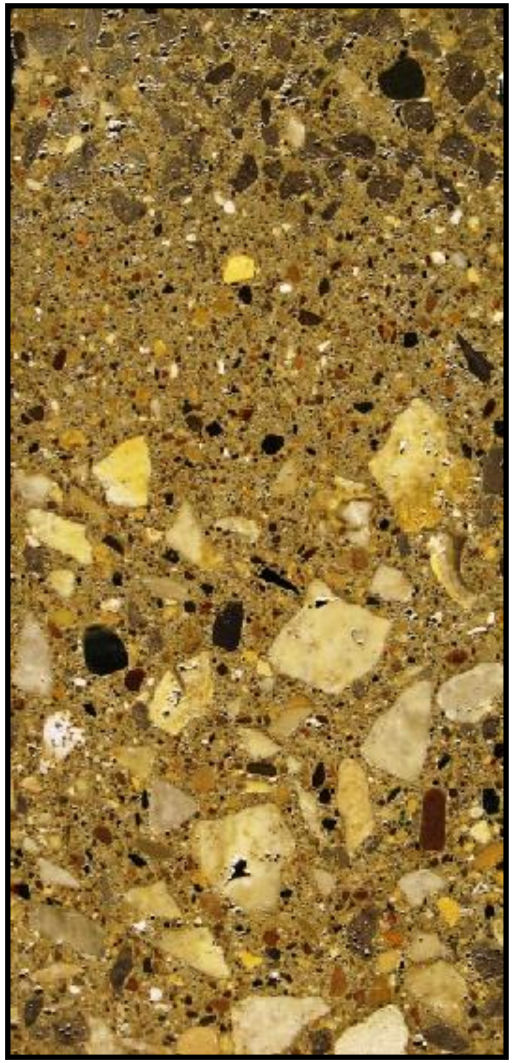
Concrete Technology

American
Concrete Pipe
Association

What is Hydraulic Cement Concrete?

- Hydraulic Cement?
- A uniform mixture of aggregates held together by a hardened hydraulic cement paste
- While concrete looks simple, it is really a highly complex material

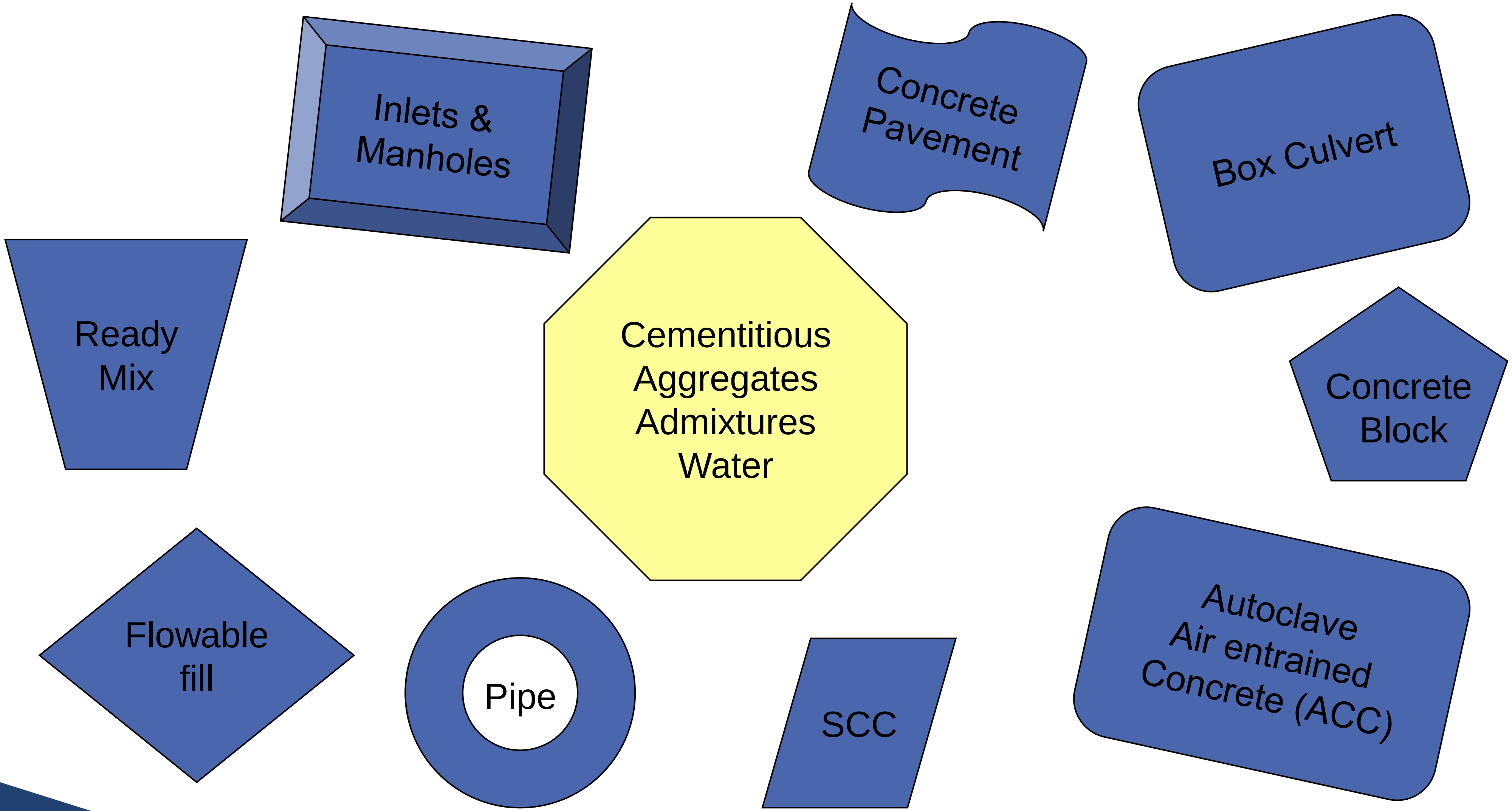
What can be said about this sample of concrete?



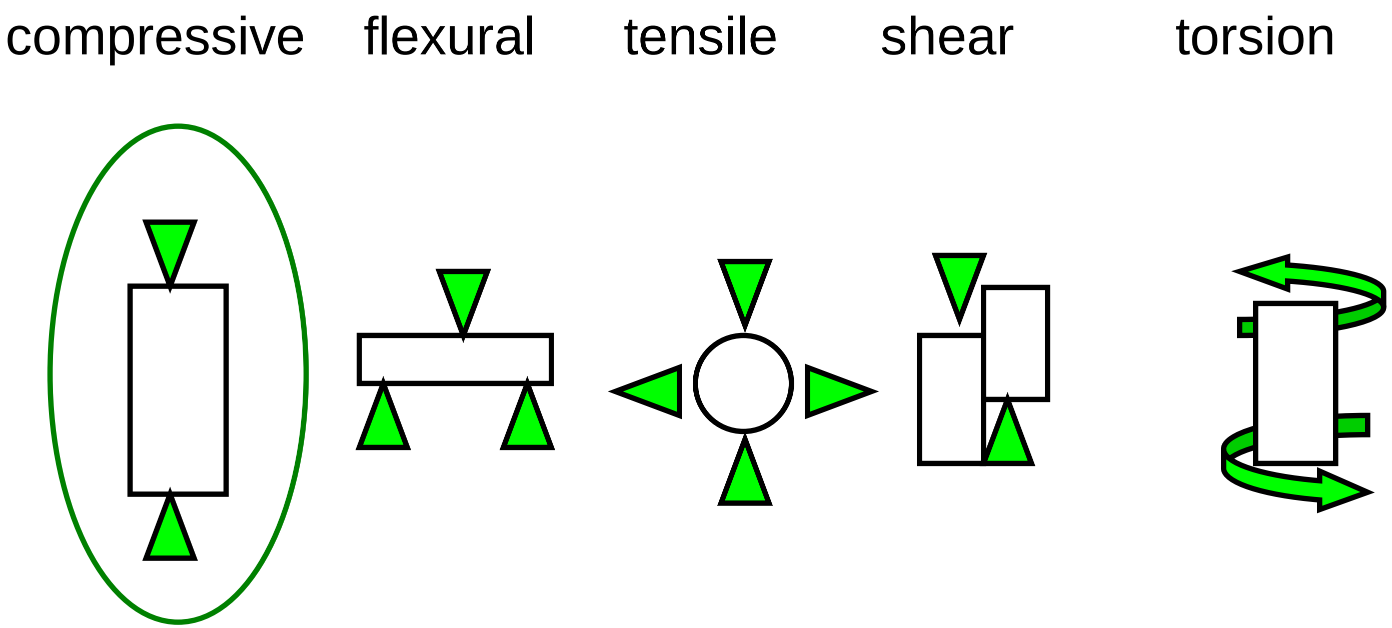
Two primary components

- Cement paste
  - Portland cement (Hydraulic)
  - Water
  - Air
  - Admixtures
- Aggregates
  - Coarse (and intermediate)
  - Fine

