Potential impact of chloride-based deicers on the deterioration of joints in concrete pavements

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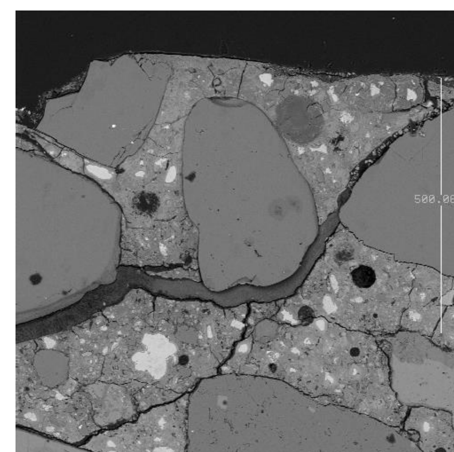

The Problem

- Some concrete pavements located in cold climates have been experiencing premature joint deterioration.
- Once initiated, the damage progresses aggressively and can result in severe damage to the pavement.
- Various contributing factors have been identified in the previous studies.

The Problem

- **Most deterioration taking place at or near:**
  - transverse joints
  - longitudinal joints
  - Intersection of transverse and longitudinal joints

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What may be causing the distress?

- **Number of potential causes suggested**
  - Poor materials selection,
  - Poor mixture proportioning
  - Poor construction practices
  - D-cracking
  - Alkali-reactive materials
  - improper timing of sawing (either early or late)
  - Uncracked joints

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What may be causing the distress?

- **Number of potential causes suggested**
  - slab warping
  - joint spacing
  - accumulation of incompressibles in joints
  - Joint sealing and sealant selection
  - Poor drainage
  - Local saturation of concrete
  - **Deicing practices**

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LABORATORY SPECIEMNS

Mixture proportions (both limestone and dolomite)

- 0.42 w/cm, (ASTM C94 for mixing procedure)

Mixture designation	PC series		FA series	
	Limestone	Dolomite	Limestone	Dolomite
w/cm	0.42	0.42	0.42	0.42
Cement	515	586	440	469
Fly ash	-	-	110	117
Water	217	246	227	246
Fine aggregate	1500	1303	1420	1303
Coarse aggregate	1700	1780	1700	1780
AEA (fl oz)	0.9	1.5	0.7	1.15
WRA (fl oz)	2.5	3.0	1.5	2.85

Exposure conditions

	Temperature (°F/°C)	Duration (24hrs for 1 cycle)
Wet	39.2°F (4°C)	16±1hr
Dry	73.4°F (23°C)	8±1 hrs at 50% RH
Freeze	-0.4°F(-18°C)	1 hr of cooling, 11hrs at -0.4°F (-18°C)
Thaw	71.6°F (22°C)	1 hr of heating, 11hrs at 71.6°F (22°C)

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Deicers

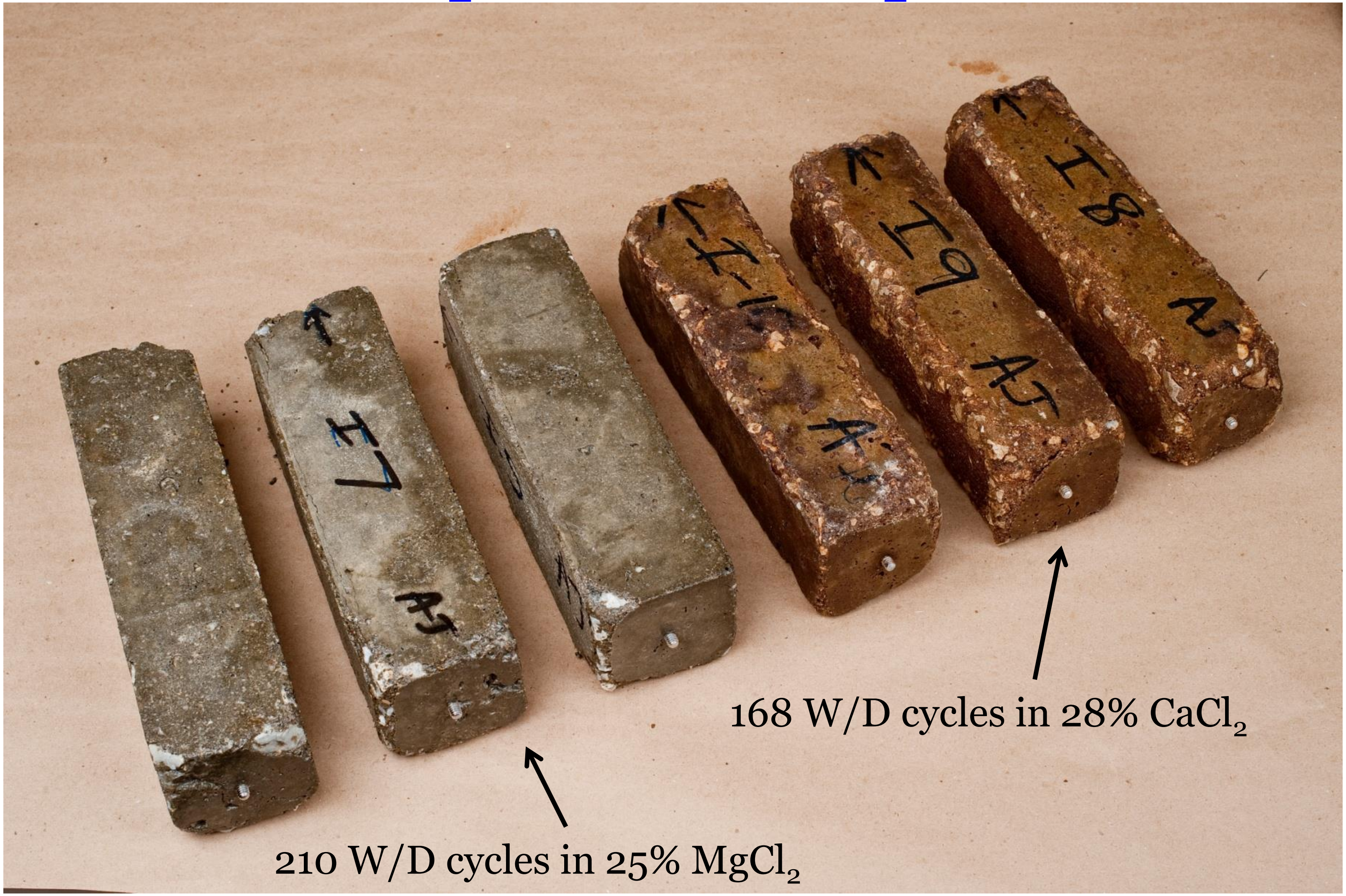
	W/D	F/T
NaCl	23.3 %	14.0 %
$MgCl_2$	25.0 %	15.0 %
$CaCl_2$	28.0 %	17.0 %

- For test F/T, 40% reduction in concentration of deicers to ensure freezeability
- Companion specimens –FT and WD in DIW
- Control specimens – stored in a standard curing room

Wetting and Drying Cycles

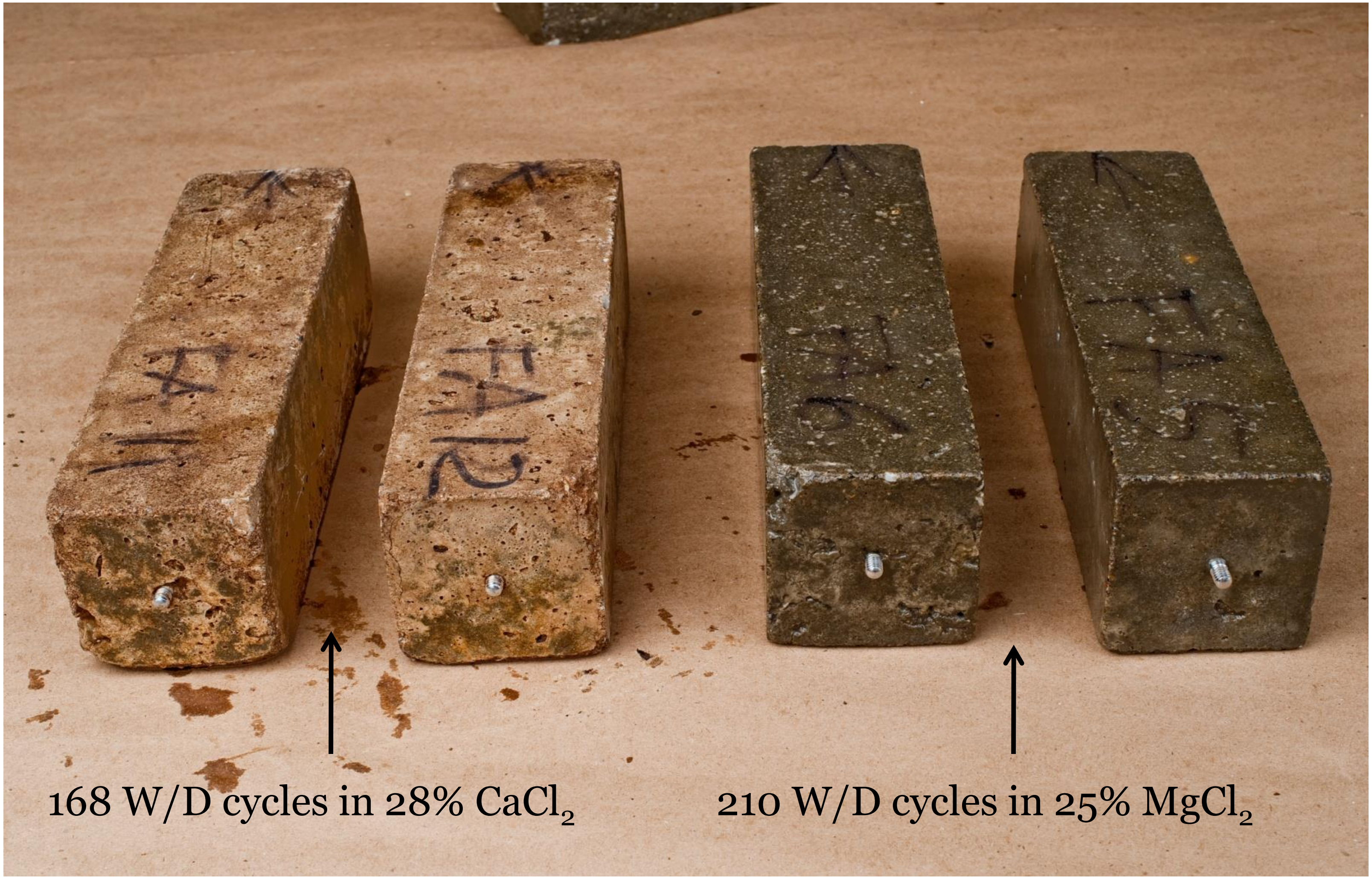
- Drying :
  - ➢ 8 hrs at 23°C (73.4°F) at 50% RH
- Wetting
  - ➢ 16 hrs at 4°C (39.2°F)

