The Influence of Mixture Composition on the Durability of Concrete Exposed to Deicing Chemicals

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Prepared for the XVIII Anna Maria Workshop
Chemical Attack on Concrete
November 15-17, 2017

Introduction

- Despite large volume of published data, not all details of physical and chemical mechanisms of interactions of deices with concrete universally accepted
- Specifics of interactions influenced by mixture composition, quality of concrete, type and concentration of deicers, and the temperature regime during testing.
- Previous studies utilized wide ranges of concentrations of deicers, temperatures and lengths of exposure cycles; some combinations resulted in unrealistic conditions (w.r.t. field exposure)

Objectives

- Investigate the effects of de-icing/anti-icing chemicals on durability of concrete as a function of:
  - Mixture composition
  - Type and concertation of the deicers
  - Temperature regime during the test

Experimental program

- The durability of the two types of concrete (plain and fly ash) when exposed to:
  - Wetting and drying (W/D) cycles
  - Freeze-thaw (F/T) cycles
  - Scaling conditions
- Periodic monitoring of mass loss/ length changes and resonance frequencies of specimens exposed to W/D and F/T cycles
- Determination of compressive strength

Materials

- Cement (Type I)
- Fly ash (Class C and Class F)
- Air entraining agents
- Deicing solutions-
  - NaCl, $MgCl_2$, $CaCl_2$
- Water reducing admixtures
- Coarse aggregates (limestone/ dolomite)

Mixture proportions - F/T and W/D Tests

(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

Deicers

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

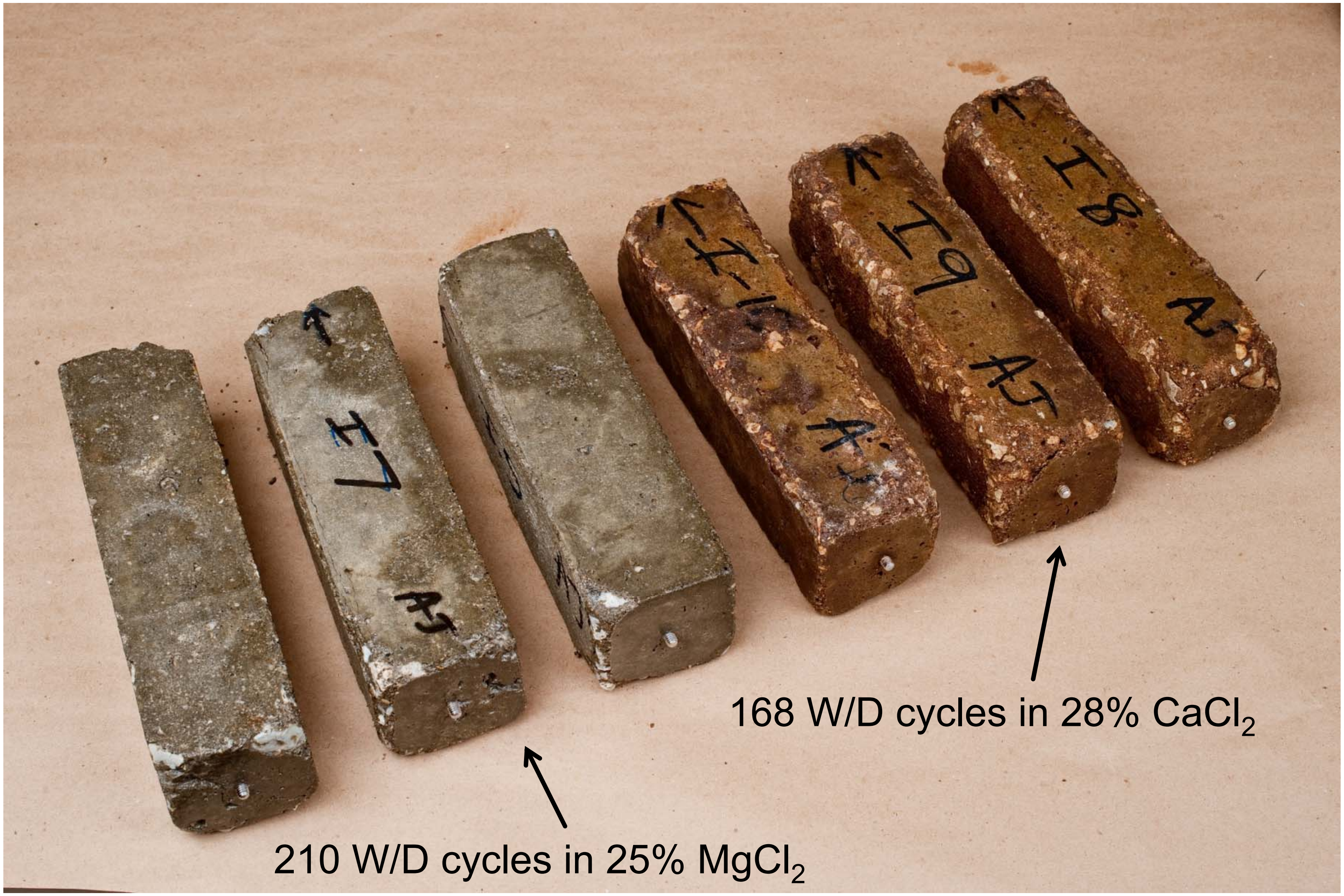
Curing

- Submerged in limewater for 28days at 73.4°F (23°C)
- Air dried for 3days at 73.4°F (23°C), 50% RH

Wetting and Drying Cycles

- 8 hrs of drying at 23C (72F)
- 16 hrs of wetting at 4C (40F)

