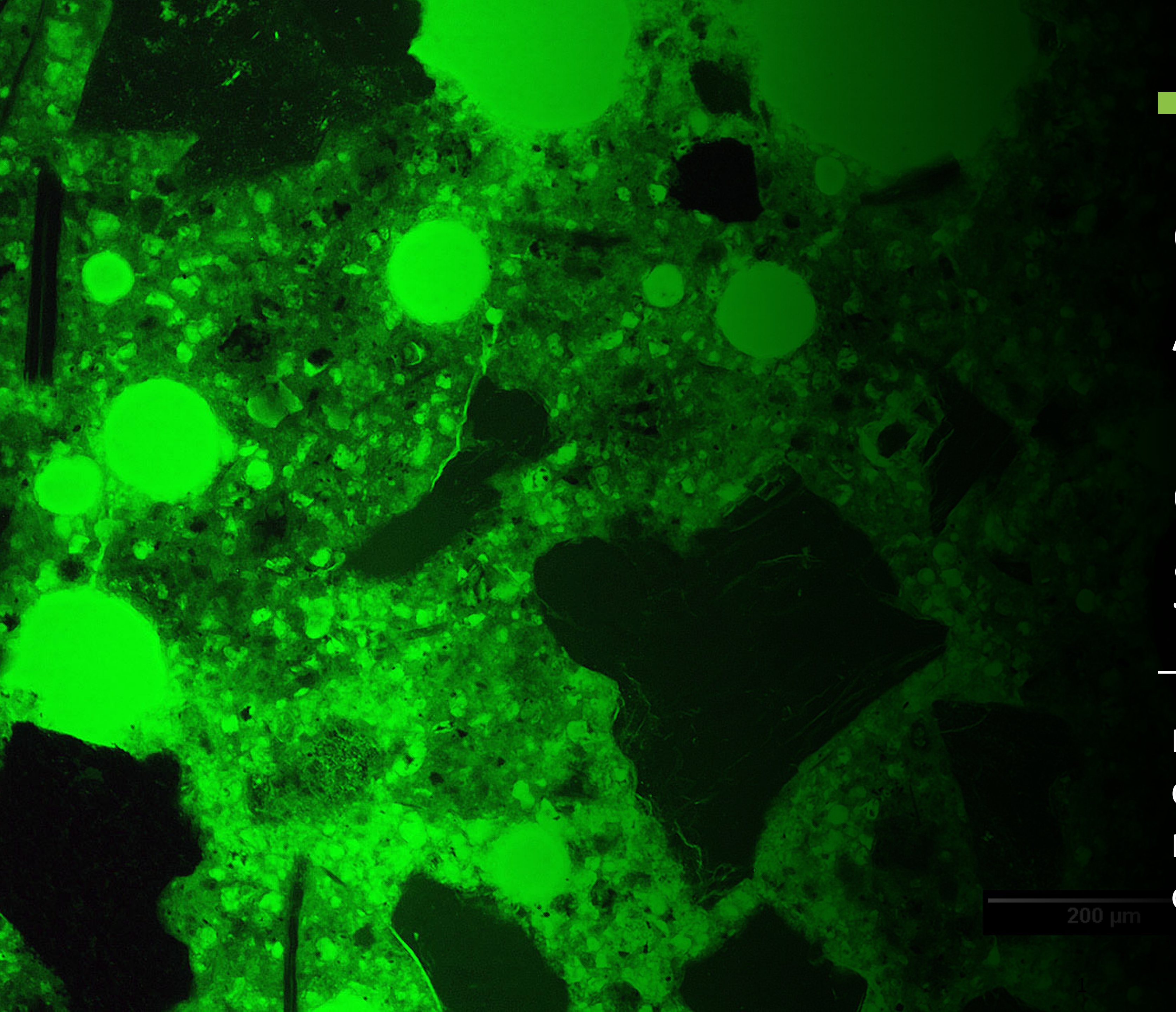

Quality Assurance of Hardened Concrete—Case Studies

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Chunyu (Joe) Qiao, Ph.D.

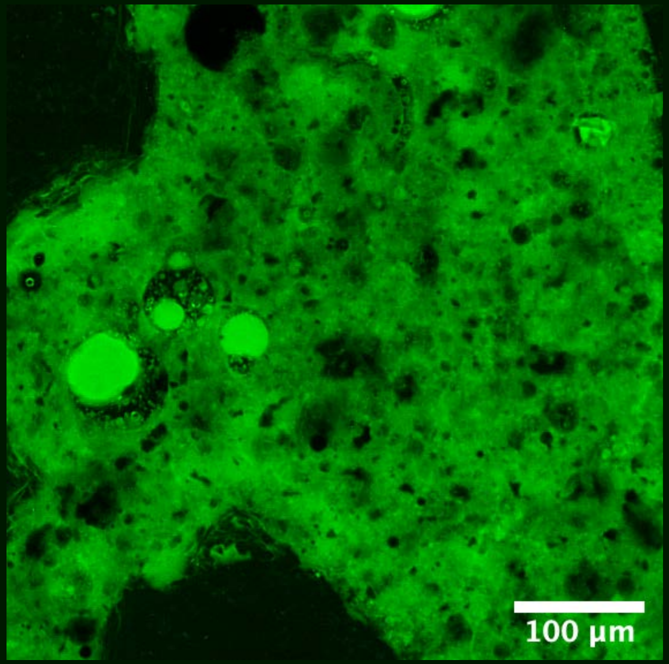
Meredith Strow

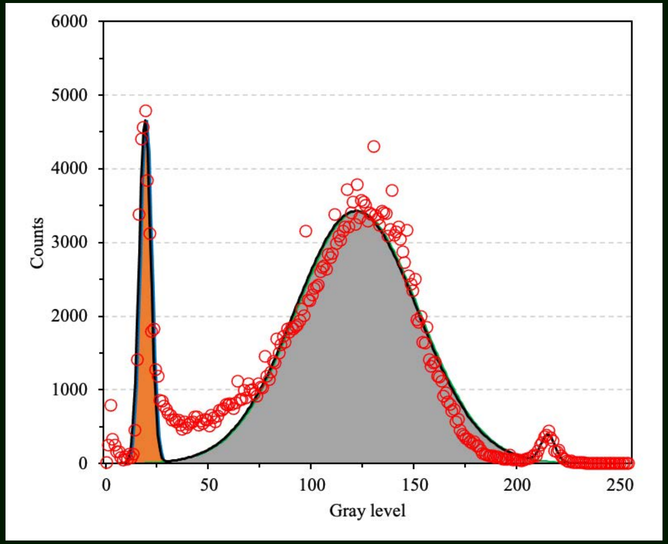
Gaines Green

DRP PETROGRAPHIC & MATERIALS INVESTIGATIONS

Outline

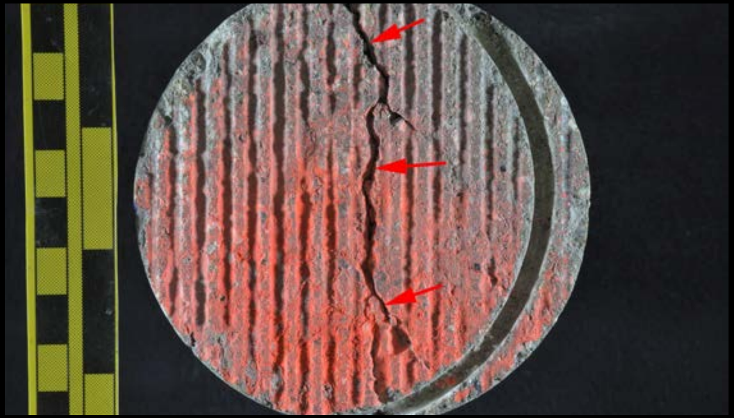
- QA Situations
- Standard Approaches
- Fluorescence Microscopy
- Case Studies
- Q&A

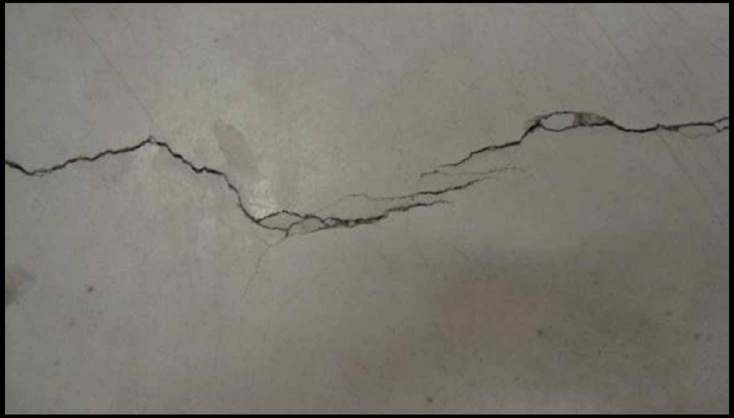




PETROGRAPHIC & MATERIALS INVESTIGATIONS

Common QA Drivers





- Early Age Cracking
- Surface Defects
- Strength
- Specifications
- New Mixtures & Products

Standard QA Methodologies

- ASTM C457
  - Air Void Systems
  - Volumetric Proportions
- ASTM C856
  - Aggregates (size, gradation, distribution…)
  - Cementitious matrix (cements/scm, hydration, w/cm…)
  - Voids (entrained, entrapped, water, consolidation)
- ASTM C1723
  - Cementitious matrix (cements/scm, hydration, w/cm…)

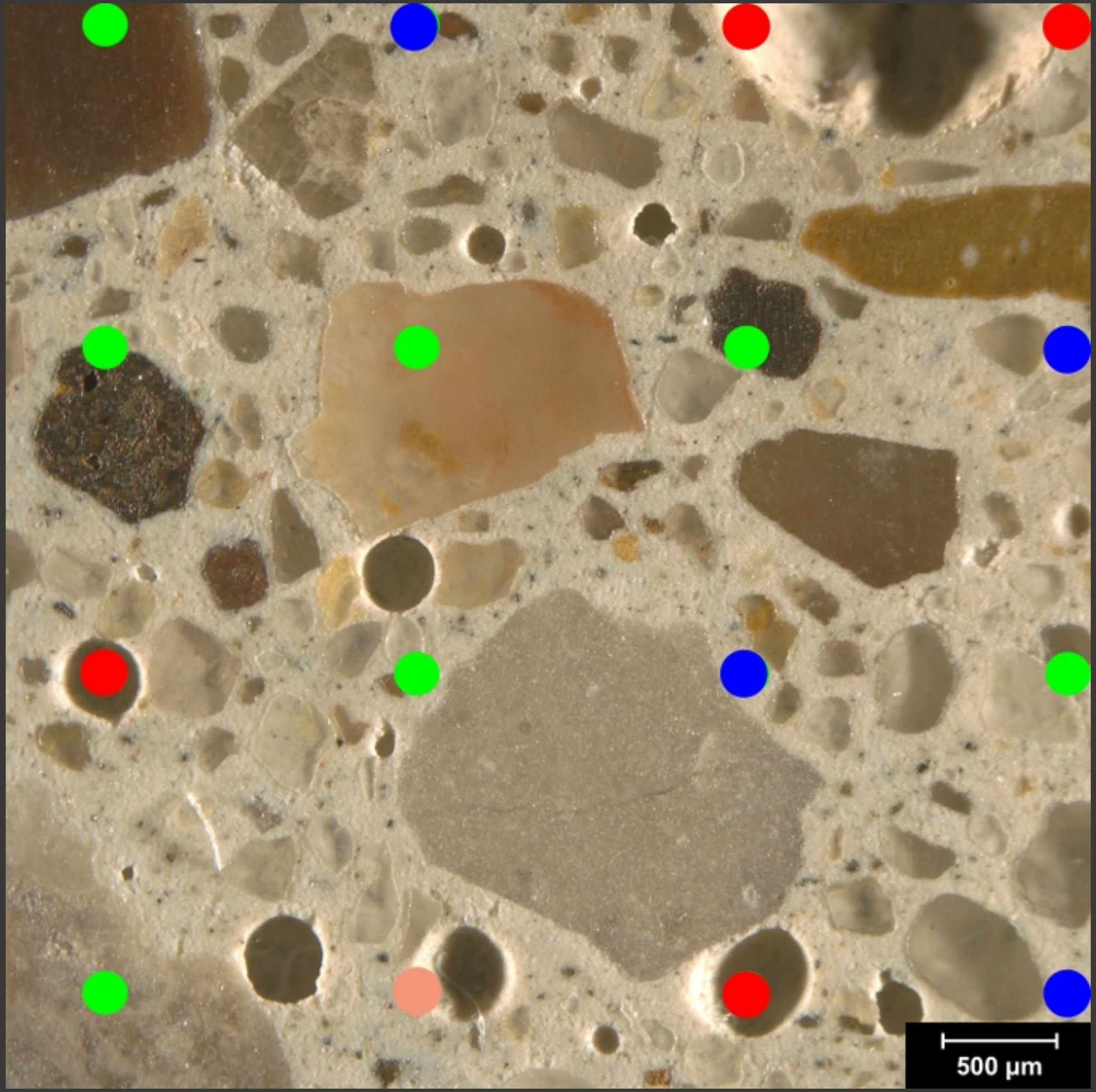
Volumetric Proportioning (C457)

