CSI: Concrete Scene Investigation

What a Petrographer Can Determine About Your Concrete

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What is Petrography?

- A branch of geology dealing with the description and classification of rocks (or in this case, concrete) mainly using microscopic examination of thin sections.

Petrographic Analysis – How Can It Help?

- Identify Causes for Common Concrete Problems
  - Low Strength
  - Surface Deterioration
    - Scaling
    - Delamination
  - Cracking
    - Plastic Shrinkage
    - Alkali-Silica Reactivity
    - Sulfate Attack
    - D-Cracking
    - Reinforcement Corrosion

Petrographic Analysis – How Can It Help?

- Customer Questions
  - Why?
  - How bad is it?
  - Can we live with it?
  - How can we prevent it next time?
- Petrographic Analysis
  - Determine cause(s) of inferior quality, distress, or deterioration
  - Determine extent of damage
  - Provide recommendations

Concrete Scene Investigation #1
Low Compressive Strength Cylinders

- The Usual Suspects:
  - Poor cylinder making
  - Poor cylinder testing
  - High air void content/void clustering
  - High water/cement ratio
  - Dirty aggregate
  - Early freezing

Examination of the Cylinder

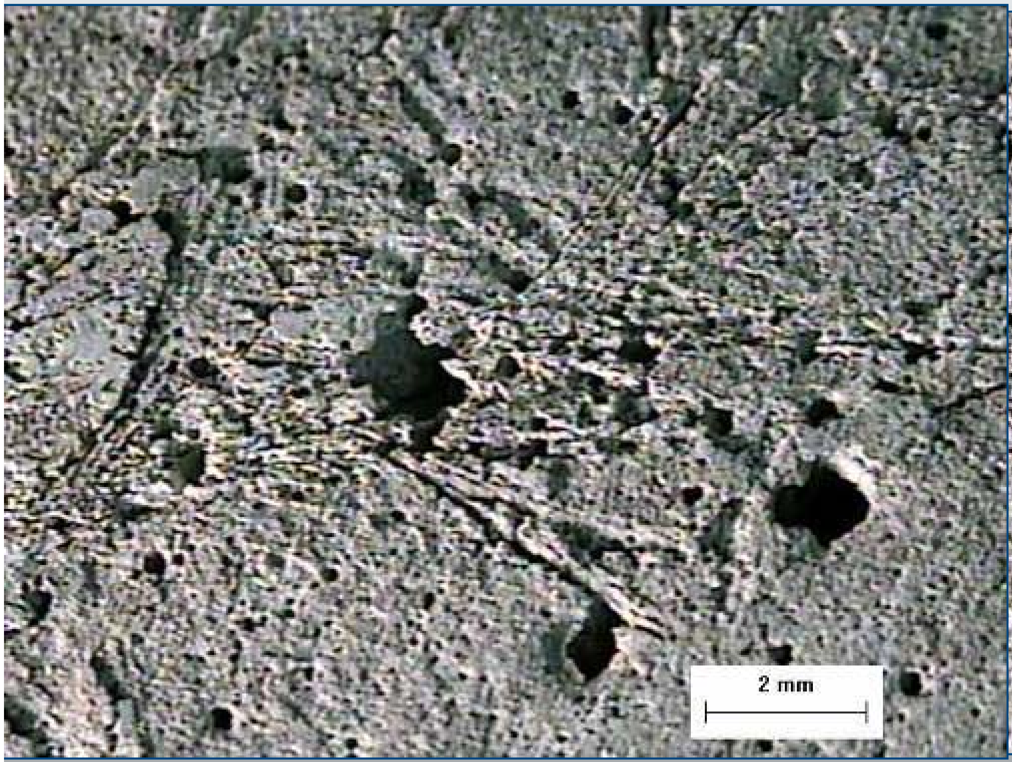
- Poor cylinder making
- Uneven loading

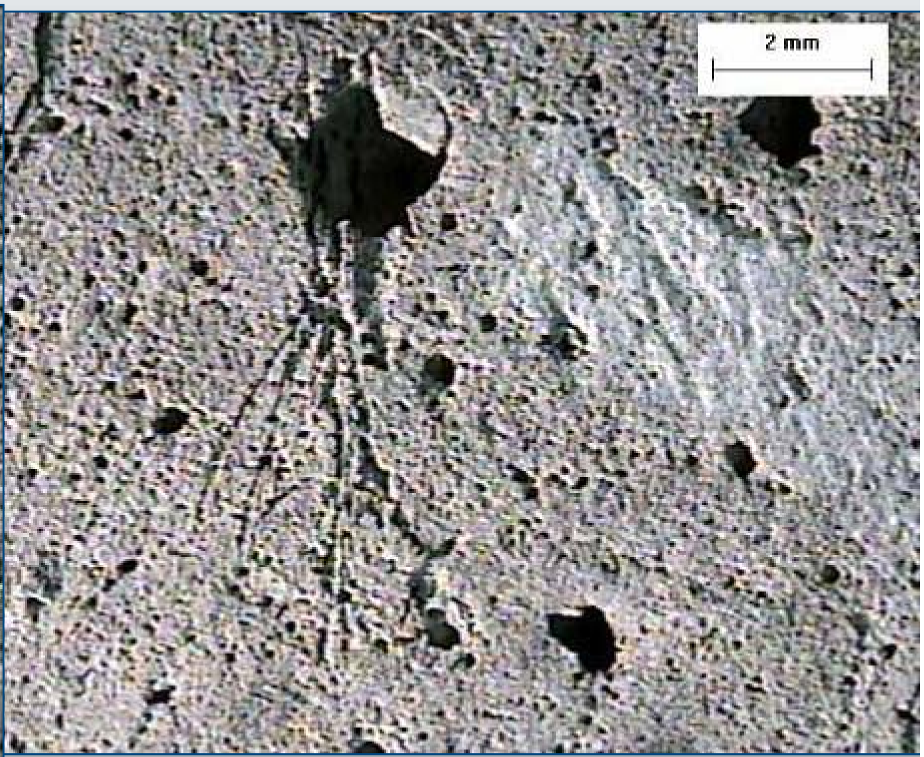
Poor Testing Practices

- Misuse of pad caps
- Poor sulfur caps
- C 617 specification states
  - 1/4 in (6 mm) max average thickness
  - 5/16 in (8 mm) maximum thickness of any part of the cap

Poor Field Curing (Early Age Freezing)

- Causes reduced strength and increased porosity
- Temperatures below 14ºF, hydration and strength gain STOP



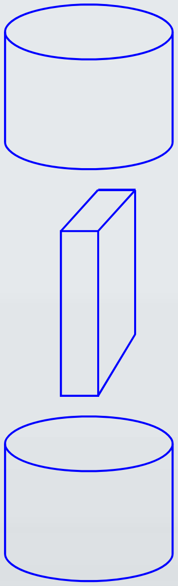


Cylinder was made, cured, and tested correctly…

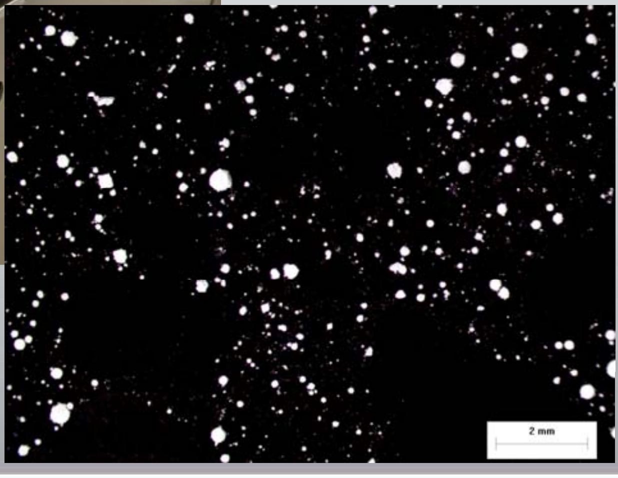
- Color
- Texture
- Paste/aggregate bond

