nanocem THE INDUSTRIAL-ACADEMIC RESEARCH NETWORK ON CEMENT AND CONCRETE

Long Time Durability Study of Femern Belt Trial Concrete - 6 months results -

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- Analysis Program
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  - Microstructural appearances
  - Sulfate, magnesium and chloride ingress

Introduction/Background

- In 2009 Denmark and Germany agreed about building a physical connection between the 2 countries, the Femern Belt Fixed Link
- 20km long connection
- Planed to finish in 2019
- 18 trial concretes have been cast for a long time durability study of concrete subjected to seawater
- Testing periods: 28days, 6 months, 2 years, 5 years, 8 years

The purpose of this presentation is to present the microscopic appearances of the concretes after 6 months of submersion in seawater.

Binder Combinations of Trial Concrete

A	Portland low alkali sulfate resistant cement (CEM I 42,5 N) w/c=0.40.
B	CEM I 42,5 N with 15% fly ash, w/c=0.40.
C	CEM I 42,5 N with 25% fly ash, w/c=0.40.
D	CEM I 42,5 N with 25% fly ash, SCC, w/c=0.40.
E	CEM I 42,5 N with 4% silica fume, w/c=0.40.
F	CEM I 42,5 N with 12% fly ash and 4% silica fume, w/c=0.40.
G	CEM I 42,5 N with 12% fly ash and 4% silica fume, no air entrainment, w/c=0.40.
H	CEM I 42,5 N with 12% fly ash and 4% silica fume, w/c=0.45.
I	CEM I 42,5 N with 12% fly ash and 4% silica fume, w/c=0.35.
J	CEM I 42,5 N with 12% fly ash and 4% silica fume, SCC, w/c=0.40.
K	Traditional slag cement (CEM III/B), w/c=0.40.
L	CEM III/B, no air entrainment, w/c=0.40.
M	CEM III/B, SCC, w/c=0.40.
N	70 % slag mixed with 30% rapid cement (CEM I 52,5 N) w/c=0.40.
O	CEM I 42,5 N with 4% silica fume with super absorbing polymers, w/c=0.40.

Basis cement (CEM II, 52.5 – containing <5% LF and FA)

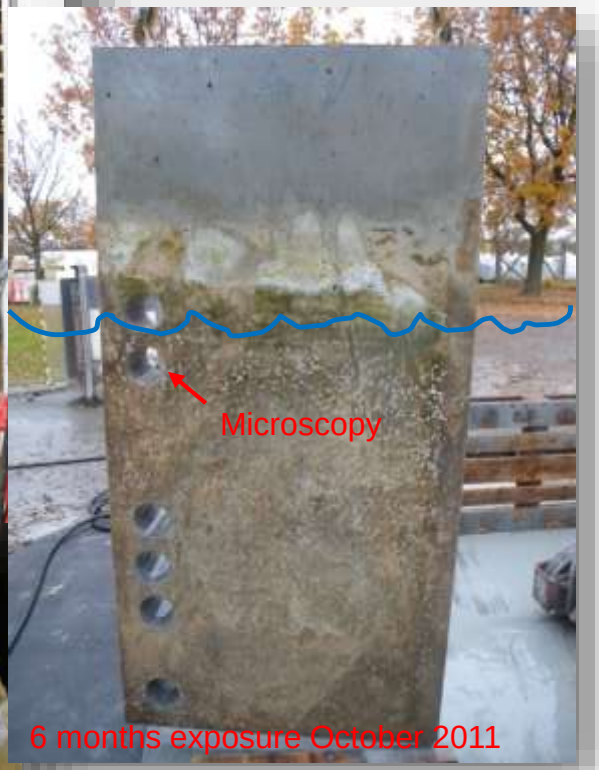
Rapid hardening cement (CEM I 52.5 LA/MS)