Measured Parameters

Aggregate Stops	918
Paste Stops (S_p)	367
Air Stops (S_a)	69
Total Stops (S_t)	1354

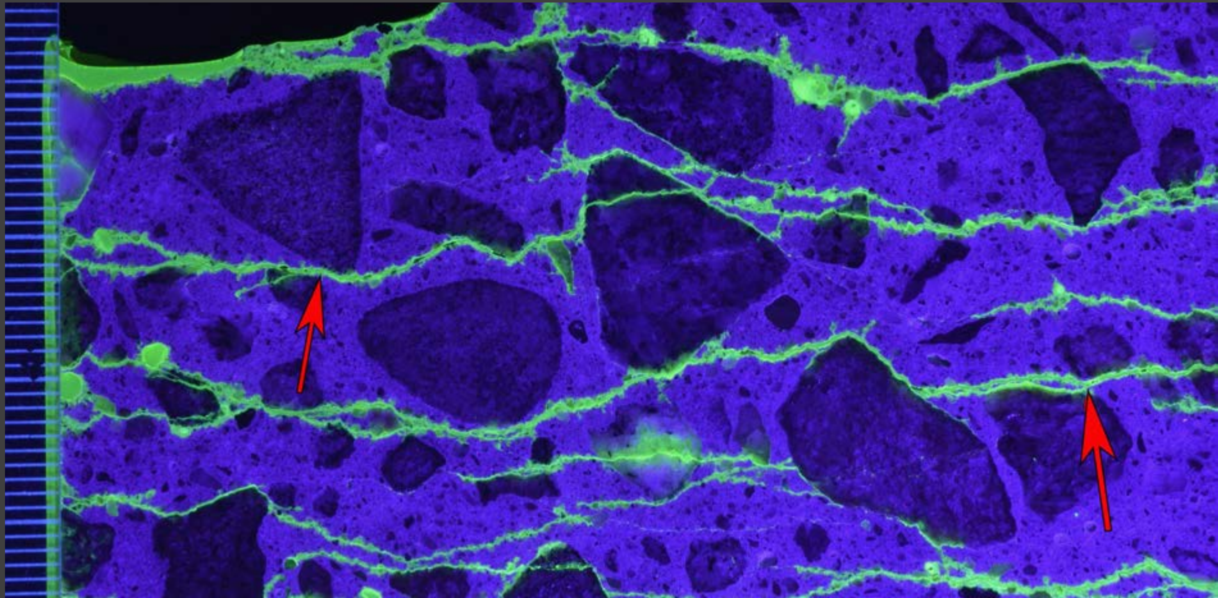
Calculated Parameters

Aggregate Content	67.8%
Paste Content (p)	27.1%
Air Content (A)	5.1%



Fluorescence Microscopy

- Very low viscosity epoxy with fluorescent dye
- Vacuum impregnation
- Polished slab
- Thin section

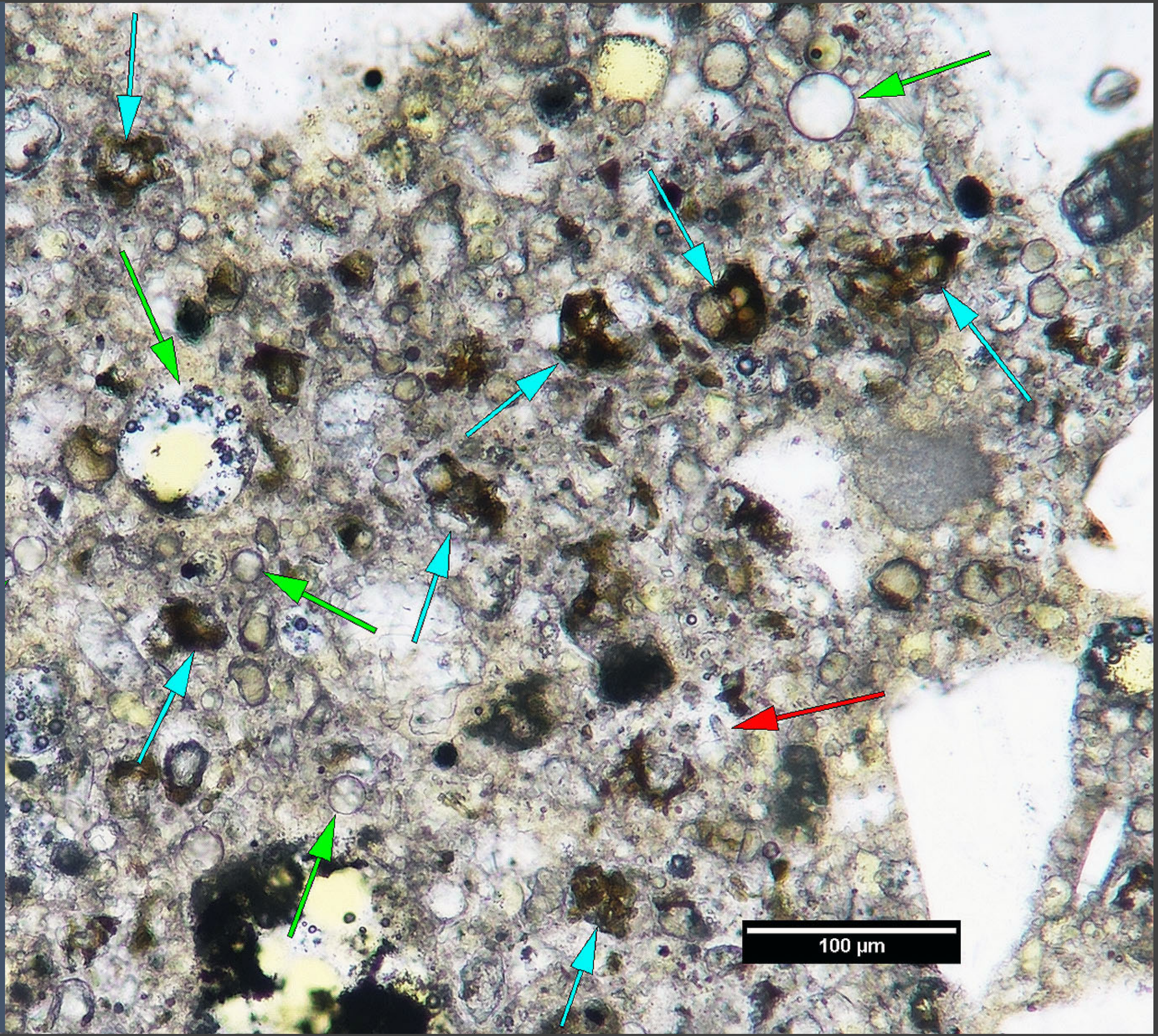


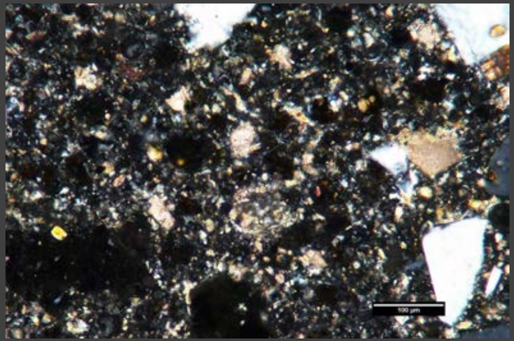
Fluorescent Thin Sections

- ~ 25 µm (1 mil) thick
- 38 x 65 mm (1.5 x 2.5 in.) area
- NT Build 361 (2nd Edition, 1999)

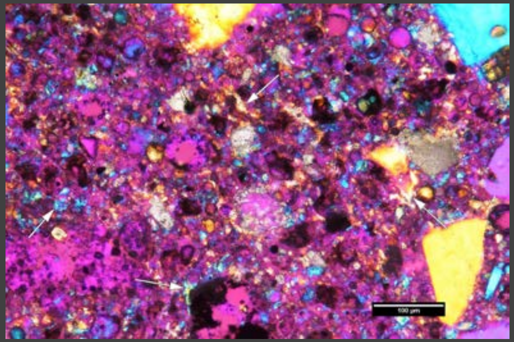
- ~ 25 µm (1 mil) thick
- 25 x 50 mm (1 x 2 in.) area