Polished Sections

Roughly ¾” thick
4” X 4”



Air Void System



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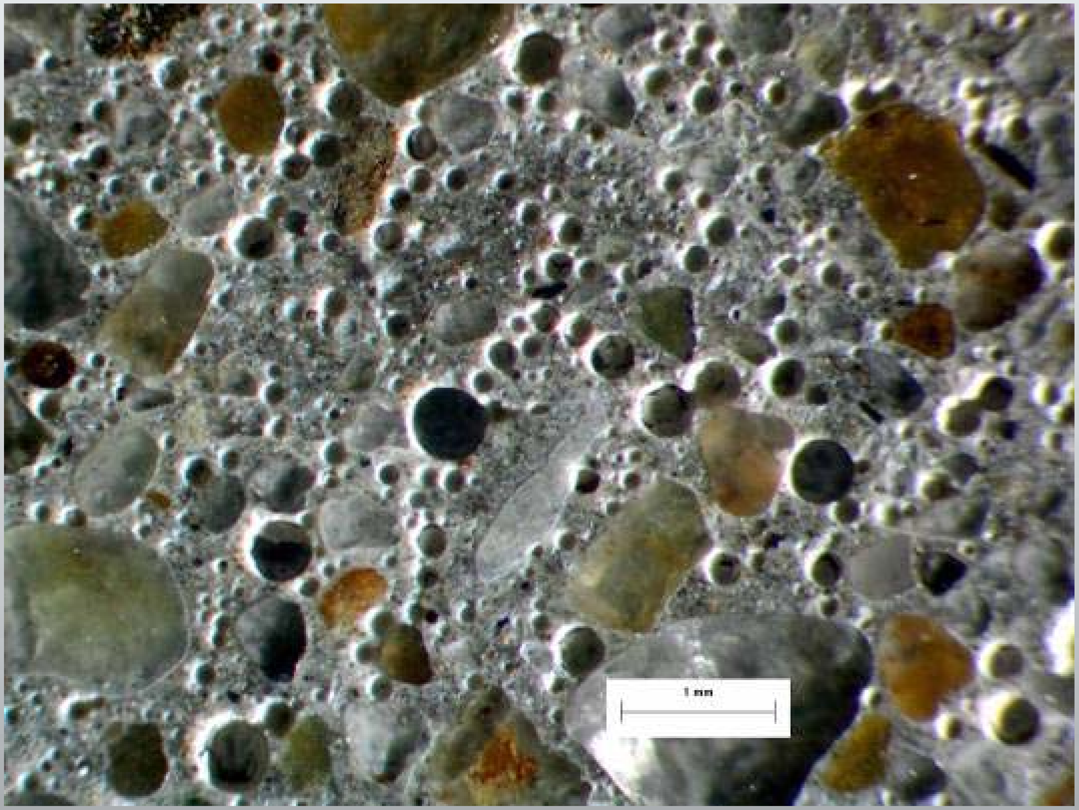
Air Void Parameters

- Total Air Content – 6%
- Specific Surface – >600 in^2/in^3
- Spacing Factor – <0.008 in.

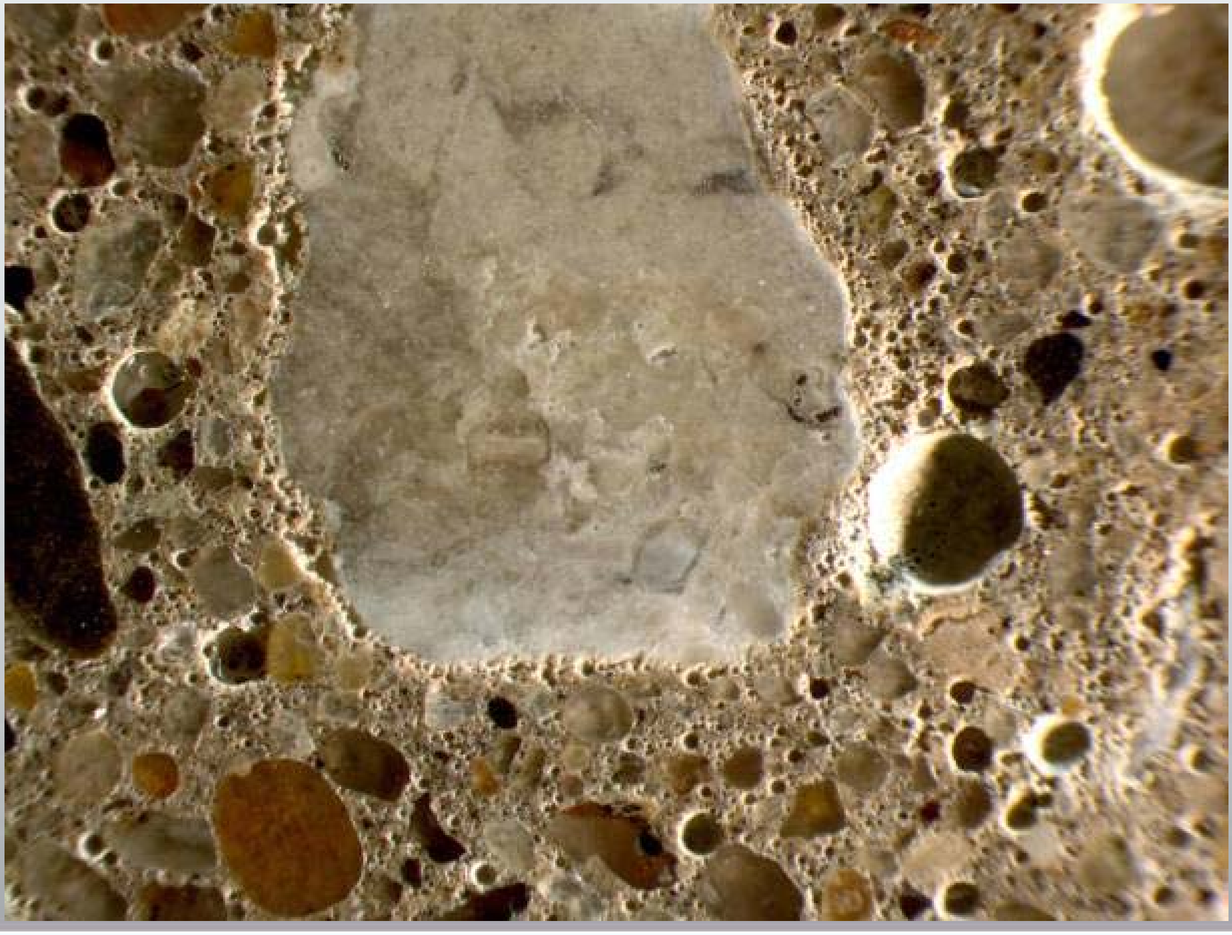
High Air Content

- For every 1% additional air, you lose 5% strength
- 10% air = 800 psi (in a 4000 psi mix with 6% design air)



Air Void Clustering

- Causes poor paste/aggregate bond

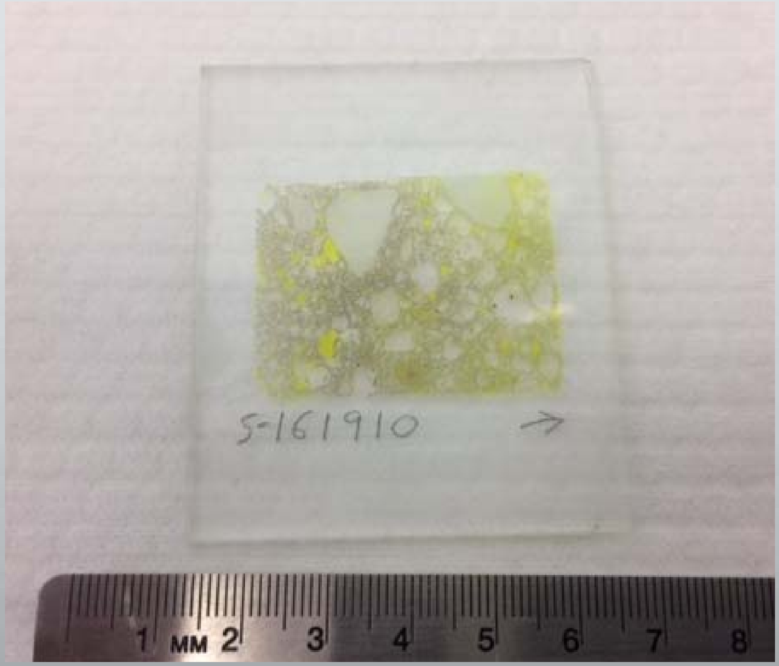


Thin Sections - What is a Thin Section?