Rapid hardening cement (CEM I 52.5 LA/MS) with 30% fly ash

Laboratory Testing, Casting, Coring …


Fresh concrete properties


Casting October 2009



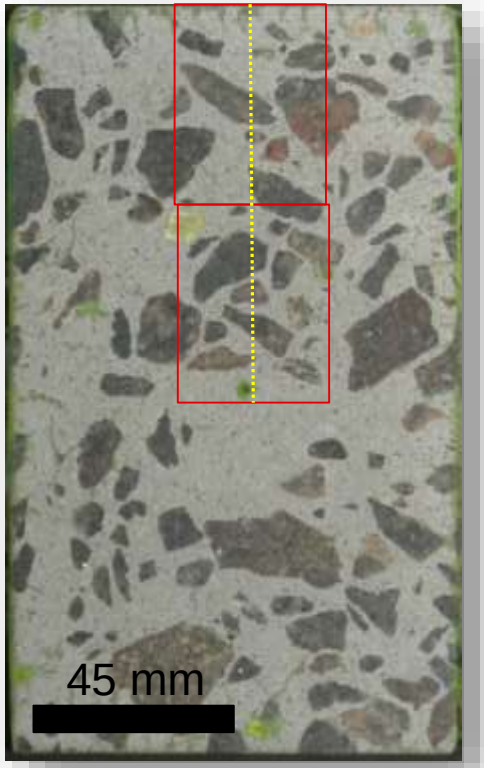
6 months exposure October 2011

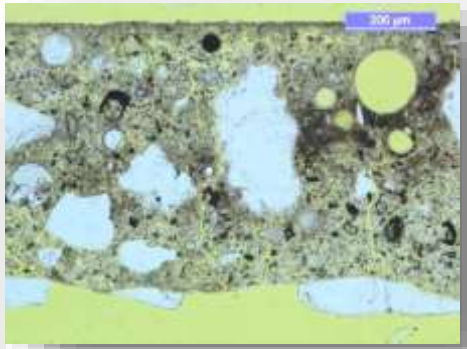

28 days maturity testing

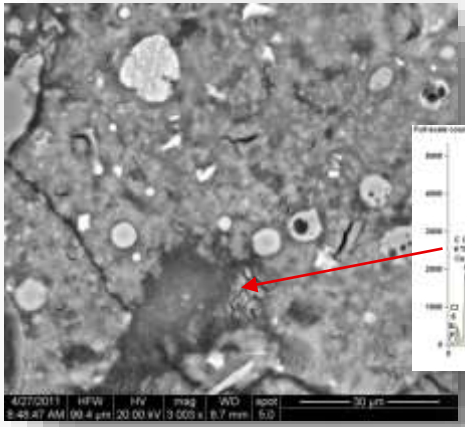

Exposure site in Rødby Harbor April 2010

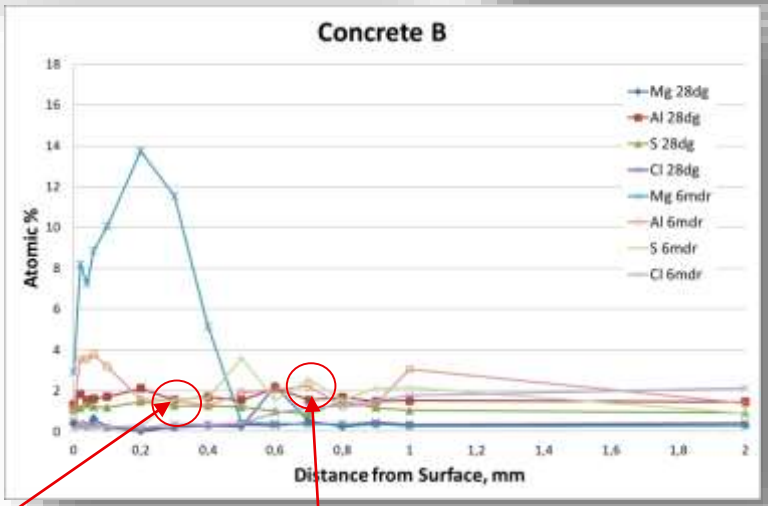
Next coring period:
April 2012

Microscopic Analysis Program





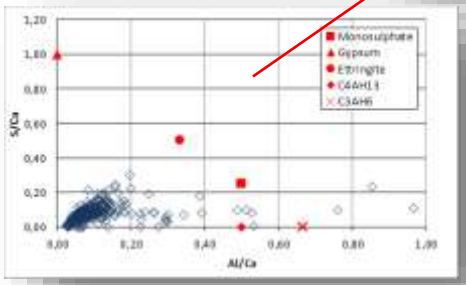




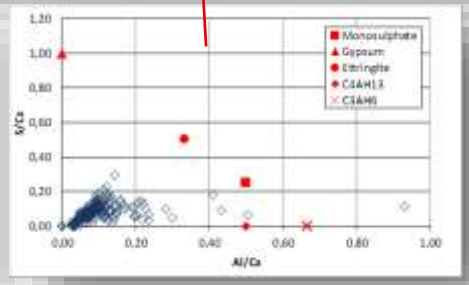
Macro-analysis: Crack pattern, homogeneity…