What percentage by volume for aggregates?


Cementitious
Aggregates
Admixtures
Water
Inlets & Manholes
Concrete Pavement
Box Culvert
Ready Mix
Concrete Block
Flowable fill
Pipe
SCC
Autoclave Air entrained Concrete (ACC)

Concrete Strength & Weakness



- <u>Unreinforced concrete</u> can provide high compressive strength, but relatively low tensile, flexural, shear and torsional strengths

Cement Hydration

Cement Hydration – Not a drying process

Tricalcium Silicate + Dicalcium Silicate + Tricalcium Aluminate + Water = Calcium Silicate Hydrate + Calcium Aluminum Hydrate

$$C_3S + C_2S + C_3A + H_2O$$

Glue

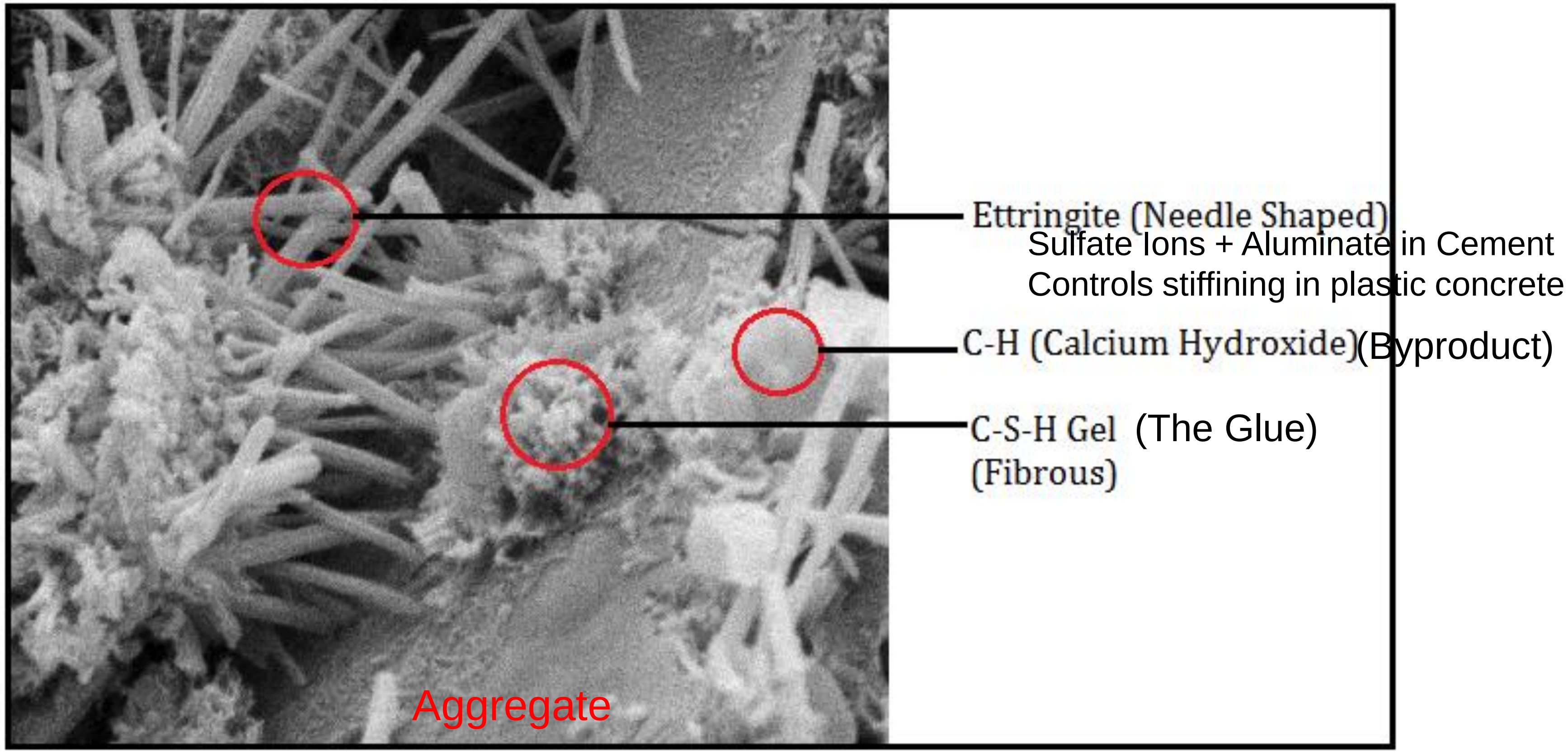
CS Hydrates **(CSH)**

+ CA Hydrates **(CAH)**

+ $Ca(OH)_2$ (CH) (Calcium Hydroxide)

+ heat

CSH gel is the glue that holds concrete together



<u>Hydrated Cement Paste -</u> Depending on the time of hydration and the Portland cement composition, several crystalline pictures can be observed in hydrated cement paste. A typical one contains Calcium Silicate Hydroxide, calcium hydroxide and ettringite as shown in this picture.

Heat of Hydration (Can Evaluate how Clinker Compound Reacts by heat evolution)

Stage 1: initial hydrolysis

Clinker, sulfates, and gypsum react > Allkaline sulfate solution > Initial heat spike last a few minutes