Type I specimens after W/D cycles in 25% $MgCl_2$ & 28% $CaCl_2$ solutions



Type I specimens after 168 W/D cycles in 28% $CaCl_2$ solution

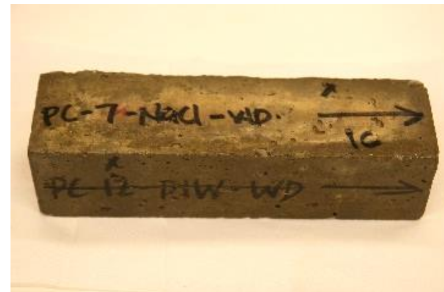
Fly Ash specimens after W/D cycles in 25% $MgCl_2$ & 28% $CaCl_2$ solution



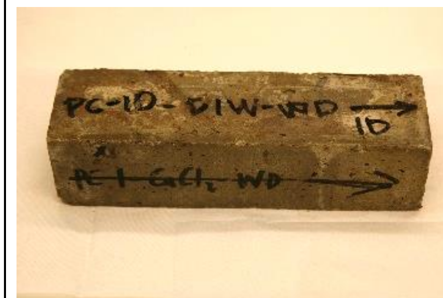
Visual appearance of the specimens (W/D)

PC-$CaCl_2$-W/D-350cycles

PC-$MgCl_2$-W/D-350cycles



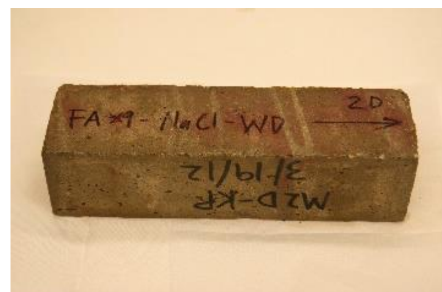
PC-NaCl-W/D-350cycles



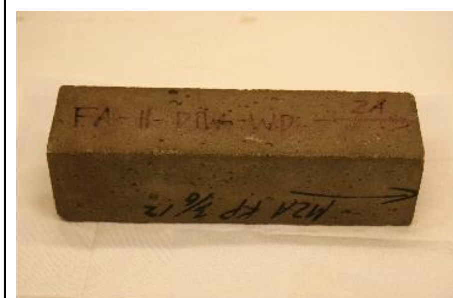
PC-DIW-W/D-350cycles

FA-$CaCl_2$-W/D-350cycles

FA-$MgCl_2$-W/D-350cycles



FA-NaCl-W/D-350cycles



FA-DIW-W/D-350cycles

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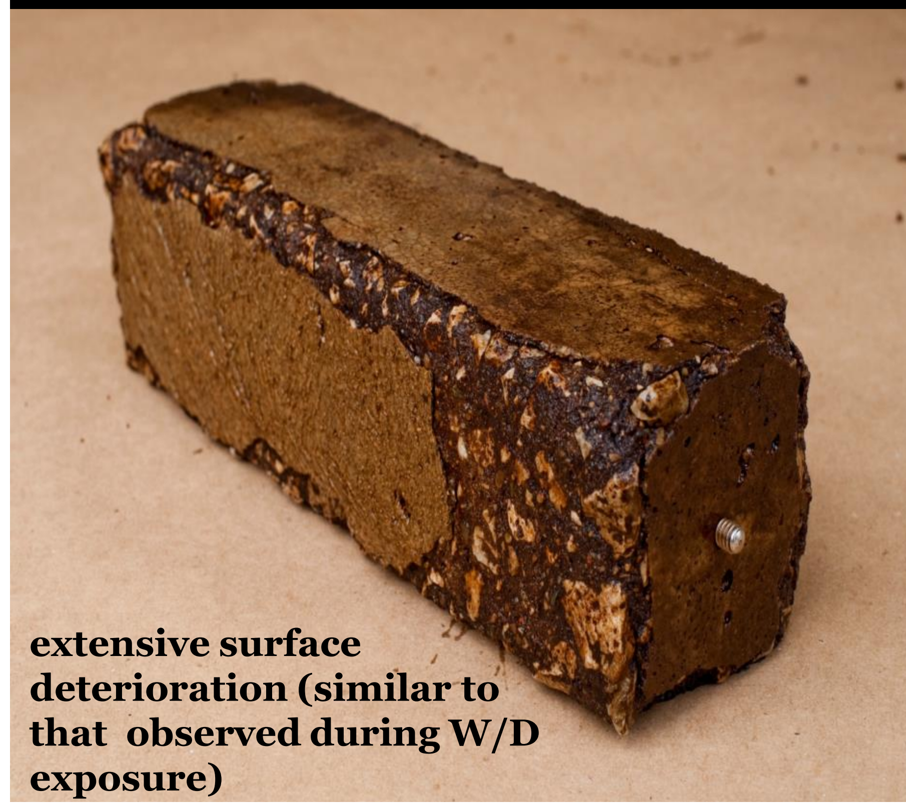
Freezing and Thawing Cycles

- Freezing
  - 1 hr of cooling and 11 hrs of freezing at -0.4°F (-18°C)
- Thawing
  - 1 hr of heating and 11 hrs at 71.6°F (22°C)

F/T exposure - Type I Specimens

166 F/T cycles in 15% $MgCl_2$ solution

166 F/T cycles in 17% $CaCl_2$ solution



F/T Exposure - Type I & Fly Ash Specimens

Type I & Fly Ash specimens after 166 F/T cycles in 15% $MgCl_2$ solution

Type I & Fly Ash specimens after 166 F/T cycles in 17% $CaCl_2$ solution

Visual appearance of the specimens (F/T)

			
PC-$CaCl_2$-F/T-185cycles	PC-$MgCl_2$-F/T-350cycles	PC-NaCl-F/T-350cycles	PC-DIW-F/T-350cycles
			
FA-$CaCl_2$-F/T-350cycles	FA-$MgCl_2$-F/T-350cycles	FA-NaCl-F/T-350cycles	FA-DIW-F/T-350cycles

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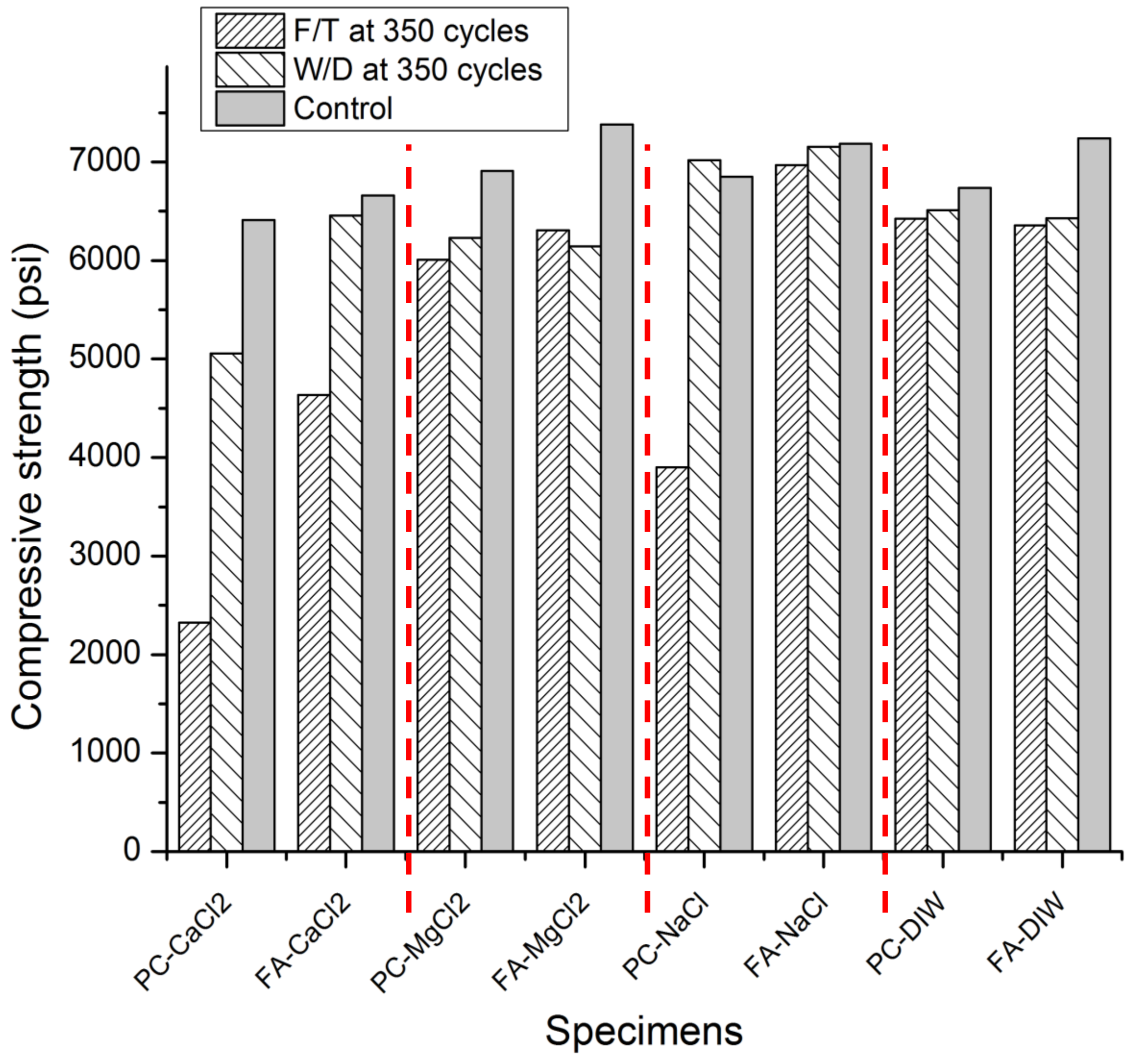
Compressive strength



