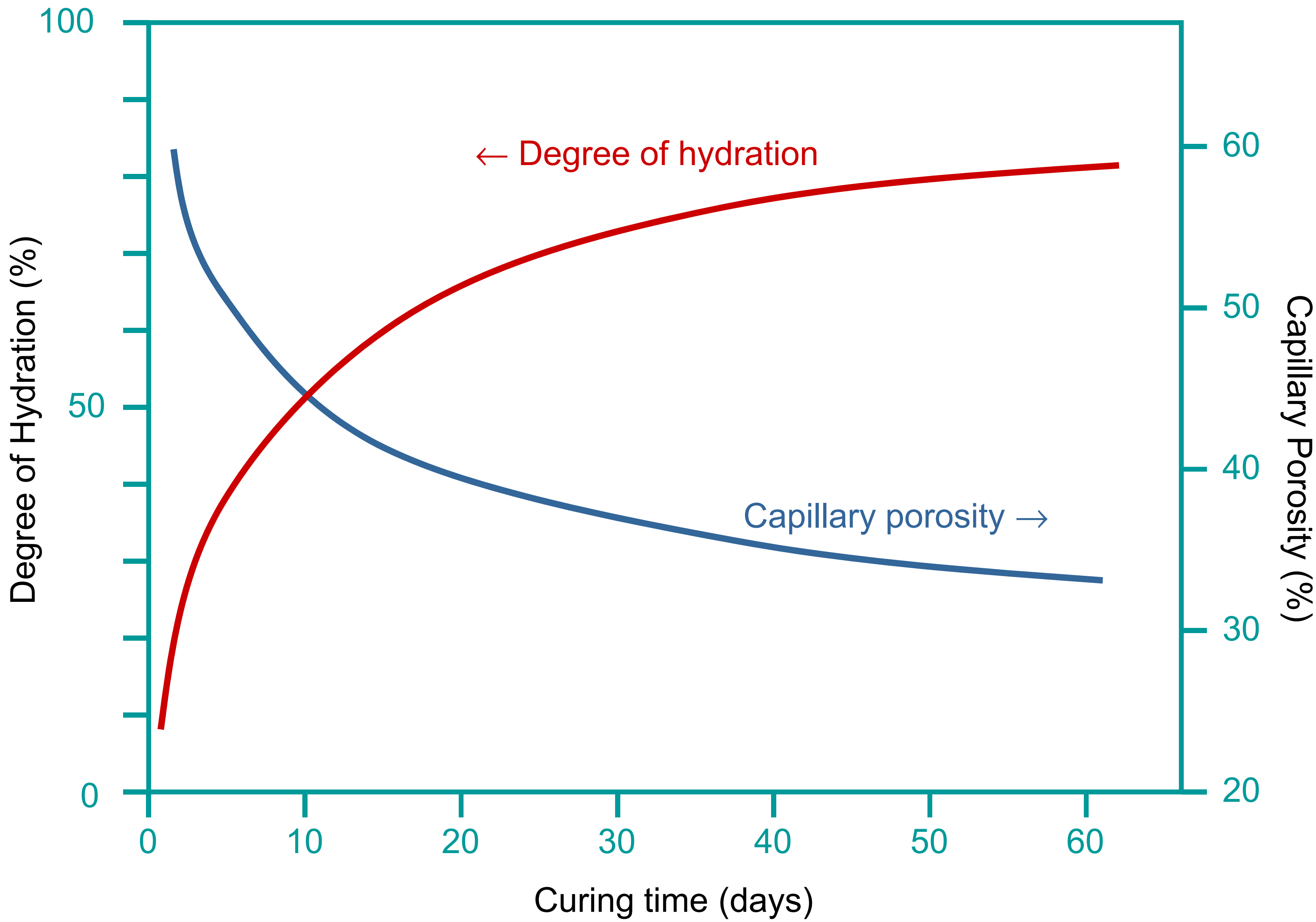
- Abrasion
- Freeze-Thaw, Scaling
- Carbonation
- Corrosion
- Reactive Aggregate
  - ASR
- Chemical Attack
  - DEF
  - Sulfate Attack

Factors Impacting Permeability



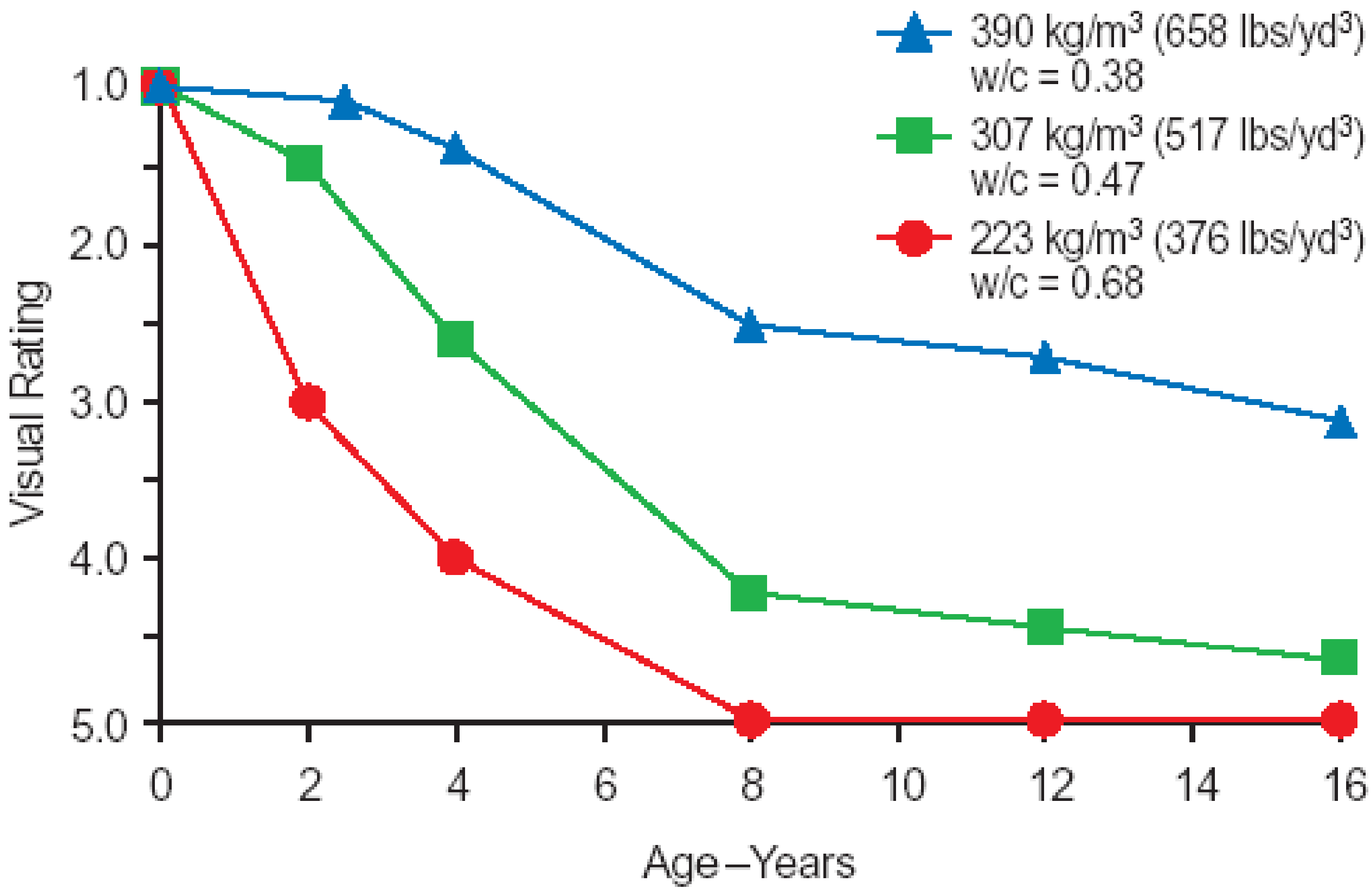
- Water:cement ratio
- Curing
- Material fineness
  - Aggregate Gradation
- Paste/aggregate ratio
  - Cement content
- Aggregate-paste bond
- Barriers