Conventional Thin Section Microscopy



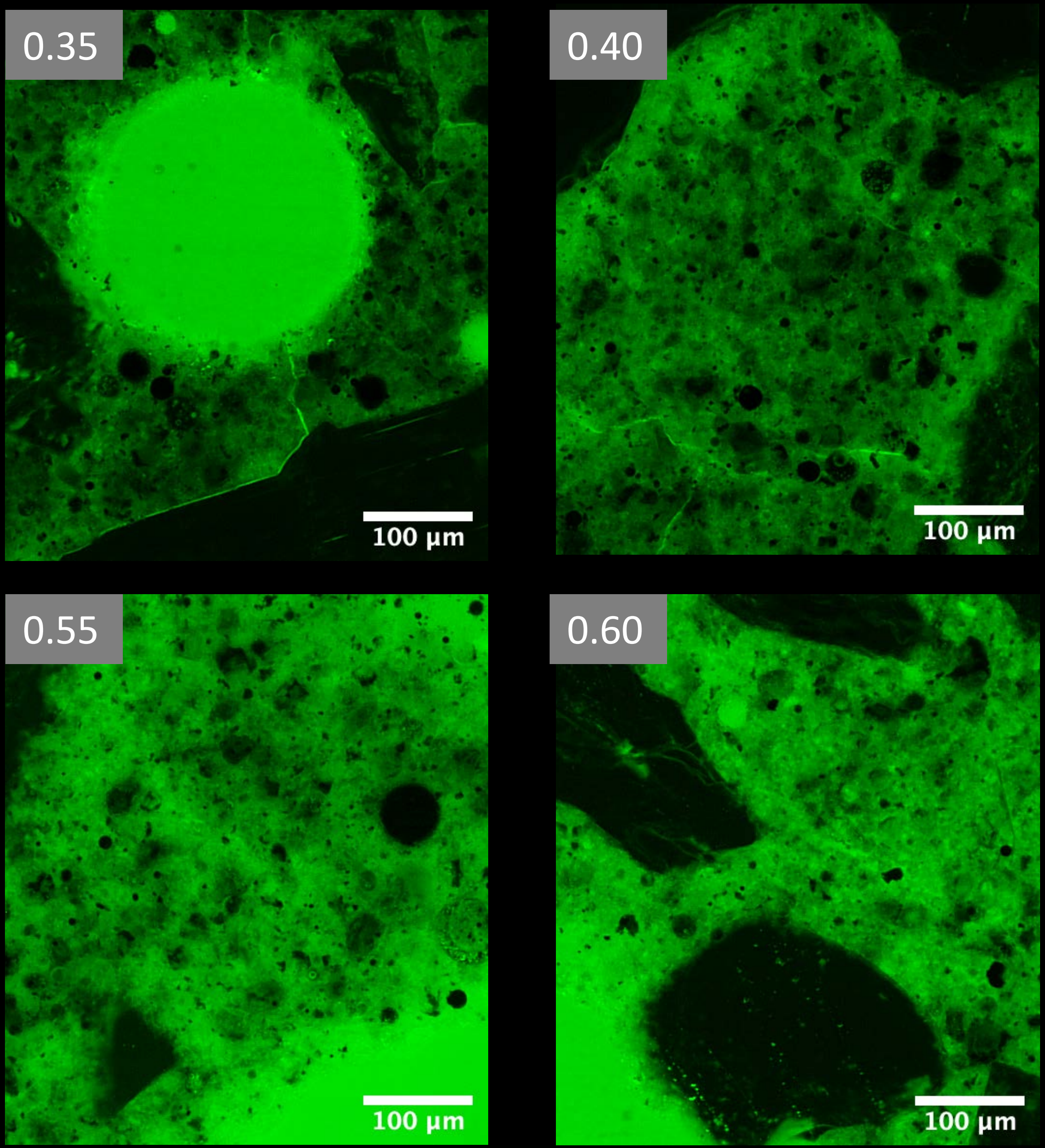


XPL



XPL+GYP

XPL+QRTR



Fluorescence Microscopy

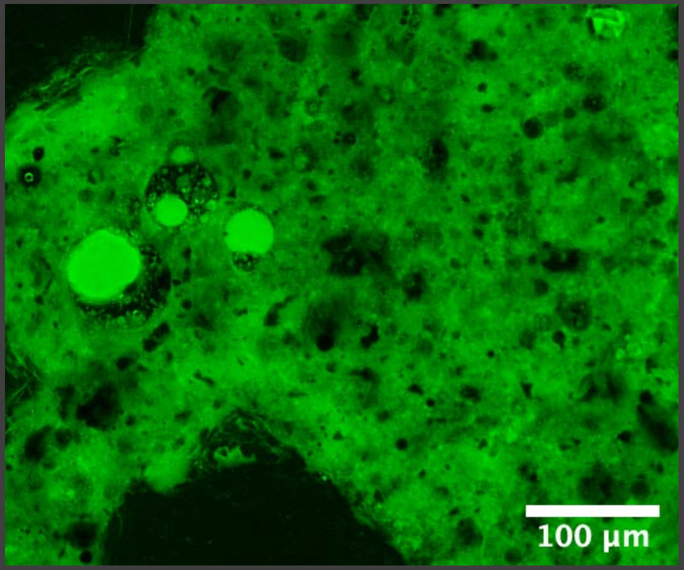
- Green tone is proportional to the capillary porosity and w/cm of the paste
- Aggregates have very low porosity (effectively zero) so show up as black
- Voids have high porosity (effectively 100%) so are very bright
- **Sample preparation is EVERYTHING**

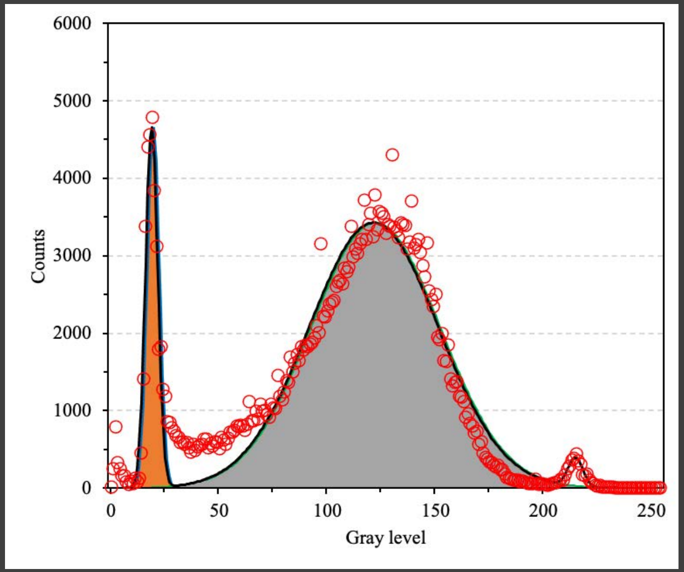
PETROGRAPHIC & MATERIALS INVESTIGATIONS

Image Analysis

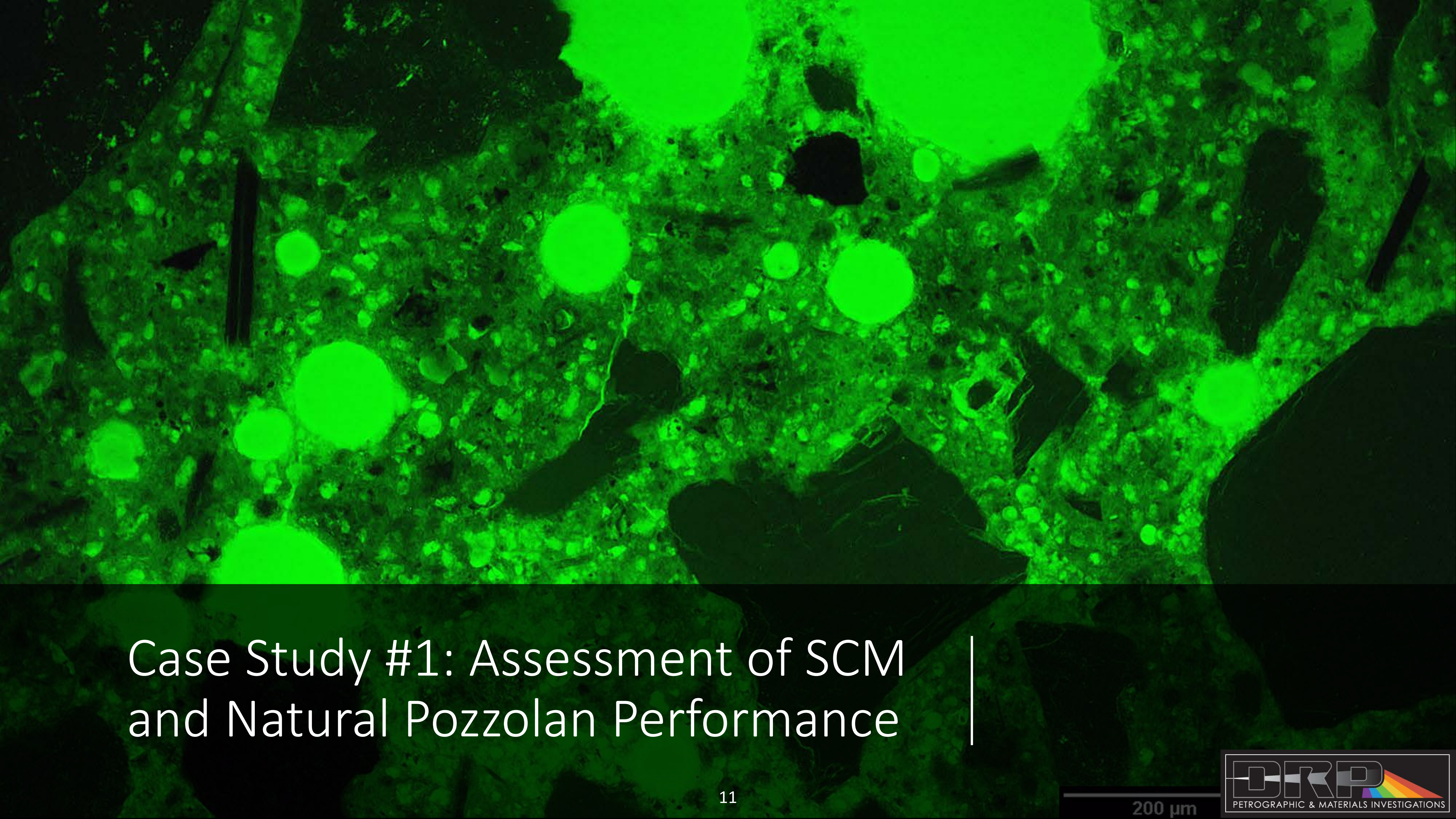
- Each pixel is a datapoint
- Standard Shareware (e.g., *Image J*) captures intensity on a pixel by pixel basis after image is binarized (B&W)
- Deconvolution of distributions using standard software
- The porosity of aggregate is 0, while the porosity of a void is 100%.
- Apparent capillary porosity (*CP*) of the paste by fluorescence microscopy (GL=gray level)

$$CP = \frac{GL_{paste} - GL_{aggregate}}{GL_{void} - GL_{aggregate}}$$





(after Lehman et al., 2006)



Case Study #1: Assessment of SCM and Natural Pozzolan Performance

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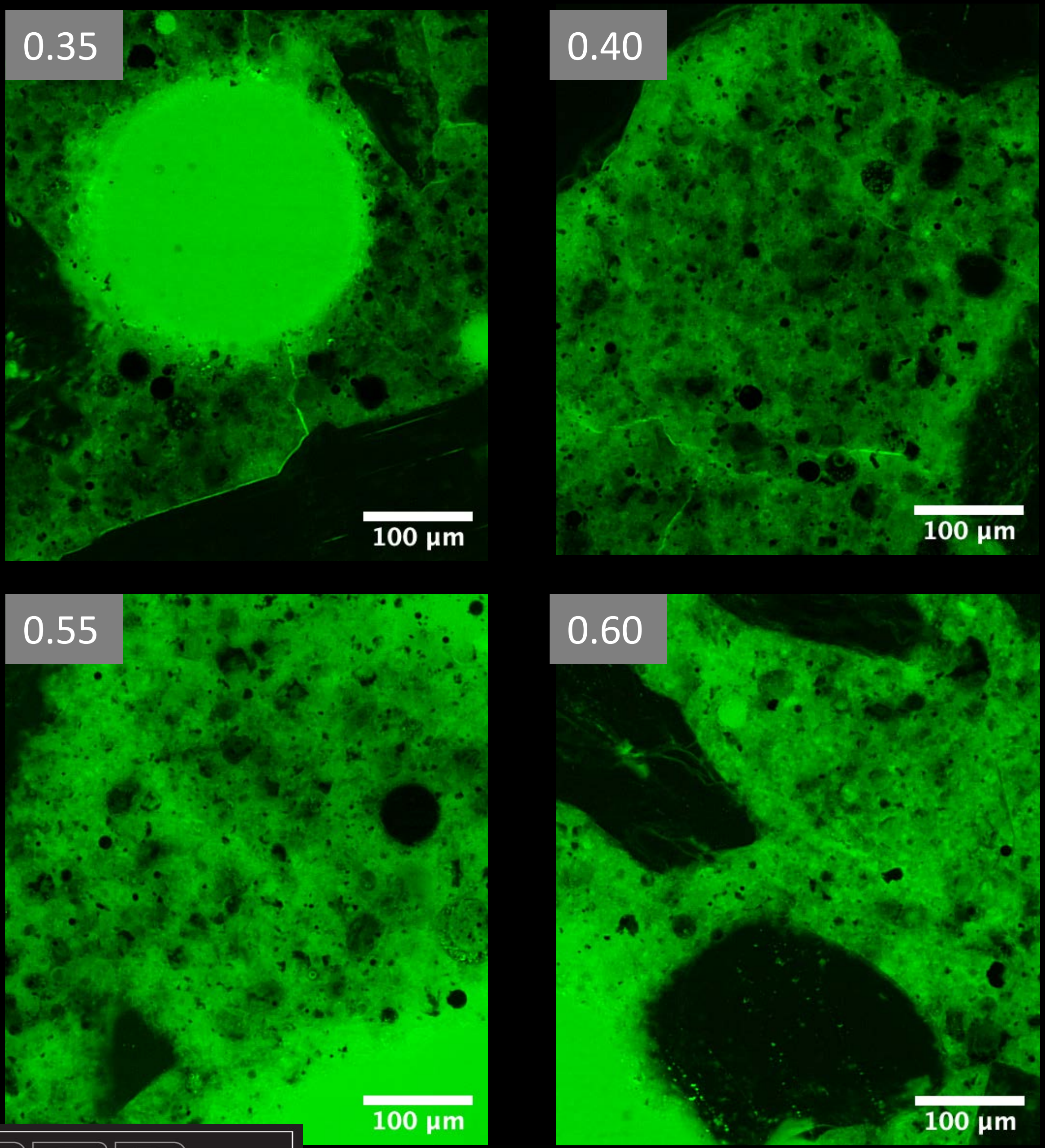