Stage 2: dormant period

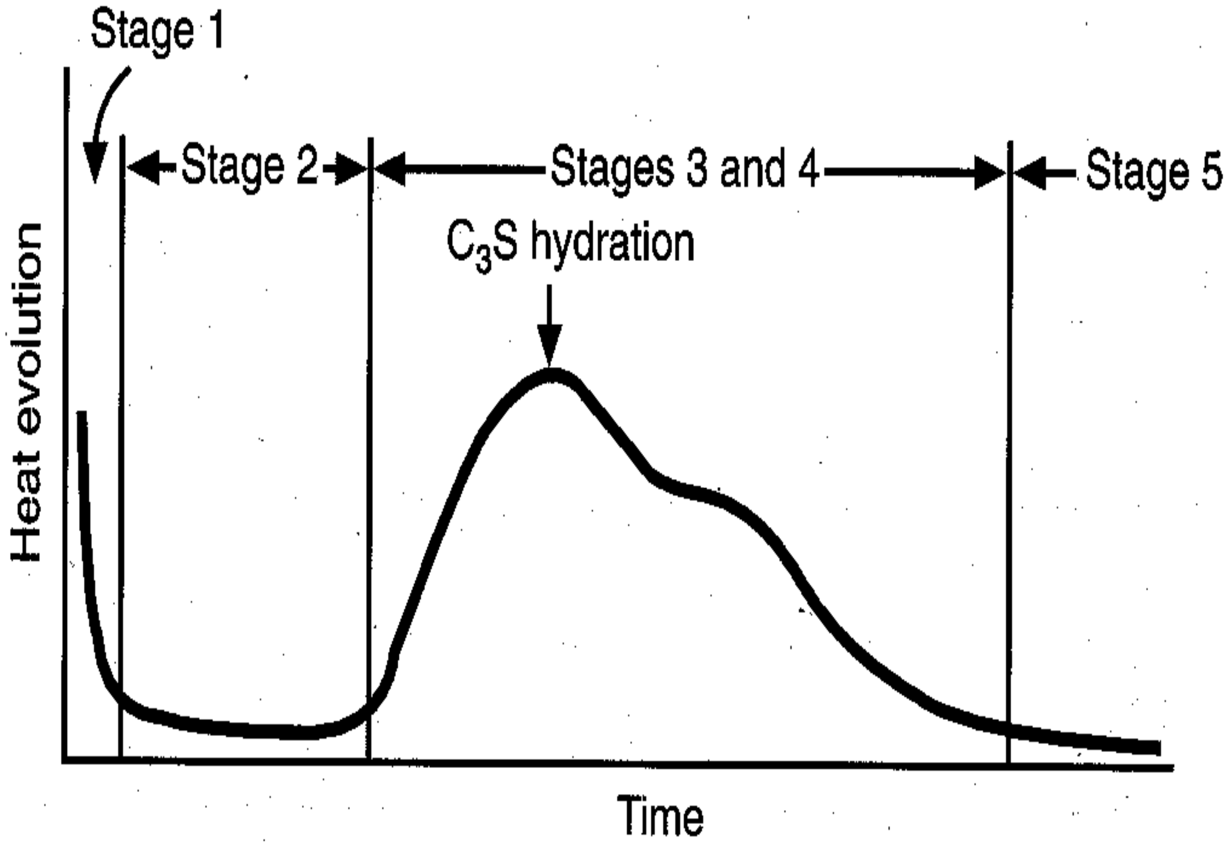
Relatively low heat evolution. Concrete can be placed about halfway through

Stage 3: accelerated hydration determines rate of hardening and final set

Stage 4: determines the rate of early strength gain

Alite (C3S) and Belite (C2S) react and form Calcium silicate Hydrate and Calcium Hydroxide

Stage 5: slow formation of hydration products establishing the rate of later strength



Water and w/c Ratio

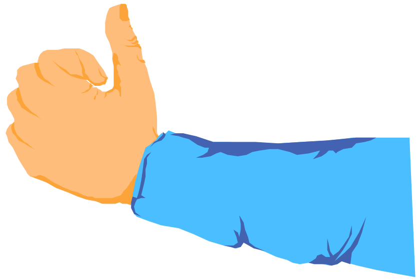
Why Water is Needed in Concrete

- Hydration:
  - The chemical reaction between cement and water which creates strength by forming interlocking crystals of CSH gel that holds aggregates in place
  - Need about 0.24 W/Cm for hydration
- Workability:
  - Can have 2 to 3 times more water in the mix than needed for hydration (known as water of convenience)

Rules of Thumb for Adding Water to Concrete

Adding 1 gal / yd^3 of water

- increases slump 1” (25 mm)
- decreases compressive strength by about 5%
- wastes the effect of 24 lbs/yd^3 of cement
- increases shrinkage by 10%
- increases permeability by up to 50%
- decreases freeze-thaw durability by 20%
- decreases resistance to deicing salts and lowers quality in many other ways



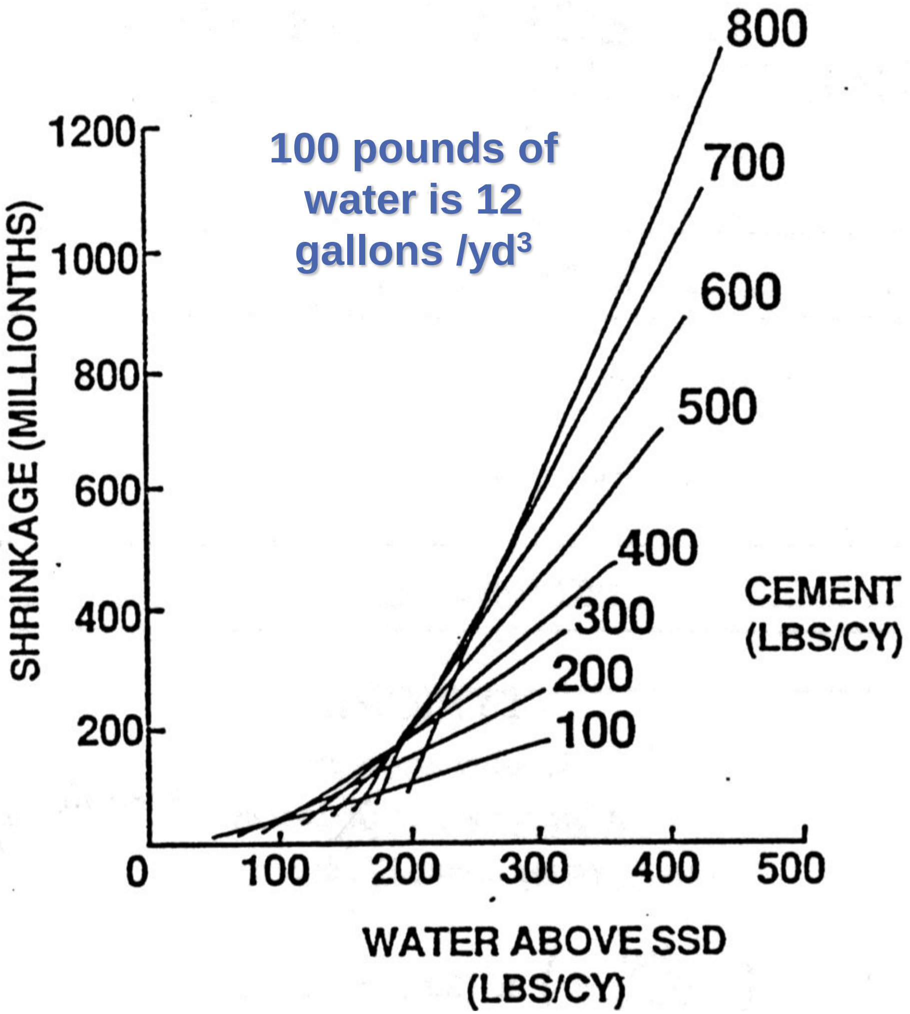
Drying Shrinkage

More Cement, More Water

Leads to more:

- Shrinkage
- Cracking

- Water Reducer?