Porosity



Young et al. 1998

Cement Content



PCA RD129

Exposure Conditions- 318-08

TABLE 4.2.1 — EXPOSURE CATEGORIES AND CLASSES

Category	Severity	Class	Condition	
F Freezing and thawing	Not applicable	F0	Concrete not exposed to freezing-and-thawing cycles	
	Moderate	F1	Concrete exposed to freezing-and-thawing cycles and occasional exposure to moisture	
	Severe	F2	Concrete exposed to freezing-and-thawing cycles and in continuous contact with moisture	
	Very severe	F3	Concrete exposed to freezing-and-thawing and in continuous contact with moisture and exposed to deicing chemicals	
S Sulfate			**Water-soluble sulfate (SO_4) in soil, percent by weight**	**Dissolved sulfate (SO_4) in water, ppm**
	Not applicable	S0	$SO_4 < 0.10$	$SO_4 < 150$
	Moderate	S1	$0.10 \leq SO_4 < 0.20$	$150 \leq SO_4 < 1500$ Seawater
	Severe	S2	$0.20 \leq SO_4 \leq 2.00$	$1500 \leq SO_4 \leq 10{,}000$
	Very severe	S3	$SO_4 > 2.00$	$SO_4 > 10{,}000$
P Requiring low permeability	Not applicable	P0	In contact with water where low permeability is not required	
	Required	P1	In contact with water where low permeability is required.	
C Corrosion protection of reinforce-ment	Not applicable	C0	Concrete dry or protected from moisture	
	Moderate	C1	Concrete exposed to moisture but not to external sources of chlorides	
	Severe	C2	Concrete exposed to moisture and an external source of chlorides from deicing chemicals, salt, brackish water, seawater, or spray from these sources	

Sulfate attack

Materials and Methods to Inhibit Sulfate Attack

- Low Permeability Concrete
- Sulfate Resistant Cements
  - Type II, V, MS, HS
  - SCM's-
    - Class F-ash, Silica Fume
- Surface Treatments

Requirement for Sulfate Exposure 318-08

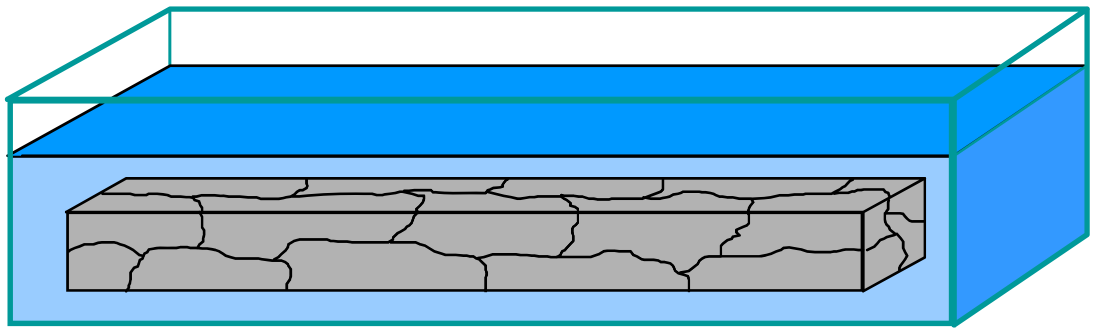
TABLE 4.3.1 — REQUIREMENTS FOR CONCRETE BY EXPOSURE CLASS

Exposure Class	Max. *w/cm*	Min. f'_c, psi	Additional minimum requirements			
			Cementitious materials*—types			Calcium chloride admixture
			ASTM C150	ASTM C595	ASTM C1157	
S0	N/A	2500	No Type restriction	No Type restriction	No Type restriction	No restriction
S1	0.50	4000	II†‡	IP(MS), IS (<70) (MS)	MS	No restriction
S2	0.45	4500	V‡	IP (HS) IS (<70) (HS)	HS	Not permitted
S3	0.45	4500	V + pozzolan or slag§	IP (HS) + pozzolan or slag§ or IS (<70) (HS) + pozzolan or slag§	HS + pozzolan or slag§	Not permitted

Note- PCA Requirements include a w/cm $\leq$ 0.40, and a minimum compressive strength of 35Mpa (5000psi) for Very Severe (S3) Sulfate Exposure.

Resistance to Sulfates

Expansion Test-



- *ASTM C1012*

Moderate- Class- S1

< 0.10% at 6 months

Severe- Class- S2

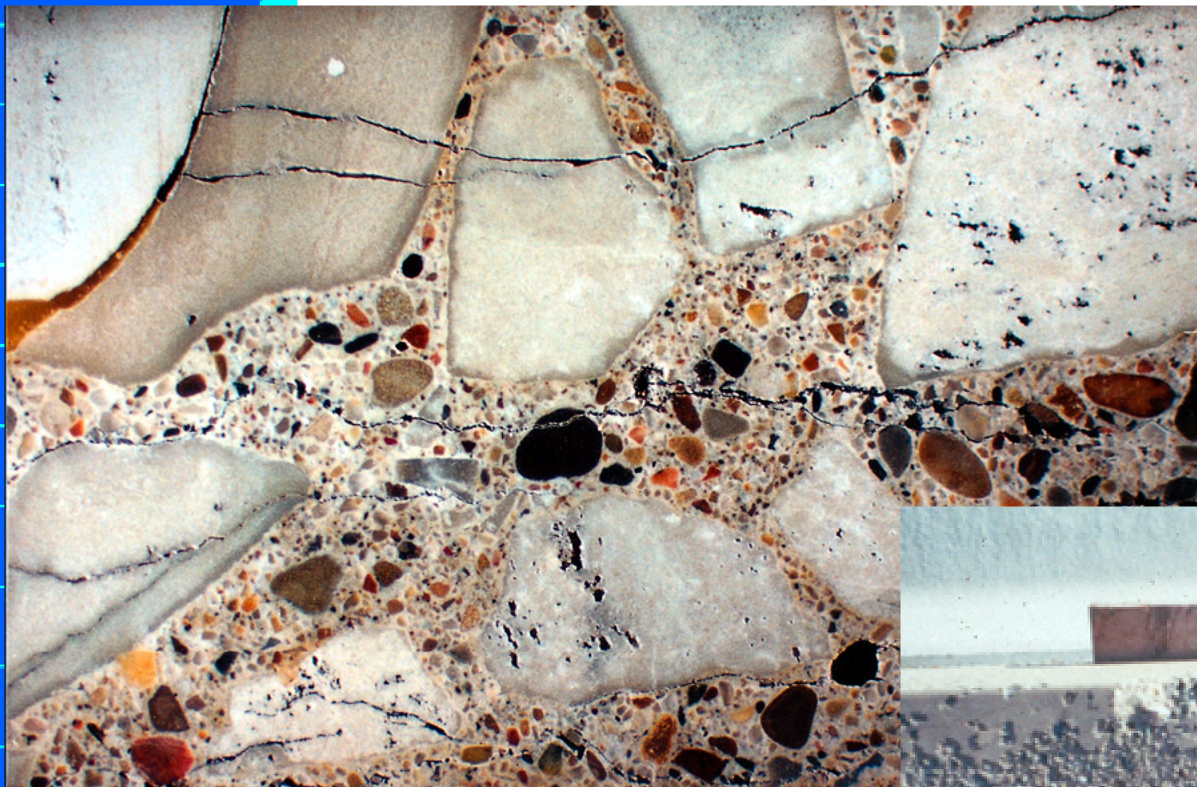
< 0.05% at 6 months

< 0.10% at 12 months*

Very Severe- Class- S3

< 0.10% at 18 months

Freeze-Thaw Exposure



Resistance to Freeze-Thaw

Criteria :