- Piece of rock (or concrete, masonry, etc.) is glued to a glass slide
- Cut to 0.5 mm thickness
- Ground down to ~20 microns thickness

Thin Sections

- Petrographic microscope (polarizing microscope or transmitted light microscope)



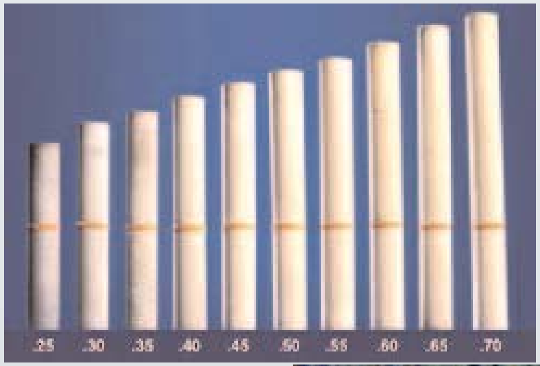
Thin Sections

- Paste
  - Contents (residual cement, fly ash, slag, etc)
  - Distribution (uneven – retempering)
  - Hydration products (calcium hydroxide, etc)
- Aggregate – dirty

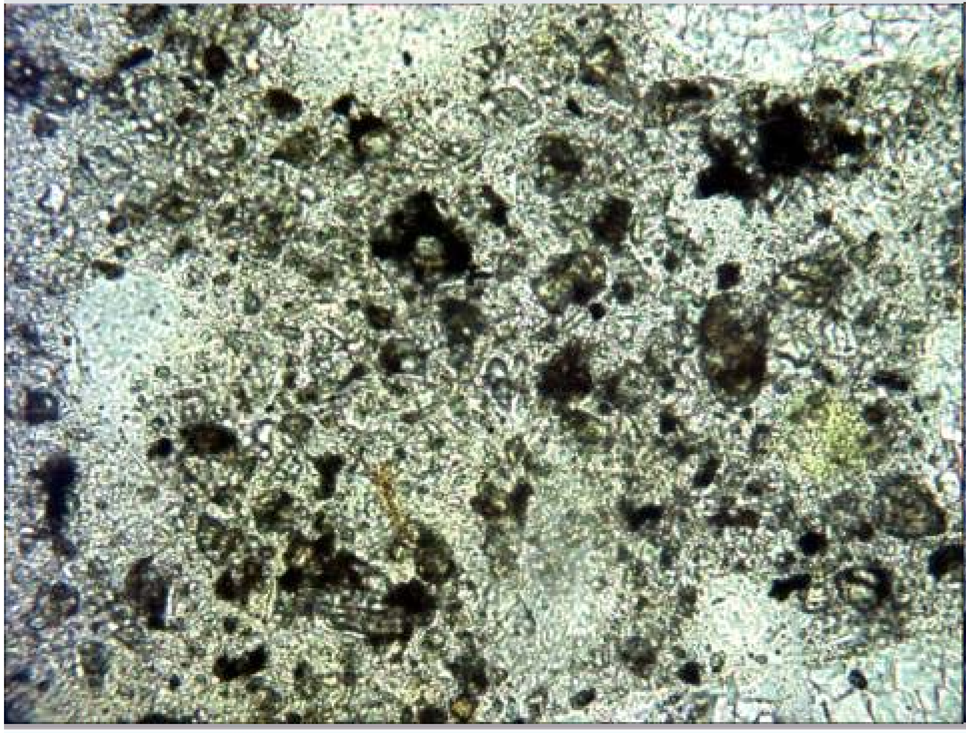
Estimate of W/CM ratio

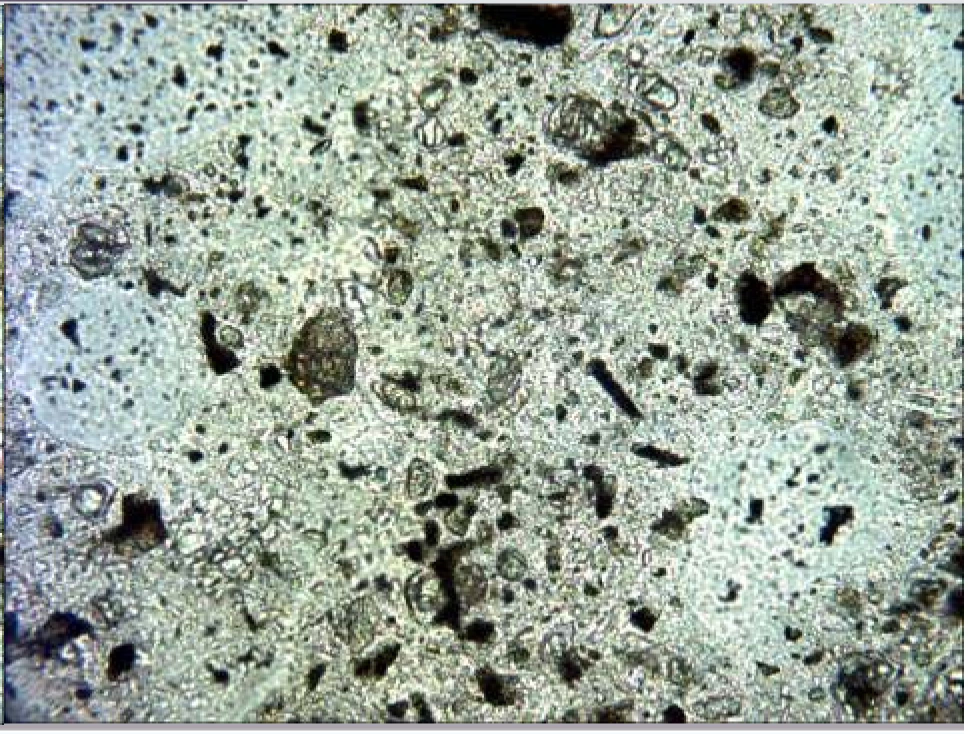
- Thin Section:
  - Amount and distribution of residual cement particles (and supplementary cementitious materials)
  - Comparison to standards
- In hand sample:
  - Color, Texture, and Luster of paste
  - Hardness of paste