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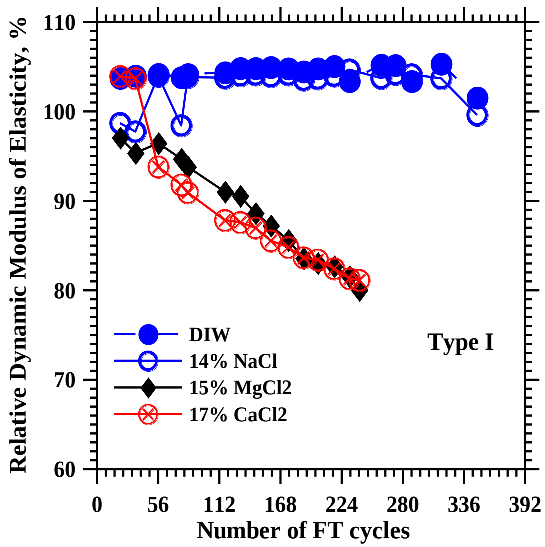
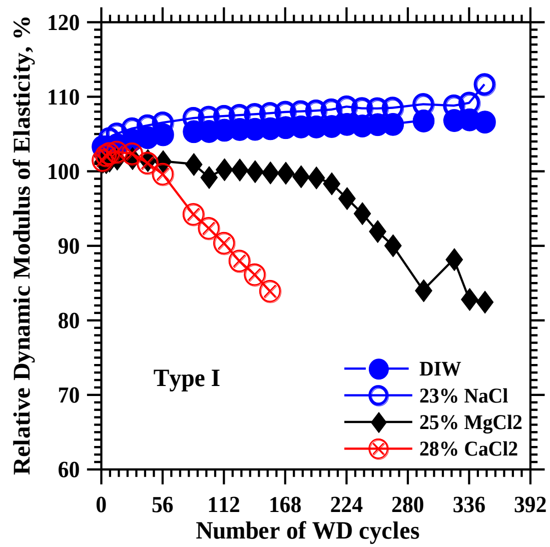
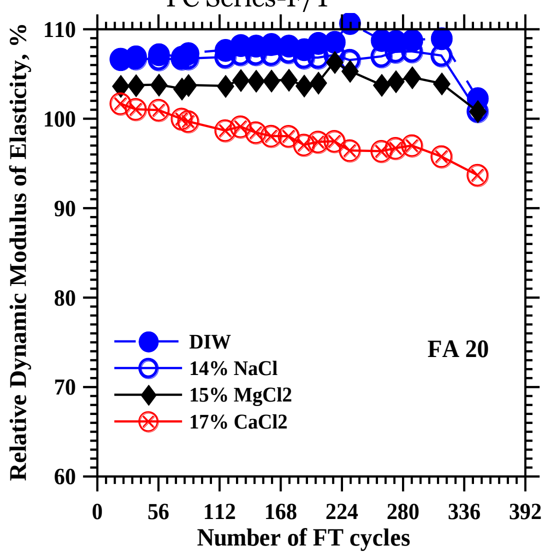
RDME changes (specimens with limestone)



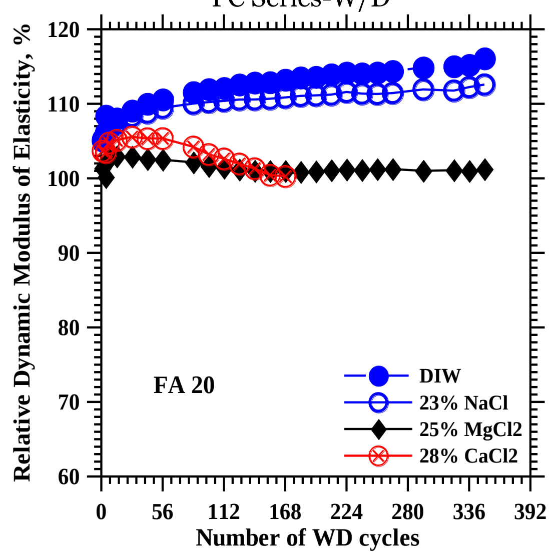
PC Series-F/T



PC Series-W/D



FA Series-F/T



FA Series-W/D

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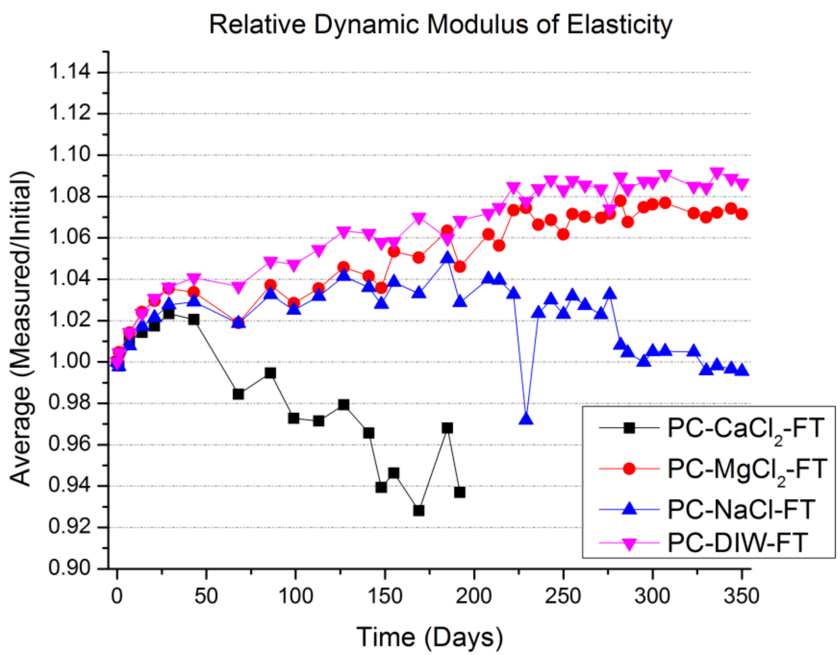
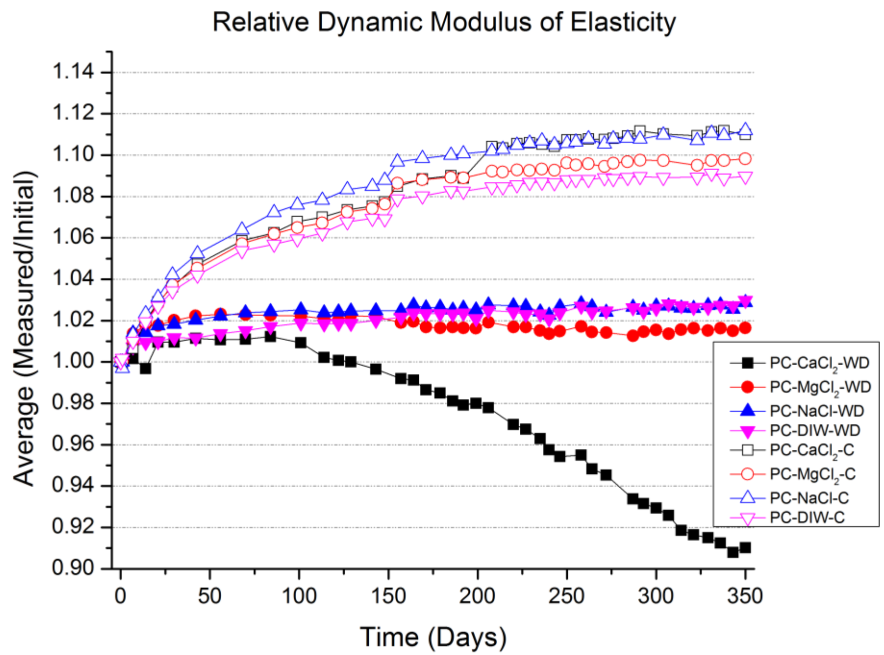
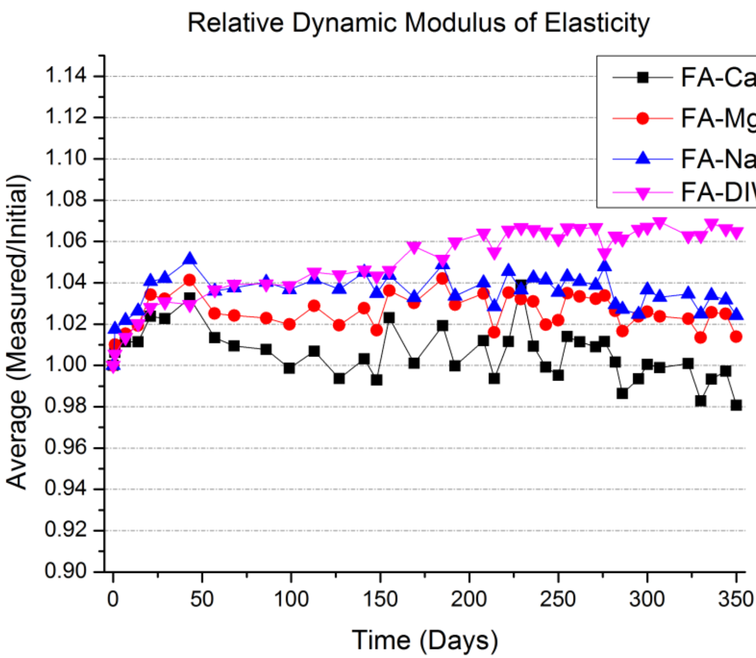
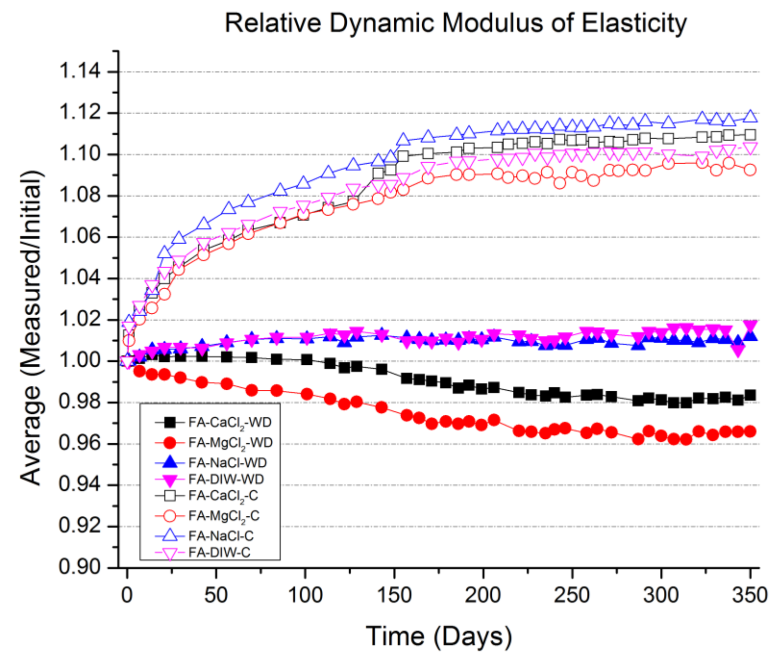
Relative DME – PC concrete F/T and W/D (dolomite)

	
PC Series-F/T	PC Series-W/D

Relative DME –FA concrete – F/T and W/D (dolomite)