- The aggregate is frost-resistant
- Sufficient strength is attained prior to first freezing (> 3.5 MPa or 500 psi)
- Sufficient strength is attained prior to cyclic freezing & thawing (> 28 MPa or 4000 psi) 318- min. 4500 psi.
- Adequate Air Void System

Strength & w/cm Requirements

Exposure Conditions- F0, F1, F2, F3

ACI 318-08

TABLE 4.3.1 — REQUIREMENTS FOR CONCRETE BY EXPOSURE CLASS

Exposure Class	Max. *w/cm*	Min. f'_c, psi	Additional minimum requirements	
			Air content	Limits on cementitious materials
F0	N/A	2500	N/A	N/A
F1	0.45	4500	Table 4.4.1	N/A
F2	0.45	4500	Table 4.4.1	N/A
F3	0.45	4500	Table 4.4.1	Table 4.4.2

Limits on SCMs
ACI 318-08

TABLE 4.4.2 — REQUIREMENTS FOR CONCRETE SUBJECT TO EXPOSURE CLASS F3

Cementitious materials	Maximum percent of total cementitious materials by weight*
Fly ash or other pozzolans conforming to ASTM C618	25
Slag conforming to ASTM C989	50
Silica fume conforming to ASTM C1240	10
Total of fly ash or other pozzolans, slag, and silica fume	50†
Total of fly ash or other pozzolans and silica fume	35†

*The total cementitious material also includes ASTM C150, C595, C845, and C1157 cement.
The maximum percentages above shall include:
(a) Fly ash or other pozzolans in Type IP, blended cement, ASTM C595, or ASTM C1157;
(b) Slag used in the manufacture of an IS blended cement, ASTM C595, or ASTM C1157;
(c) Silica fume, ASTM C1240, present in a blended cement.
†Fly ash or other pozzolans and silica fume shall constitute no more than 25 and 10 percent, respectively, of the total weight of the cementitious materials.

Total Air Content
ACI 318-08

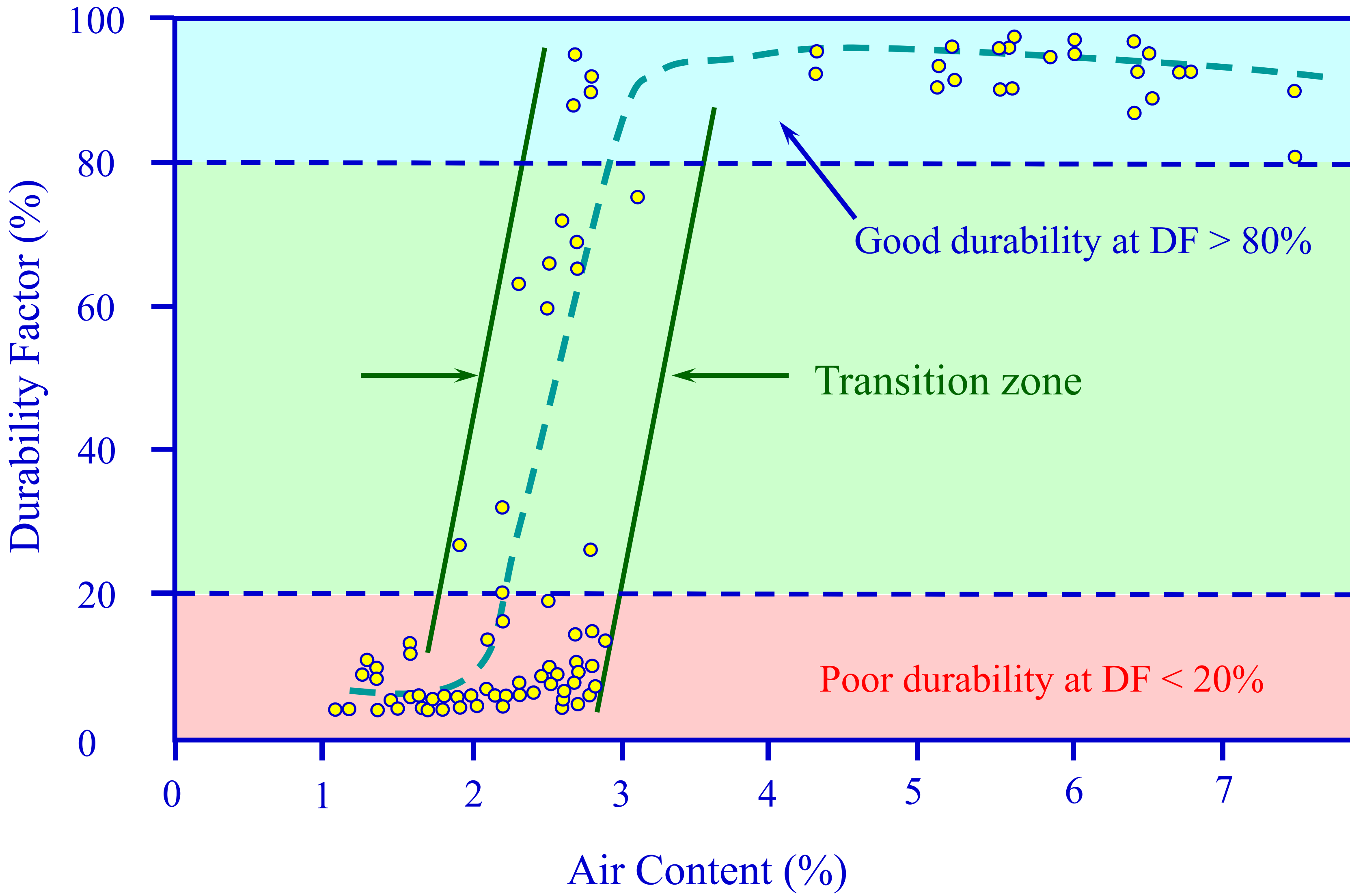
TABLE 4.4.1 — TOTAL AIR CONTENT FOR CONCRETE EXPOSED TO CYCLES OF FREEZING AND THAWING

Nominal maximum aggregate size, in.*	Air content, percent	
	Exposure Class F1	Exposure Classes F2 and F3
3/8	6	7.5
1/2	5.5	7
3/4	5	6
1	4.5	6
1-1/2	4.5	5.5
2†	4	5
3†	3.5	4.5

*See ASTM C33 for tolerance on oversize for various nominal maximum size designations.