- Laboratory-prepared mortars
- Straight cement, cement + fly ash, cement + natural pozzolan mixes
- W/CM spans from 0.35-0.60 in 0.05 steps
- Natural sand
- Non-air-entrained
- 10 images analyzed for each thin section

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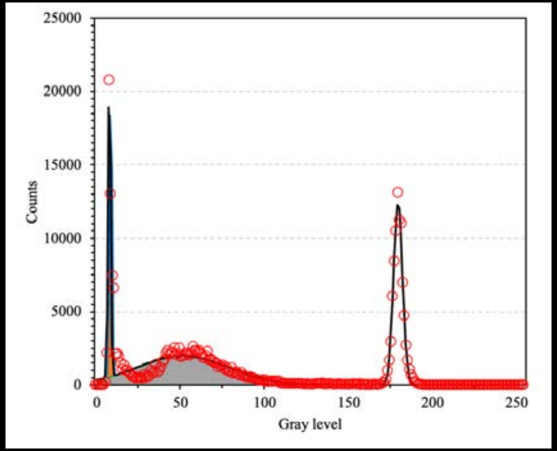
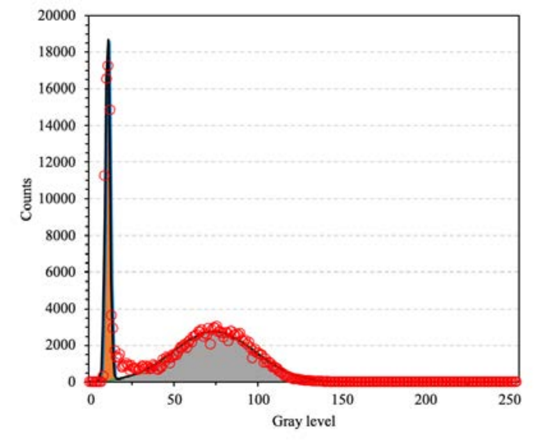
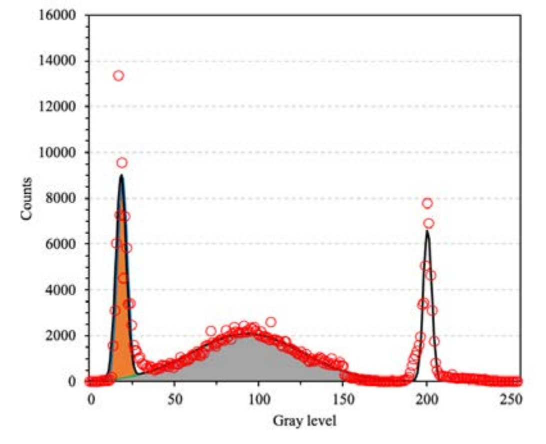
0.35



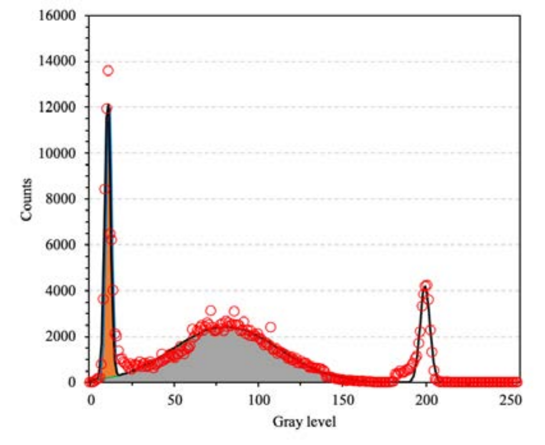
0.40



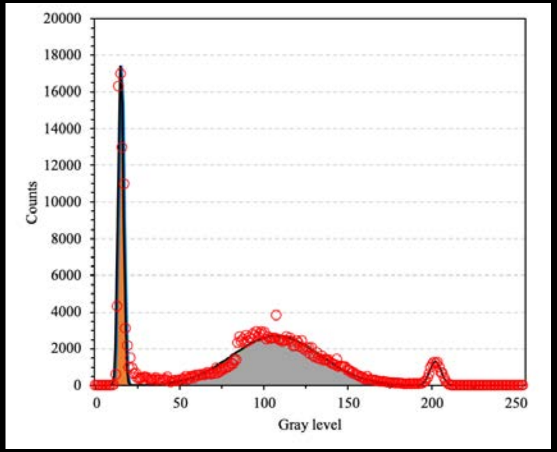
0.45



0.50



0.55



0.60

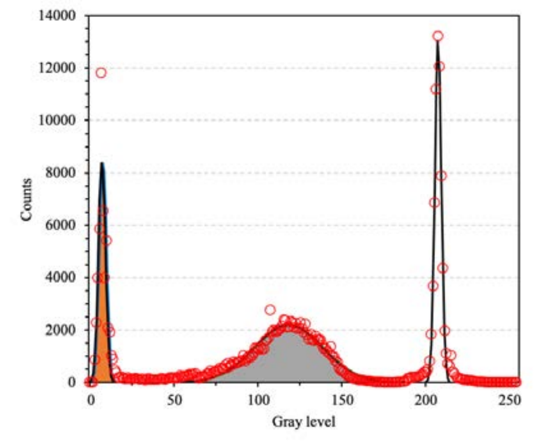


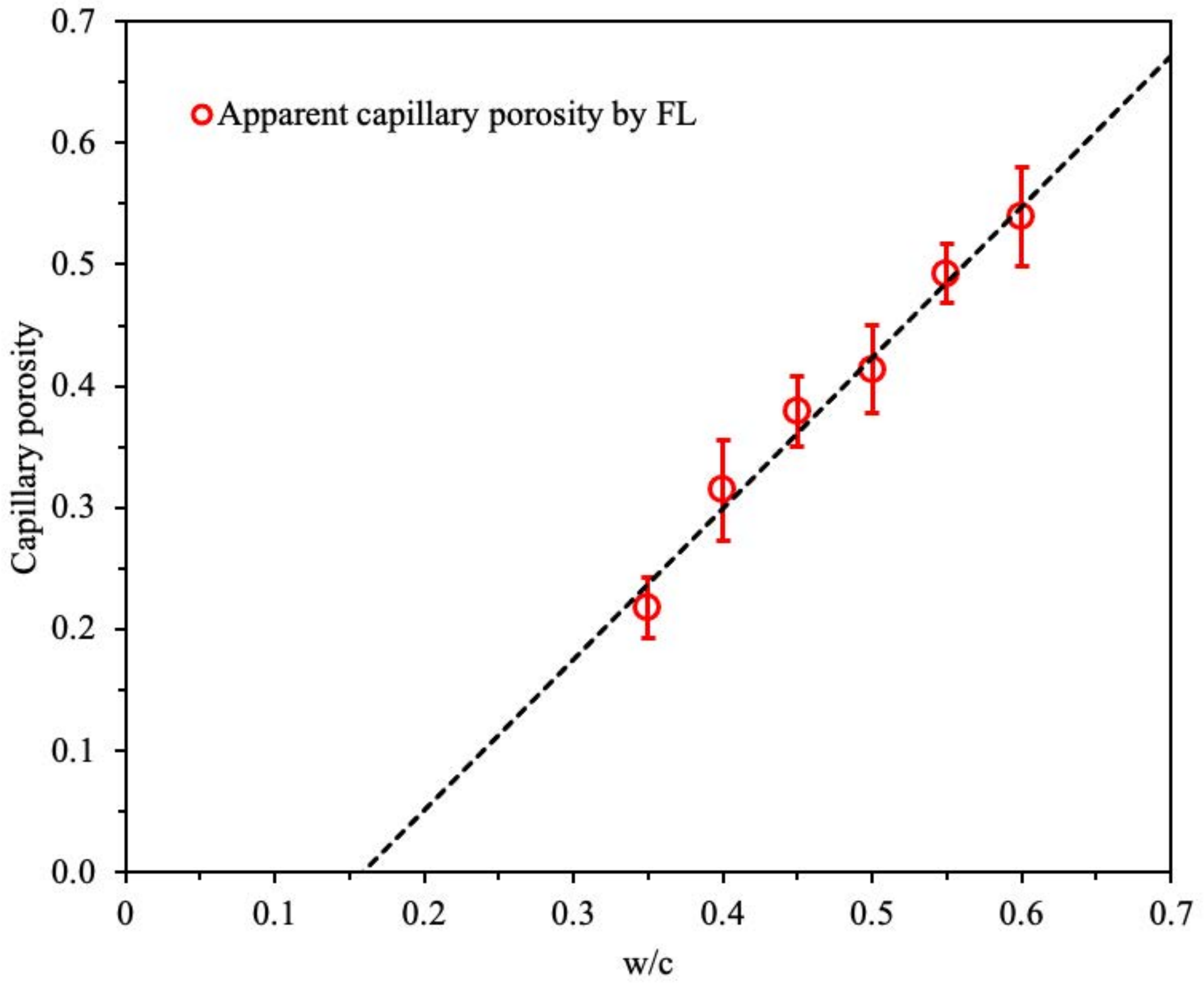
Image Analysis

- Three peaks correspond to aggregate, paste and voids
- Paste peak is in the middle and migrates to higher gray levels with increasing w/c