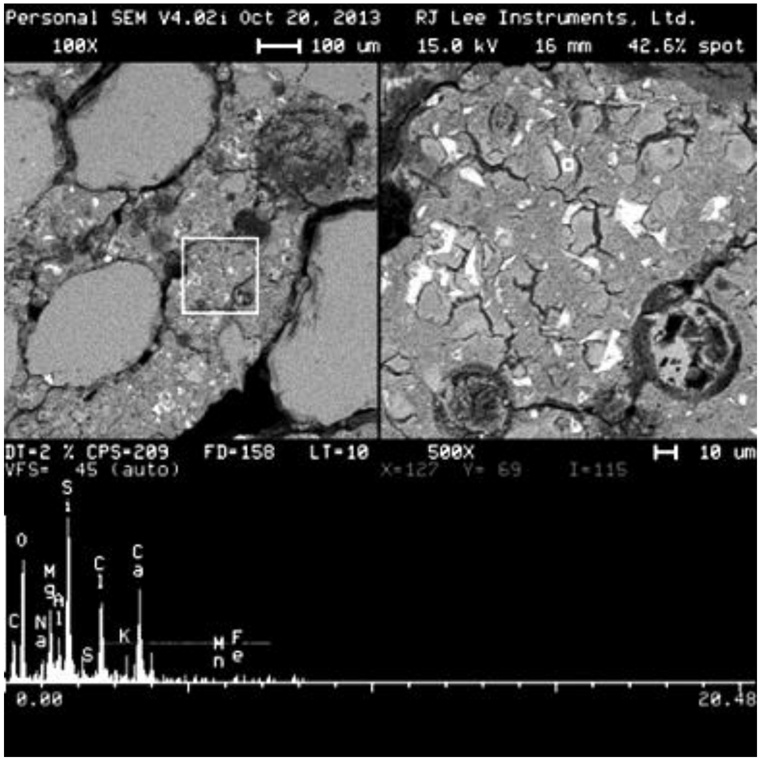


FA Series-F/T

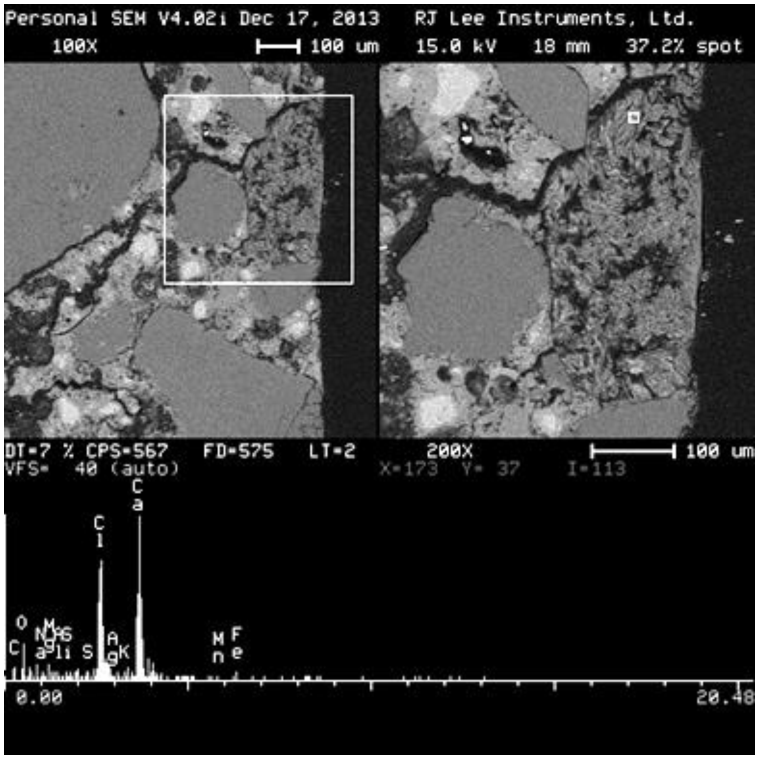


FA Series-W/D

Microstructure –PC concrete - W/D and F/T



(a) Deposits of Chlorides (PC-$CaCl_2$-W/D)



(b) Crystals of $CaCl_2$ (PC-$CaCl_2$-F/T)

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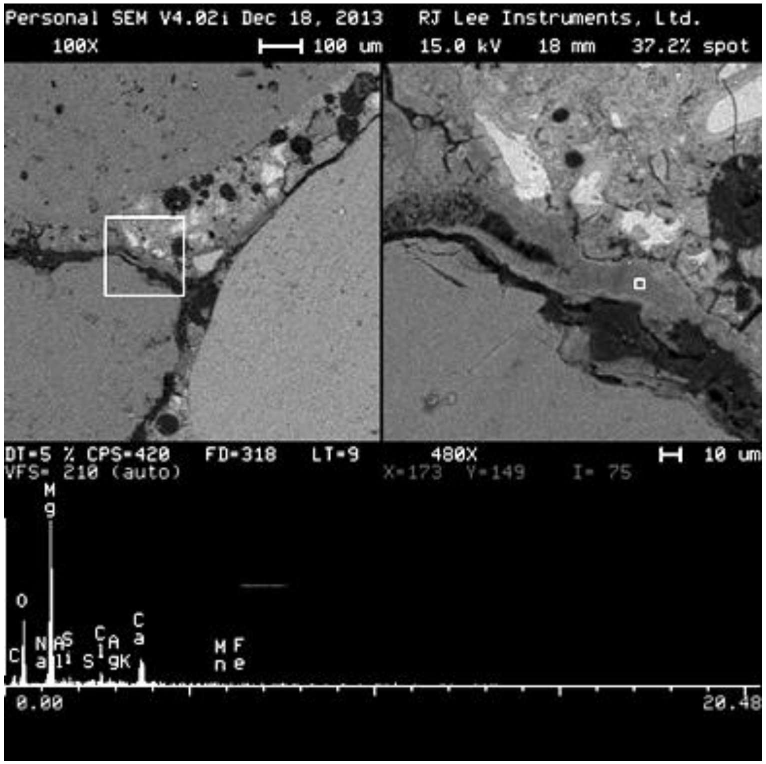
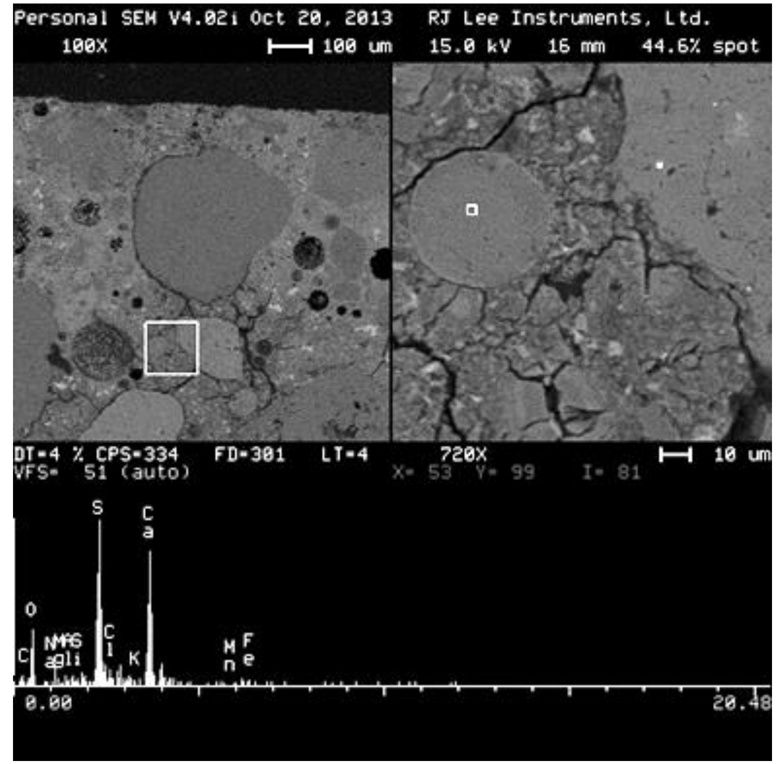
Microstructure –PC concrete – F/T and W/D

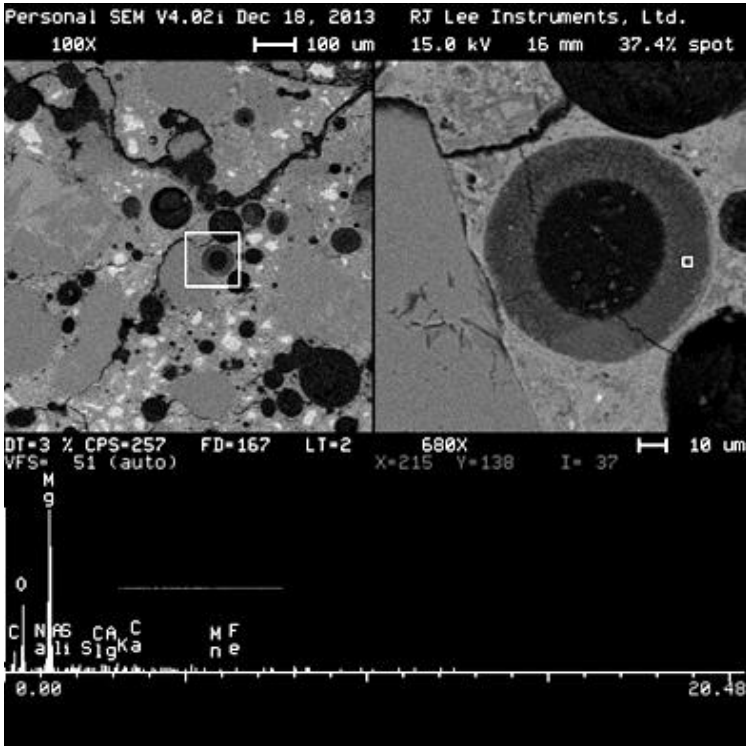


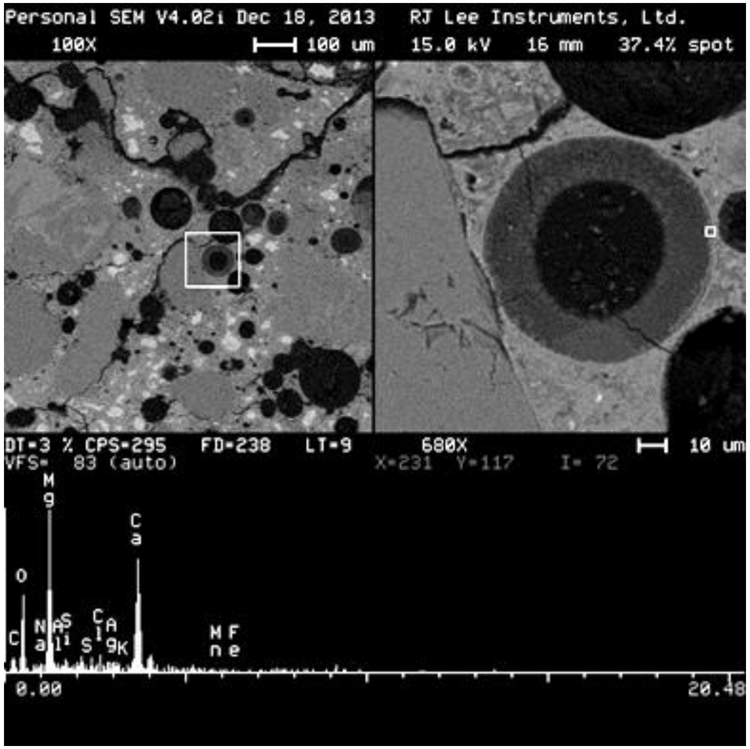
(c) Brucite (PC-$CaCl_2$-F/T)