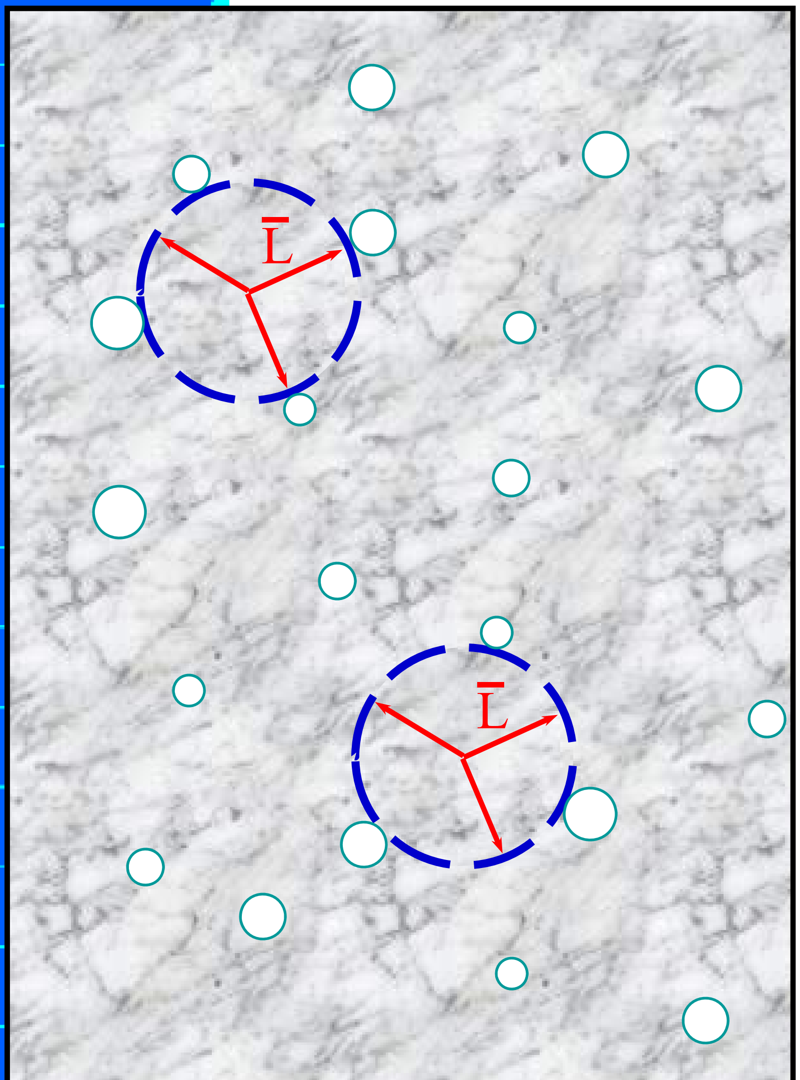
†Air contents apply to total mixture. When testing concretes, however, aggregate particles larger than 1-1/2 in. are removed by sieving and air content is measured on the sieved fraction (tolerance on air content as delivered applies to this value). Air content of total mixture is computed from value measured on the sieved fraction passing the 1-1/2 in. sieve in accordance with ASTM C231.

Effect of Air Content



From Newlon & Mitchell, 1994

Air Void Spacing & Volume

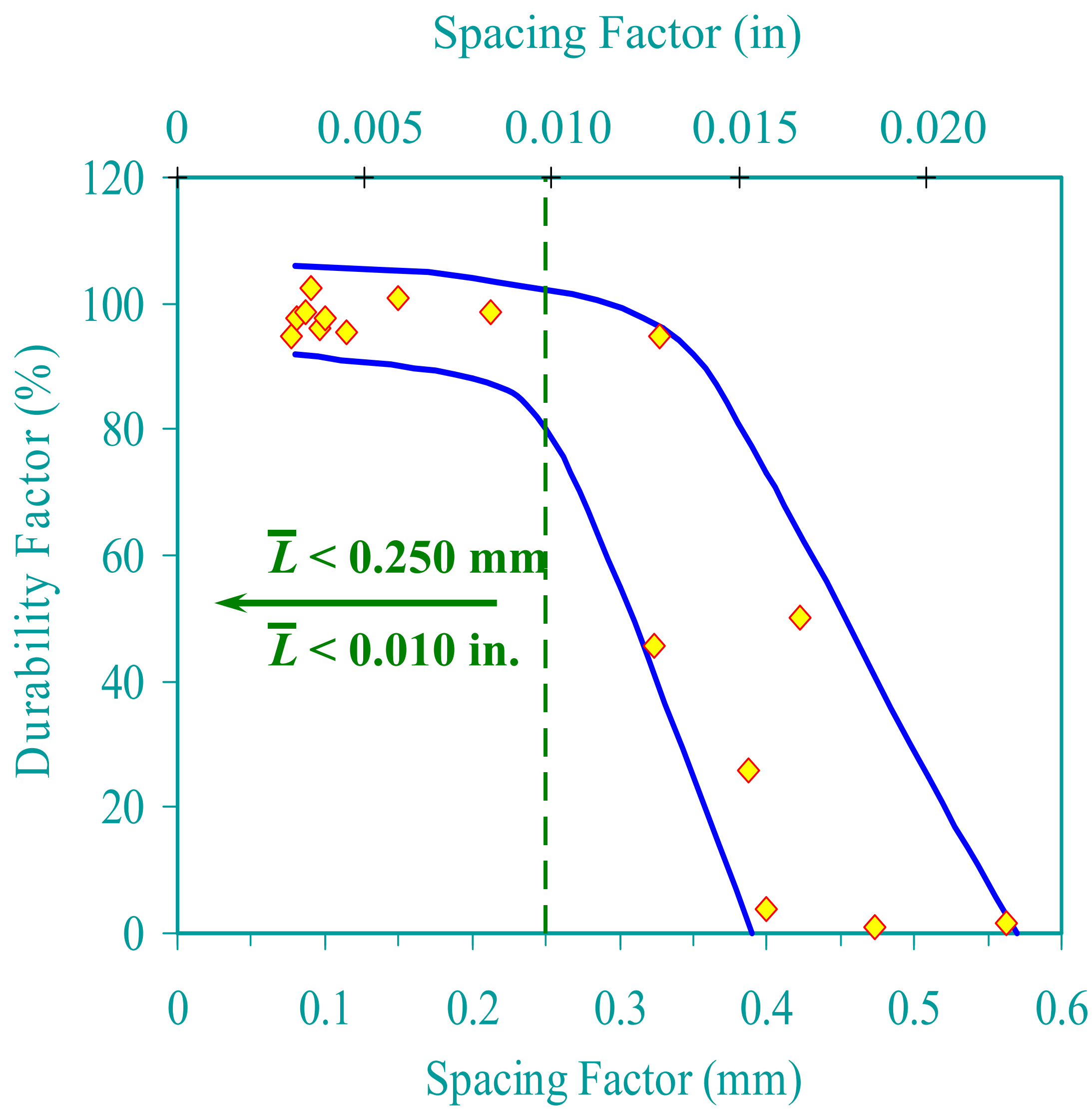


The **Spacing factor** $\bar{L}$ is defined as the maximum distance of any point in the the cement paste from the periphery of an air void
ASTM 457 < 0.2 mm (0.008 in.)