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



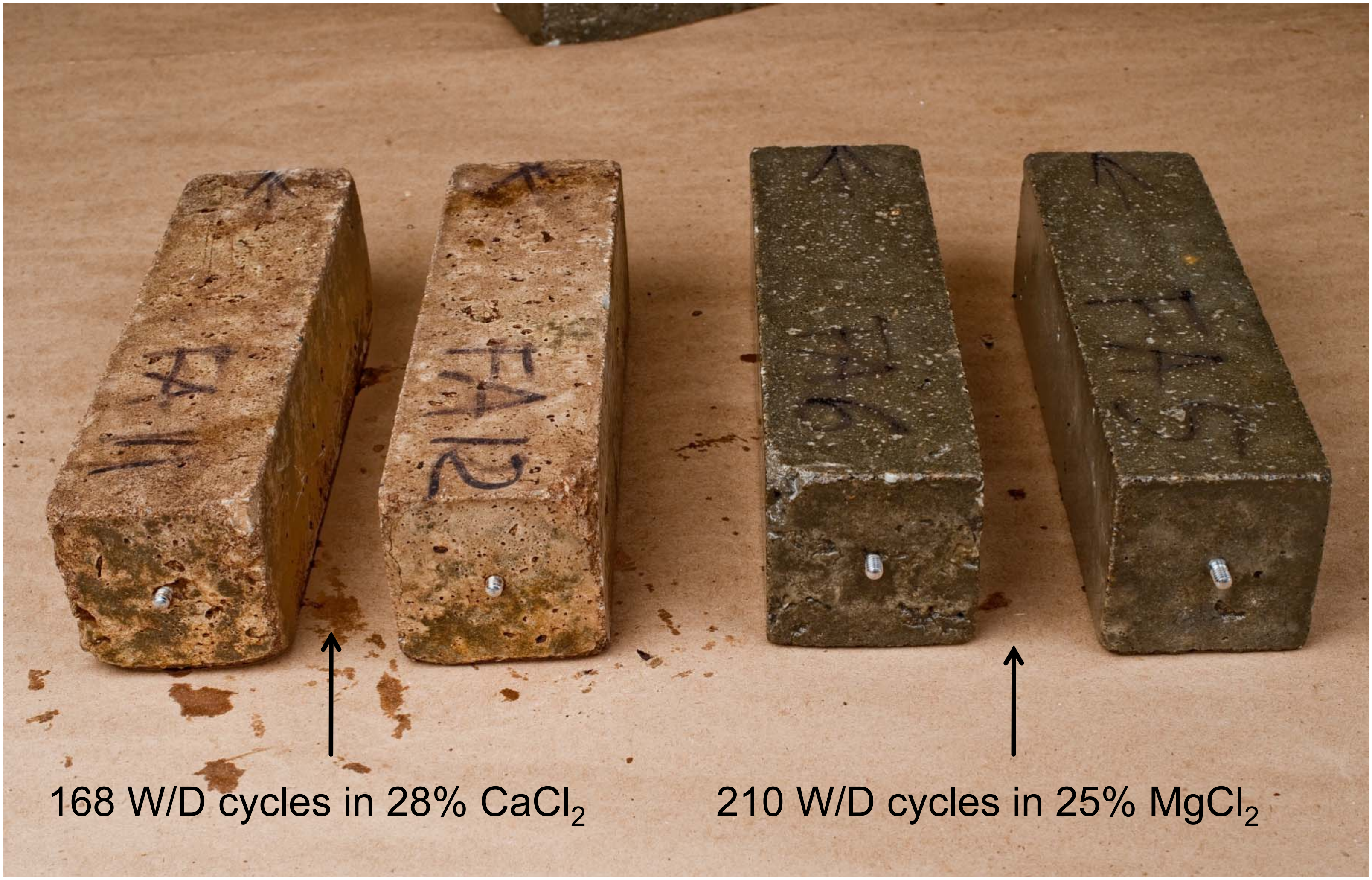
168 W/D cycles in 28% $CaCl_2$

210 W/D cycles in 25% $MgCl_2$

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

Testing stopped after 168 W/D cycles due to extensive deterioration.

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



168 W/D cycles in 28% $CaCl_2$

210 W/D cycles in 25% $MgCl_2$

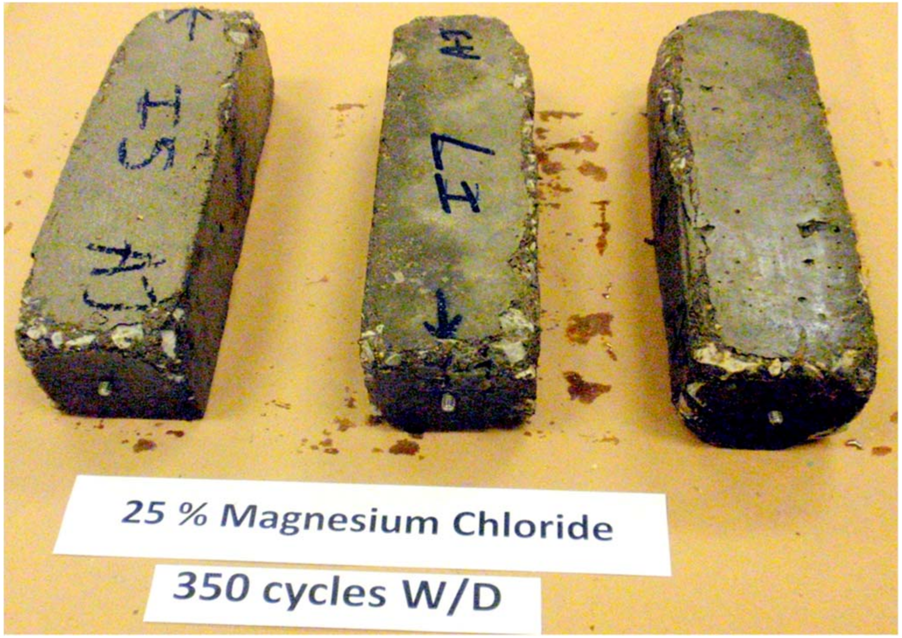
Type I & Fly Ash specimens after 168 W/D cycles in 28% $CaCl_2$ solution

The use of fly ash helps reduce the rate of deterioration.