(d) Gypsum (PC-$CaCl_2$-W/D)

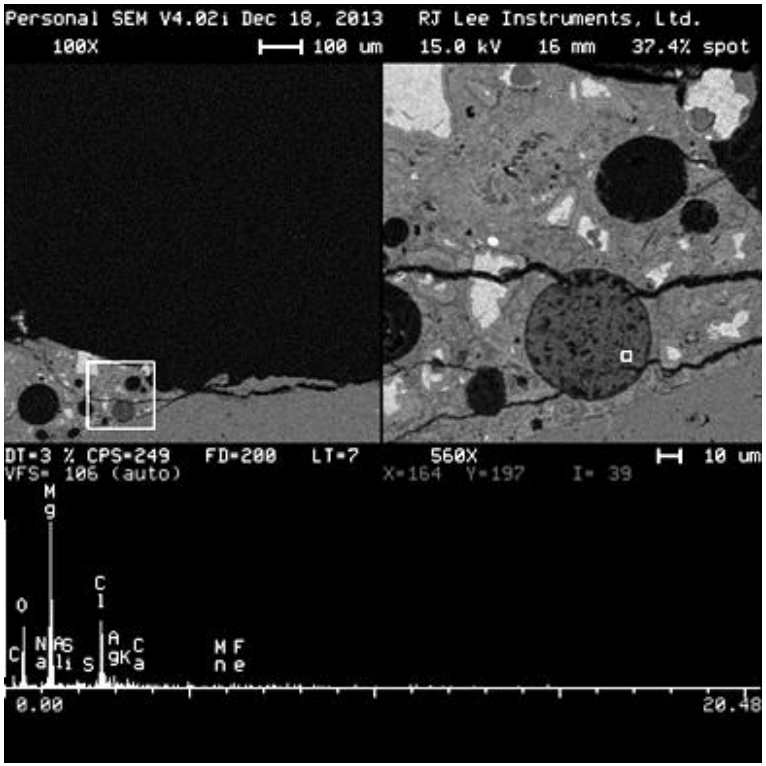
Microstructure –PC concrete - F/T



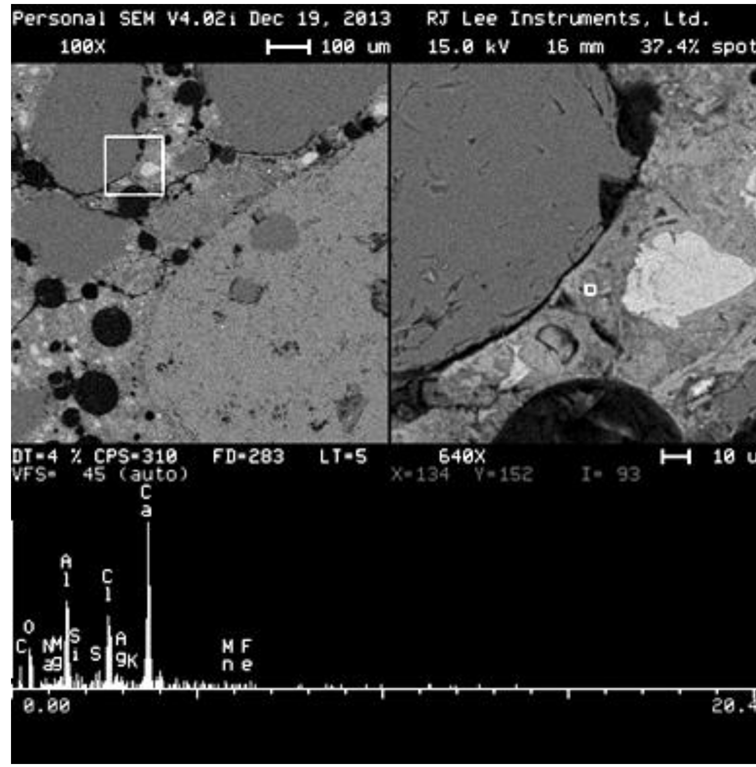


(a) Brucite (PC-$MgCl_2$-F/T)	(b) CH surrounding brucite (PC-$MgCl_2$-F/T)

Microstructure –PC concrete - F/T



(c) Magnesium chloride (PC-$MgCl_2$-F/T)



(d) Friedel's salt (PC-$MgCl_2$-F/T)

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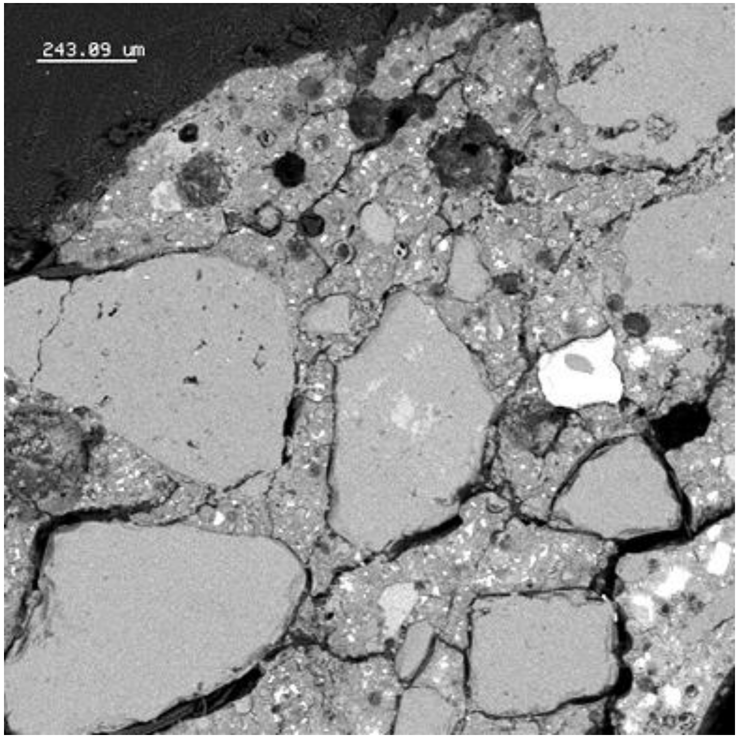
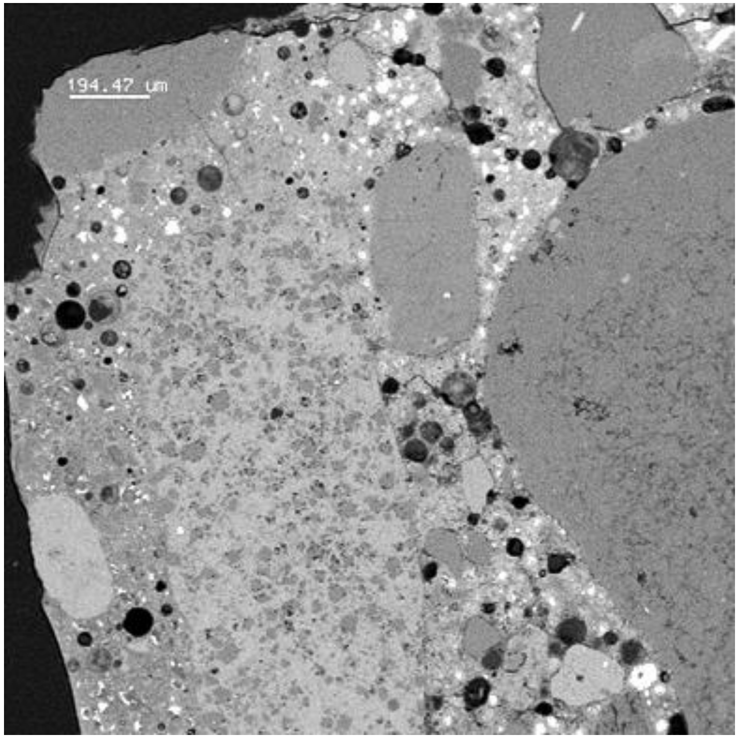
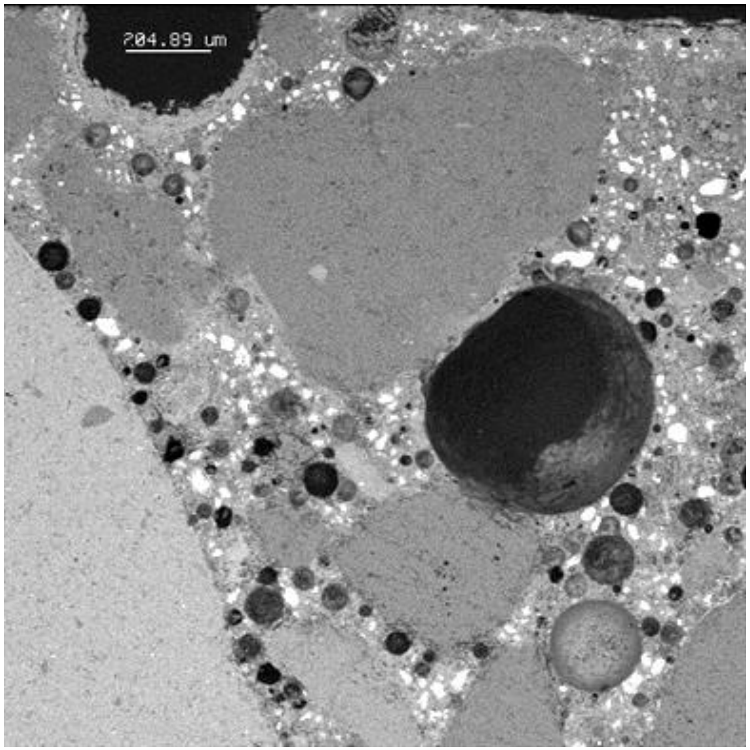
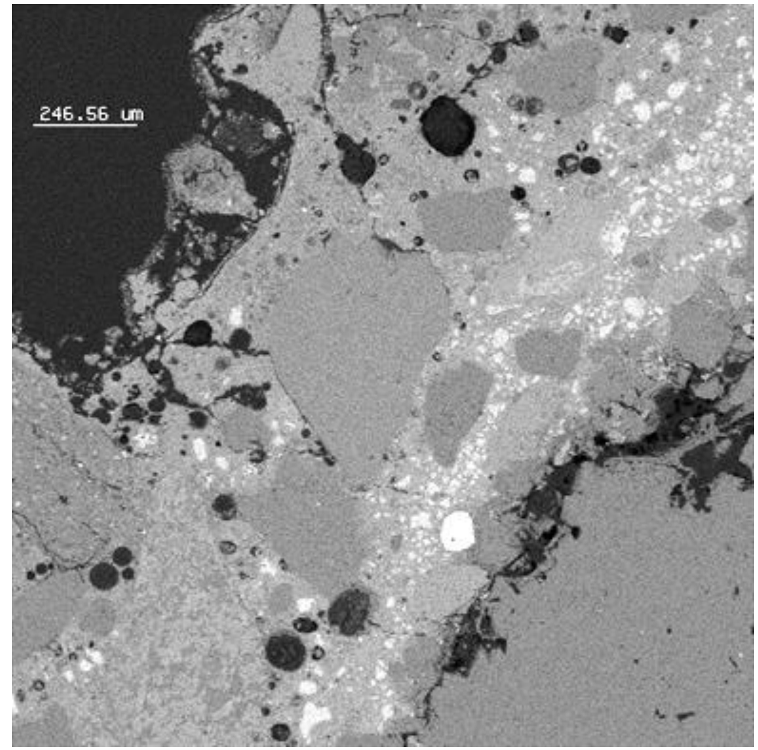
Microstructure –PC concrete - W/D