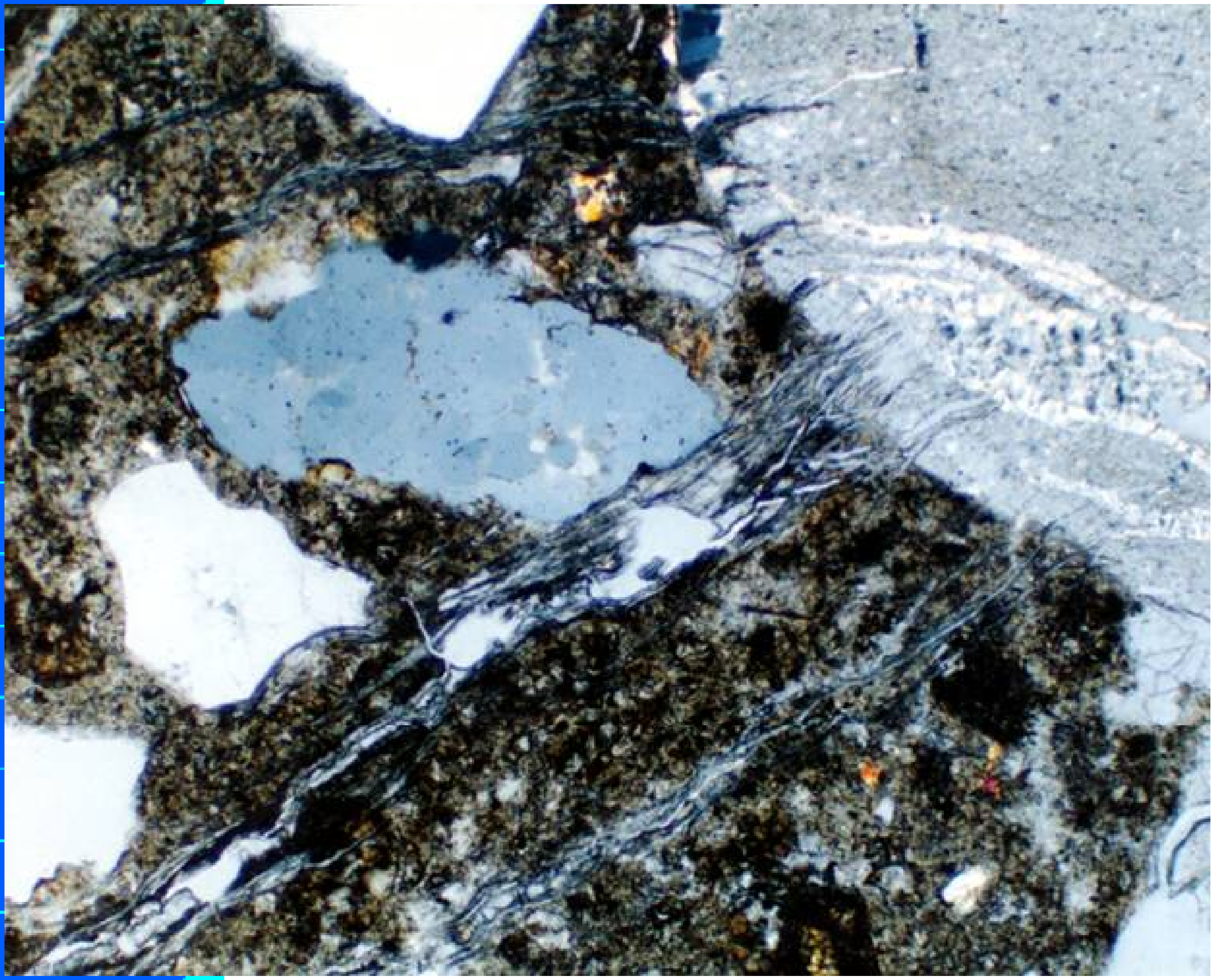
Specific surface (α) is defined as the surface area of a quantity of air voids that have a volume of 1 mm^3

- ASTM 457 ≥ 24 mm^2/mm^3 (600 $in.^2/in.^3$)