Type I & Fly Ash specimens after 275 W/D cycles in 25% $MgCl_2$ solution

After 275 W/D cycles Type I specimens showed signs of slight surface deterioration. Testing continued until 350 W/D cycles

Type I Specimens Subjected to WD Conditions



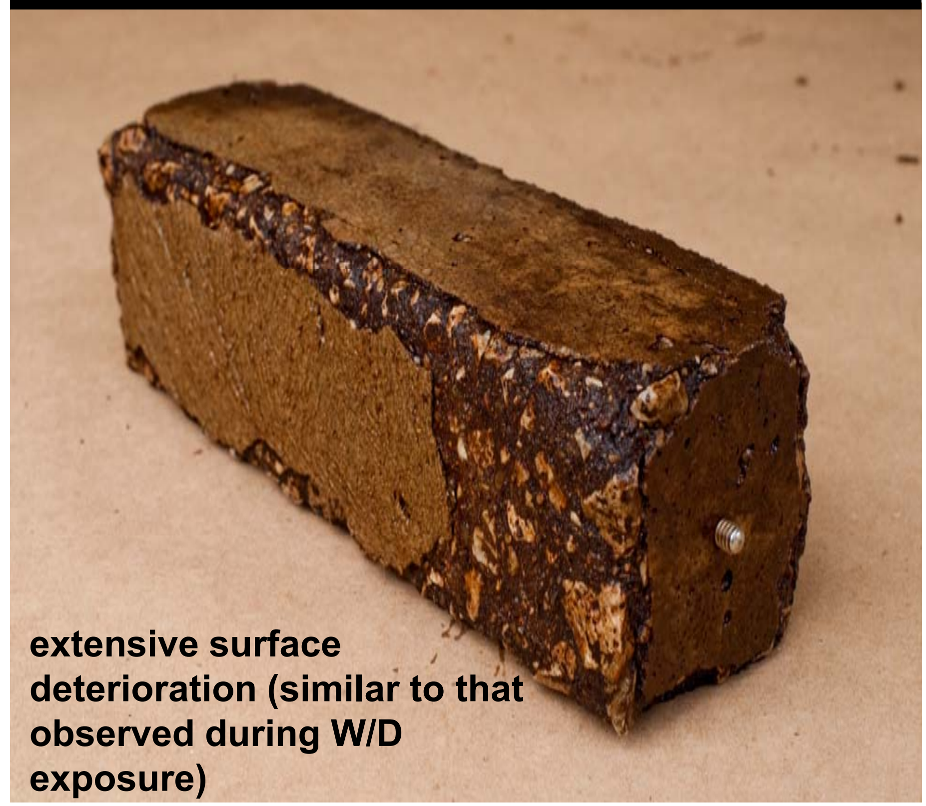
Freezing and Thawing Cycles

- 6 hrs long cycles (-20C to +20C (-4F to 68F)

F/T exposure - Type I Specimens

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

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



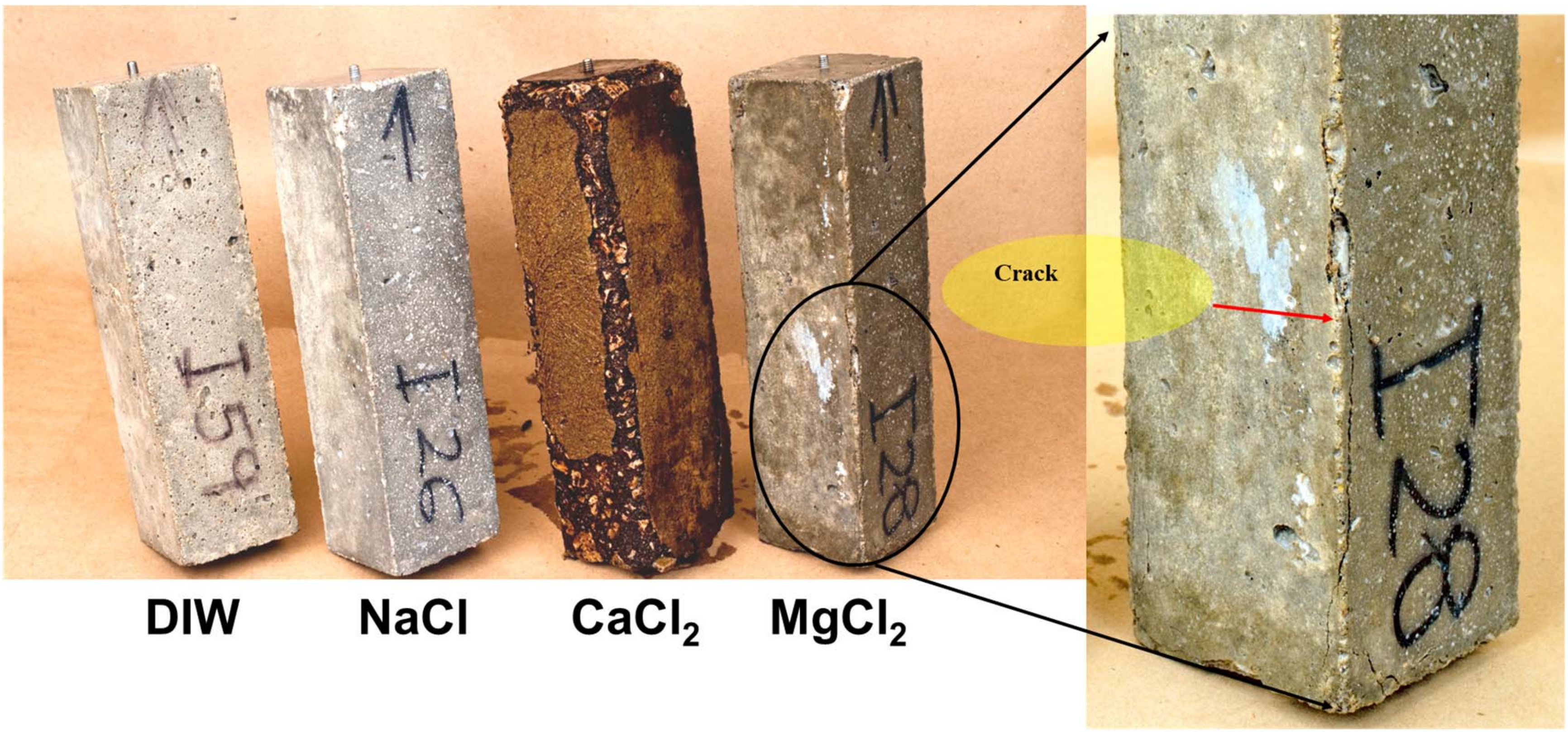
extensive surface deterioration (similar to that observed during W/D exposure)