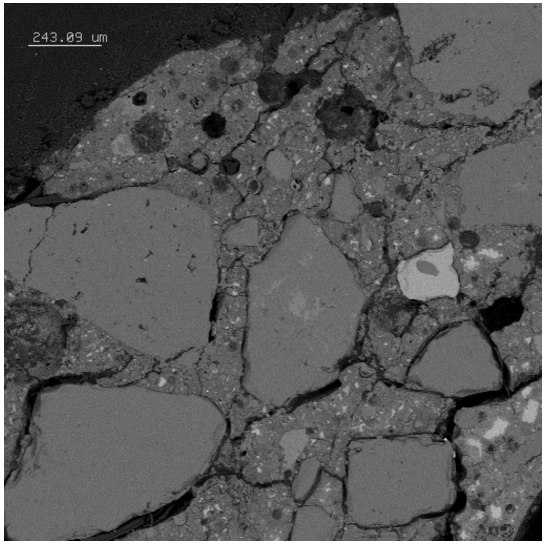




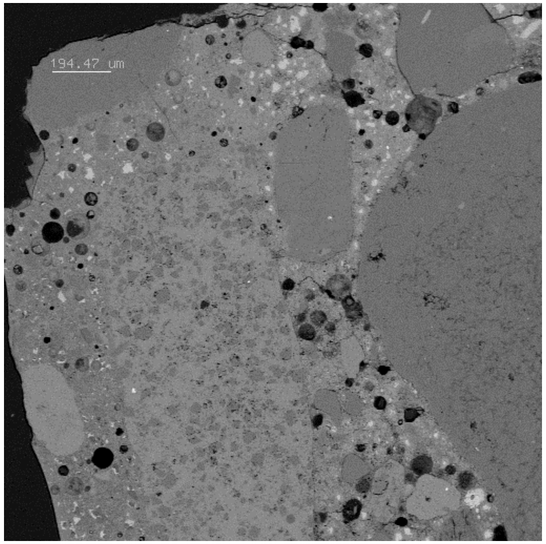
(a) PC-$CaCl_2$-W/D	(b) PC-$MgCl_2$-W/D

Microstructure –PC concrete - W/D

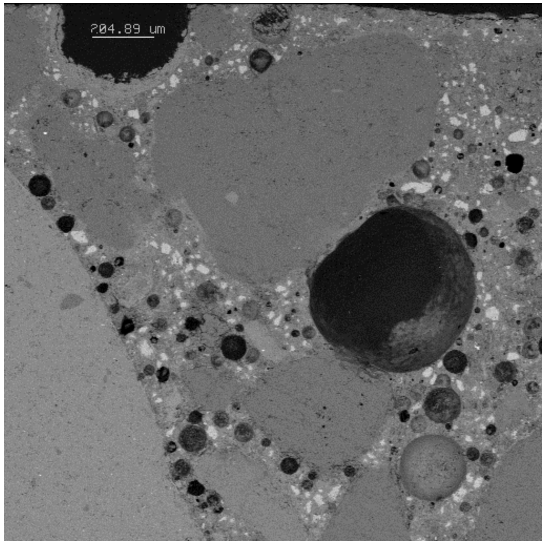
	
(c) PC-NaCl-W/D	(d) PC-DIW-W/D



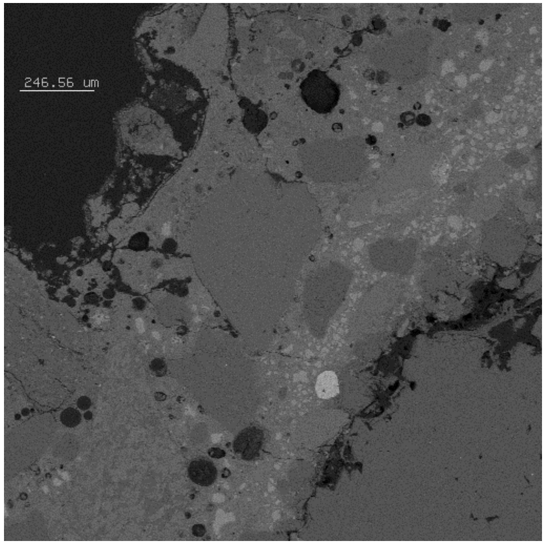
(a) PC-$CaCl_2$-W/D



(b) PC-$MgCl_2$-W/D



(c) PC-NaCl-W/D



(d) PC-DIW-W/D

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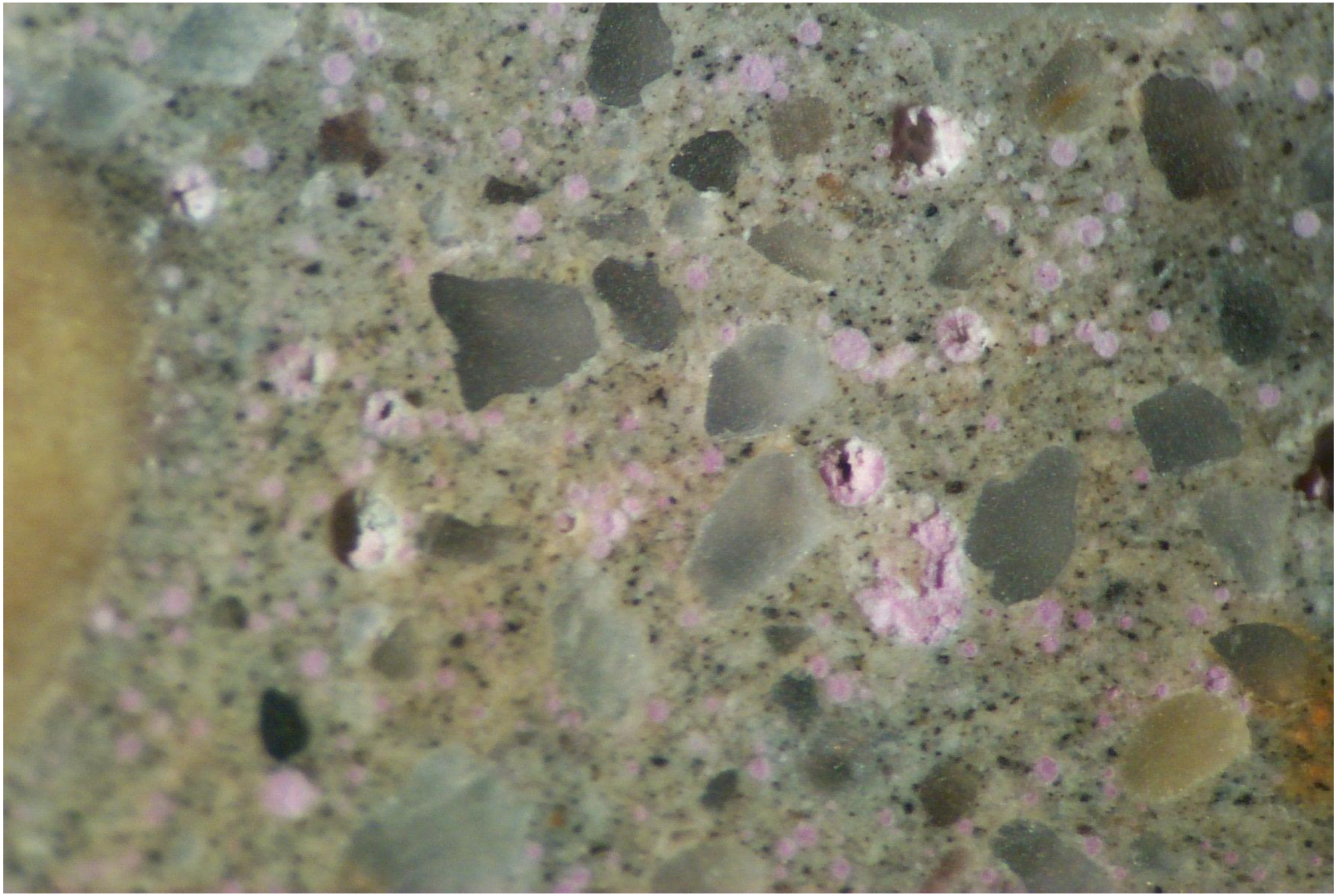
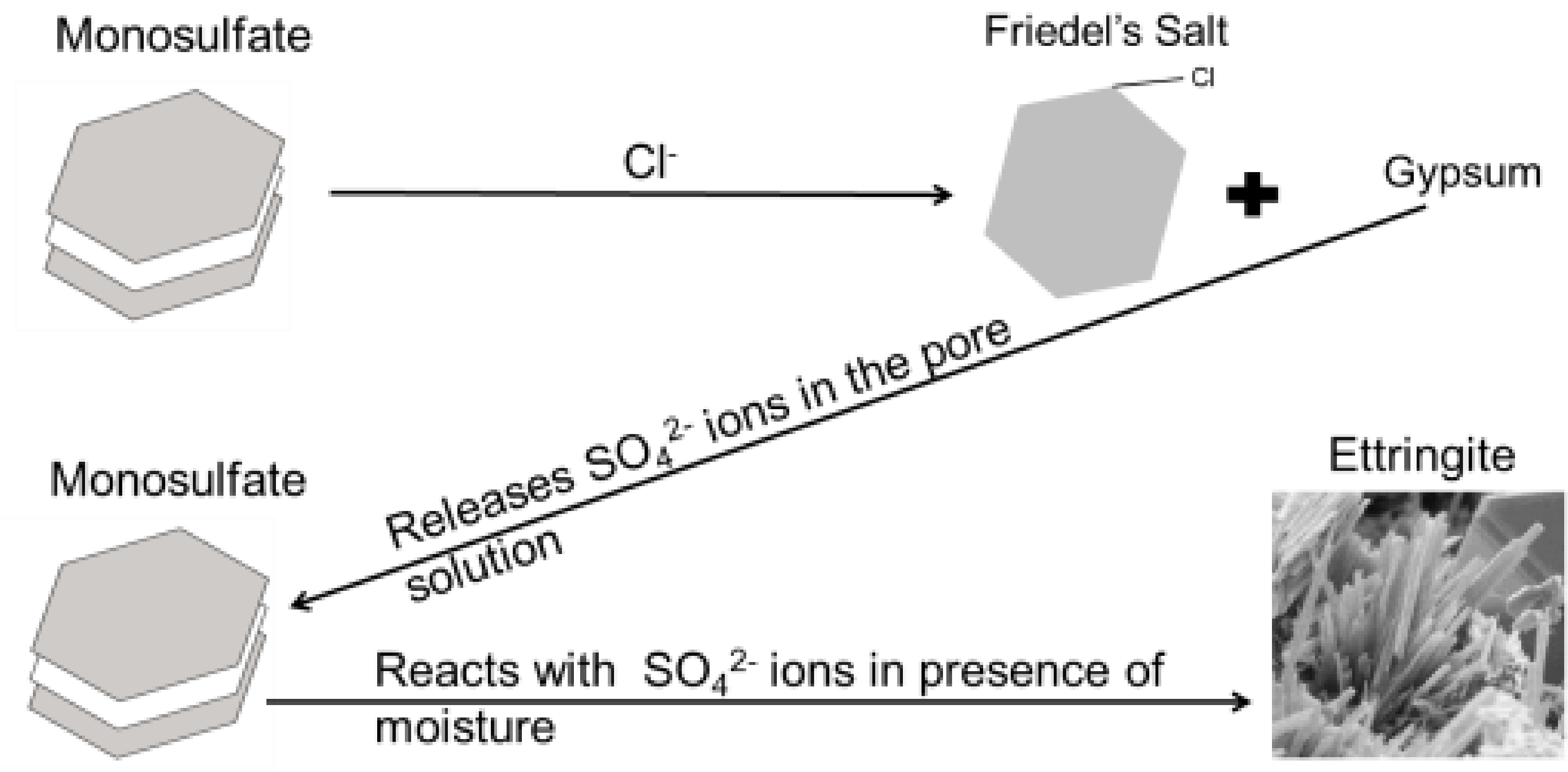
FIELD SPECIEMNS