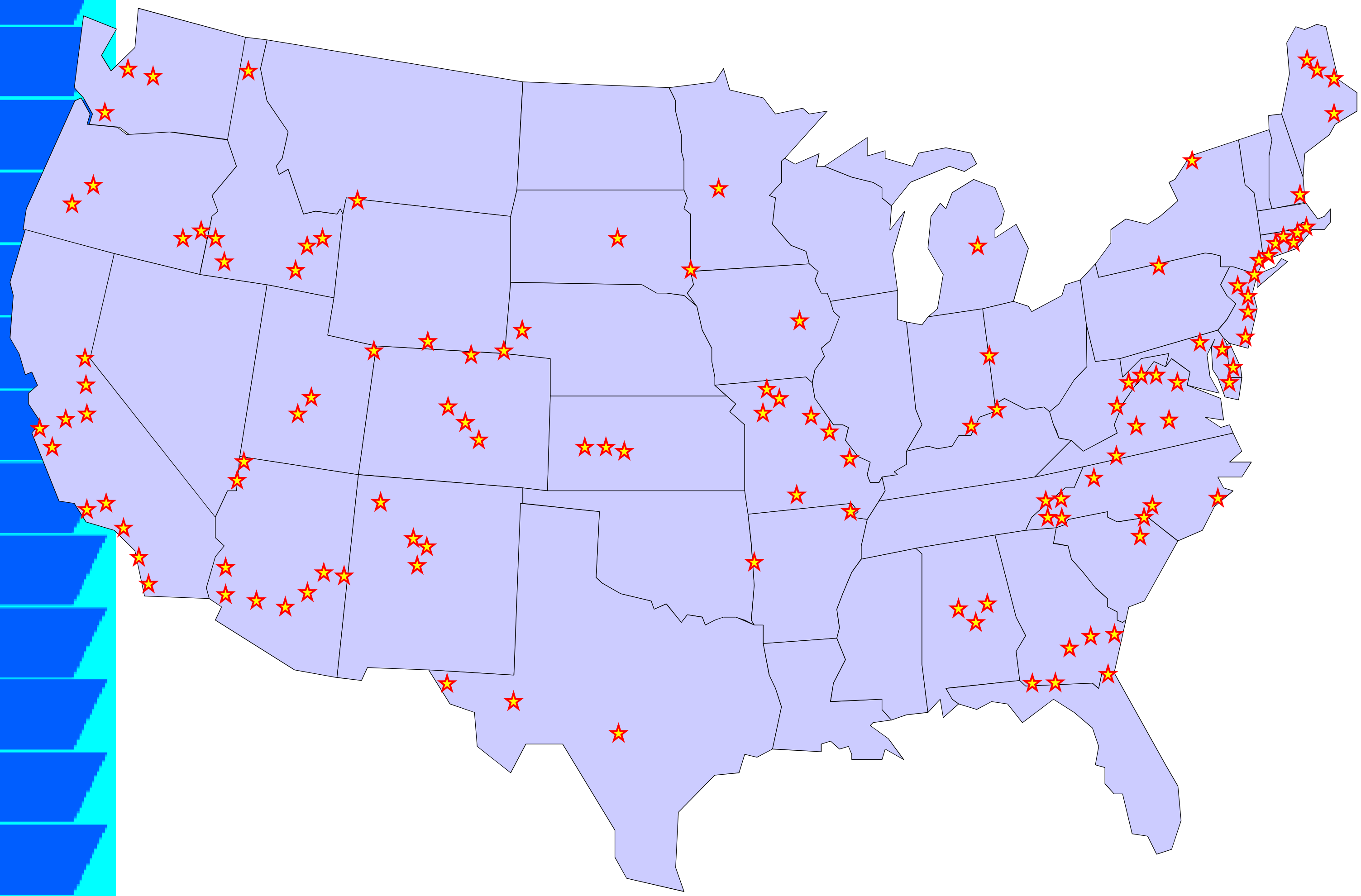
Effect of Spacing Factor



Alkali-Aggregate Reaction



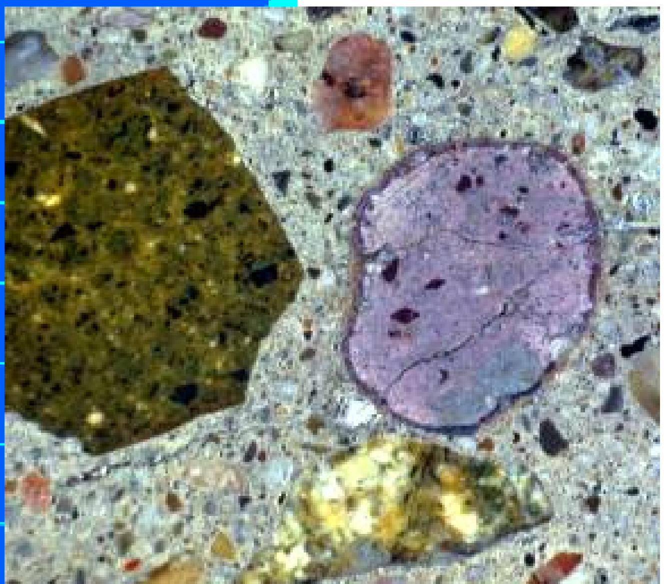
Occurrence of ASR in the United States



Materials and Methods to Inhibit ASR

- Pozzolans, Slag, and Blended Cement
- Low Alkali Portland Cement
- Limit Concrete Alkalies
- ASR Inhibiting Compounds-Lithium
- Aggregate Selection and Beneficiation

Resistance to Alkali-Aggregate Reactivity



ASR-

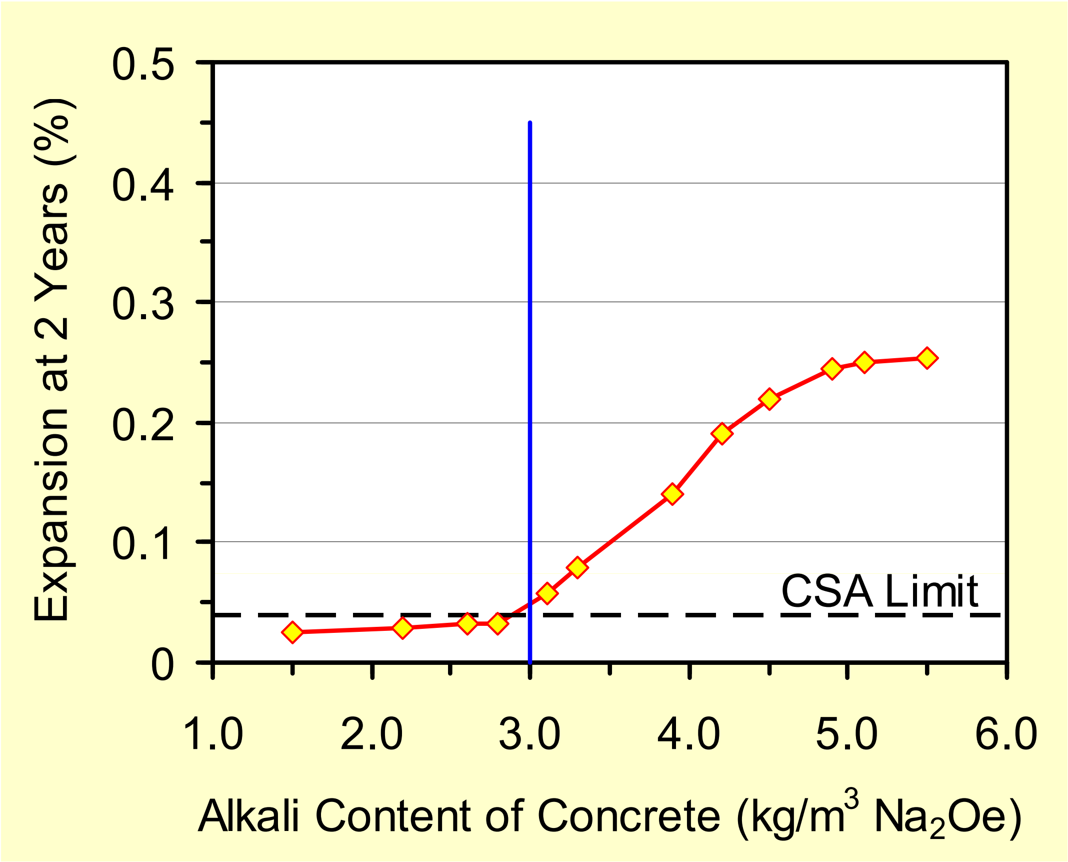
- Prism Test- *ASTM C1293* < 0.04% expansion (1 year)
- Mortar Bar Test- *ASTM C1260* < 0.10% expansion (14 days)
- Use of SCMs ASTM C1567

  < 0.10% expansion (14 days)

Caution: Limiting the alkali level of cement (<0.6%) may not be enough to mitigate ASR- focus must be on TOTAL alkalies in concrete.