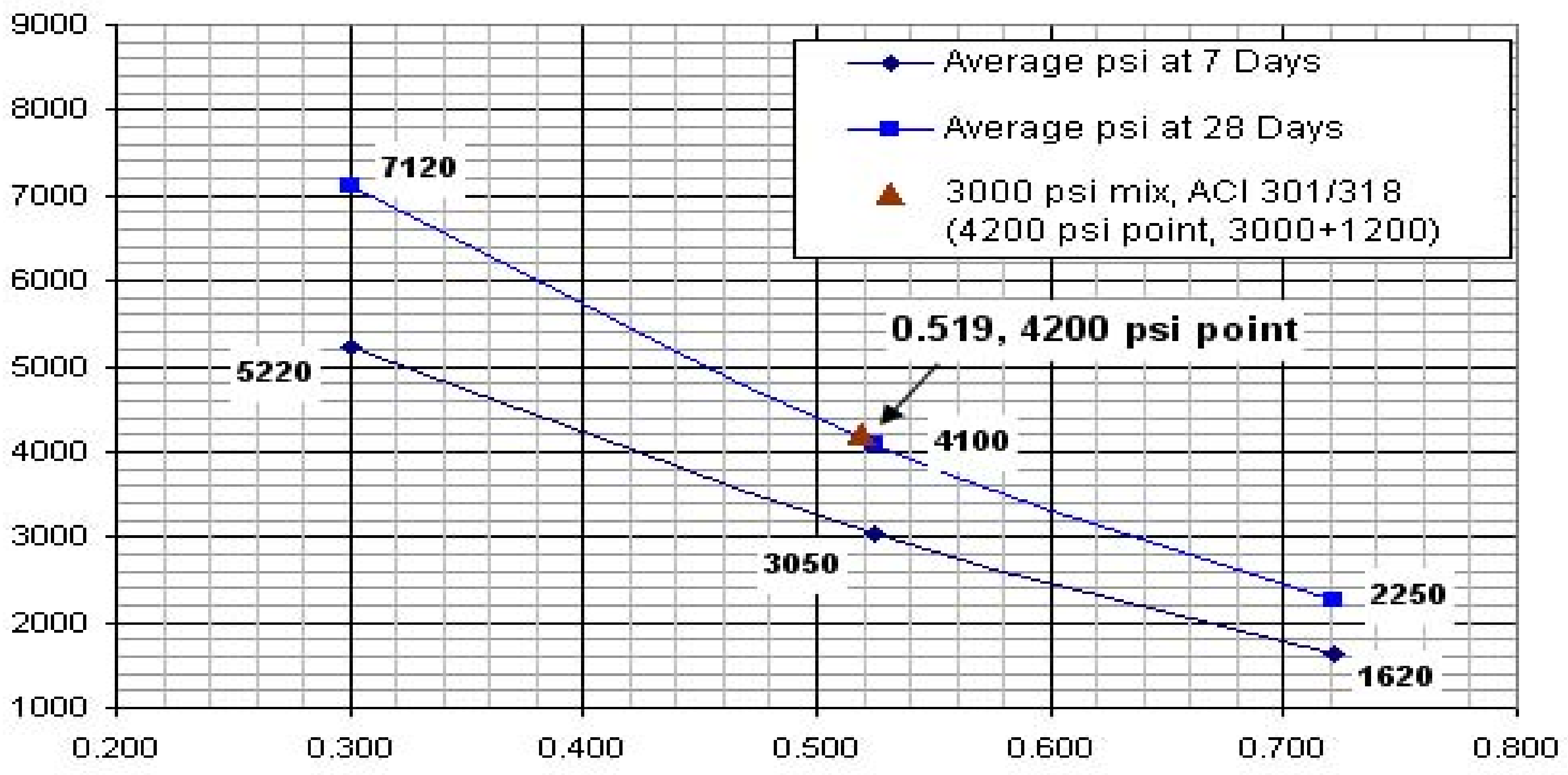


Water / Cementitious Ratio – Abram's Rule

- As the w/c ratio increases, the strength of a concrete mix decreases
- In other words: If everything else is constant and you add more water, you get less strength

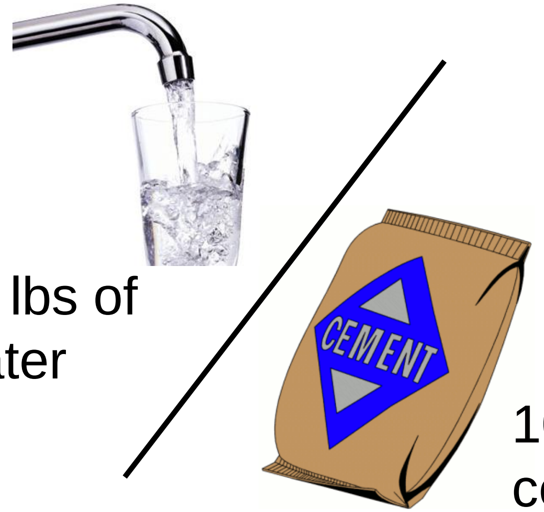
Water / Cementitious Ratio

The strength and durability of concrete is <u>greatly influenced</u> by the w/c ratio!



Water / Cementitious Ratio

Often when w/c is discussed its really w/c_m that is intended as the reference



45 lbs of water

100 lbs of cement

= Water cement ratio

0.45 expressed as decimal

It's a calculation:

- w/c ~ lbs. of water / lbs. of cement
- w/c_m ~ lbs. of water / lbs. of cementitious

- **w/c_m = w/c**

Durability of Concrete

Durability of Concrete

- Freeze/Thaw Attack
- Alkali-Aggregate Reaction
- Chemical Attack
  - Sulfate attack from sources external to concrete
  - Physical salt attack & seawater exposure
  - Acid Attack
- Corrosion