Micro-analysis - OPM: Paste porosity, leaching, carbonation, precipitates, micro-cracks …

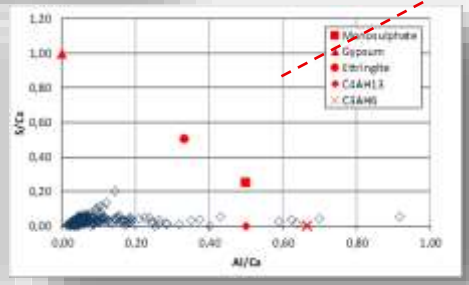
SEM-EDX: Structural analysis, chemical trends, phase identification, phase analysis …



Depth: 0,3mm

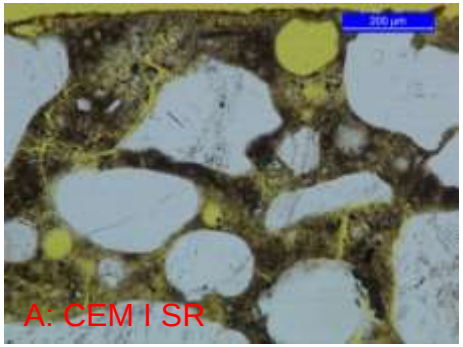


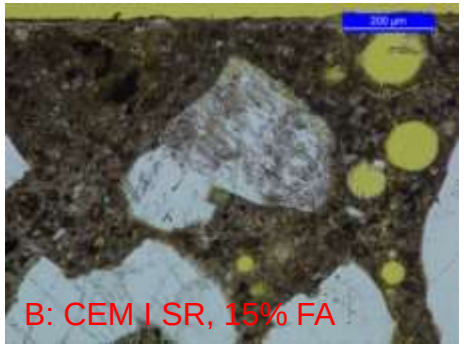
Depth: 0,7mm

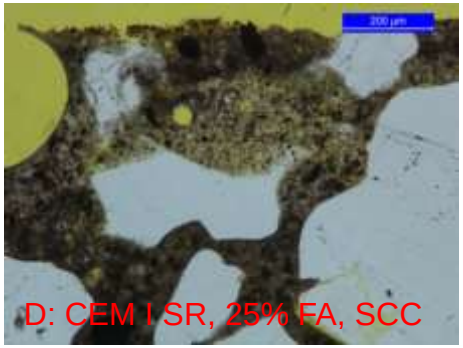


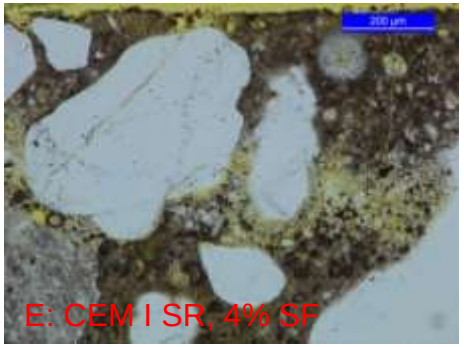
Depth: 23mm

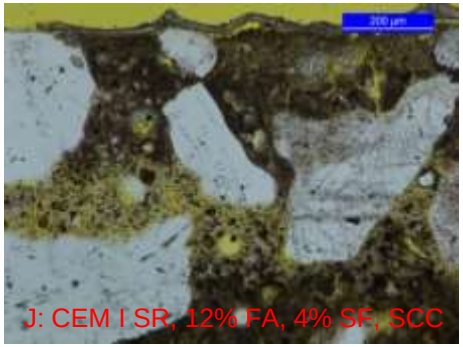
Surface Alteration

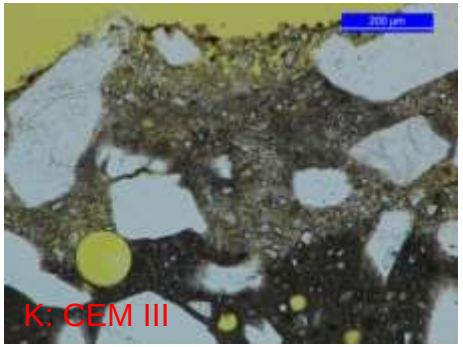


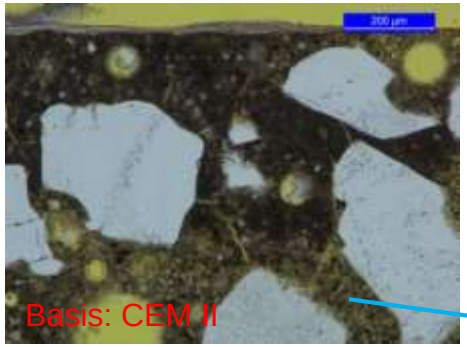


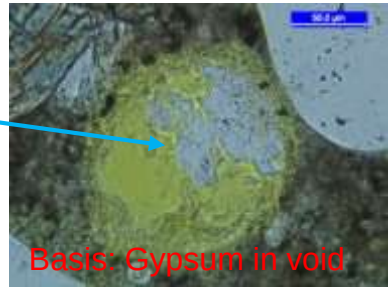










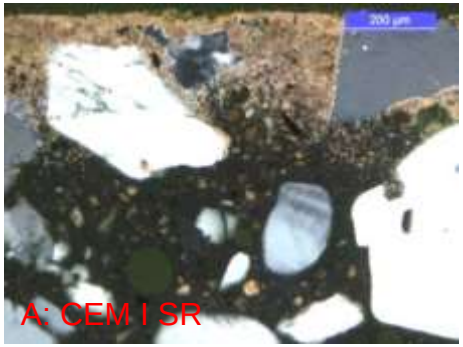


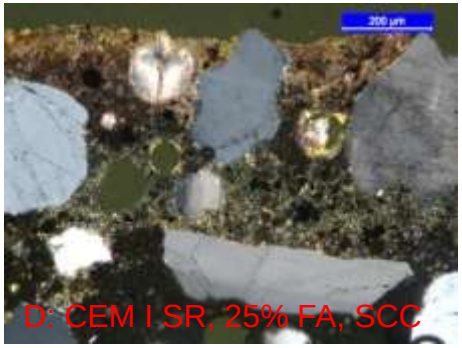
All surfaces show after 6 months submersion in seawater sign of water ingress in the form of alternating porous, cracked, dense and leached zones.