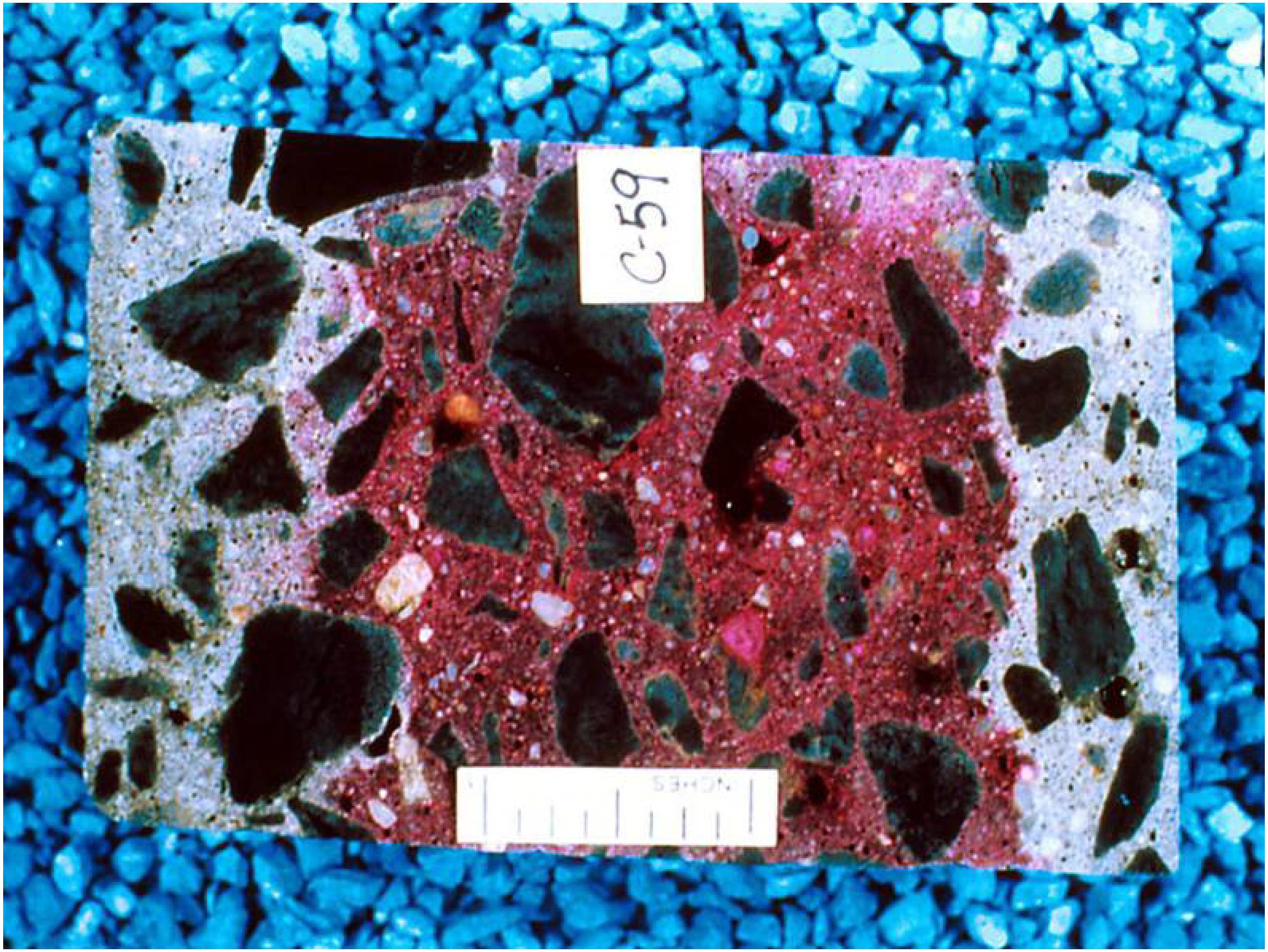
Limiting the Alkali Content of Concrete

Laboratory testing of concrete indicates expansion is unlikely to occur with most aggregates when the alkali content of the concrete is less that 3.0 kg/m^3 (5.0 lb/yd^3).



Corrosion

Carbonation



ACI 318-08-

Chloride Limits and Design Requirements

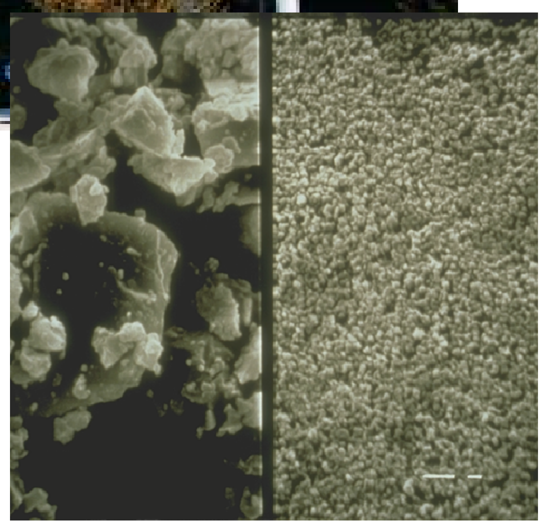
TABLE 4.3.1 — REQUIREMENTS FOR CONCRETE BY EXPOSURE CLASS

Exposure Class	Max. w/cm	Min. f'_c, psi	Additional minimum requirements		
			Maximum water-soluble chloride ion (Cl^-) content in concrete, percent by weight of cement[‖]		Related provisions
			Reinforced concrete	Prestressed concrete	
C0	N/A	2500	1.00	0.06	None
C1	N/A	2500	0.30	0.06	
C2	0.40	5000	0.15	0.06	7.7.6, 18.16[#]

Materials and Methods to Inhibit Corrosion

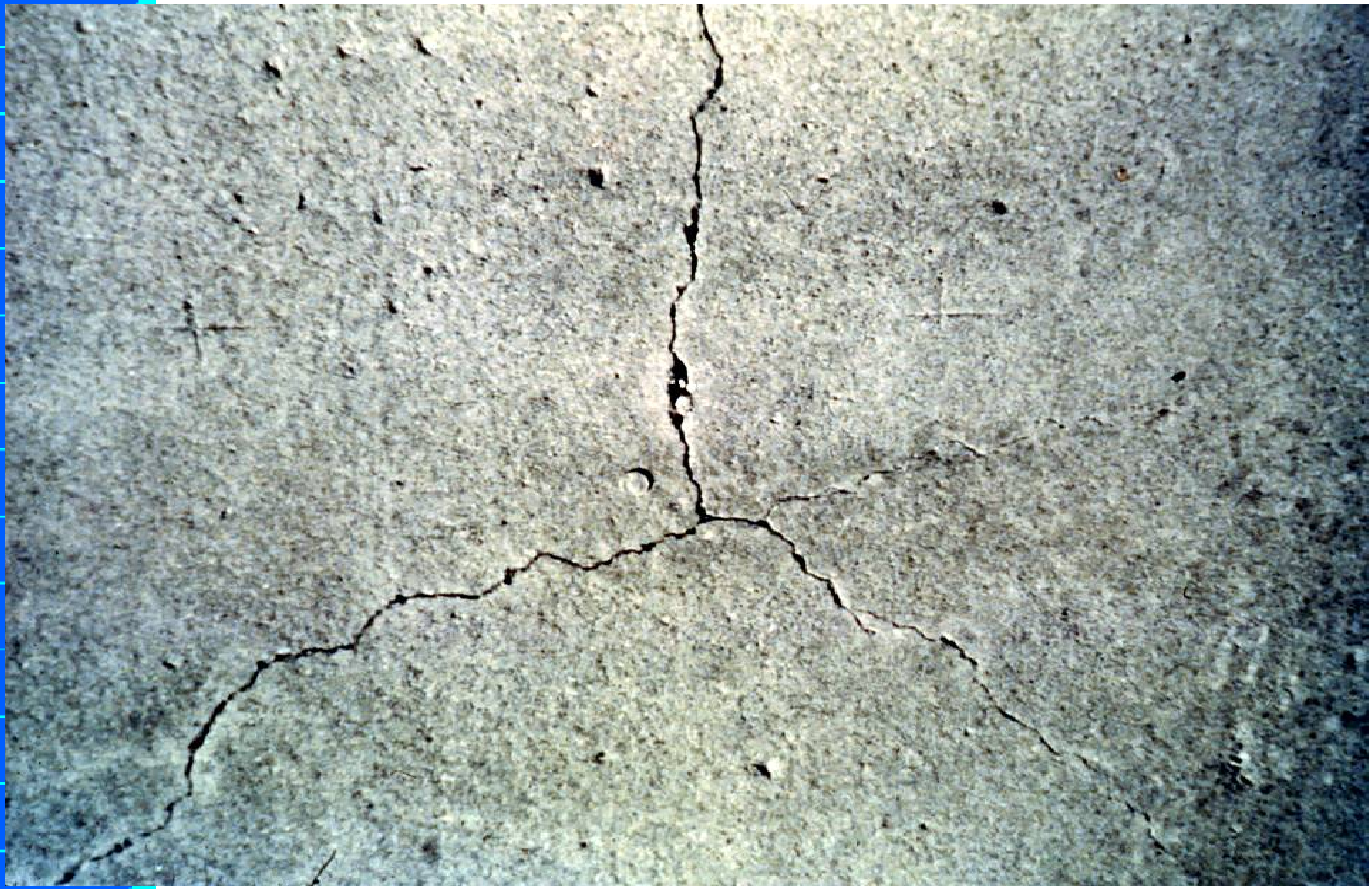
- Low w/cm (0.40)
- 7 days Moist Cure
- SCM's- Silica Fume
- Proper Cover Depth
- Epoxy Coated Reinforcement
- Sacrificial Anode
- Cathodic Protection
- Surface Treatments