Transverse Damaged Joint from *US 67*

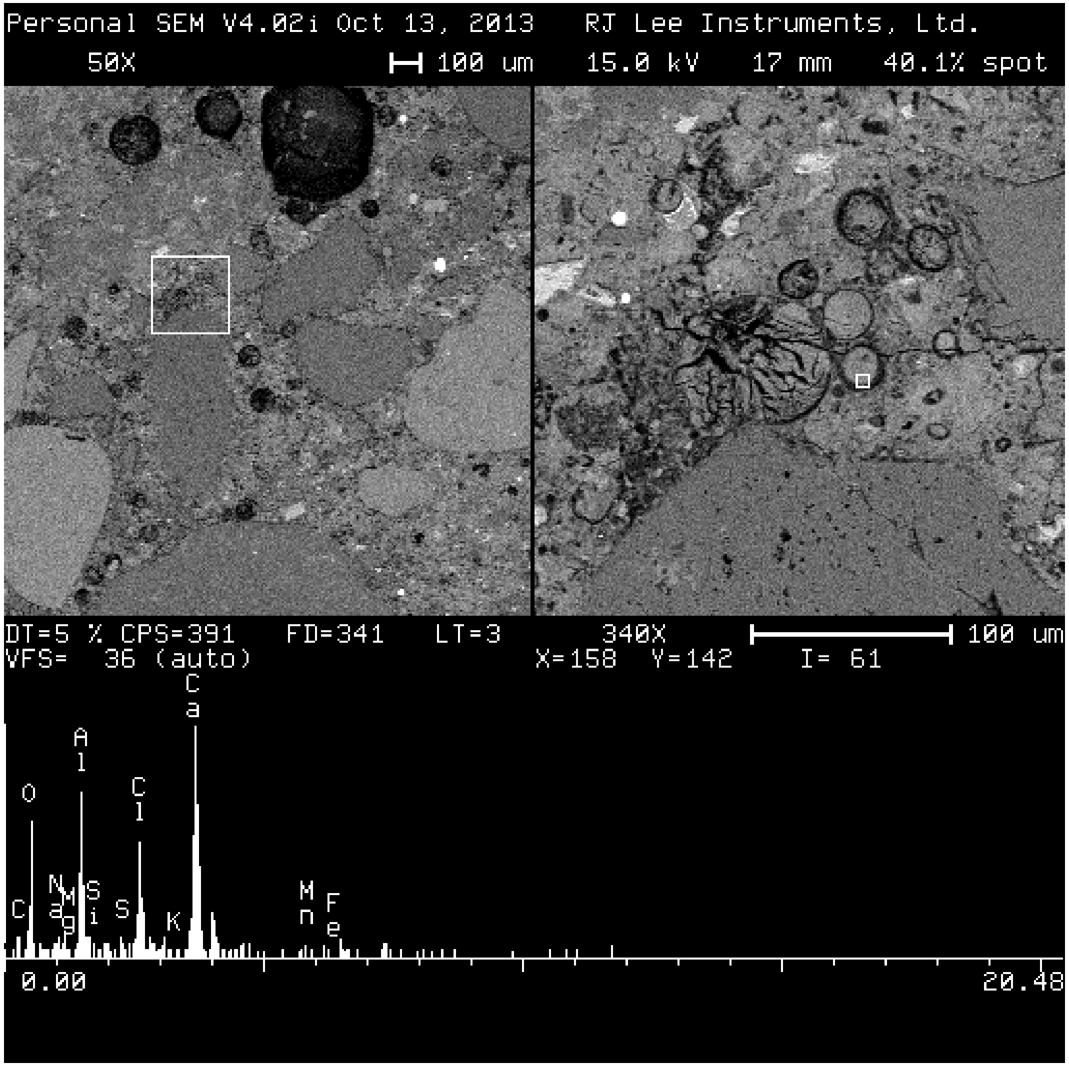



Monosulfate
Friedel's Salt
Cl
Cl-
Gypsum
Releases SO42- ions in the pore solution
Monosulfate
Ettringite
Reacts with SO42- ions in presence of moisture

SEM Observations

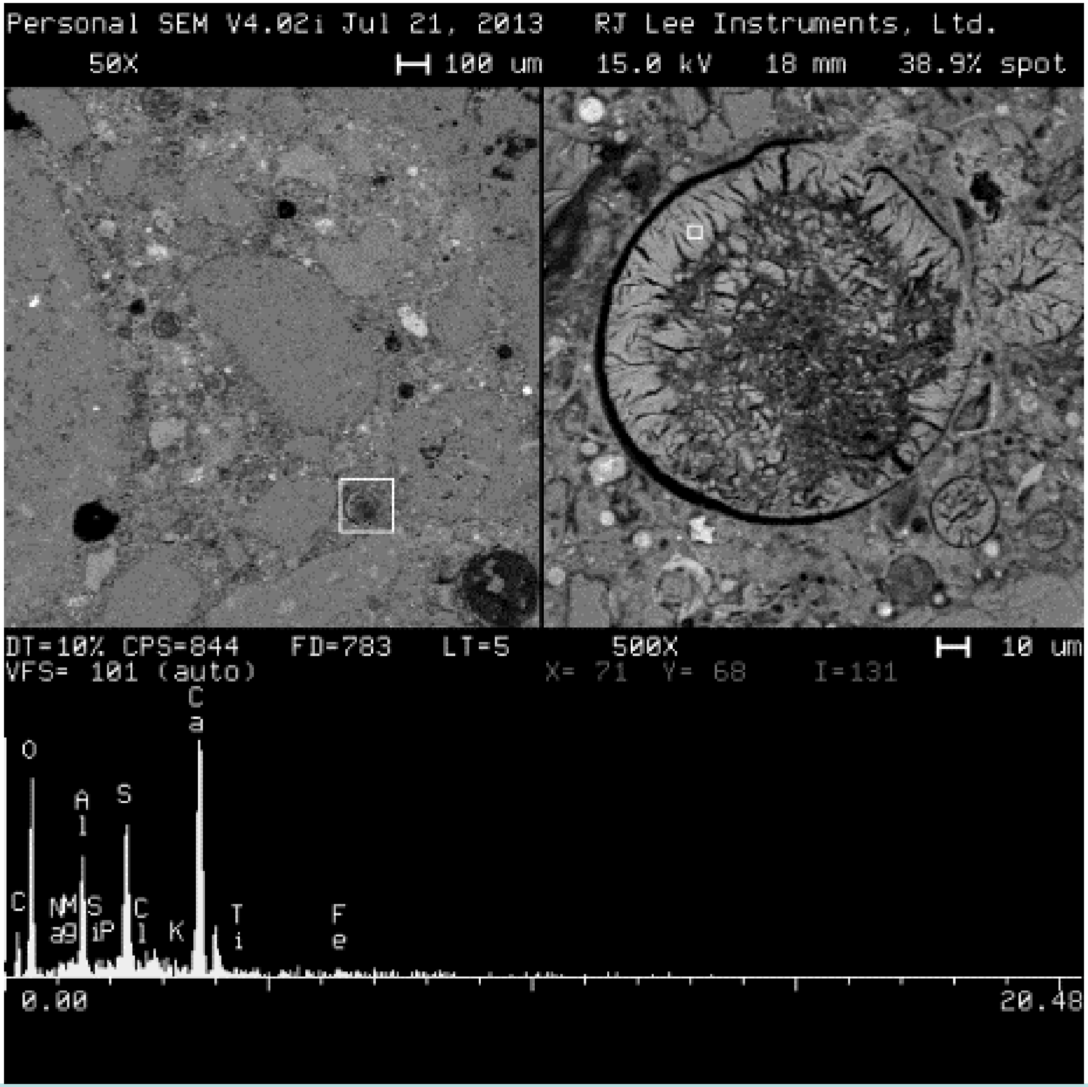
$$C_4A\bar{S}H_{12} + 2Cl \rightarrow C_3A \cdot CaCl_2 \cdot 10H + C\bar{S}H_2$$