Freeze - Thaw Attack

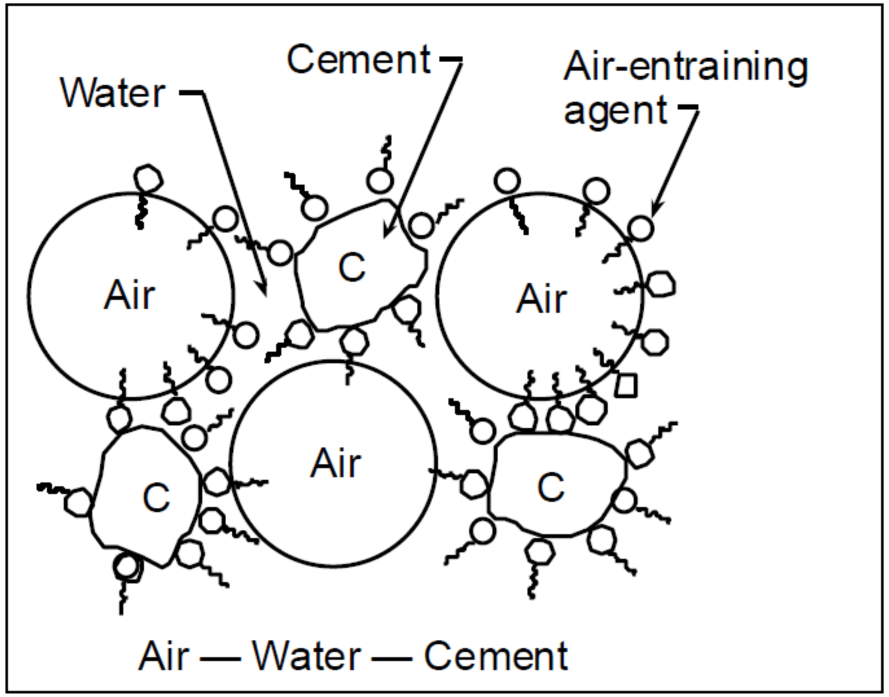
Water Expands about 9% when frozen

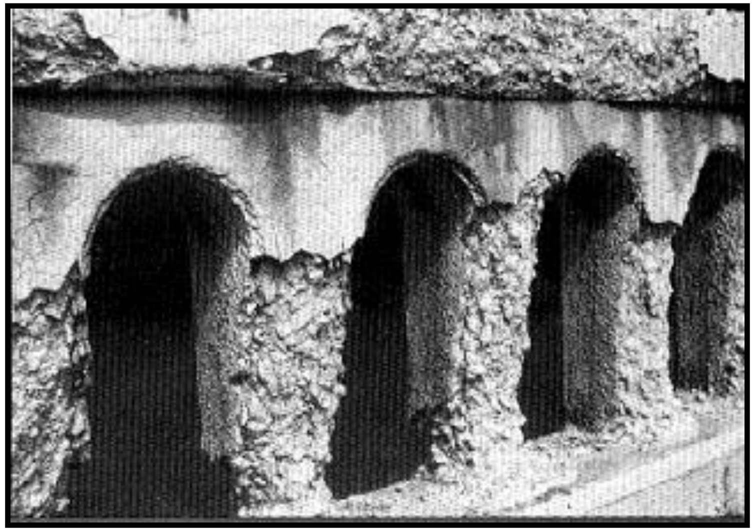
Water is incompressible

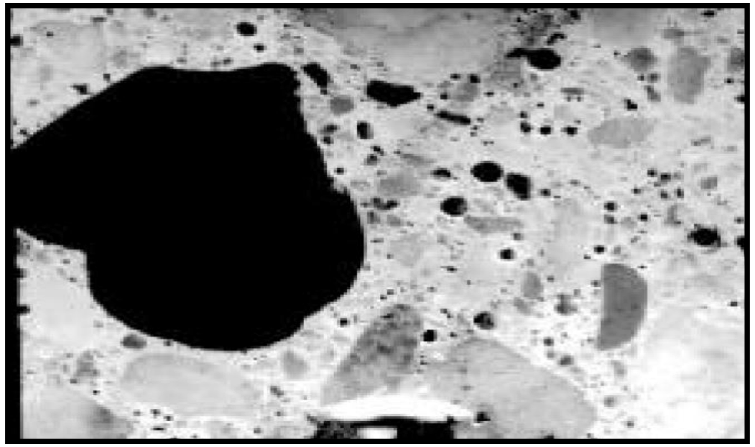
Causes microcracks

Air-entraining agent binds cement grains around air

Bubbles relieve pressure







Freeze - Thaw Attack

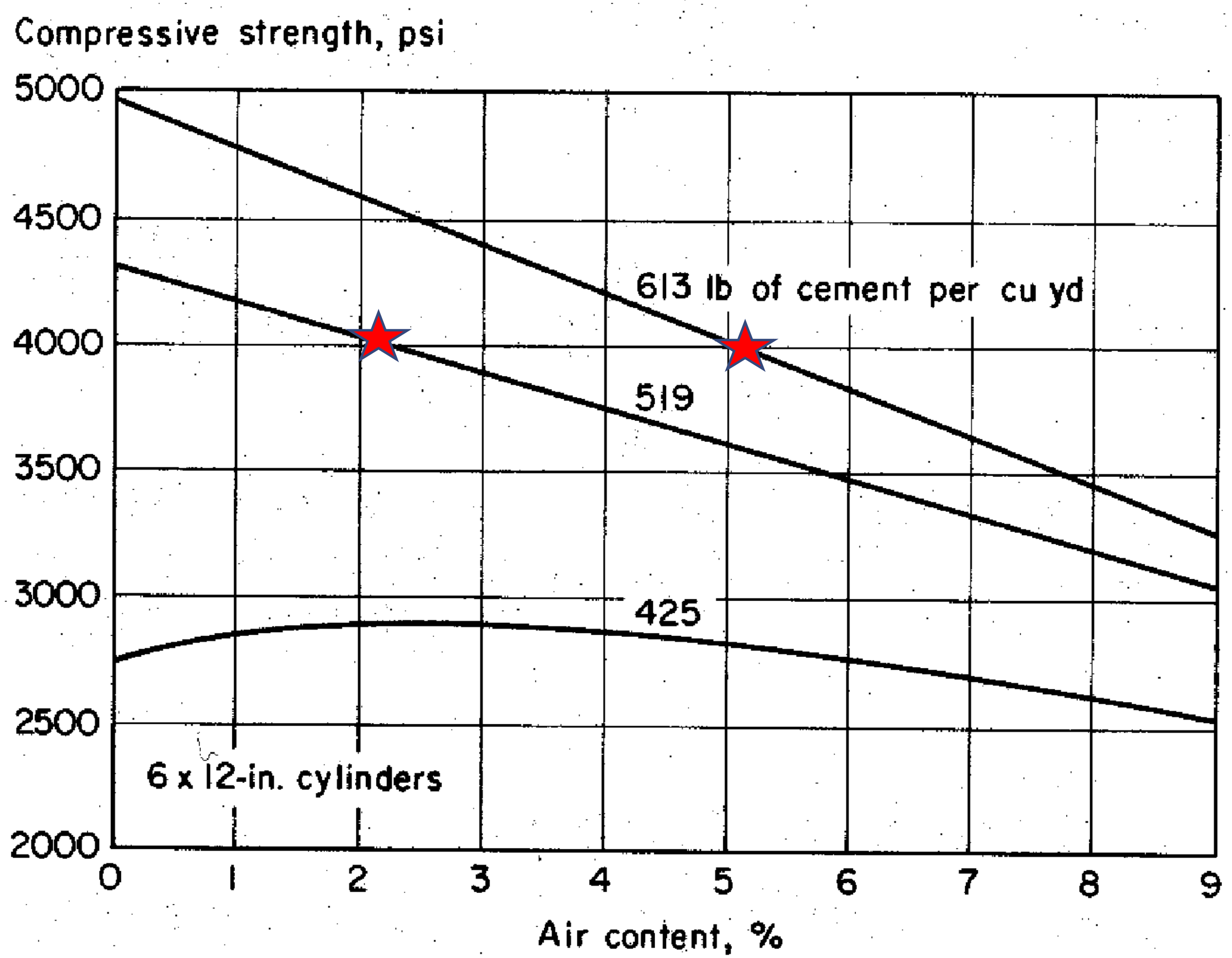
Aggregates with a total smaller pore size result in a lower resistance to freezing & thawing

Air entraining is for wetcast
No historical F/T issues in drycast

Table 1-1. Recommended Total Target Air Content for Concrete

Nominal maximum aggregate size, in. (mm)	Air content, percent*		
	Severe exposure**	Moderate exposure†	Mild exposure††
< 3/8 (< 9.5)	9	7	5
3/8 (9.5)	7-1/2	6	4-1/2
1/2 (12.5)	7	5-1/2	4
3/4 (19.0)	6	5	3-1/2
1 (25.0)	6	4-1/2	3
1-1/2 (37.5)	5-1/2	4-1/2	2-1/2
2 (50)‡	5	4	2
3 (75)‡	4-1/2	3-1/2	1-1/2

Compressive Strength vs %Air



Water content was reduced with increased air content to maintain a constant slump