PETROGRAPHIC & MATERIALS INVESTIGATIONS

Results

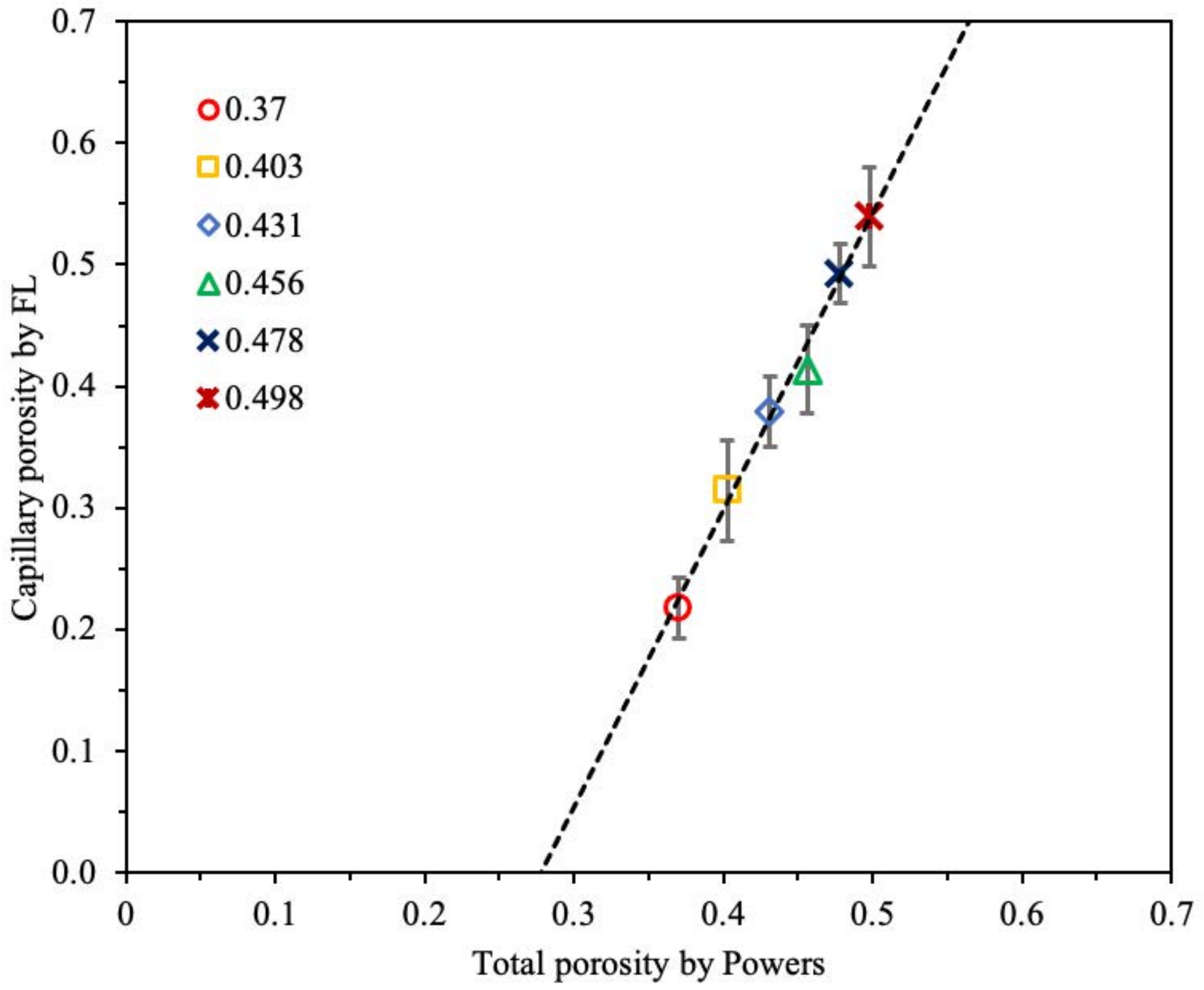
- Tight correlation of “apparent” capillary porosity and w/c
- See similar relationships when scm and natural pozzolans are present



PETROGRAPHIC & MATERIALS INVESTIGATIONS

Results

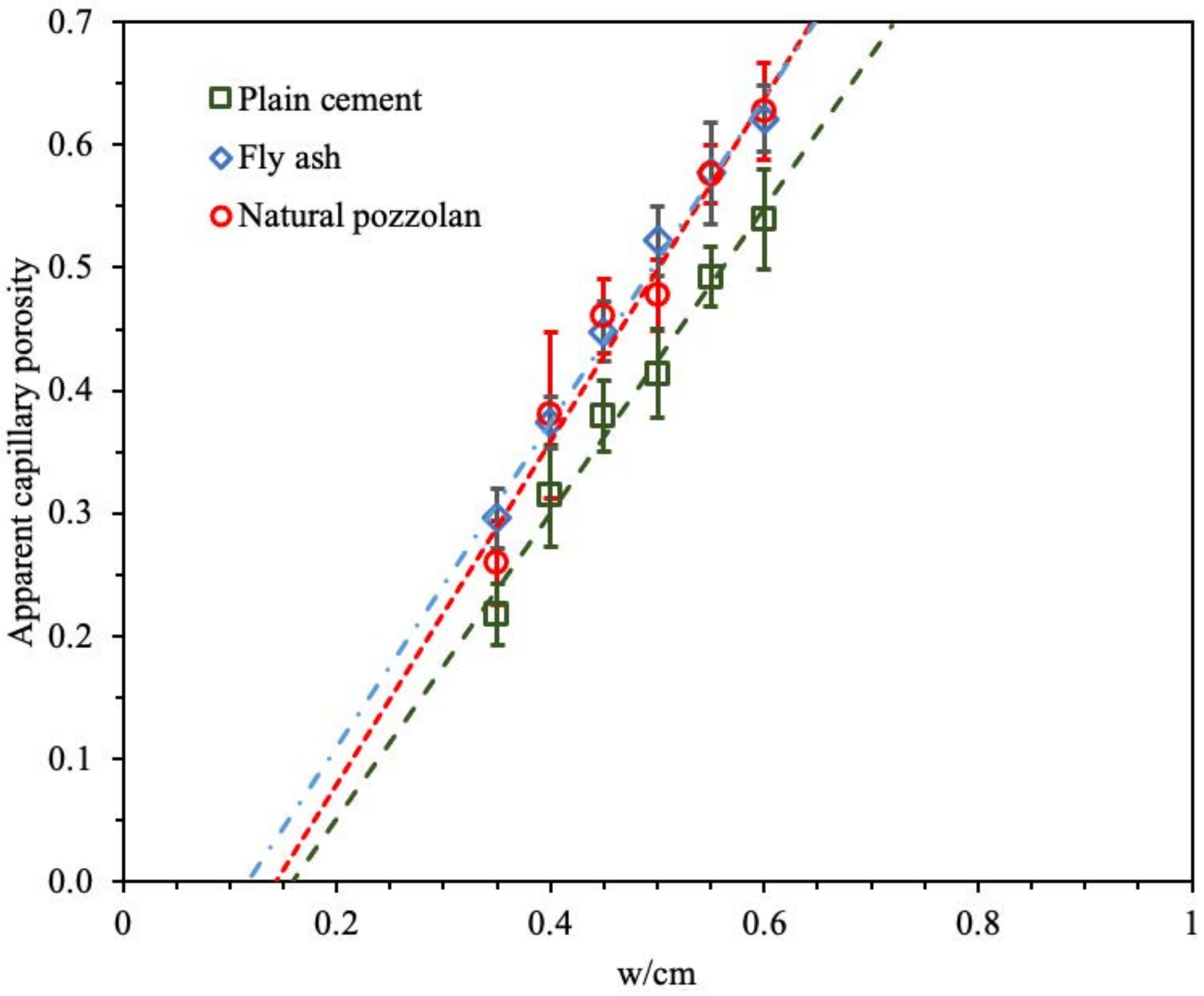
- Tight correlation between capillary porosity from fluorescence and total porosity calculated using Powers model
- See similar relationships when scm and natural pozzolans are present



PETROGRAPHIC & MATERIALS INVESTIGATIONS

Results

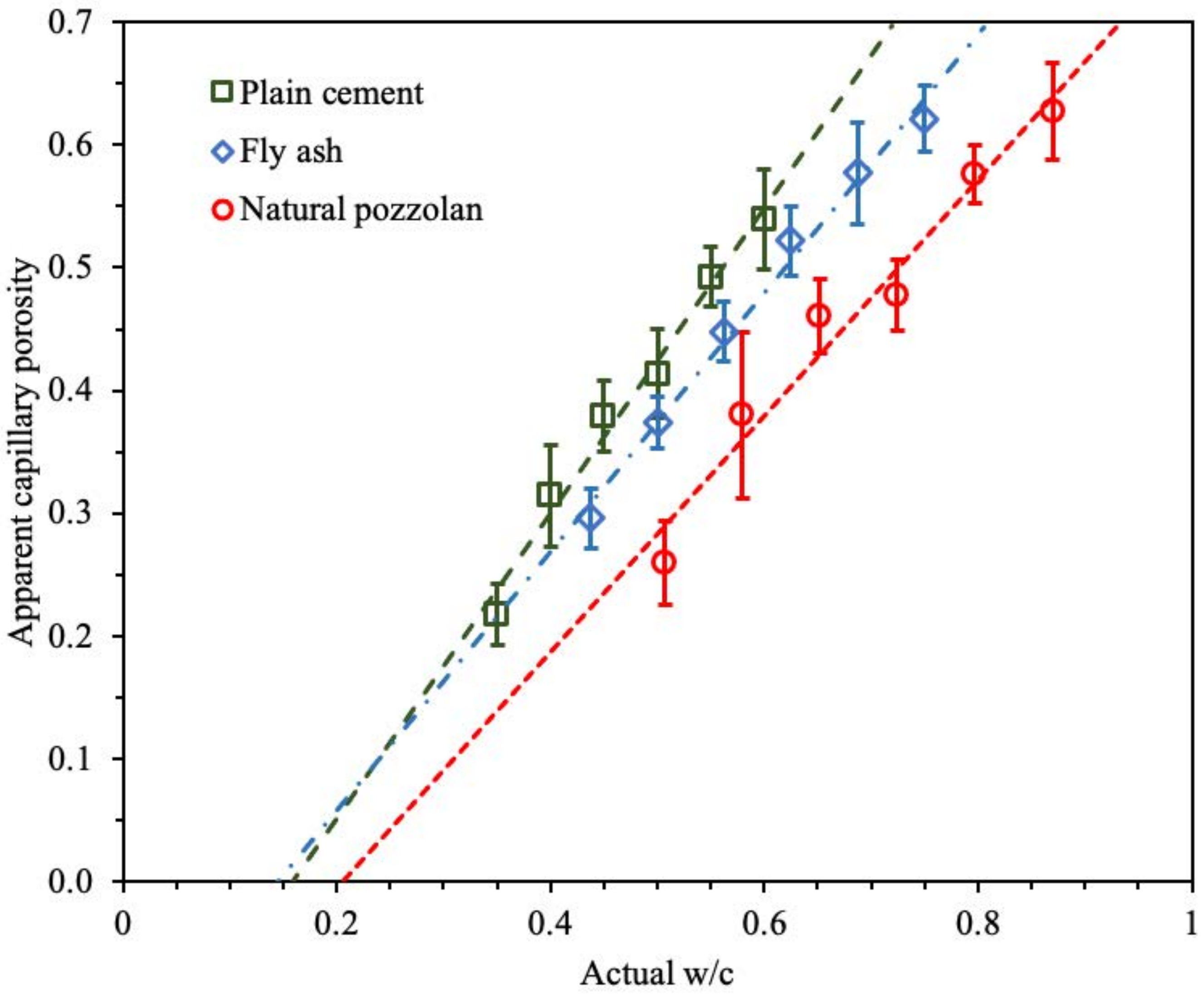
- At 28 days fly ash and natural pozzolan blend mortar shows higher capillary porosity than plain cement mortar.