Residual Cement Particles



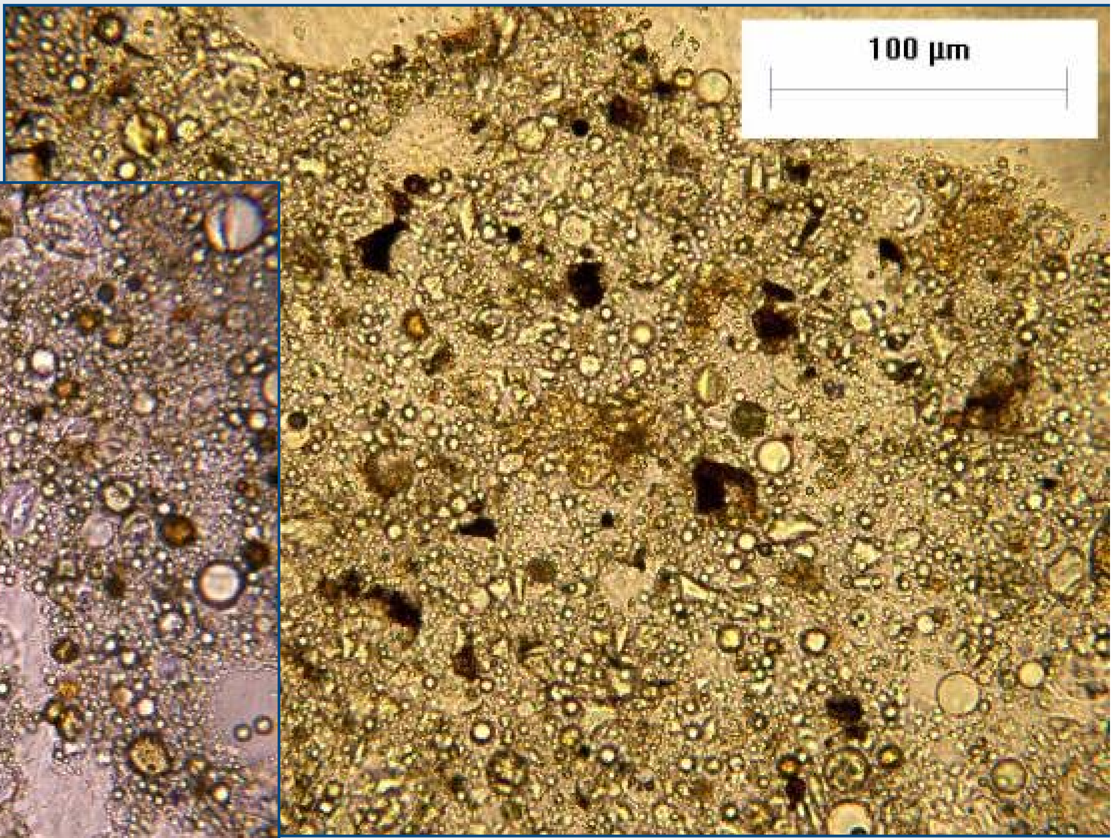
- Low w/c ratio ~0.40
- High w/c ratio ~ 0.60