F/T Exposure - Type I & Fly Ash Specimens

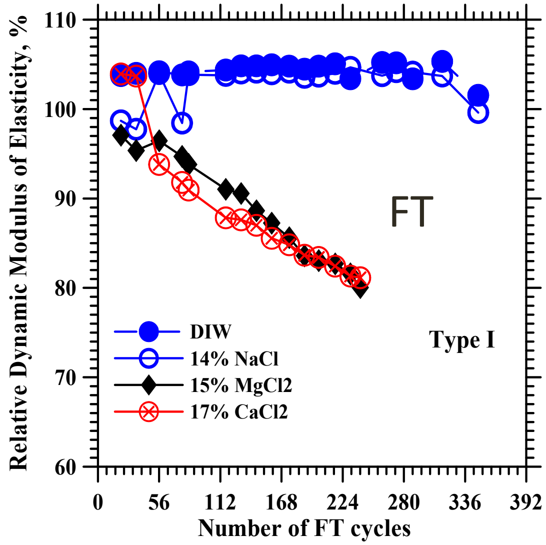
Type I & Fly Ash specimens after 166 F/T cycles in 15% $MgCl_2$ solution

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

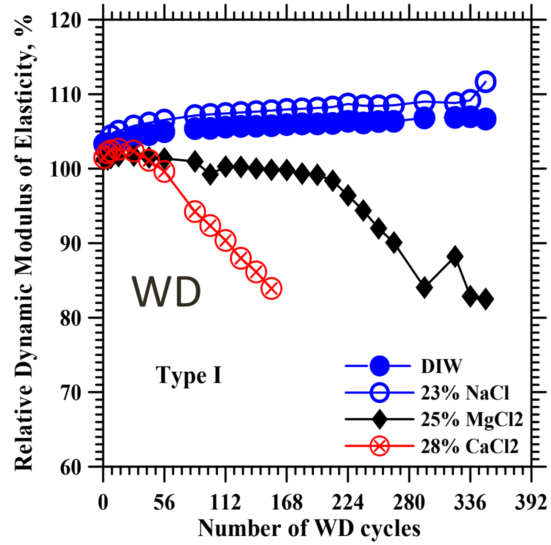
Type I Specimens - FT exposure



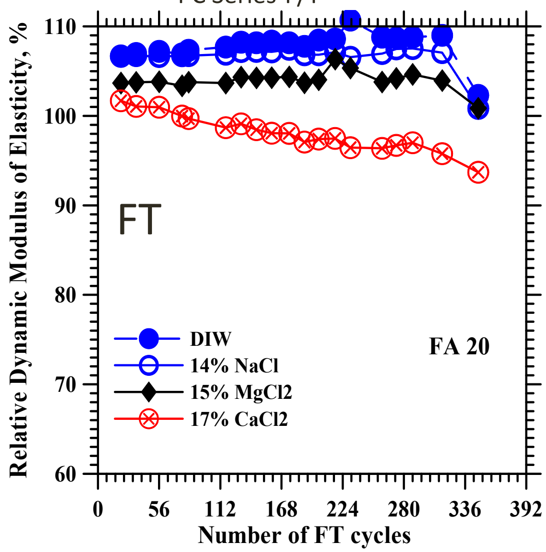
RDME changes(specimens with limestone)



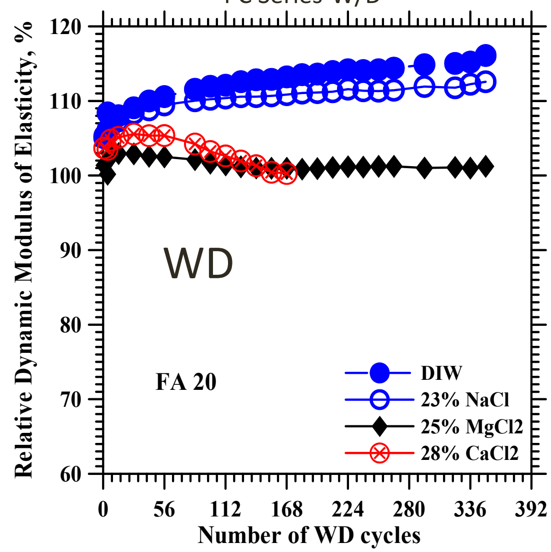
PC Series-F/T



PC Series-W/D

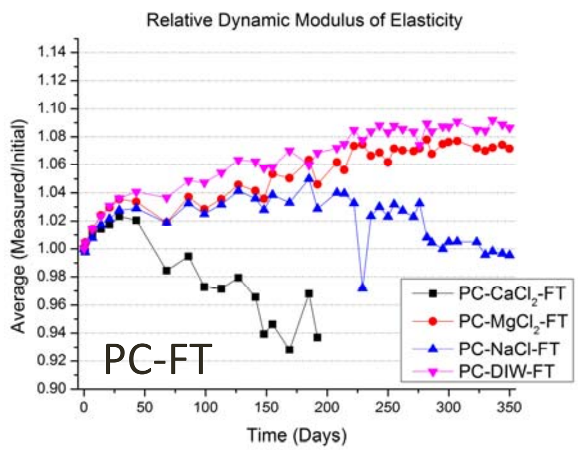


FA Series-F/T

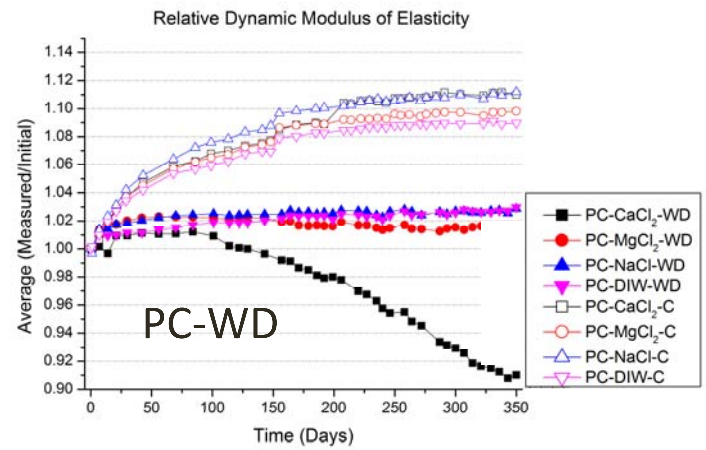


FA Series-W/D

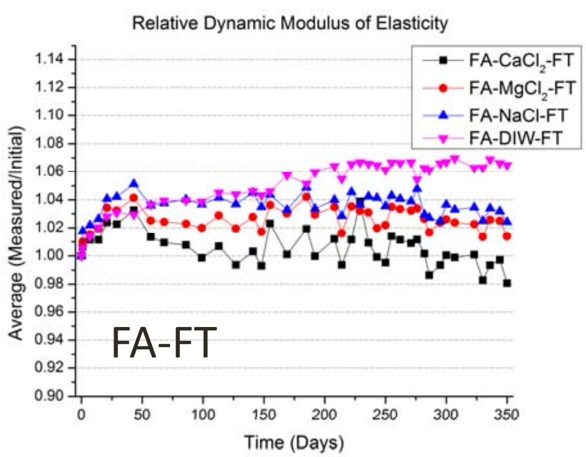
RDME changes(specimens with dolomite)