PETROGRAPHIC & MATERIALS INVESTIGATIONS

Results

- Fly ash and natural pozzolan blend mortars show a refined pore structure indicated by lower capillary porosity than the straight cement mortar after calculating the actual w/c and assuming the scm is essentially inert



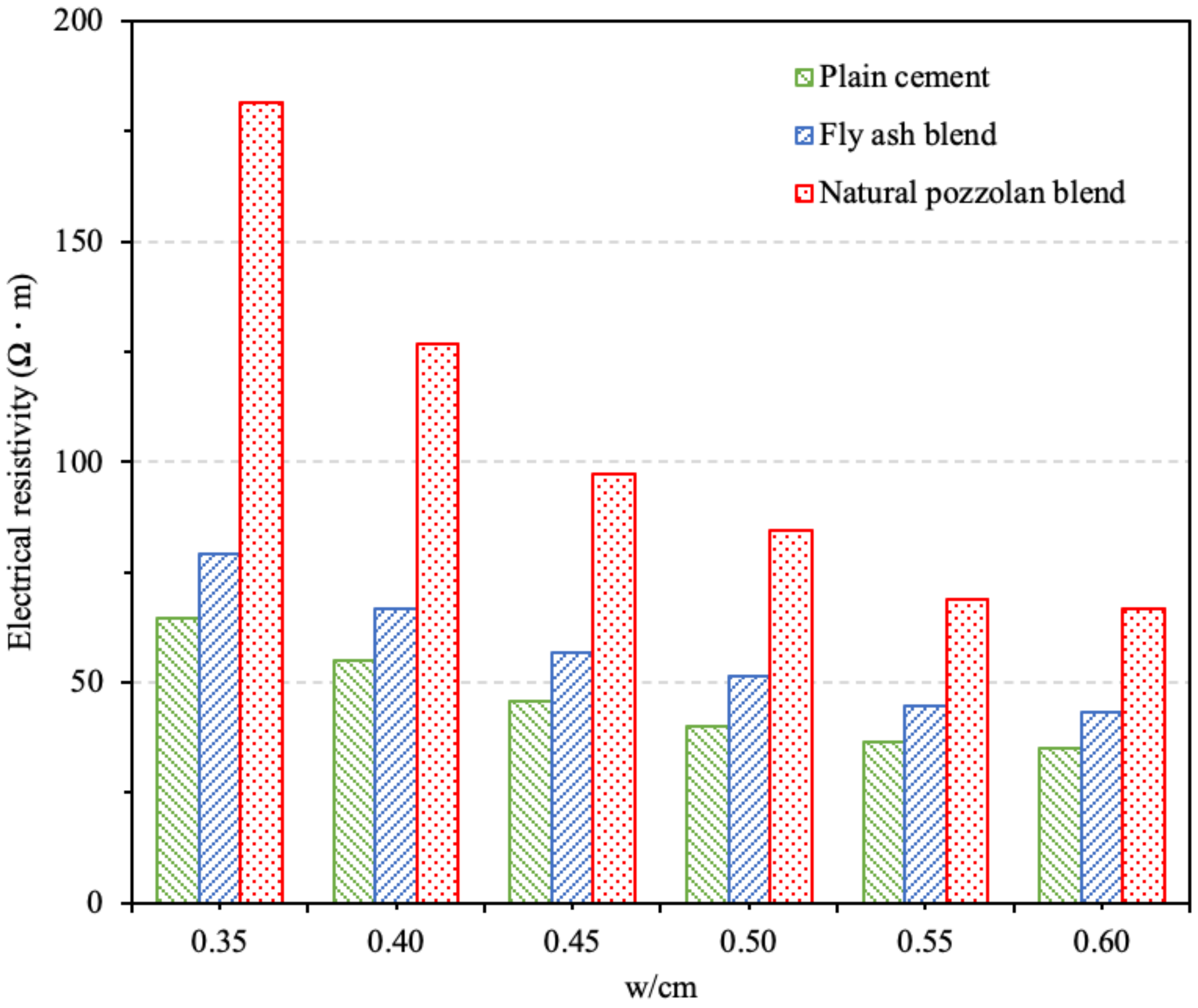
PETROGRAPHIC & MATERIALS INVESTIGATIONS

Resistivity

Electrical resistivity is an indicator of the microstructure refinement.

- w/c ↑ ⟹ electrical resistivity ↓
- Electrical resistivity increases in the order:

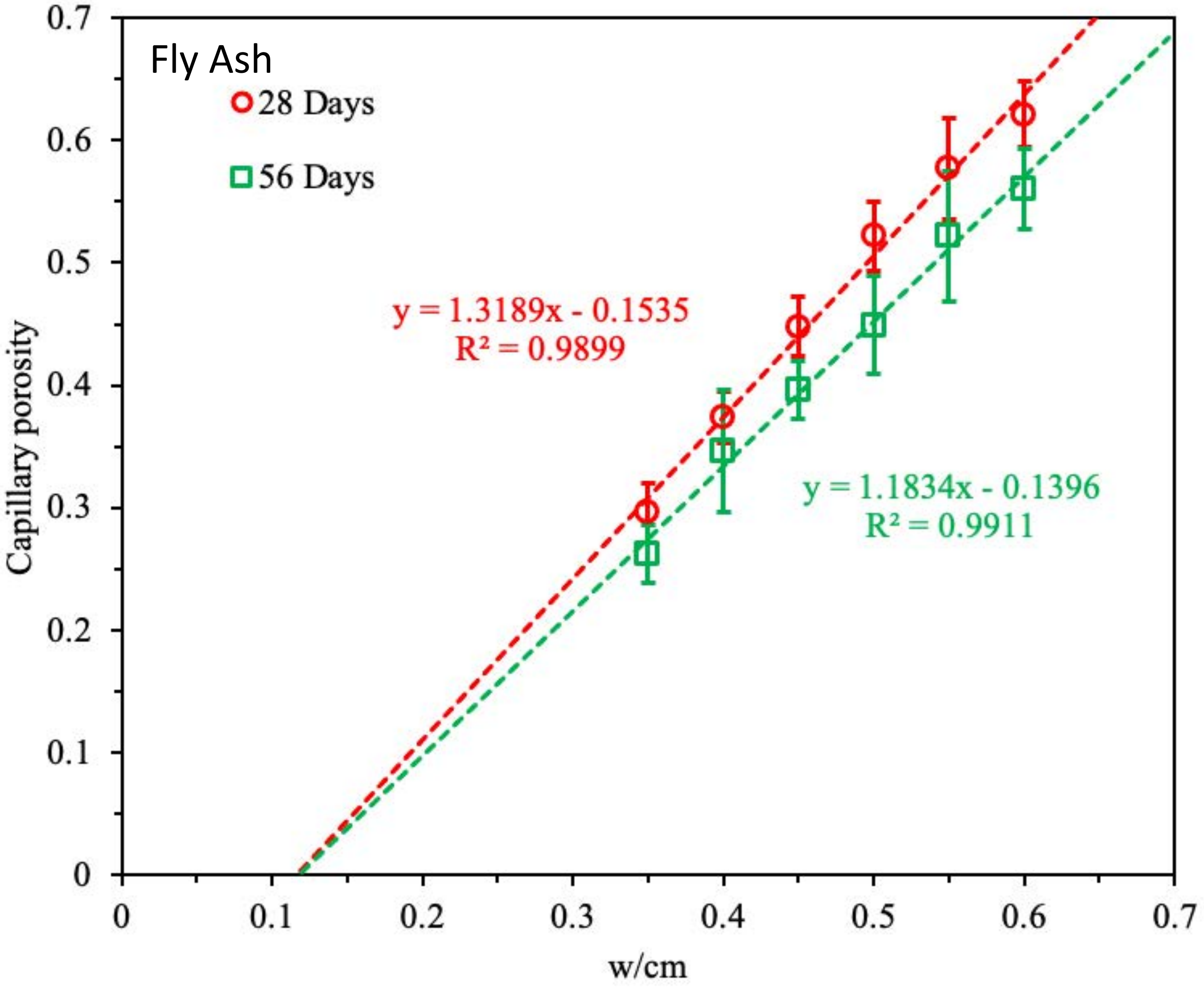
  plain cement< fly ash< natural pozzolan



PETROGRAPHIC & MATERIALS INVESTIGATIONS

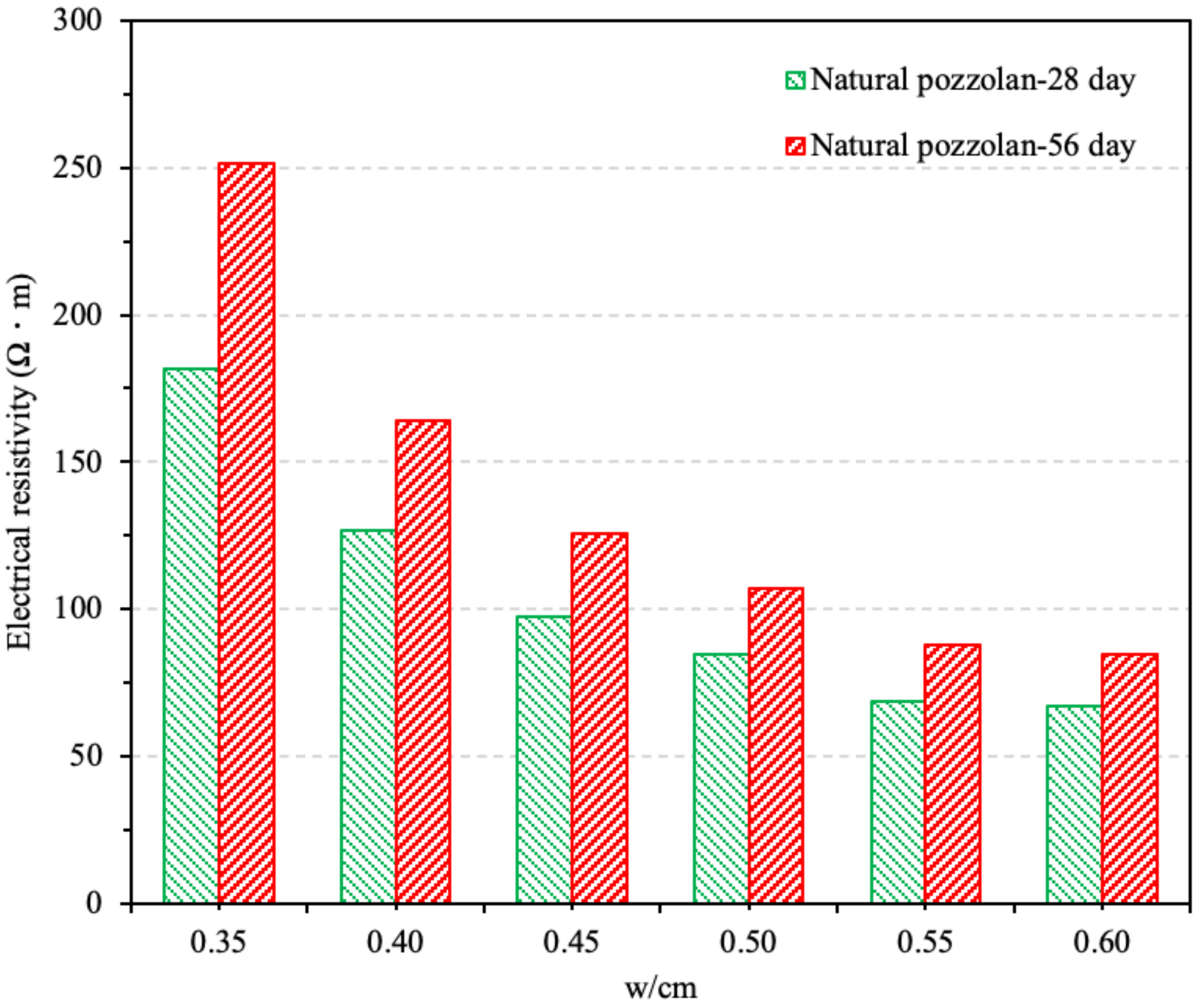
Time vs CP

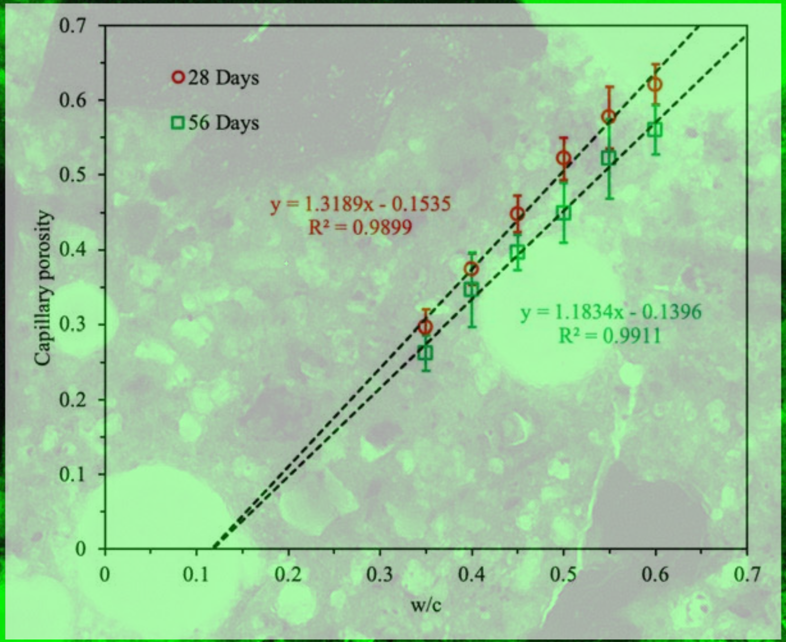
- The OPC, FA and NP mixes show a drop in capillary porosity between 28 days and 56 days.
- Fluorescence microscopy is therefore suited to monitor the progression of hydration in different cementitious systems