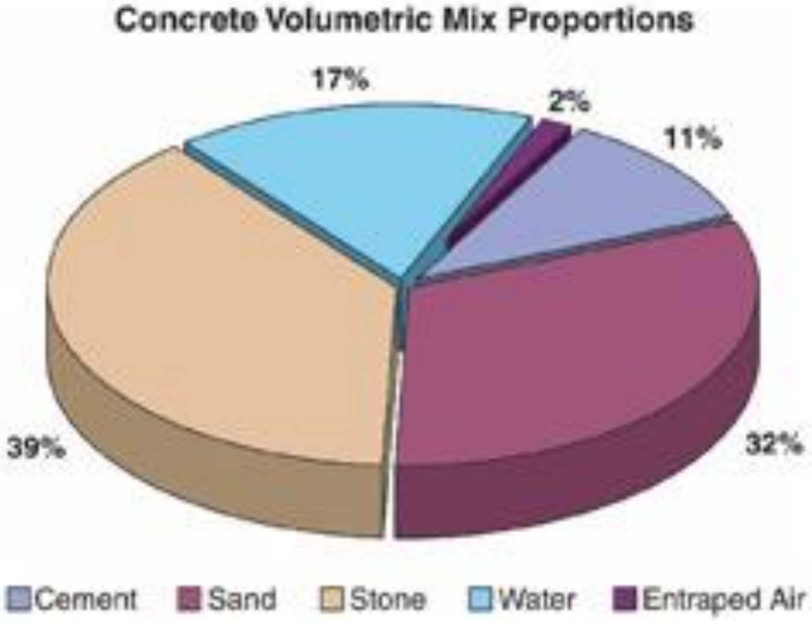
Freeze - Thaw Attack

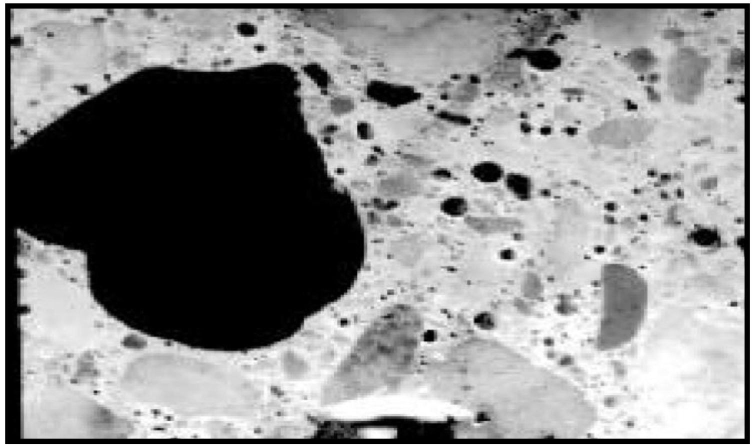
Air Content

- Entrapped air
- Entrained air

Entrapped Air

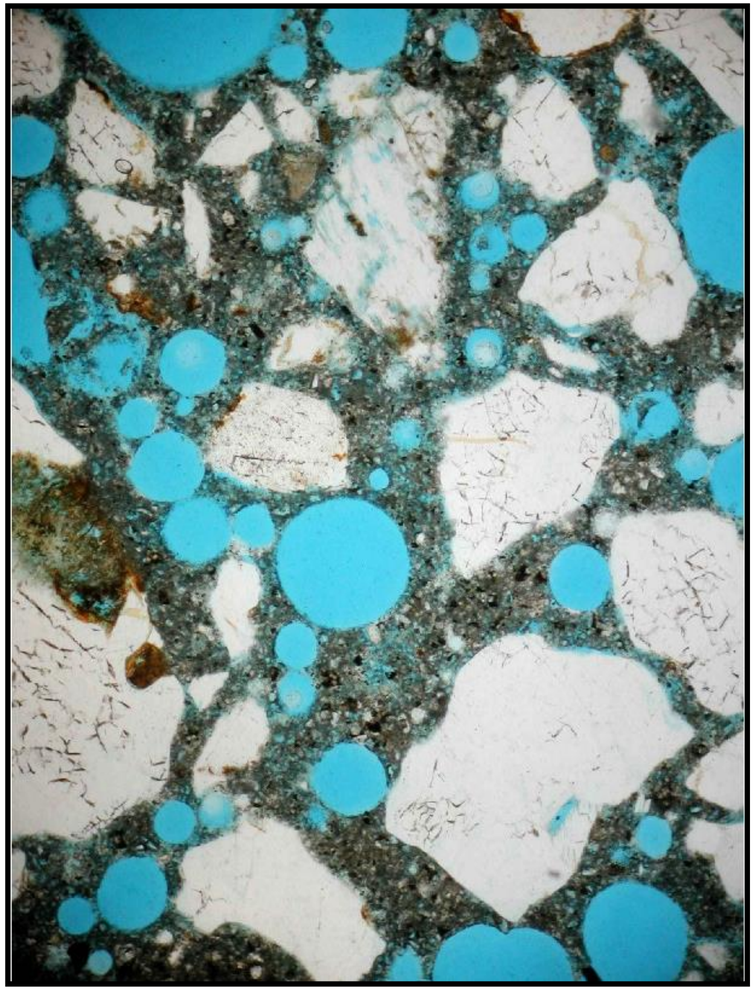
- Air trapped during mixing and placement process
- Large, non-uniform voids, generally undesirable
- Reduced through proper vibration & consolidation
  - Still 2-3%





Entrained Air (Wetcast)

- Additive creates a uniform network of small spherical voids/bubbles (From existing air)
- Voids provide relief reservoirs and prevent freeze/thaw damage
- Required for all wetcast products exposed to freeze/thaw conditions



It’s the quality of air that gives durability

How do You Measure Air?

Wetcast

ASTM C231 Test Method for Air Content of Freshly Mixed Concrete by the pressure method

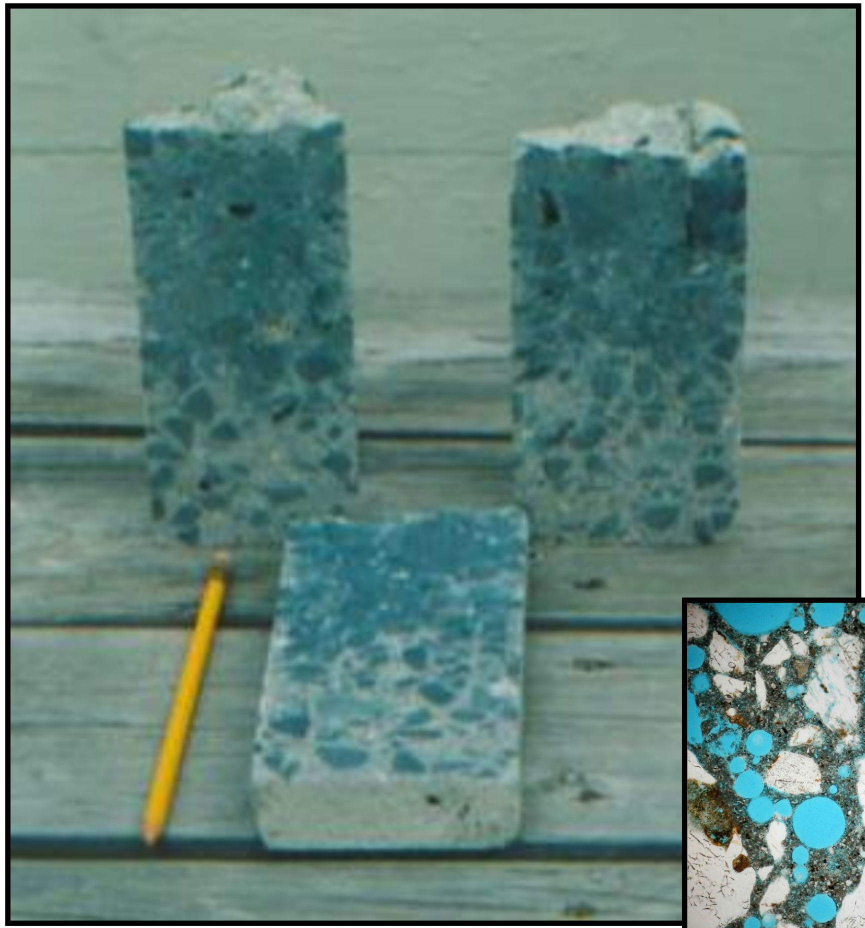
ASTM C173 Air Content of Freshly Mixed Concrete by Volumetric Method

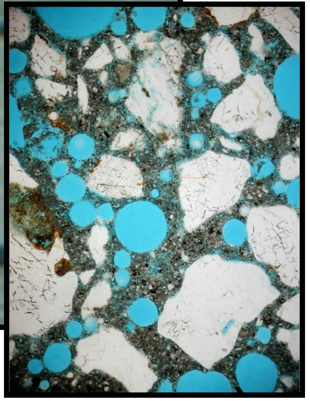
How do You Measure Air?