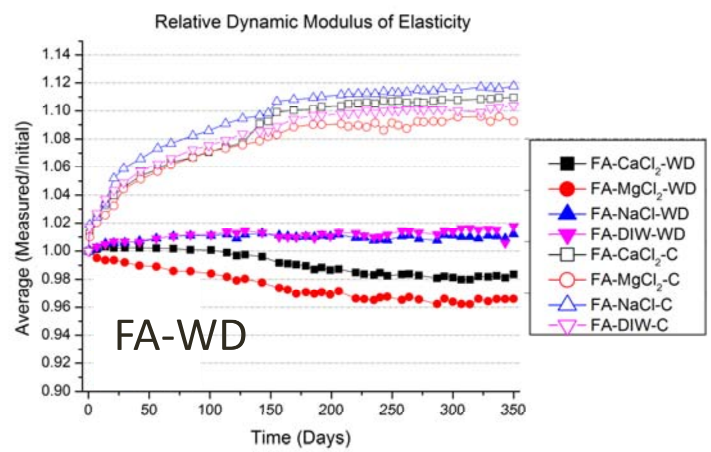
PC Series-F/T



PC Series-W/D



FA Series-F/T

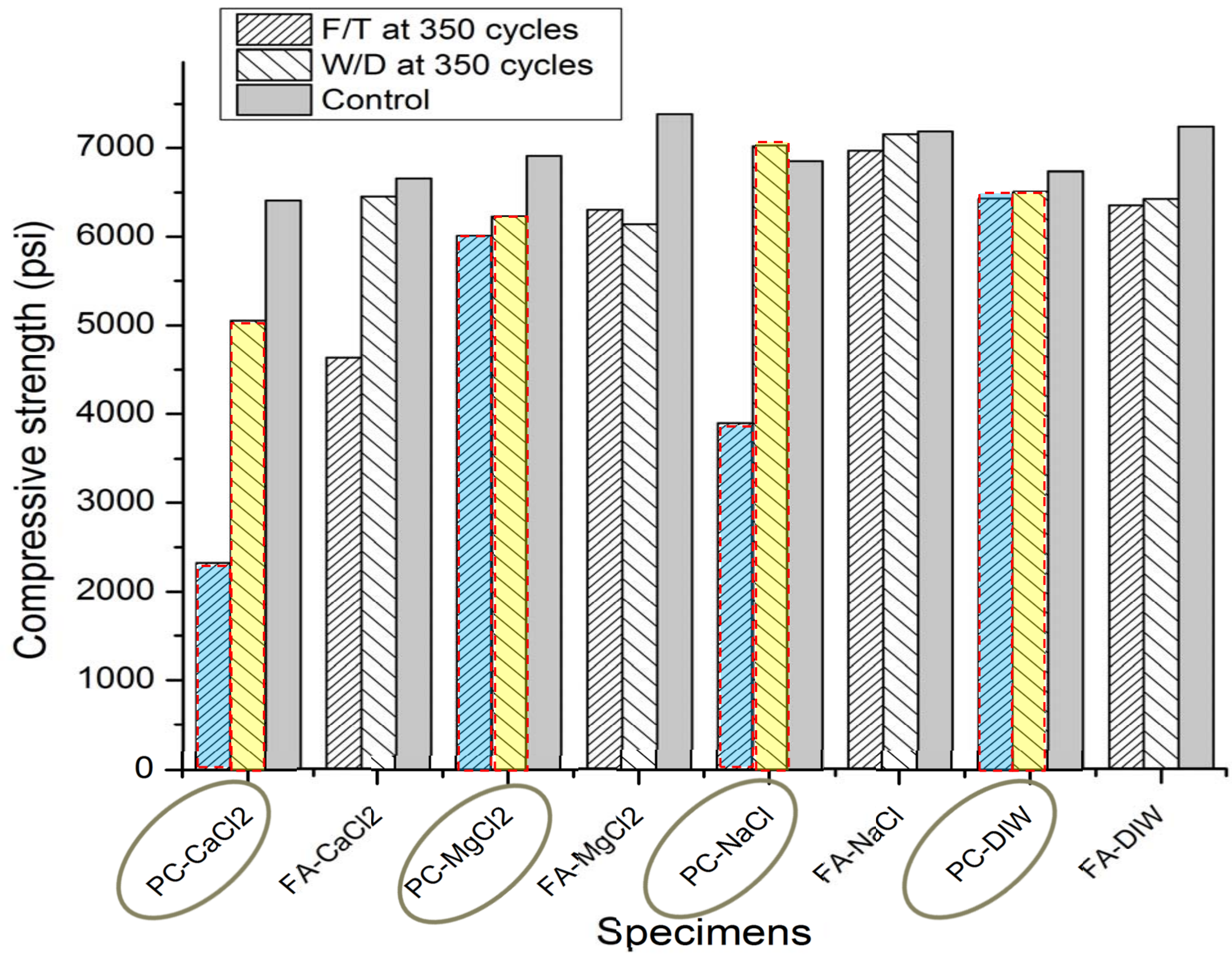


FA Series-W/D

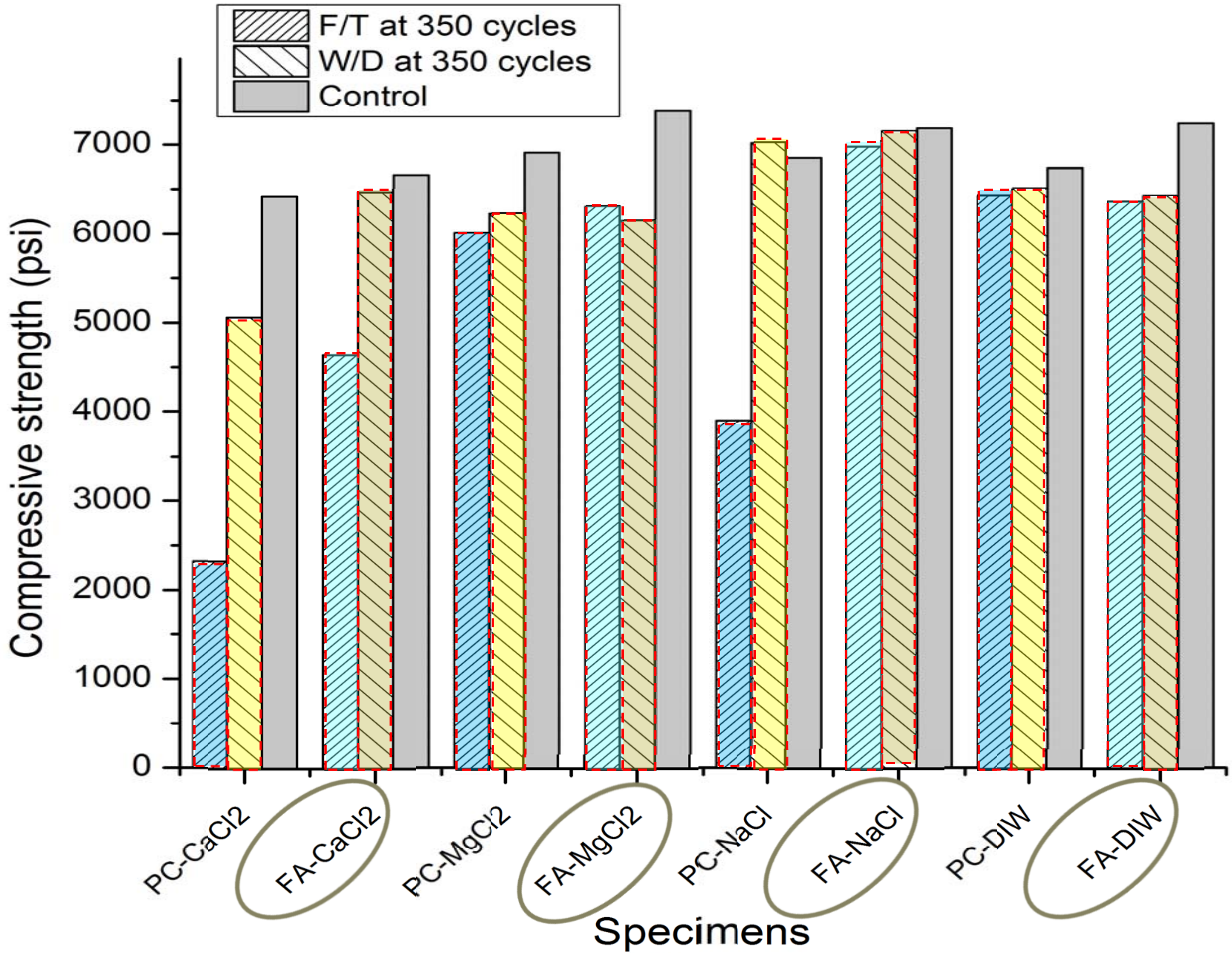
Compressive Strength measurements

- Compressive strength was measured on cylinders exposed to W/D regime (limestone specimens) or both F/T and W/D (dolomite specimens) after the completion of exposure in respective solutions.