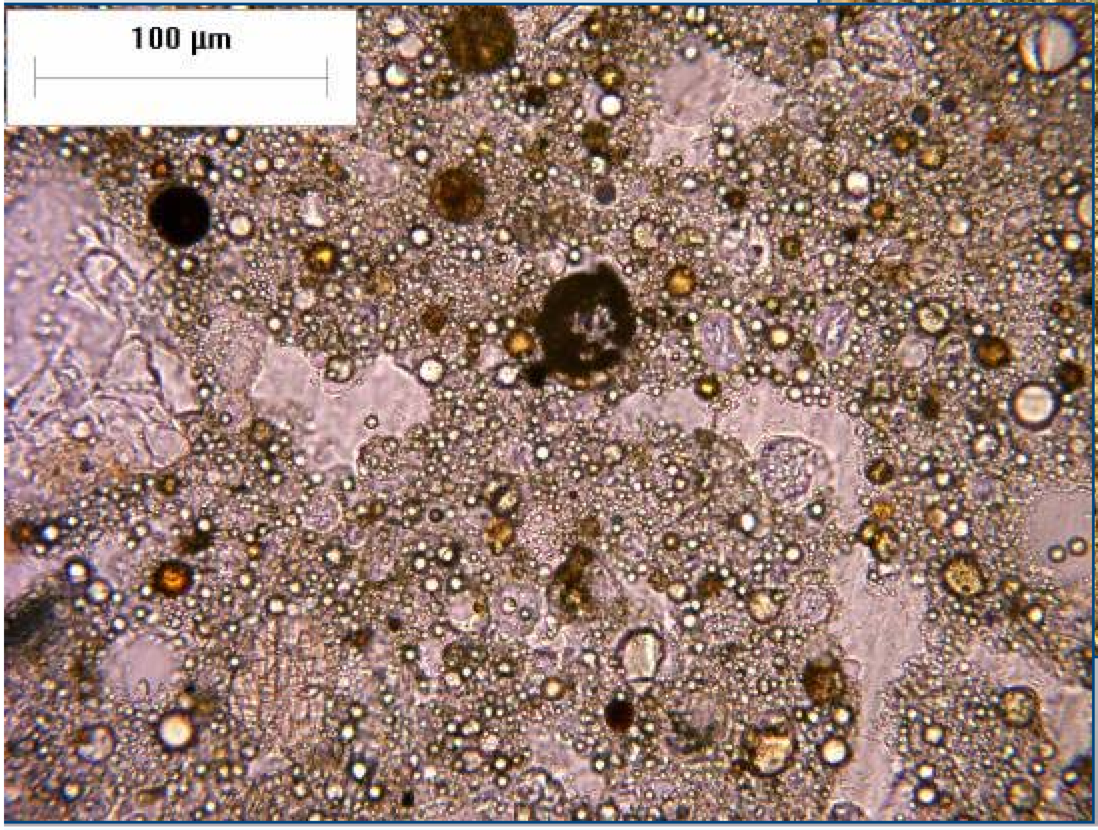




Overdose of Fly Ash

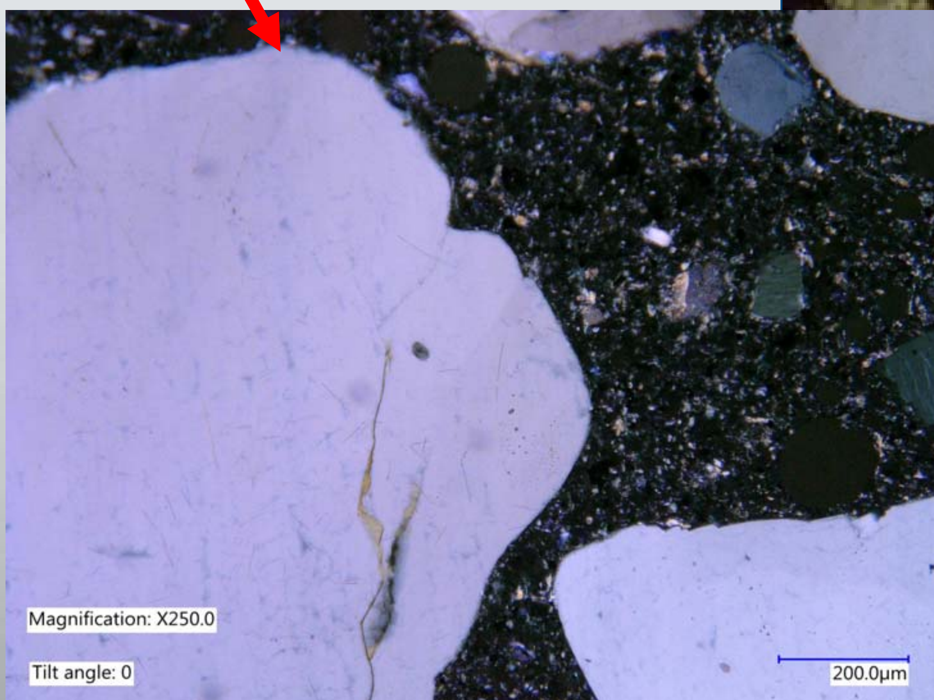
- Low strength
- Retarded set

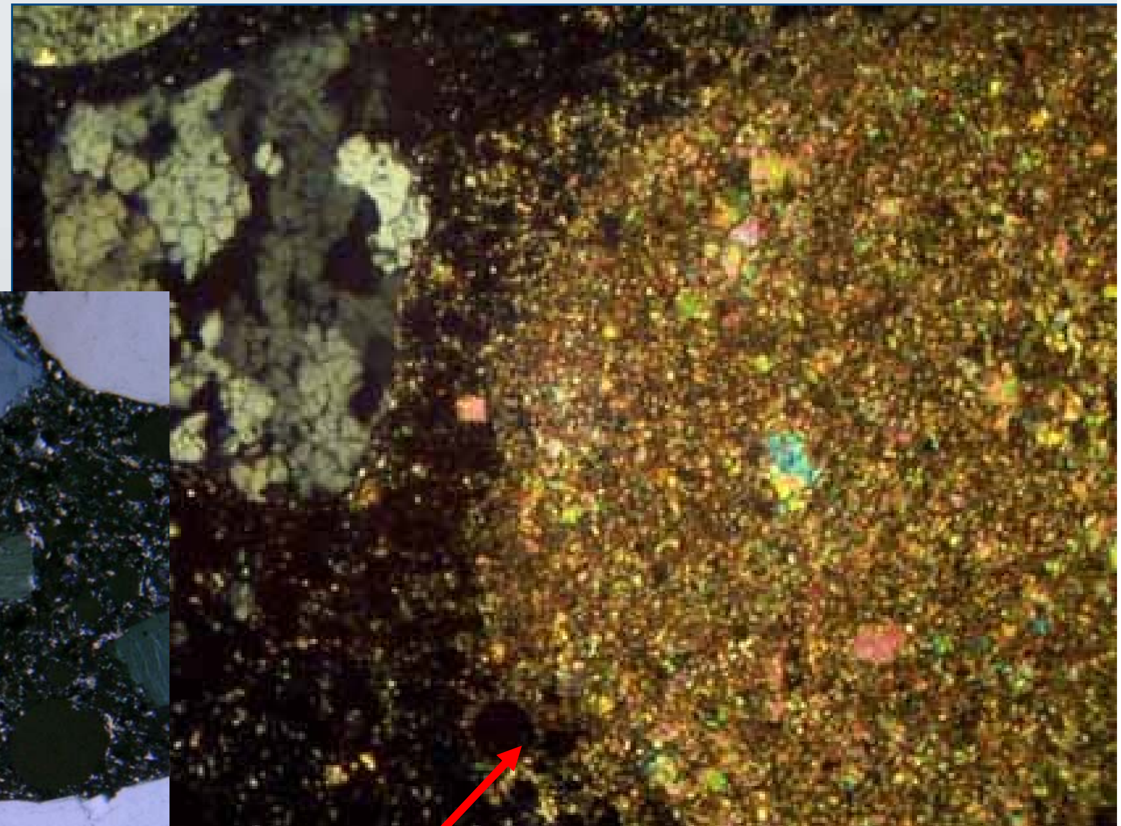




Dirty/Dusty Aggregate

Clean Aggregate



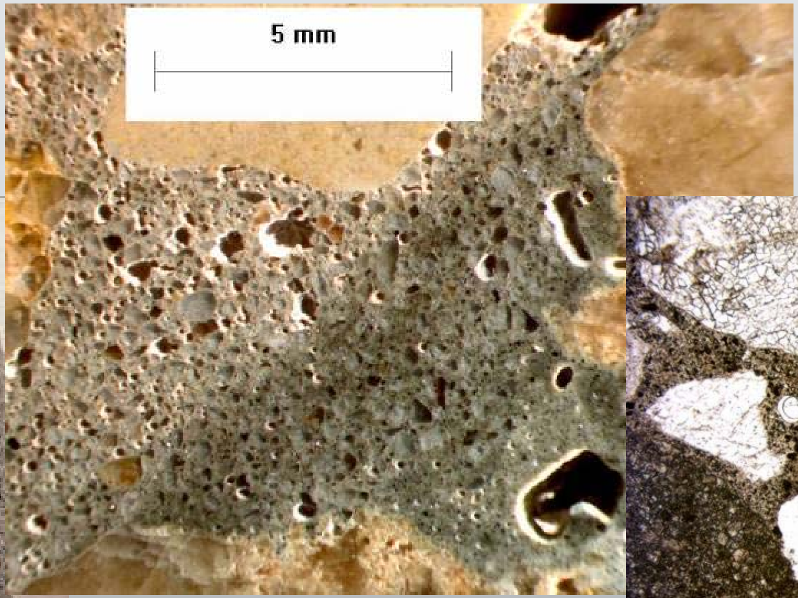


Dirty Aggregate

Retempering

- All other things being equal, lighter colored paste = higher w/c ratio
- Inhomogenious distribution of cement particles in paste

0.35 vs 0.55



Perpetrator - Low Strength

- Evidence observed in as received sample, polished sections and thin sections
- Usually not just one suspect, can be a combination of several
- Example:
  - Addition of water at jobsite (retempering) lead to:
    - Air void clustering
    - Higher than designed air content
    - Higher than designed w/cm ratio
  - Then poor cylinder making resulted in:
    - Uneven cylinders
  - Poor testing practices led to:
    - Uneven sulfur capping – uneven loading
    - Erroneous compressive strength results?

Concrete Scene Investigation #2 Surface Deterioration

- Scaling

Scaling

- Usual Suspects:
  - High w/cm ratio (>0.45)
  - Poor air void system (<6%, specific surface <600 in^2/in^3, spacing factor >0.008 in)
  - Improper finishing (before bleed water evaporates, over-working the surface)
  - Proper drainage (1/8 in/linear foot)
  - Cement content <564 lbs/yd^3 (ASTM C 1084)
  - Less than 30 days of drying before exposure to deicing chemicals (AASHTO T260)

Observations/Examination

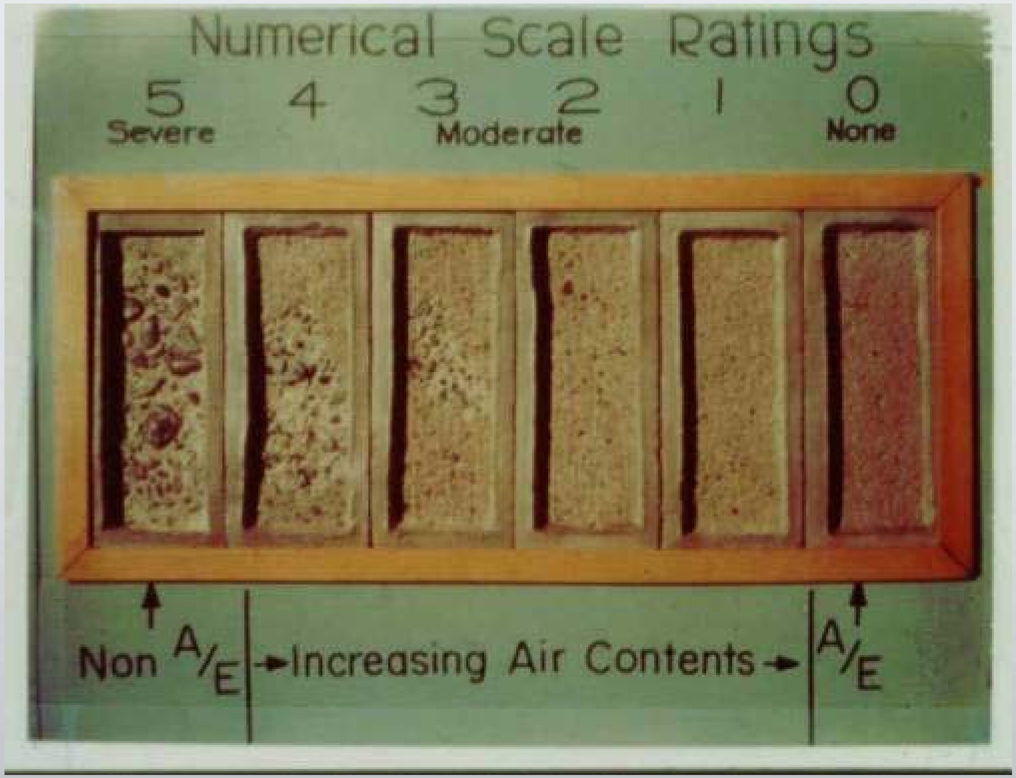


Image Source: PCA

- W/CM Ratio
  - Thin Section
- Air Void System
  - Polished Section
- Finishing
  - Both thin sections and polished sections