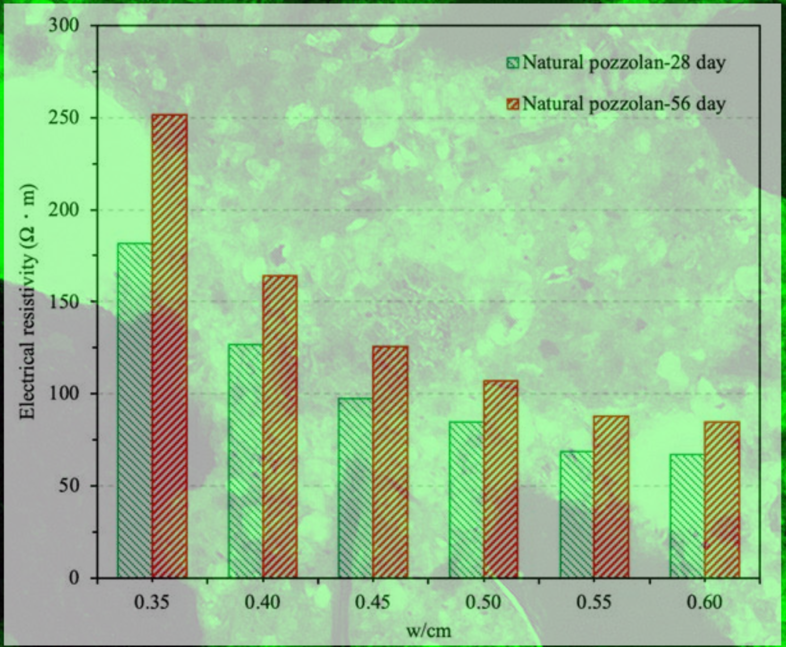


Time vs Resistivity

- Plain cement: Electrical resistivity remains constant.
- Fly ash: Electrical resistivity increases by 25%-27%.
- Natural pozzolan: Electrical resistivity increases by 26%-39%.



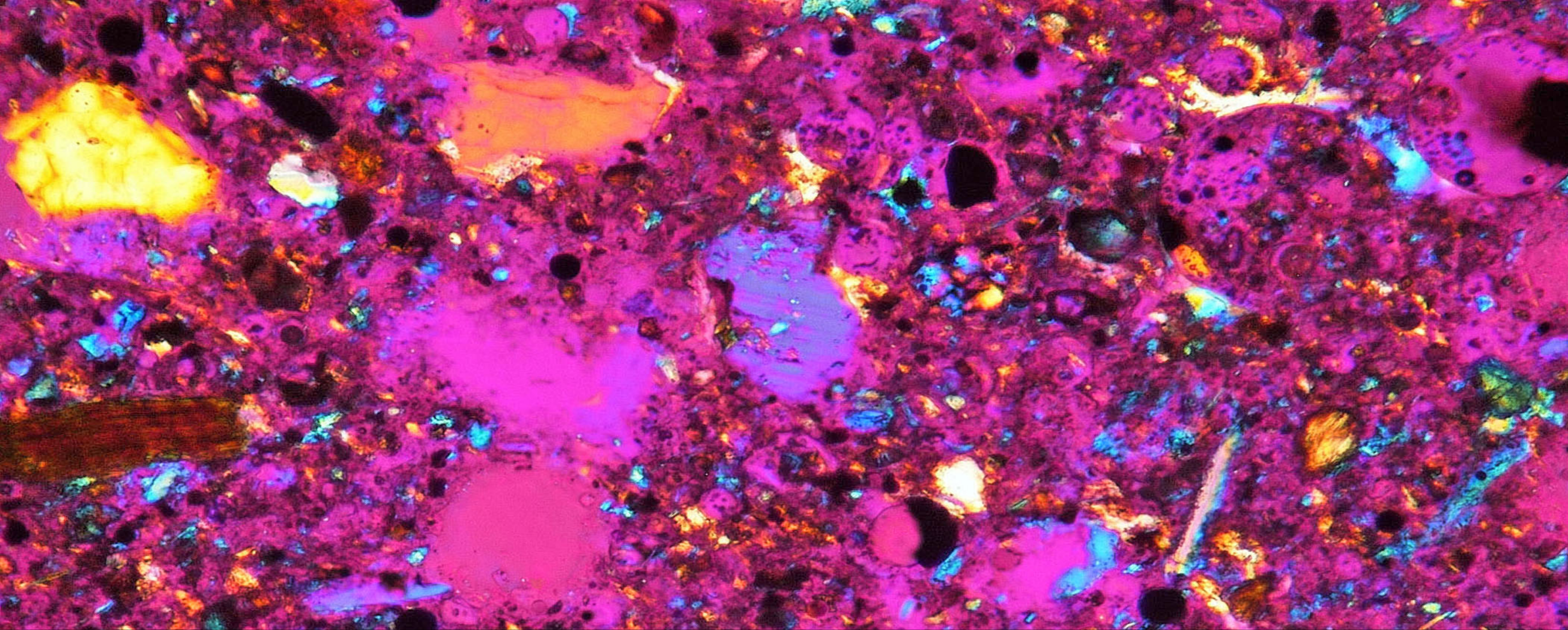




Laboratory Mortars– Conclusions

- Strong correlations between green tone and w/cm for all three mixtures
- Image analysis provides mechanism to deconvolute images and obtain quantitative measurements of capillary porosity
- Strong correlations between capillary porosity and paste microstructure models from Powers
- Findings from microscopy correlate with independent measurements of microstructure characteristics (resistivity)
- Track how capillary porosity changes with progression of hydration
- Powerful tool to assess potential benefits of supplemental cementitious materials, natural pozzolans and other materials

PETROGRAPHIC & MATERIALS INVESTIGATIONS



Case Study #2: Bridge Pier Columns Strength

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Project Info

- Interstate highway pier columns
- Mix design
    - 4500 psi at 28 days
    - 0.41 w/cm
    - 6% air
    - Five admixtures
    - Fibers
- Core 1: 2630 psi (58%) at 28+ days.
- Core 2: 3780 psi (84%) at 28+ days.

Why does Core 1 have lower strength than Core 2?

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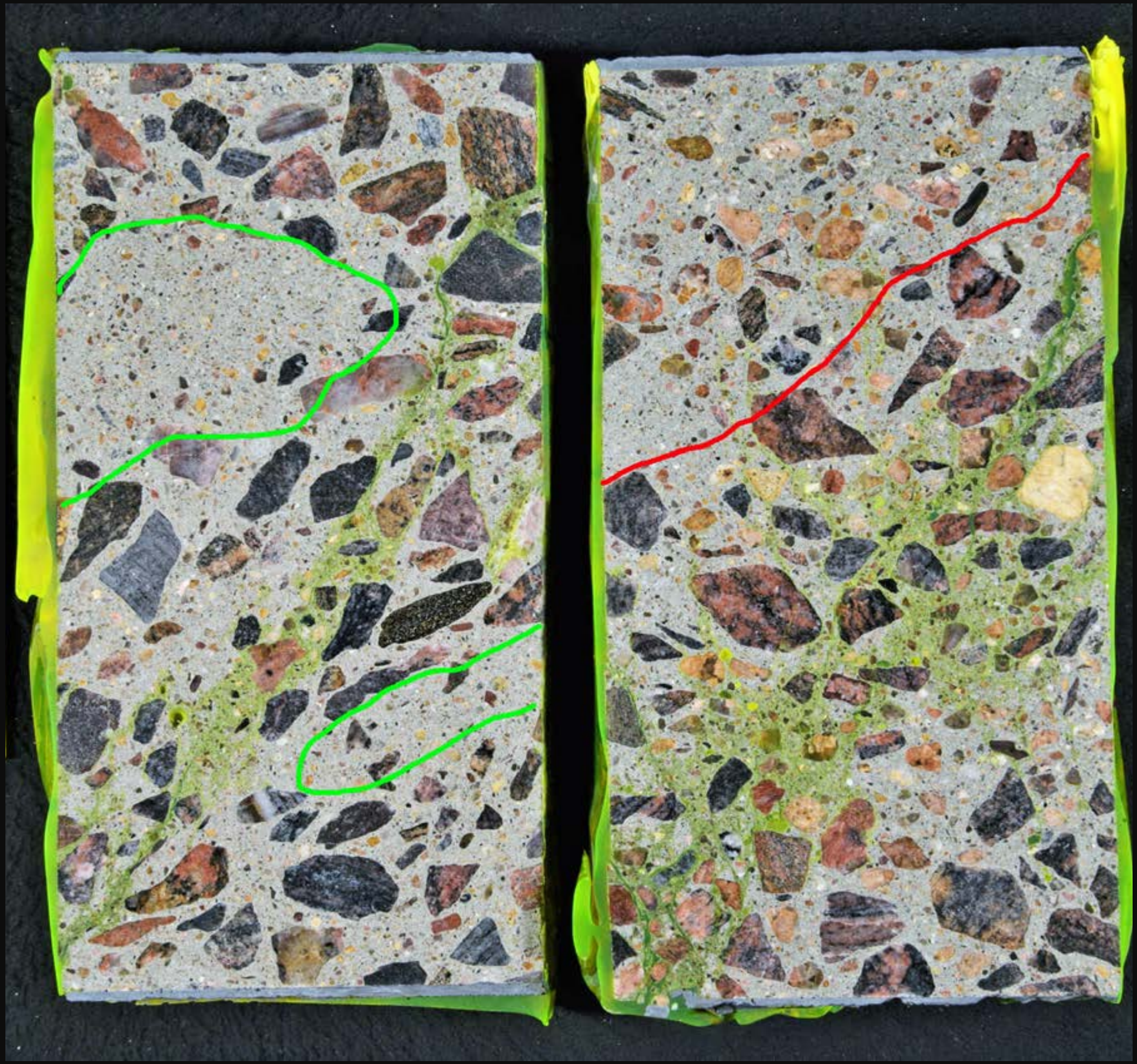
Core 1

Core 2

Observations in Stereo

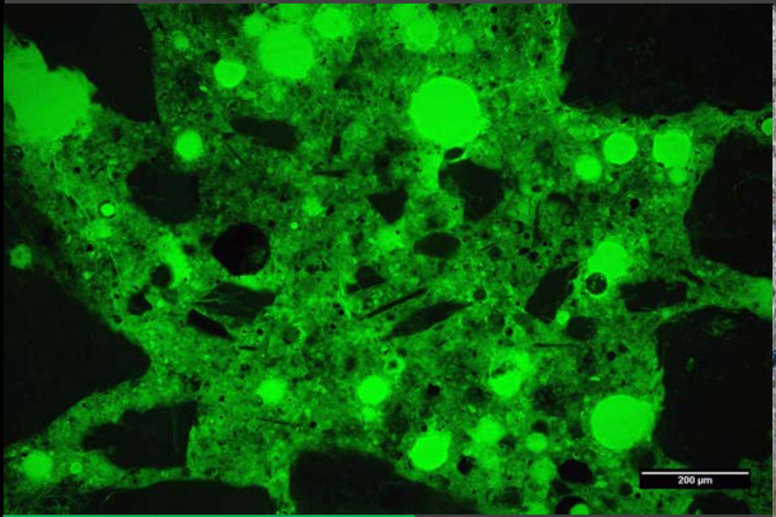
- Non-uniform aggregate distribution
- Components are consistent with mix design:
  - Crushed ¾ in. granitic rock and natural siliceous sand
  - Air-entrainment
  - Portland cement and fly ash
  - Synthetic fibers