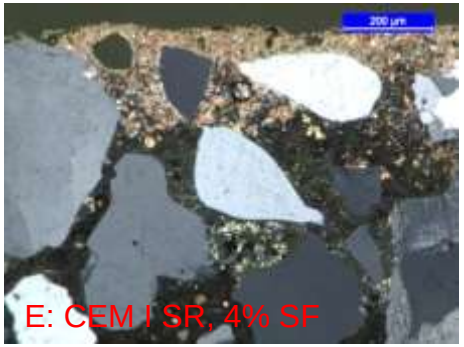
Max depth of altered surface, mm

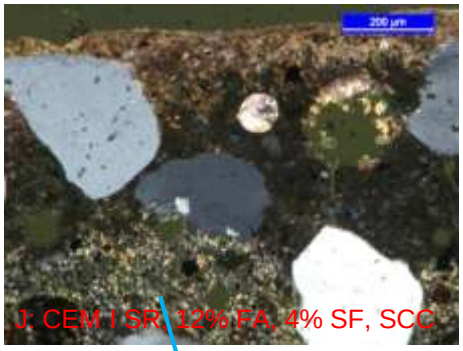
A	B	D	E	J	K	CEMII
2	3	2	2.5	2.5	0.8	1

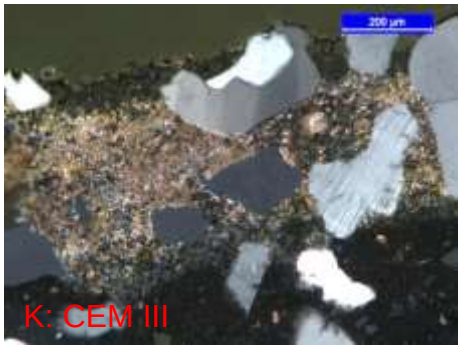
Carbonation

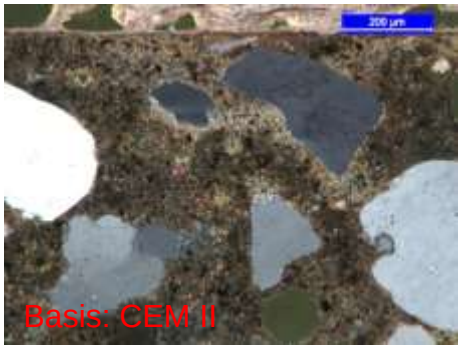










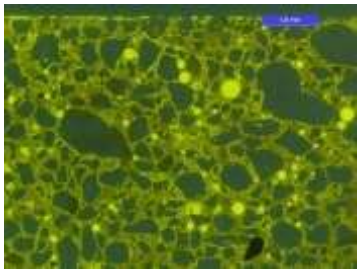


- Most concrete are carbonated in the surface.
- A black zone, leached in CH appears behind carbonated surface.
- Surfaces are partly intact, covered by calcite crust, or scaled.