Finishing

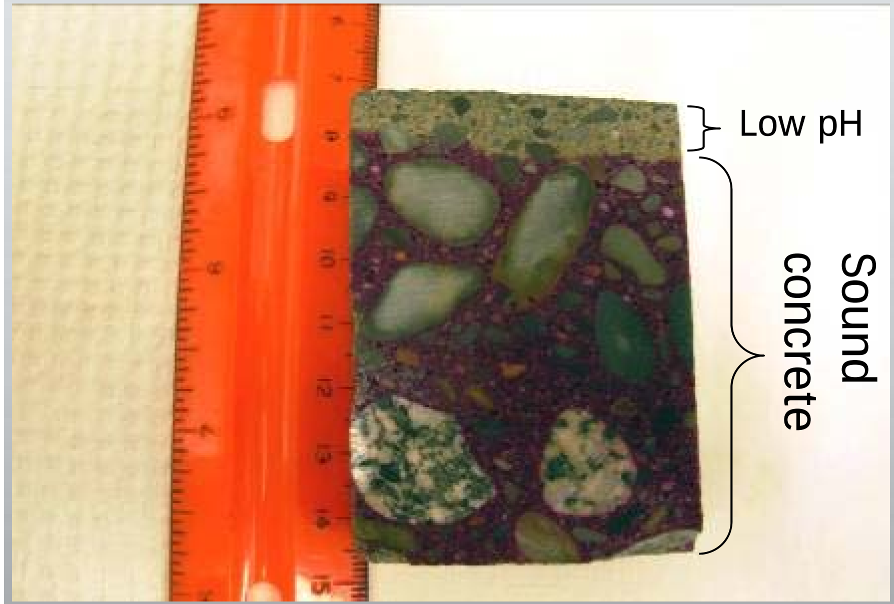
- Finishing while bleed water is present/adding water "blessing"
  - Increases w/cm ratio at the surface
  - Increases porosity and likelihood of the ingress of moisture and salt solutions
  - Reduces abrasion resistance
- Over-finishing
  - Densifies surface and brings up excess paste
  - Decreases air voids at surface

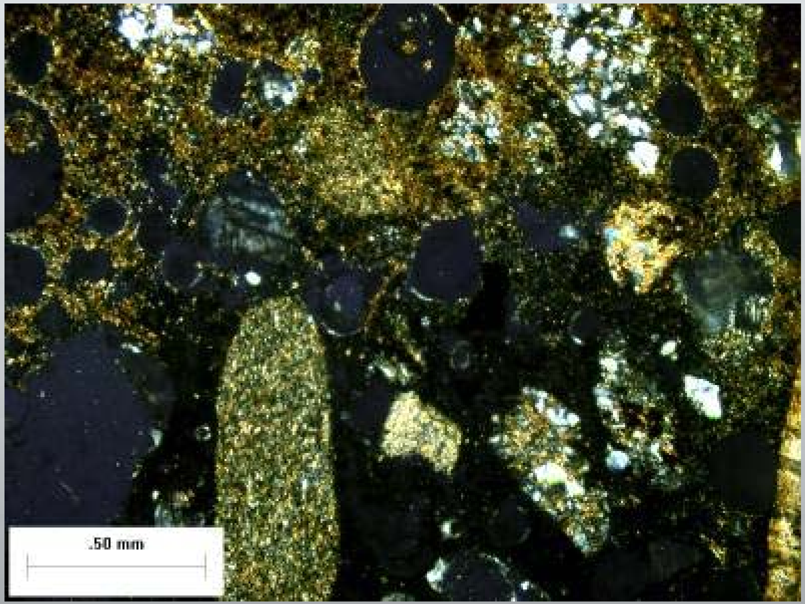
Carbonation

Indication of porosity

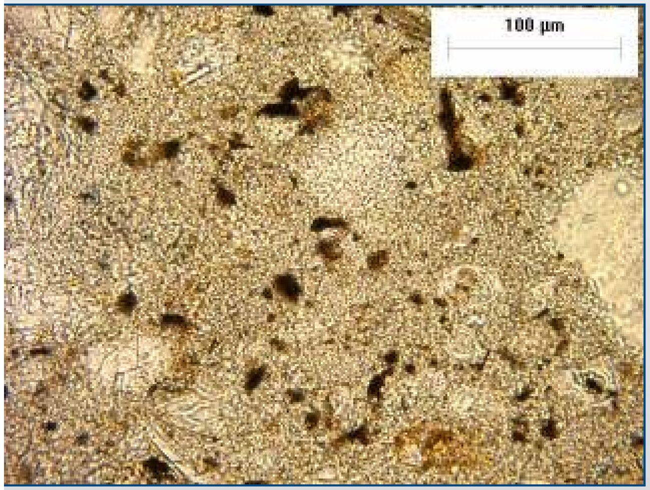
- Phenolphthalein (indicator) changes to red at pH of ~8.6 to 10 (sound concrete ~12 to 13).
- $Ca(OH)_2 + CO_2 = CaCO_3 + H_2O$