PETROGRAPHIC & MATERIALS INVESTIGATIONS

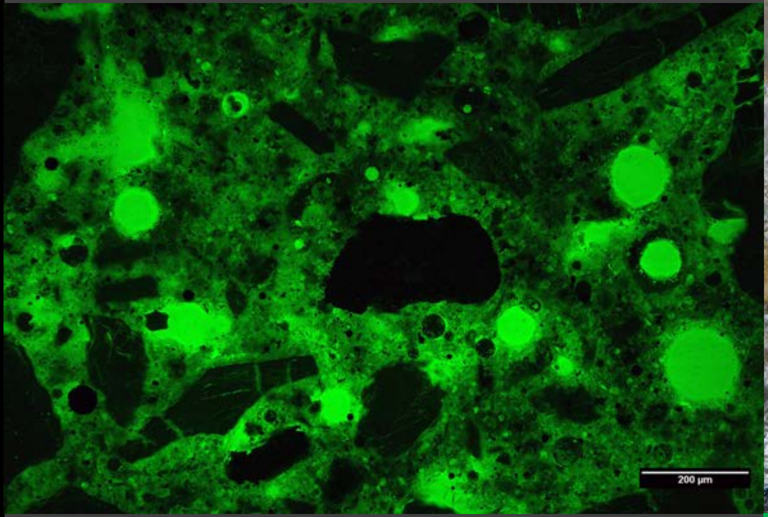
Measurements

	Core 1	Core 2
Estimated w/cm	0.50 ± 0.05	0.40 ± 0.05
Capillary Porosity	0.28-0.40	0.13-0.28
Air Content	9.1%	4.9%
Paste Content	33.1%	29.6%
Aggregate Content	57.8%	65.5%

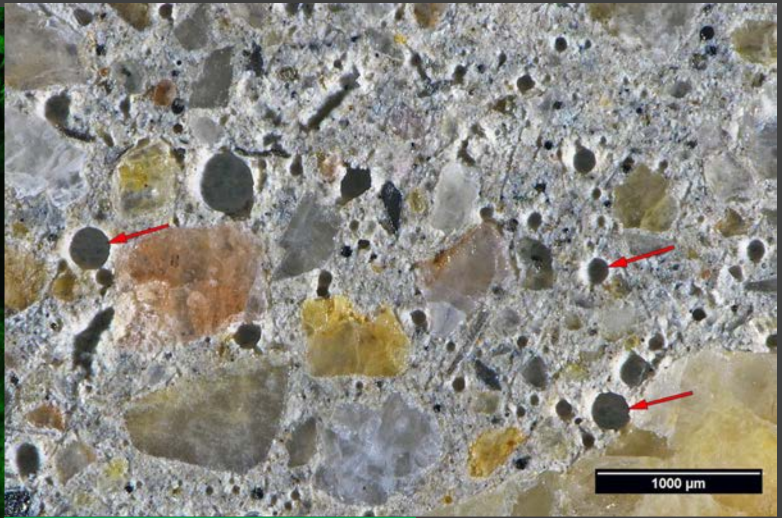


Core 1: 0.50 ± 0.05

Core 1: 9.1% air



Core 2: 0.40 ± 0.05



Core 2: 4.9% air

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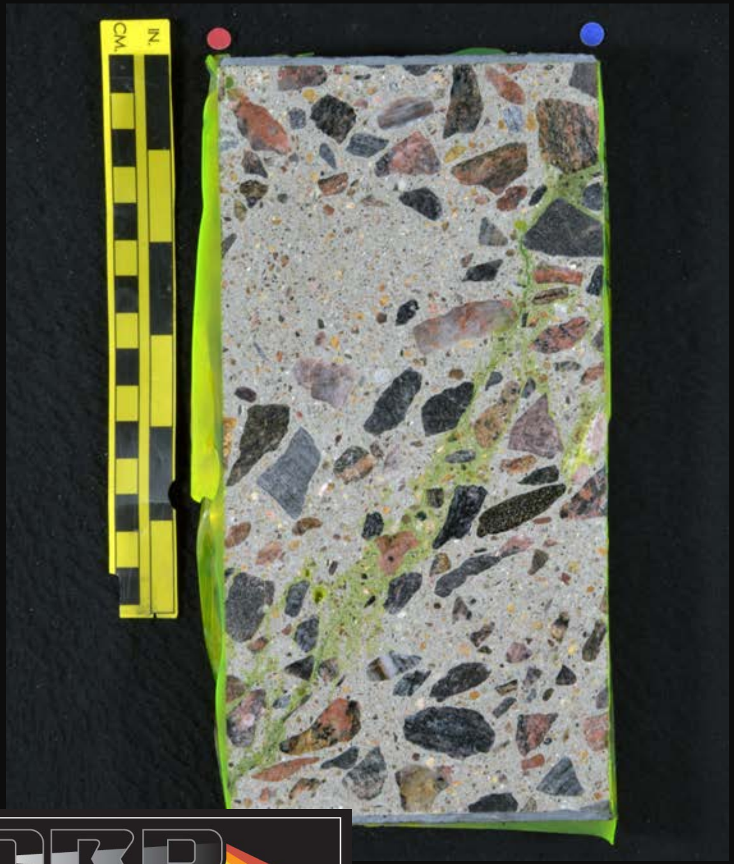
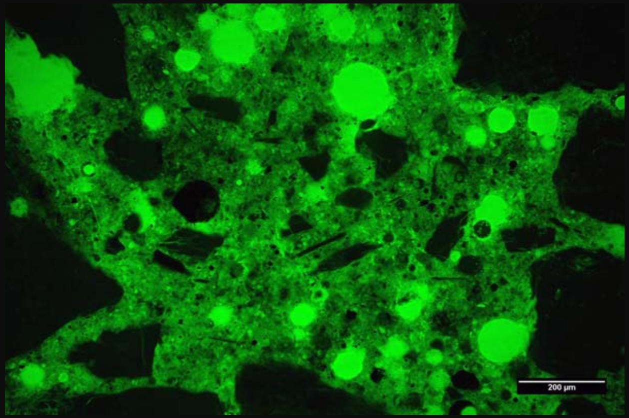
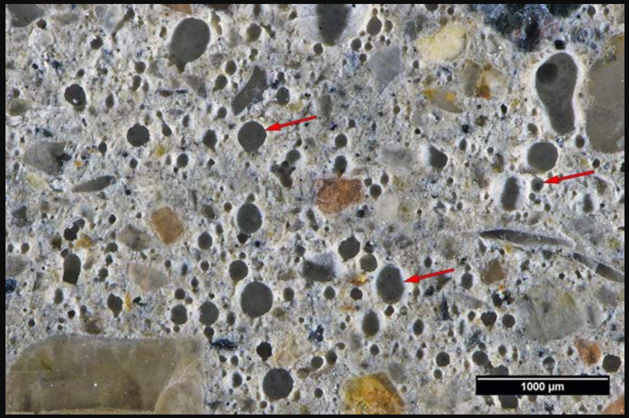
Pier Column Study– Conclusions

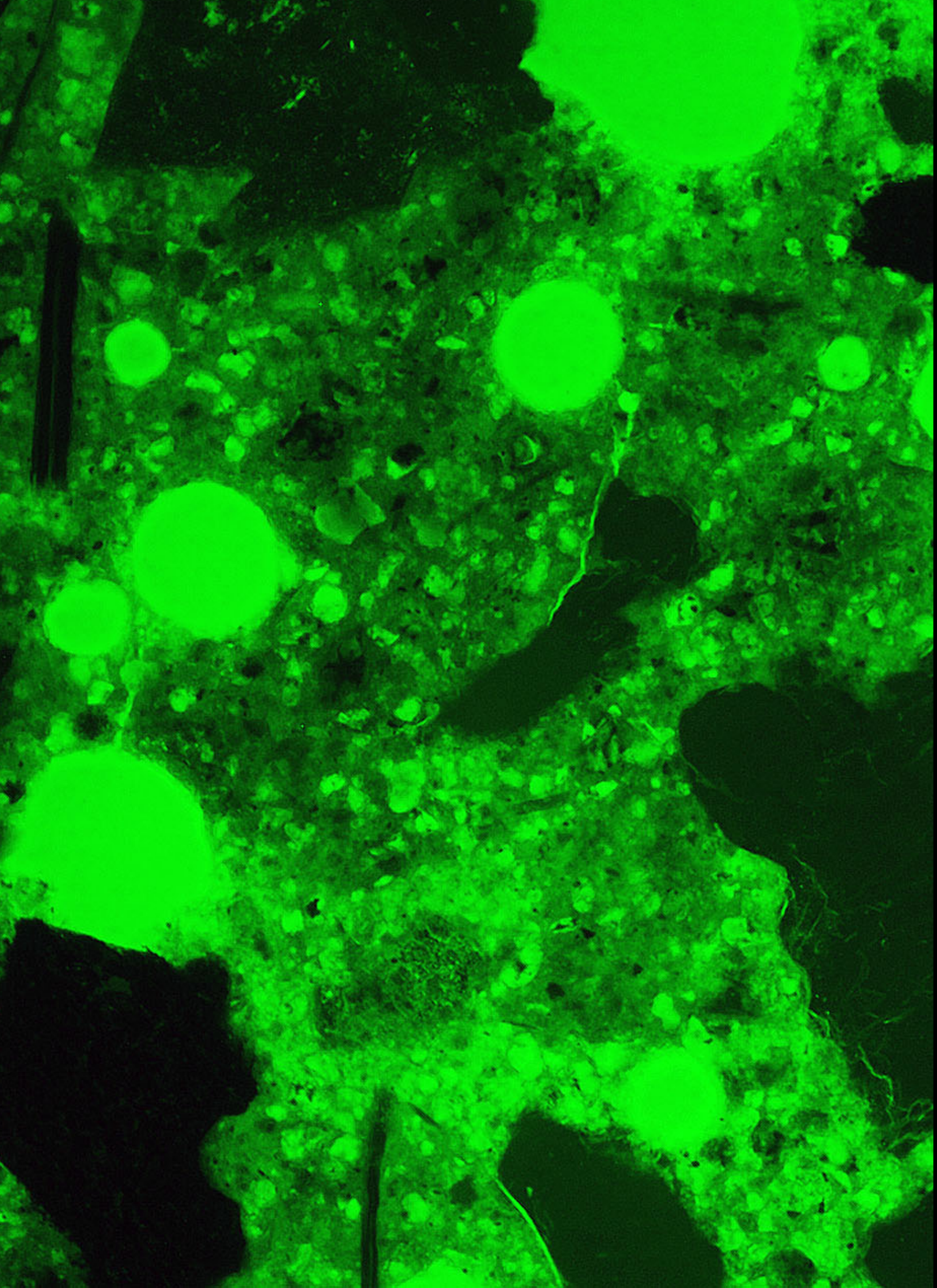






- Higher air in Core 1
- Higher w/cm in Core 1
- Higher paste content in Core 1
- Uneven aggregate distribution may also contribute to lower strength results

PETROGRAPHIC & MATERIALS INVESTIGATIONS



Conclusions

- "Standard" approaches such as volumetric proportioning measurements are low tech but still powerful
- Fluorescence microscopy provides mechanism to image capillary porosity and w/cm
- Fluorescence microscopy coupled with image analysis allows for quantitative analysis of capillary porosity and w/cm
- Coupling microscopical techniques with resistivity offers further insight toward understanding development of microstructure and transport properties
- Excellent tool to assess potential benefits of SCMs, NPs and other materials and to understand microstructural development over time

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Thank you!
Feel free to contact us with questions and ideas…

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