Drycast (or wetcast)

ASTM C457 Standard Test Method for Microscopical Determination of Parameters of the Air-Void System in Hardened Concrete

Total air content
Entrained air consists of bubbles 0.04”-0.004”
Spacing factor is distance water needs to travel between bubbles
Specific surface is relative number of bubbles in a given volume of air





Quality Harden Air
- Spacing Factor < 0.008
- Specific Surface > 600
- Model Chord length

Alkali-Aggregate Reaction

- ACR (Alkali-Carbonate Reaction)

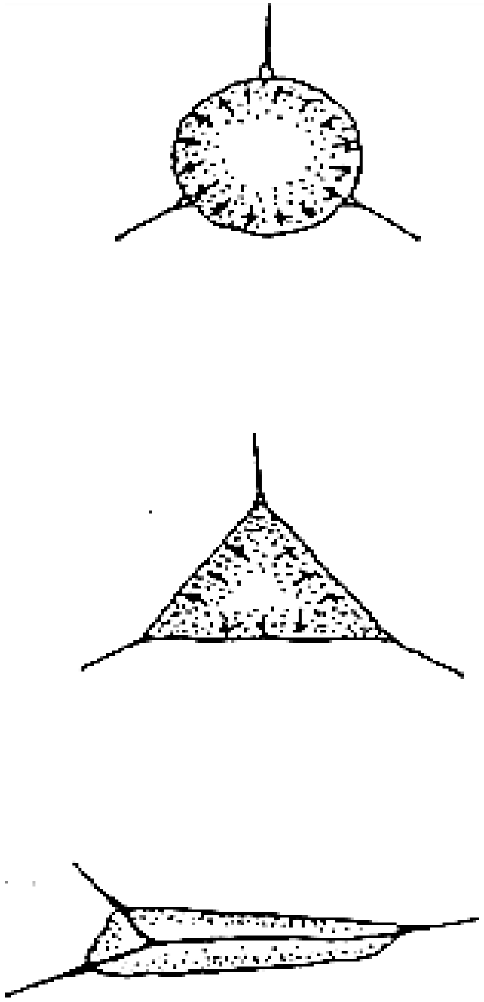
    A reaction between an alkali source and certain calcium magnesium carbonate rocks (dolomites)

- ASR (Alkali-Silica Reaction)

    Reaction between an alkali and certain forms of reactive silica that can originate from some types of siliceous aggregate – far more widespread than ACR

ASR – How it Works

- Cement paste and reactive siliceous aggregate form a gel around the aggregate particle
- Gel reaction product & moisture creates expansion
- Expansion usually creates three cracks