- Related to poor finishing, poor curing, and w/cm ratio

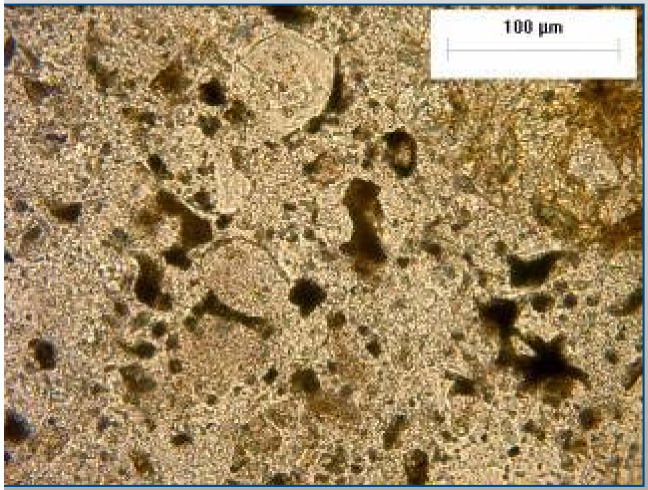




Blessing/Working in Bleed Water

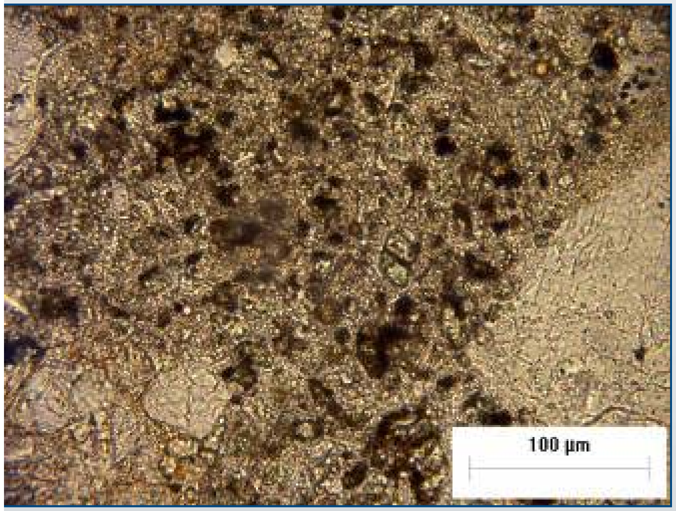


- Thin section at surface
- W/CM ratio ~ 0.57
- Higher porosity

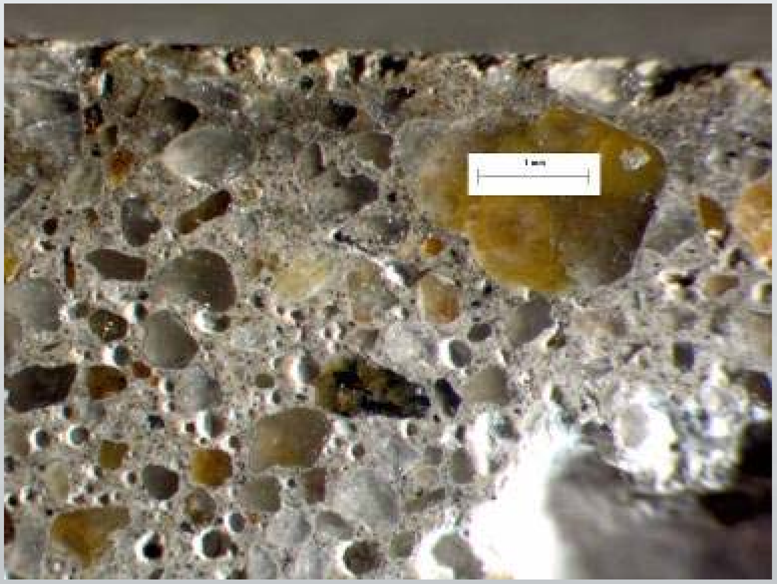


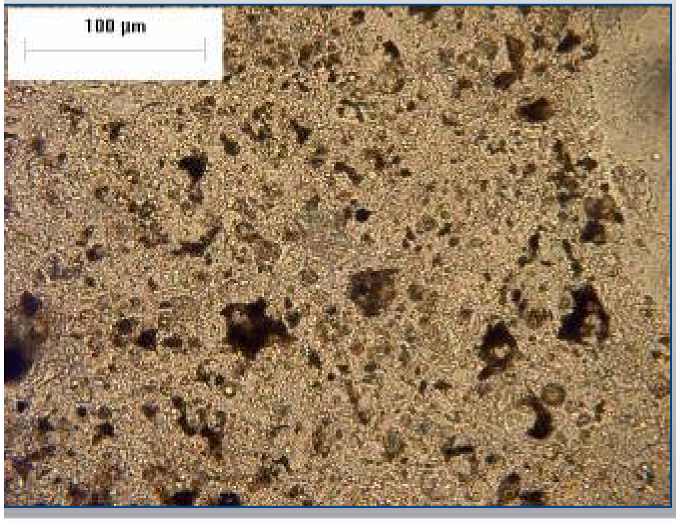
- Thin section at depth
- W/CM ratio ~ 0.47

Excessive Finishing



- Thin section at surface
- W/CM ratio ~ 0.40

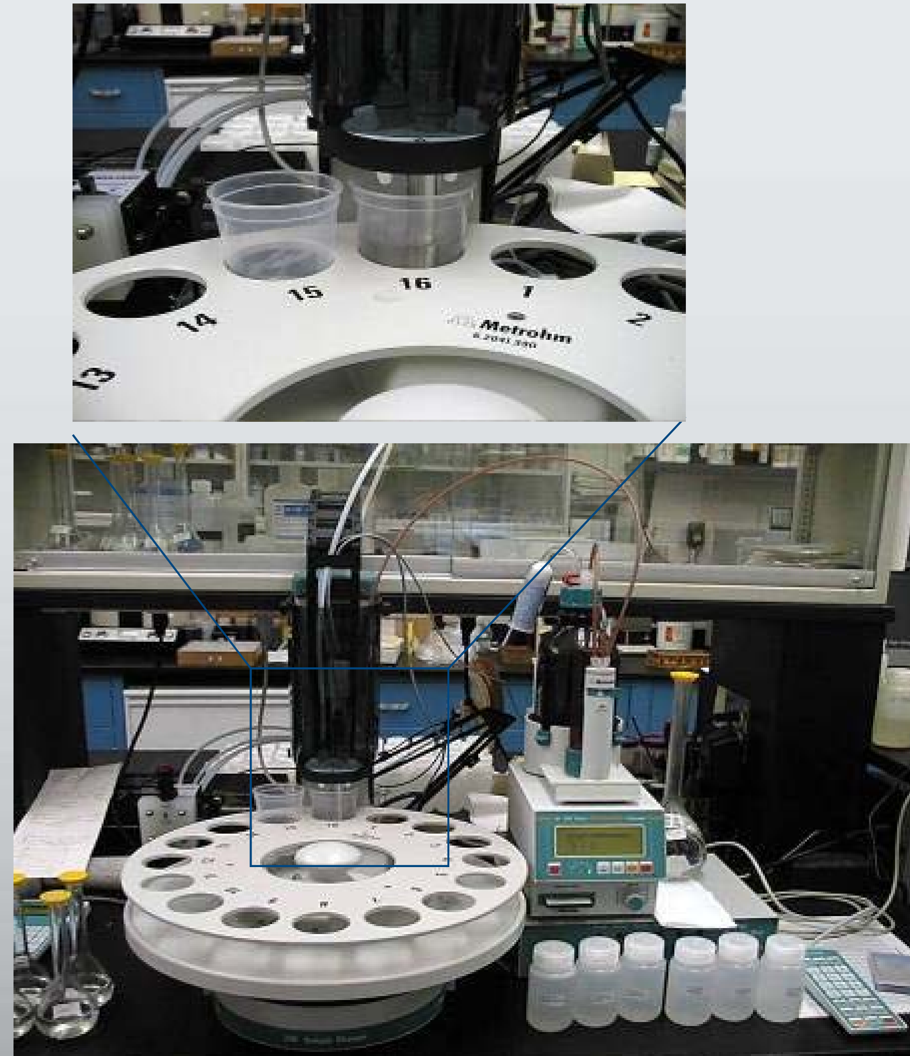




- Thin section at depth
- W/CM ratio ~0.55

Chemical Tests

- Cement Content (ASTM C1084)
  - Concrete sample is crushed, acid and base digested, residues measured. Calculations determine the amount of silica, and calcium which are related to the amount of cement in the mix.
- Chloride Content (AASHTO T260)
  - Concrete sample is crushed, acid digested, then chloride present is precipitated and detected using an electrode. This is related to the total amount of chloride ions in the sample.



Perpetrator - Scaling

- Theory based on evidence from observation of field reports, polished sections, thin sections, and chemical data.
- Usually a combination of mix design, placing, finishing, curing, and treatment after placed.

Concrete Scene Investigation #3 Durability Issues

- Alkali-silica reaction (ASR)
- D-Cracking

ASR

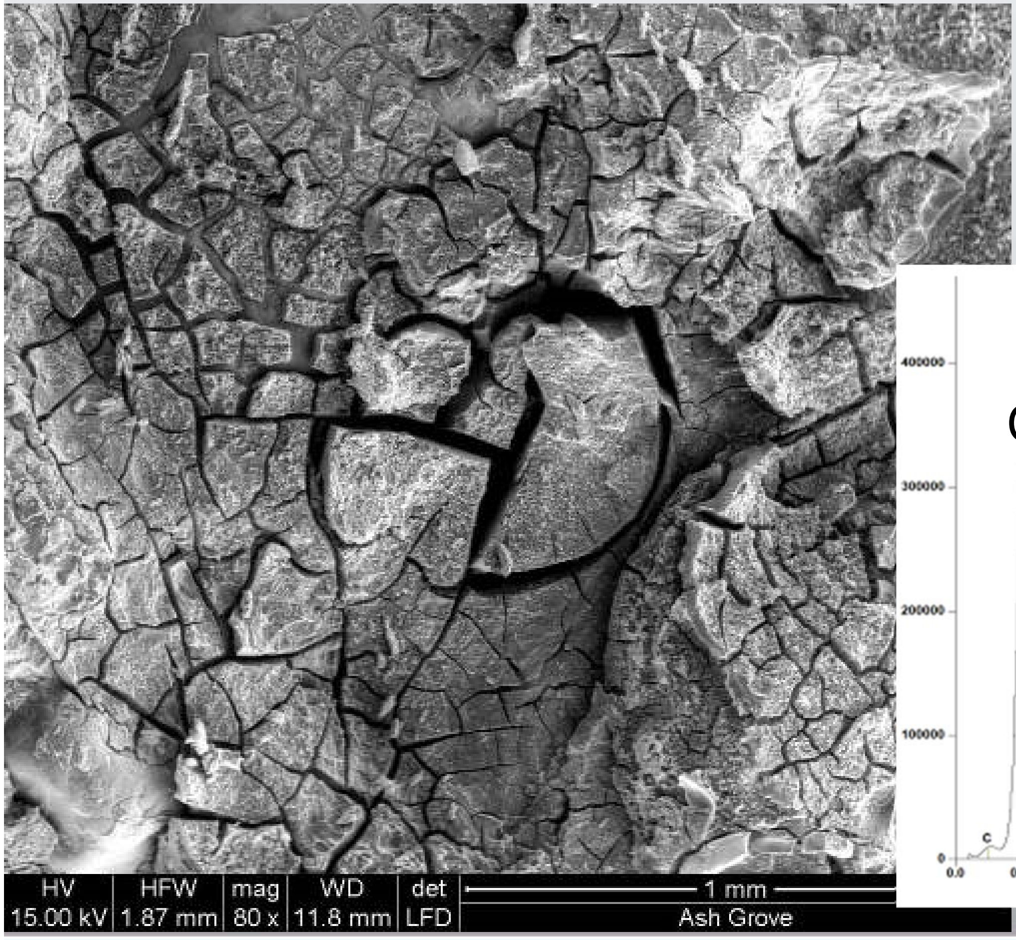
- Map cracked surface
- White or clear gel
- Cracking through paste and aggregates