Friedel's salt



SEM Observations

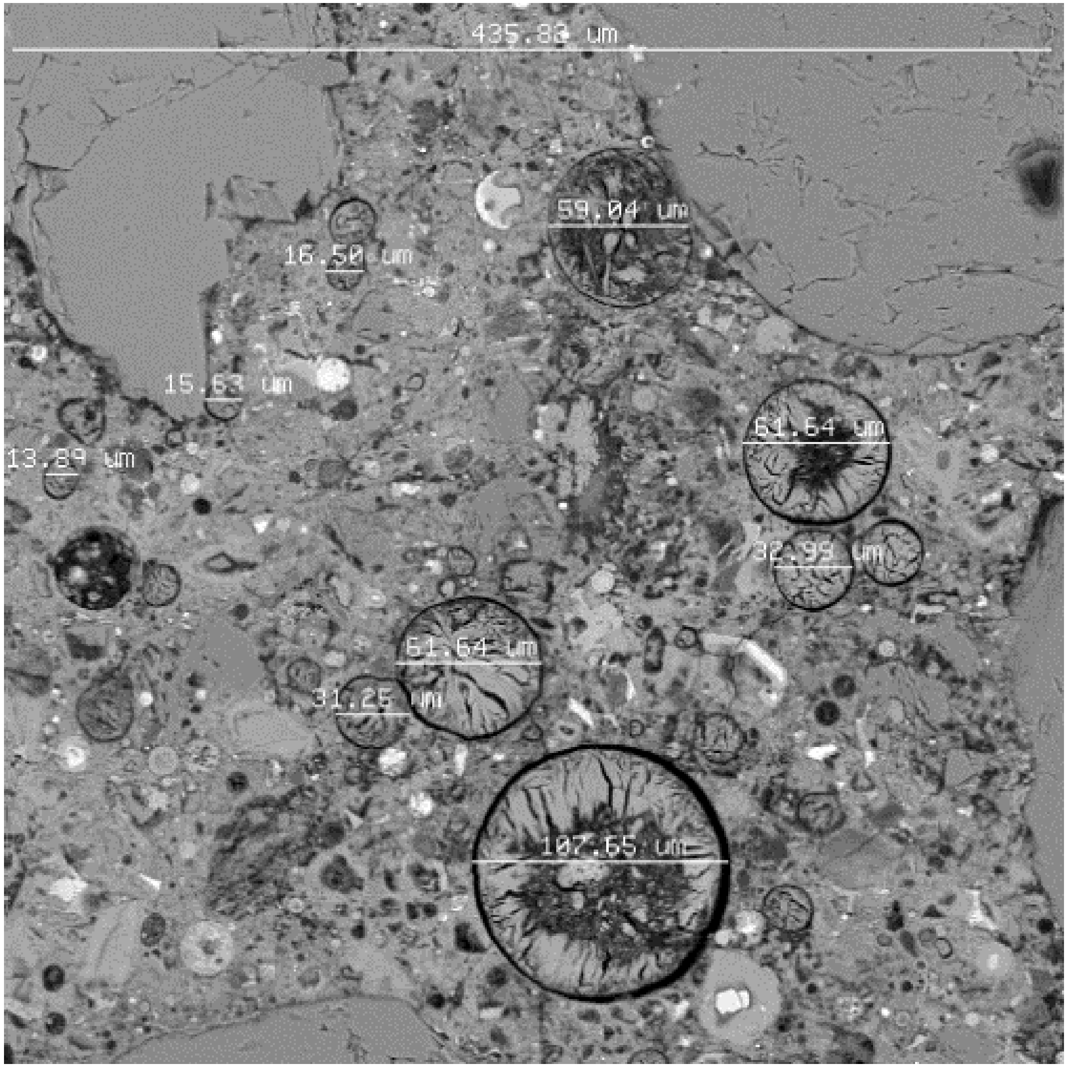
$2C\bar{S}H_2 + C_4A\bar{S}H_{12} + 16H \rightarrow C_6A\bar{S}_3H_{32}$ Ettringite



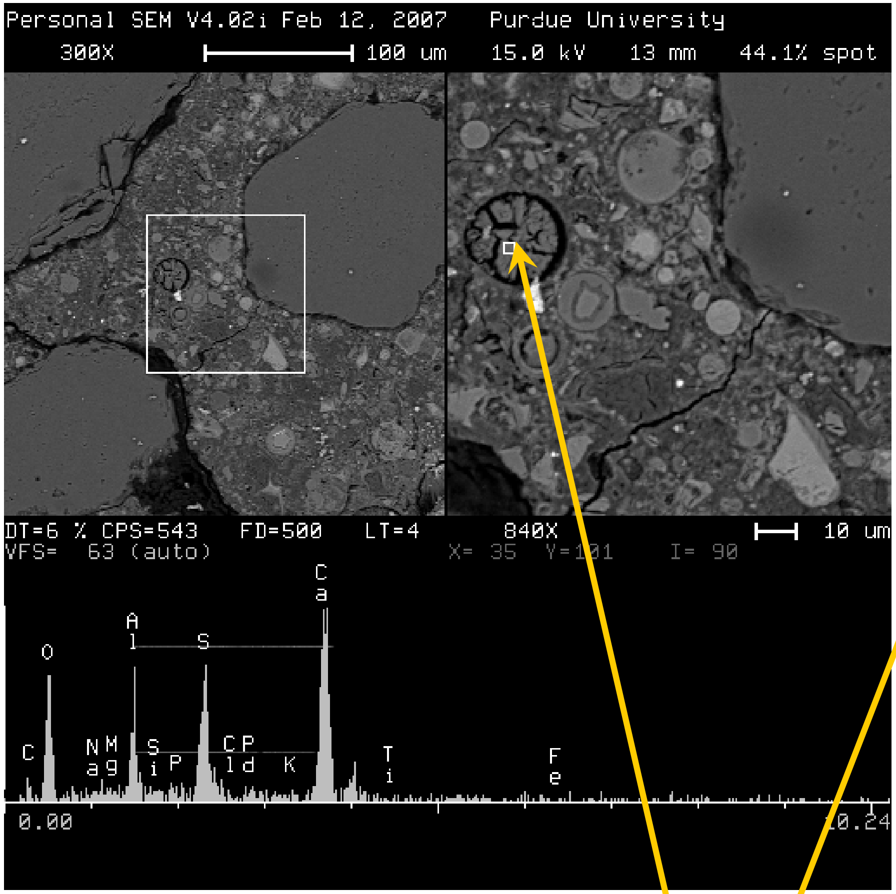
SEM Observations

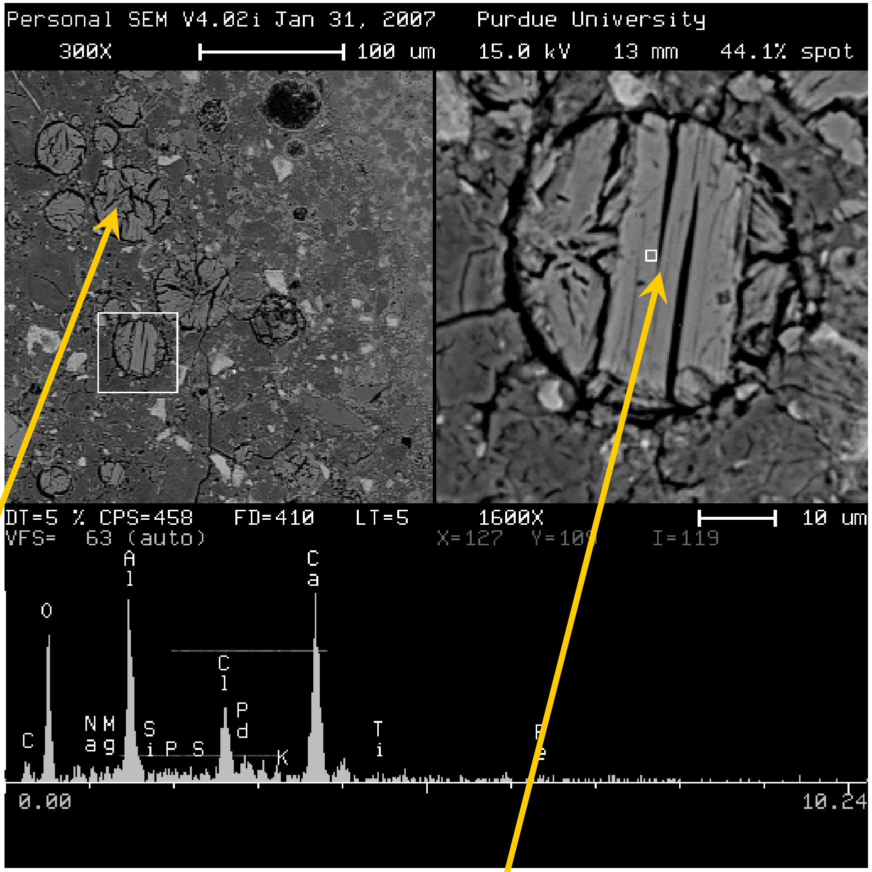
$$2C\bar{S}H_2 + C_4A\bar{S}H_{12} + 16H \rightarrow C_6A\bar{S}_3H_{32}$$

Ettringite



SEM Observations





- **Voids frequently filled with <u>Ettringite</u> and/or <u>Friedel's salt</u>**

Lab Specimens

- **Calcium chloride**
  - Most visibly damaged specimens (cracking and lost of material along the edges)
  - Highest (15~17%) reduction in RDME
  - Gypsum, CH, and Friedel's salt deposits in the matrix
  - Lowest compressive strength – PC after 350 FT cycles (~2,350psi)

Lab Specimens

- **Magnesium chloride**
  - Reduction in RDME ~14% (F/T), 10%(W/D) Onset of the reductions in RDME occurred later than in case of $CaCl_2$ exposure
  - Some spalling along the edges
  - Lowest compressive strength - PC after 350 FT cycles (~6, 000 psi)
  - Deposits of brucite in the near-surface region and occasional nests of M-S-H within the paste

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Lab Specimens

- **Sodium chloride**
  - Initial increase in the RDME over time (dropped to its original value after 350 F/T cycles),
  - No visible cracks
  - Lowest compressive strength – PC after 350 FT cycles (~4,000 psi)

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Field Specimens

- Compared to laboratory specimens the field specimens exhibited larger degree of infilling of the air voids (AFt, Friedel's salt)
- Infilling increased with depth and was more extensive in areas located near the sealed joints
- In general, specimens obtained from mid-span of the slab exhibited better air void parameters, good FT resistance and relatively lower rates of absorption compared to cores from joints

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Thank you