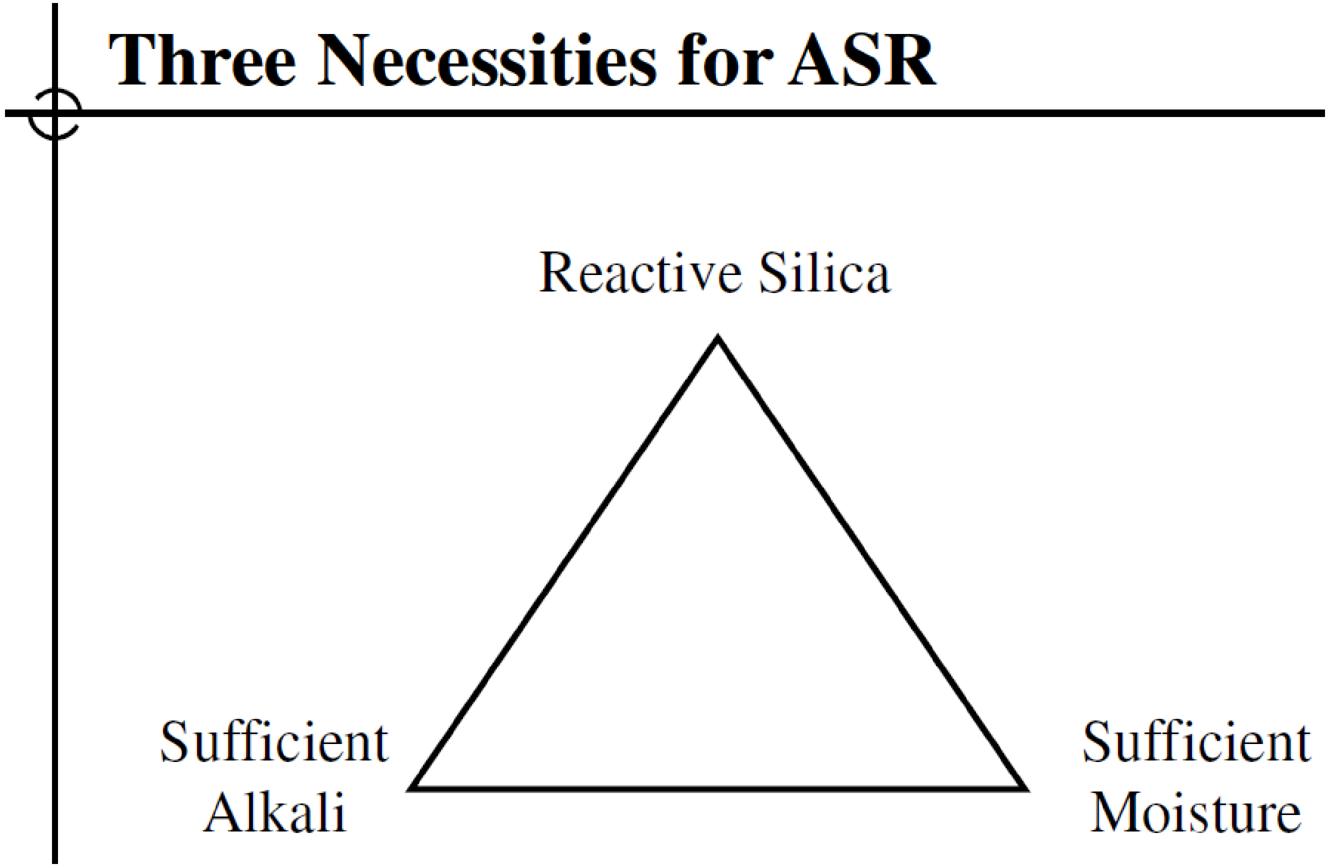


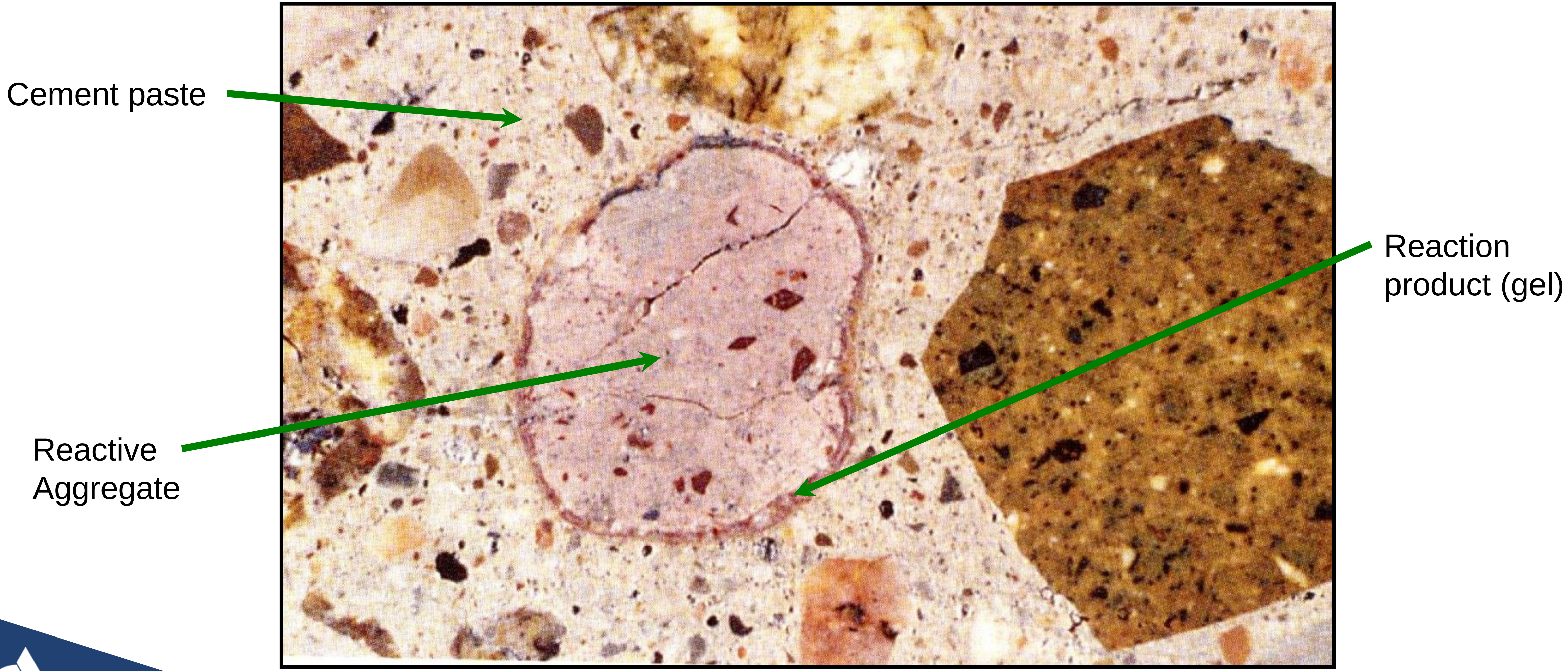
ASR – How it Works

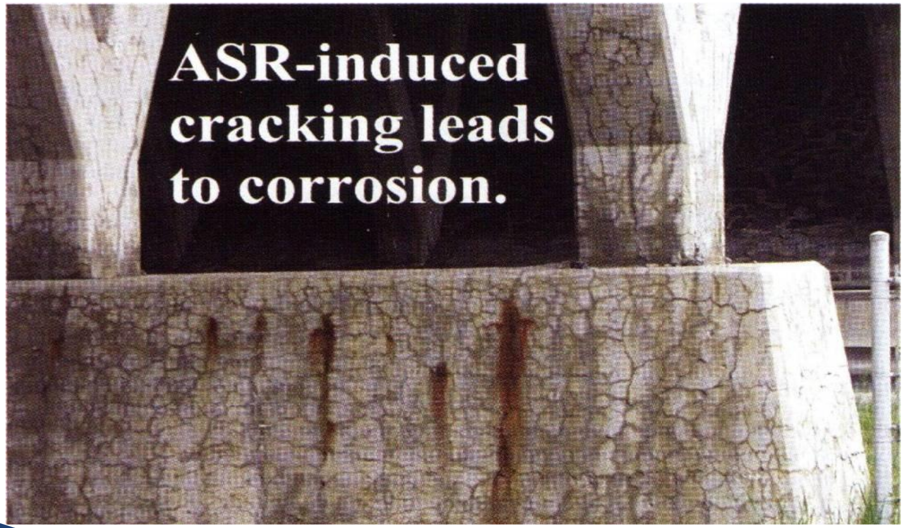
Alkali in cement. Silica in aggregates

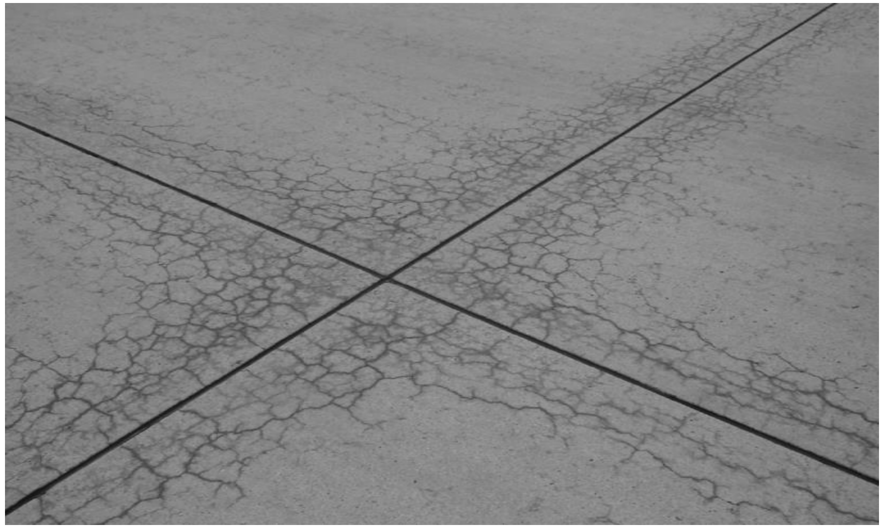
Not all ASR Gels cause destructive expansion

Potential for ASR widespread due to reactive aggregates




Cement paste
Reaction product (gel)
Reactive Aggregate


ASR-induced cracking leads to corrosion.



Preventative Measures for ASR

- Use of non-reactive aggregate
- Use of low-alkali cement
- Limited alkali content of concrete
- Use of supplementary cementing materials (typically Class F or slag)
- Use of suitable chemical admixtures

- Although reactive aggregates are typical across N. America, thanks to these measures ASR damage is not that common

Chemical Attack

- Sulfate attack from sources external to concrete (Not to be confused with hydrogen sulfide from sanitary sewers)
- Physical salt or seawater attack
- Acid attack (for example sanitary sewers)

How does *Sulfate Attack* Work in Concrete?

Sulfate salts, when present in solution, react with the hydration products

- Sodium Sulfate attacks the Calcium Hydroxide & Calcium Aluminate Hydrate
  - Yields a semi-hydrated form of gypsum and ettringite
  - ✓ Can lead to softening of the paste, loss of strength & Increase in porosity
- Calcium Sulfate attacks the CAH
  - Yields ettringite
  - ✓ Increases the solids volume causing expansion and cracking
- Magnesium Sulfate attacks CH, CAH, & Calcium Silica Hydrate
  - Yields gypsum, ettringite, and brucite ($Mg(OH)_2$)
  - ✓ Destroys CSH
  - ✓ Particularly devastating
- Other sulfate related processes can damage concrete without expansion
  - Evidence of sulfate attack verified by petrographic and chemical analyses

Sulfate Attack

Recommendations for protection

- Use concrete that retards the ingress of the external sulfate
  - Low w/c ratio
  - Low permeability
  - Sulfate resistant cement (low C_3A<5% Type V; <8% Type II)
  - Slag cement and or Class F Fly ash

Sulfate Attack

Table 2.3—Requirements to protect against damage to concrete by sulfate attack from external sources of sulfate

Severity of potential exposure	Water-soluble sulfate $(SO_4)^*$	Sulfate $(SO_4)^*$ in water, ppm	*w/cm* by mass, max.[†‡]	Cementitious material requirements
Class 0 exposure	0.00 to 0.10	0 to 150	No special requirements for sulfate resistance	No special requirements for sulfate resistance
Class 1 exposure	> 0.10 and < 0.20	> 150 and < 1500	0.50[‡]	C 150 Type II or equivalent[§]
Class 2 exposure	0.20 to < 2.0	1500 to < 10,000	0.45[‡]	C 150 Type V or equivalent[§]
Class 3 exposure	2.0 or greater	10,000 or greater	0.40[‡]	C 150 Type V plus pozzolan or slag[§]
Seawater exposure	—	—	See Section 2.4	See Section 2.4

Physical Salt or Seawater Exposure

Deterioration occurs by physical action of salts from groundwater or seawater containing sodium sulfate, sodium carbonate, & sodium chloride

Damage typically occurs at exposed surfaces of moist concrete that is in contact with the salts

The distress in surface scaling is similar in appearance to freezing-and-thawing damage

Salts carried into concrete by water and crystals expand causing microcracking

Acid Attack

- Acids attack concrete by dissolving cement compounds as well as calcareous aggregate
- Concrete deterioration increases as the pH of the acid decreases from 6.5
- Will not hold up in PH of 3 or lower

Improve resistance to acids by:

- Make it as impermeable as possible
- Use a suitable coating
- Modifying the environment

Corrosion

- The leading cause of concrete deterioration is the corrosion of reinforcing steel due to the expansion created by the rust
- As the rust expands, internal pressure builds until the concrete fails resulting in spalling
- Concrete has a high pH value, which prevents corrosion under normal conditions
- Exposure of the concrete to elements such as sewater or deicing salts create a corrosive environment

How to Make Durable Concrete?

- Low w/c_m ratio
- Ample amount of cementitious
- Quality Aggregates
- Correct admixtures
- Proper mixing & placing
- Adequate Curing


Thank You