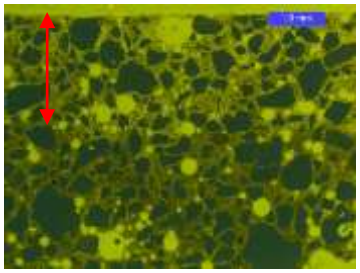
Max. depth of surface carbonation, mm

A	B	D	E	J	K	CEMII
0.3	<0.1	0.2	0.4	0.2	0.8	1.0

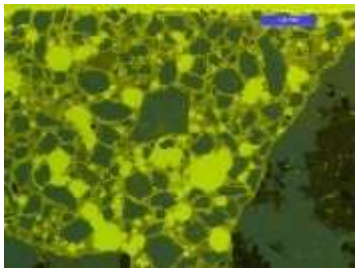
Porosity



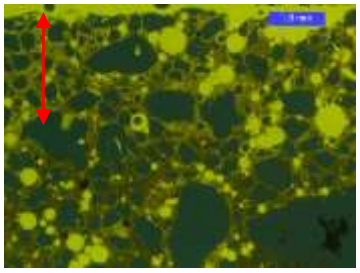
A: 0.40 28dg



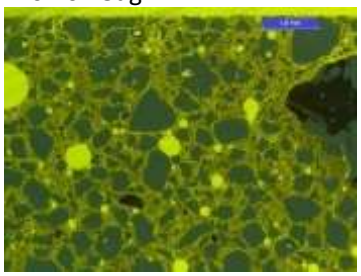
A: 0.40 6mdr



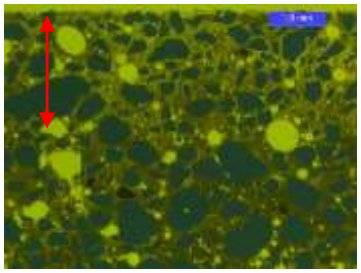
B: 15% FA, 0.40 28dg



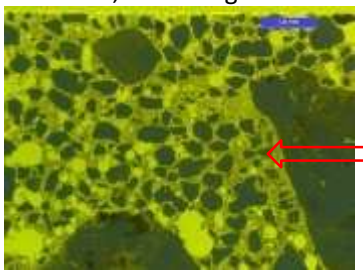
B: 15% FA, 0.40 6mdr



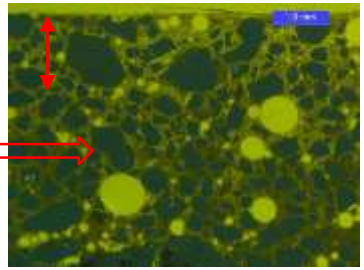
D: 25% FA, 0.40, SCC 28dg



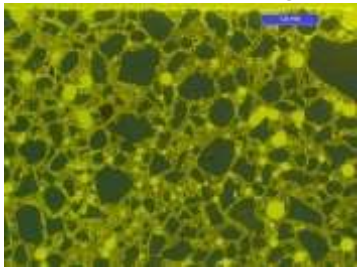
D: 25% FA, 0.40, SCC 6mdr



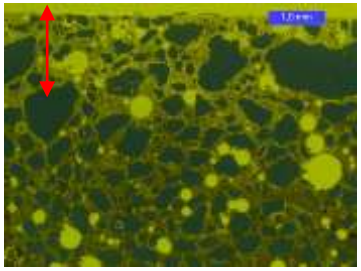
E: 4% MS, 0,40 28dg



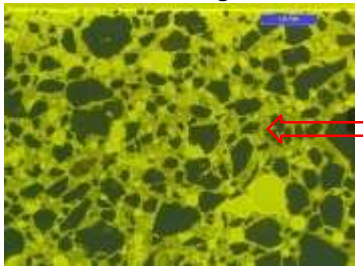