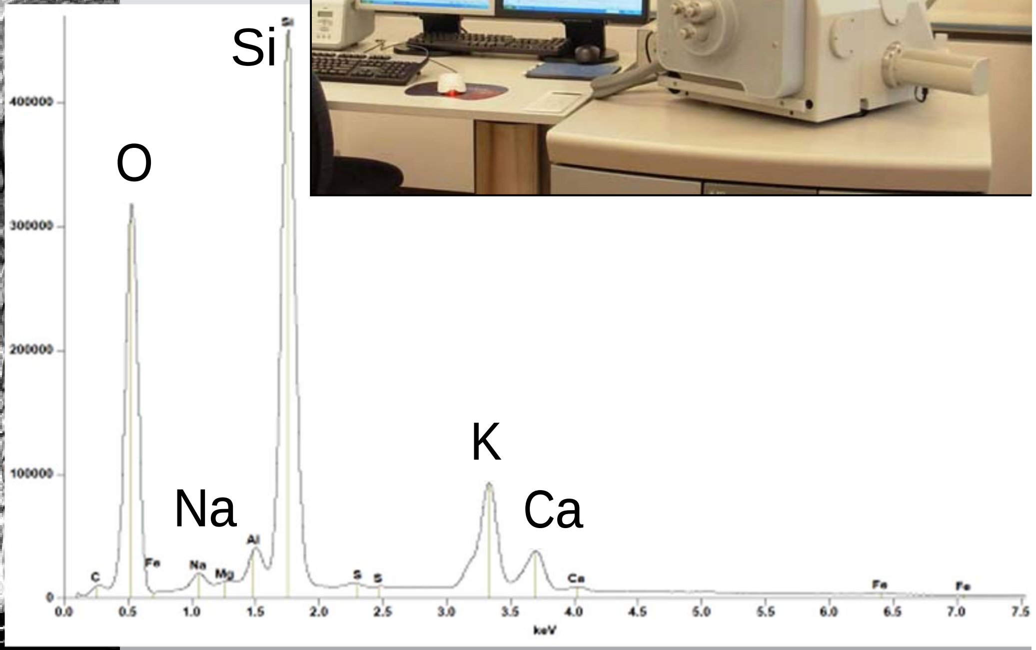
ASR Detection: Staining Methods

- Uranyl Acetate
- ASR Detect™

Potassium/Sodium Rich C-S-H Gel

SEM/EDS Analysis



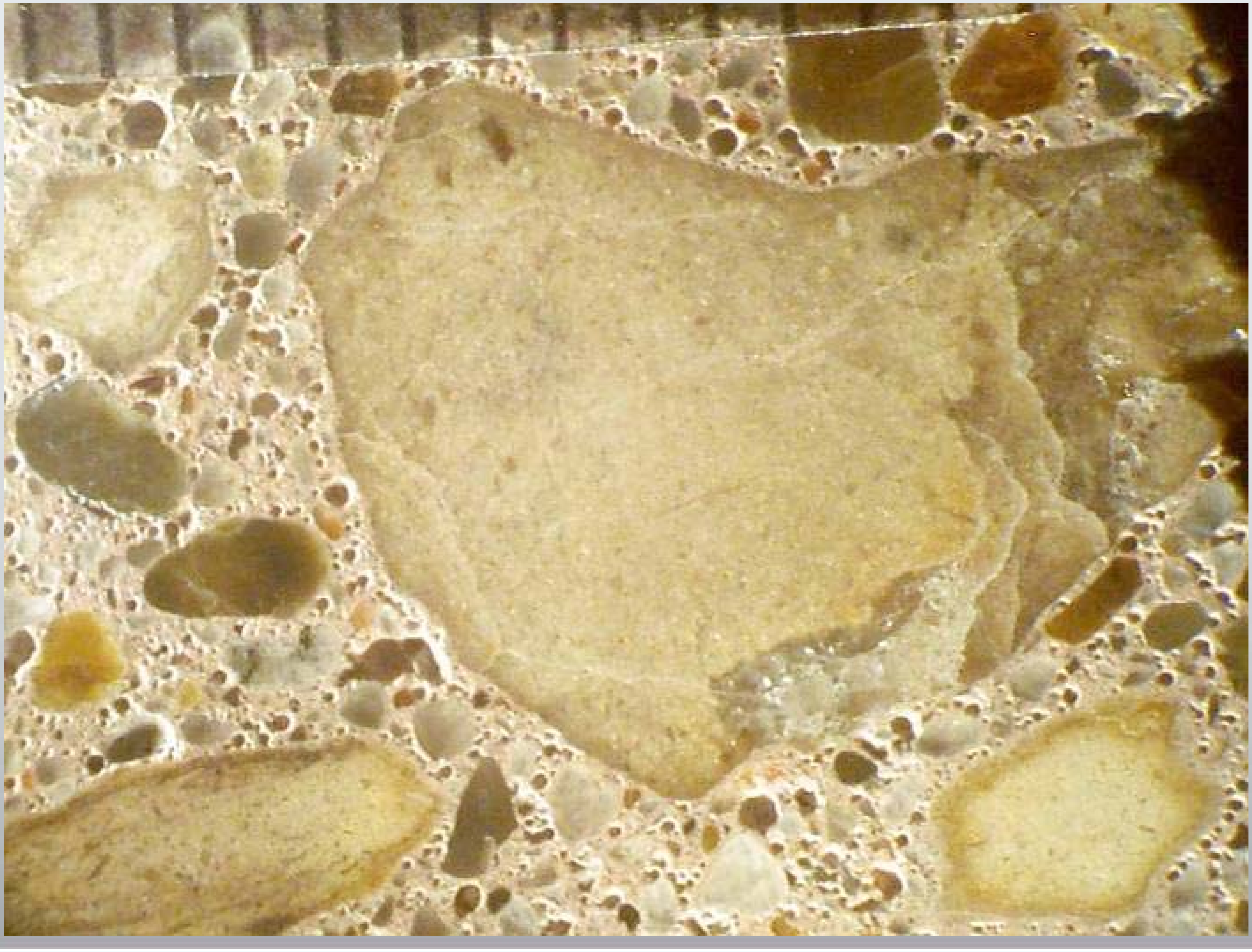


D-Cracking

- Freeze/thaw damage to aggregates

Figure 13.5: Split and cracked carbonate rock particles after 5 cycles of freezing and thawing. Typical cracks along particle edges. (Magn. 0.35X; Photo by G. Woda)

Polished section



Conclusions

- Many variables affect concrete quality
- Petrographic analysis is a powerful tool but has limitations
  - Admixture types and dosage rates cannot be identified petrographically
  - Slump cannot be determined
- Additional information is helpful
  - Concrete age
  - Curing conditions
  - Mix design
- Good sample selection is important (i.e. taking cores from the problem area and a good area)

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