Low-Permeability Concrete -Corrosion Resistance

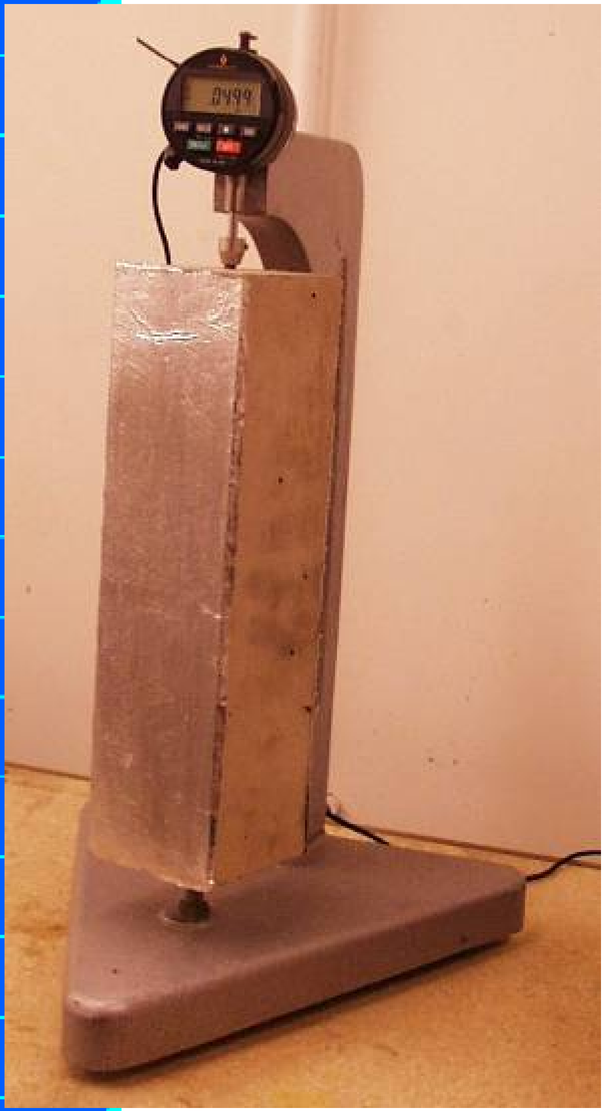


- Permeability-
  ASTM C1202
- Less than 2000 Coulombs
- Effect of test age?

Cracking vs. Durability



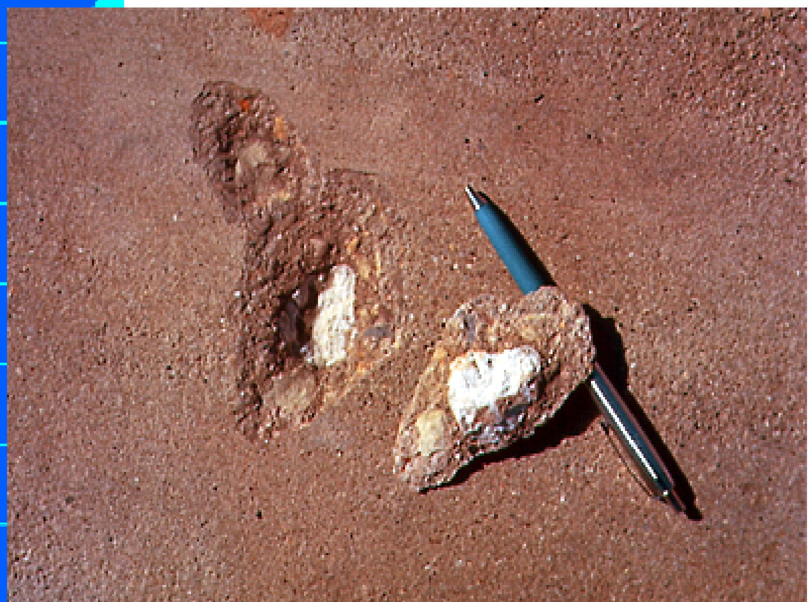
Volume Stability-
Low Shrinkage Concrete

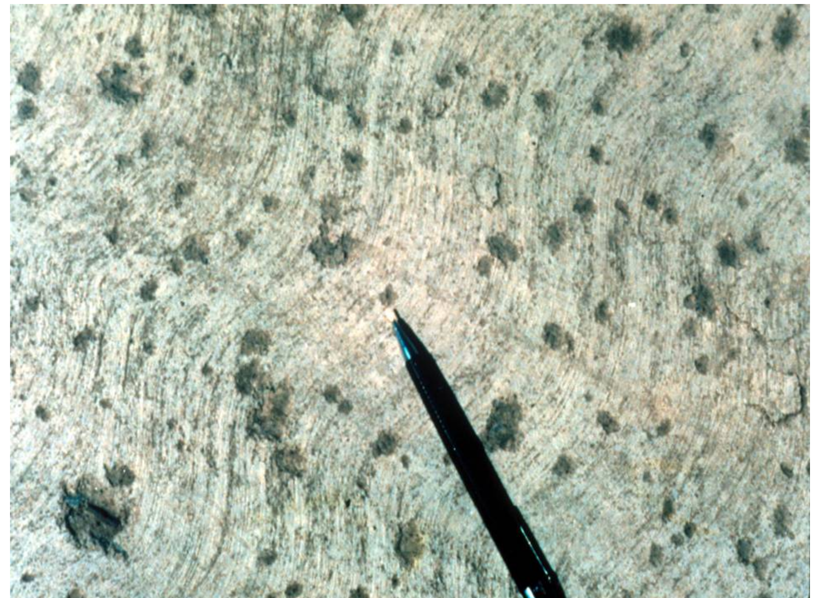


- Low Shrinkage Concrete
  ASTM C157
- Less Than 400 millionths

Surface Blemishes vs. Defects

Is it a Durability Issue??





Acceptance Criteria

- General Acceptance criteria-

  -Architecturally acceptable concrete surfaces should be aesthetically compatible with minimal color and texture variations and minimal surface defects when viewed at a distance of approximately 20 ft (6m) or more as agreed upon by architect, owner, and contractor, or as otherwise specified.

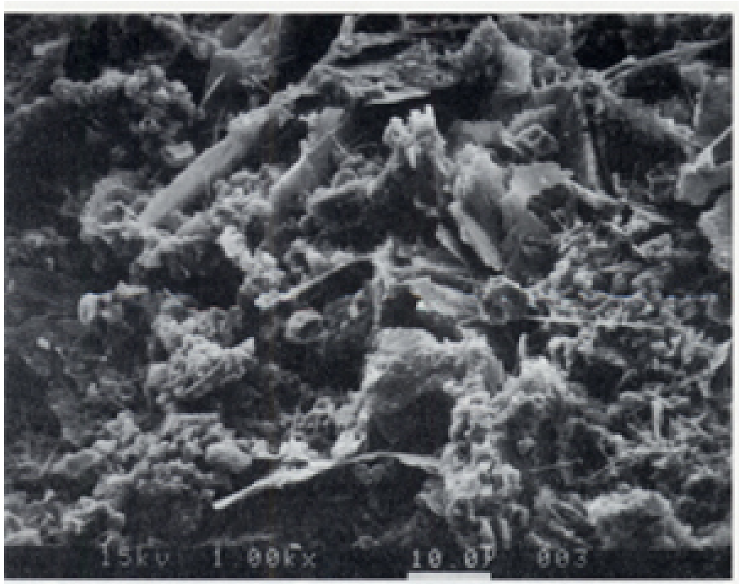
QA/QC

- Preconstruction meeting
- Prequalification of finishing crew
- Test panels, Mock ups

Specify Curing Regime

When not otherwise specified (ACI 301):

- Concrete shall be maintained above 50° F and in a moist condition for at least the first 7 days after placement.
- High-early strength concrete shall be maintained above 50° F and in a moist condition for at least the first 3 days.



- Cement Hydrates in Layers…

- Concrete cures from outside in.

Be Clear on Desired Outcome

- Specify enough “hoops” to jump through to get the performance you require for service conditions.

Caution Requirements that Bind Contractors Hands

- Means and Methods
- Materials Types

State the Obvious

- If it isn't in the Specification, it probably won't happen.
  - Ex: Curing Regime

?