Compressive strength - dolomite

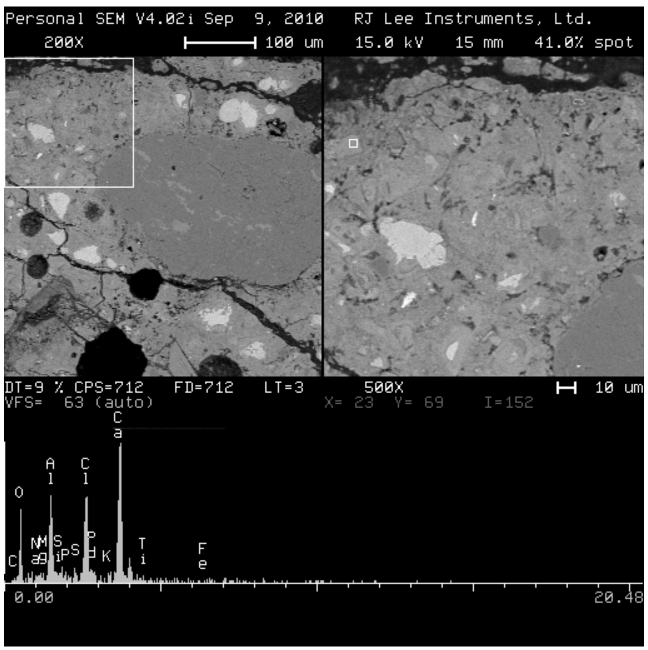


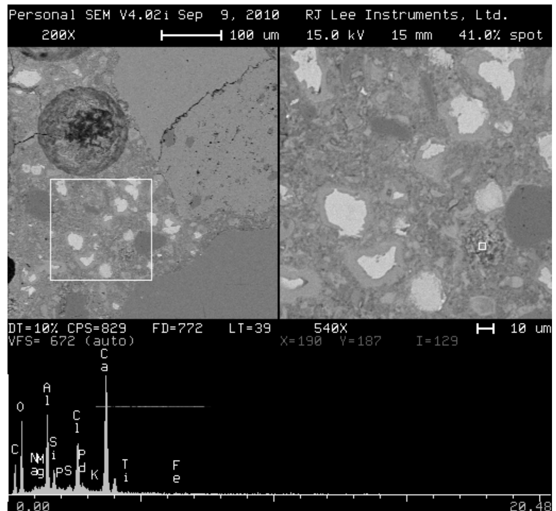
Compressive strength - dolomite

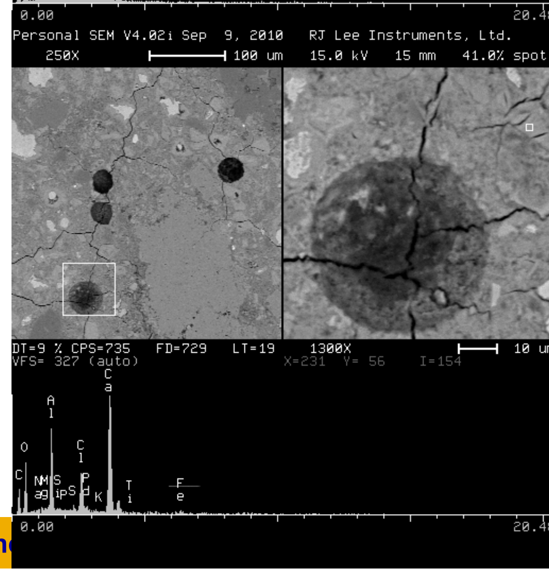


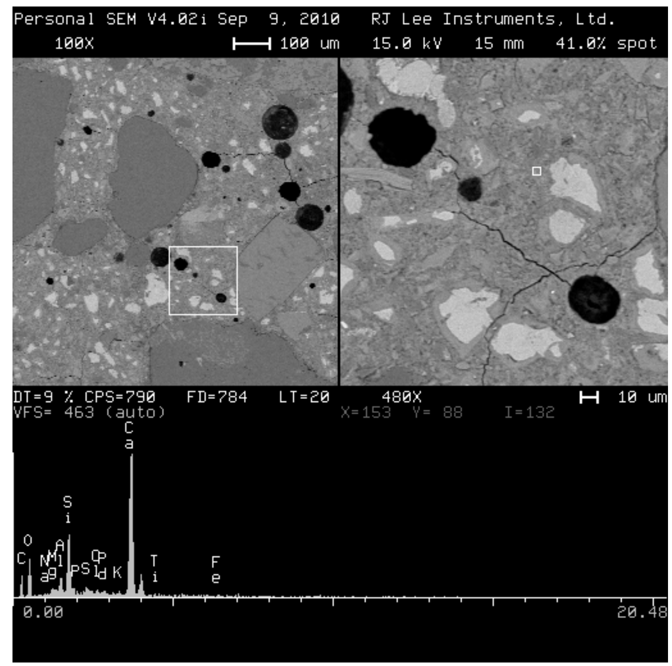
Distribution of Friedel's salt in the matrix Type I, $CaCl_2$

top surface (0 -0.5 cm) | **middle (~0.8-1.3 cm)** | **bottom (~ 1.8-2.2cm)**





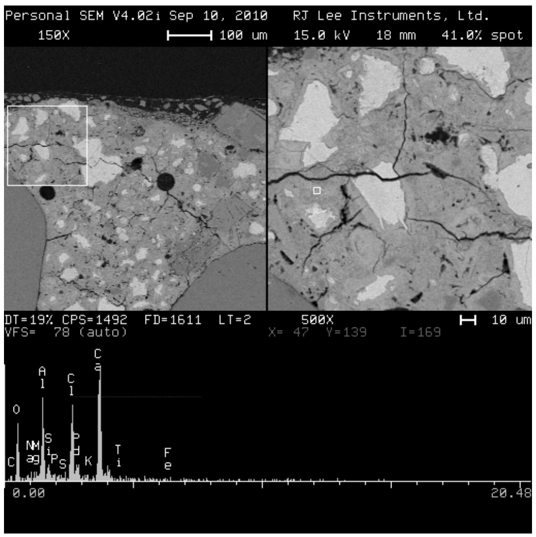
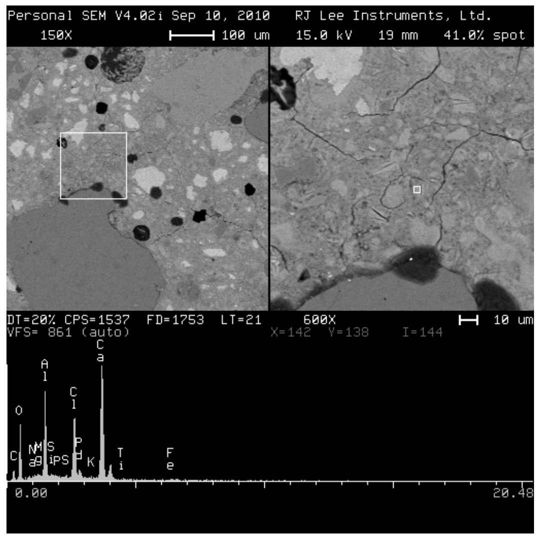
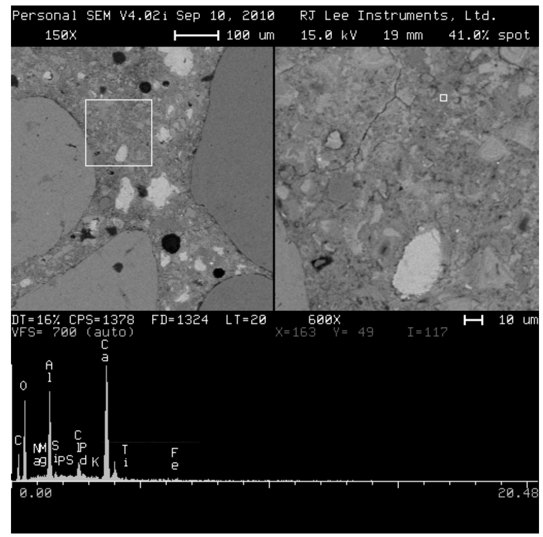




$3CaO \cdot Al_2O_3 \cdot CaCl_2 \cdot 10\,H_2O$

No traces of Cl in bottom part of specimen

Distribution of Friedel's salt in the matrix, Type I, $MgCl_2$

top surface (0 -0.4 cm)	middle (~0.8-1.3 cm)	bottom (~ 1.8-2.2cm)
		

$3CaO \cdot Al_2O_3 \cdot CaCl_2 \cdot 10\ H_2O$

Small peak of Cl in bottom part of specimen

Conclusions FT & WD

- External signs of deterioration were more extensive in Type I specimens exposed to 168 W/D cycles in $CaCl_2$ solution than those observed in specimens exposed to 210 W/D cycles in $MgCl_2$ solution (despite 25% longer exposure).
- Initial signs of distress were observed in the $MgCl_2$ exposed specimens only after 275 W/D cycles but even then the overall damage was still much lower than that observed in the $CaCl_2$ specimens after 168 W/D cycles (60% shorter exposure).
- Surface deterioration of Type I specimens exposed to the $MgCl_2$ solution for 350 W/D cycles was observed to be comparable to the surface deterioration of the equivalent specimens in the $CaCl_2$ for 168 W/D cycles. This indicates the specimens in the $CaCl_2$ were deteriorating at the rate at least twice as fast as the specimens in the $MgCl_2$ solution.

