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 $\frac{3}{4}''$ thick
4'' X 4''
Air Void System
Air Void Parameters

- Total Air Content – 6%
- Specific Surface – >600 $\text{in}^2/\text{in}^3$
- 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

Magnification: X250.0
Tilt angle: 0

200.0µm

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Retempering

• All other things being equal, lighter colored paste = higher w/c ratio

• Inhomogeneous 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 in²/in³, 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/yd³ (ASTM C 1084)
  - Less than 30 days of drying before exposure to deicing chemicals (AASHTO T260)
Observations/Examination

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

Image Source: PCA
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).
- $\text{Ca(OH)}_2 + \text{CO}_2 = \text{CaCO}_3 + \text{H}_2\text{O}$

- 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

[Image of SEM/EDS analysis with elements Si, O, Na, K, Ca]
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)