Conclusions FT & WD

- The RDME values of the specimens exposed to $MgCl_2$ stayed at the 100% level for almost 200 W/D cycles as opposed to about 30 cycles for specimens exposed to the $CaCl_2$. This indicates that the $CaCl_2$ solutions accelerate the deterioration rate to approximately 3 times that of the $MgCl_2$ solutions.
- The fly ash concrete demonstrates better performance compared with the Type I specimens.

Scaling Resistance

- 50 cycles – ASTM C672

Materials and mixtures.

Concretes

Concrete	w/cm	% Fly Ash (Class F)	Target air content (%)
A	0.42	0	6.5
B	0.45	0	4.5
C	0.42	30	6.5
D	0.45	30	4.5

Deicers

$CaCl_2$, $MgCl_2$ and NaCl - all at 4% concentration

Concrete A – plain concrete, w/c=0.42,Target air: 6.5 %

$CaCl_2$ $MgCl_2$ NaCl DiW

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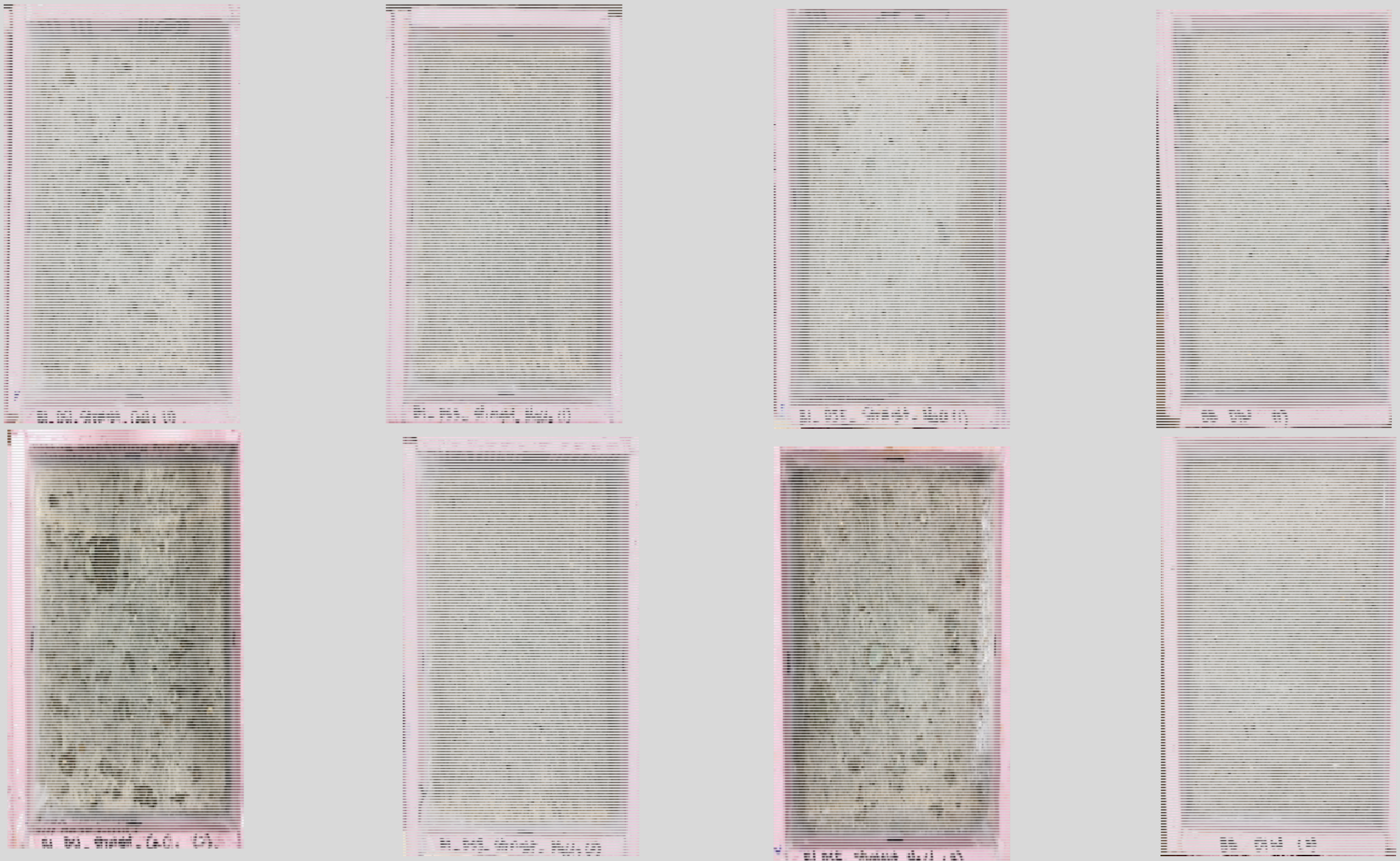
Concrete B – plain concrete, w/c=0.45, target air: 4.0 %



$CaCl_2$ $MgCl_2$ NaCl DiW

Concrete C - FA concrete, w/c = 0.42, target air 6.5%

Concrete D – FA concrete, w/cm = 0.45, target air 4.0%

$CaCl_2$ | $MgCl_2$ | NaCl | DiW

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Conclusions – Scaling Test

Concrete	w/cm	% Fly Ash	Target air content (%)
A	0.42	0	6.5
B	0.45	0	4.5
C	0.42	30	6.5
D	0.45	30	4.5

Effect of the type of concrete:

- **Concretes without fly ash (A and B)** -> No scaling with $MgCl_2$ and NaCl deicers. Slight to moderate scaling with $CaCl_2$.
- **Concretes with fly ash (C and D)** -> No scaling using $MgCl_2$ deicers. Scaling observed when using $CaCl_2$ and NaCl
- Scaling of concrete D > Scaling of concrete C. This was expected because “air content D” < “air content C” and w/cm D > w/cm C

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