E: 4% MS, 0,40 6mdr



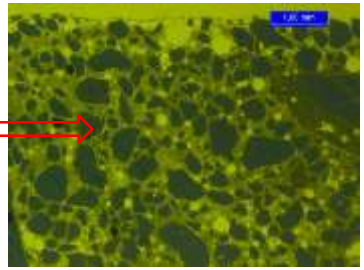
J: 4% MS, 12% FA, SCC 28dg



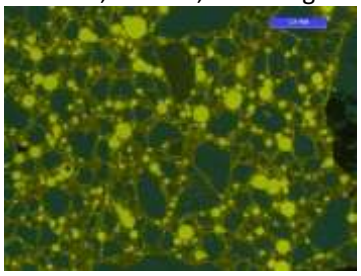
J: 4% MS, 12% FA, SCC 6mdr



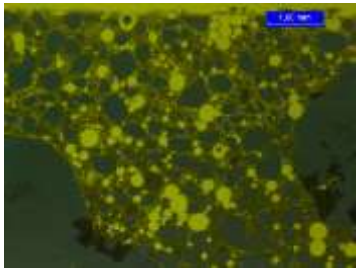
K: Slag cement, 0.40 28dg



K: Slag cement, 0.40 6mdr



Basis: CEMII 28dg



Basis: CEMII 6mdr

Generally the paste becomes denser with time
Increased surface porosity appears in most concrete
Porosity of CEM II does apparently not change with time

CEM I SR, 12% FA, 4% SF, SCC, 6 months exposure

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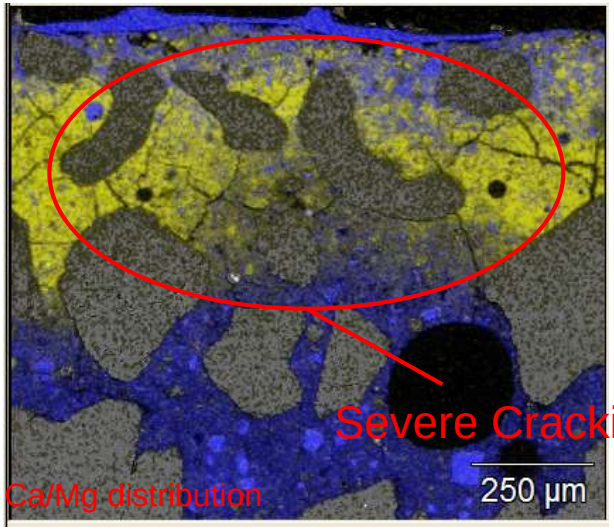

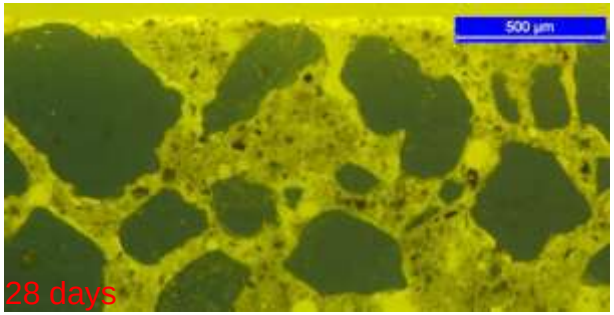

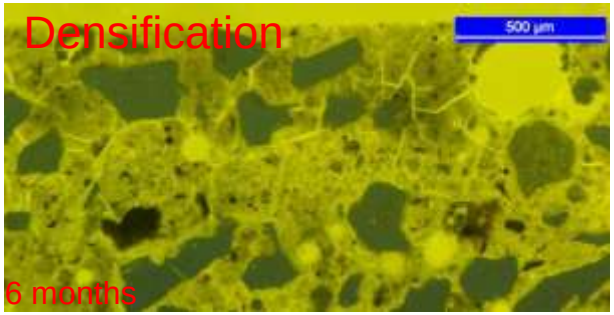

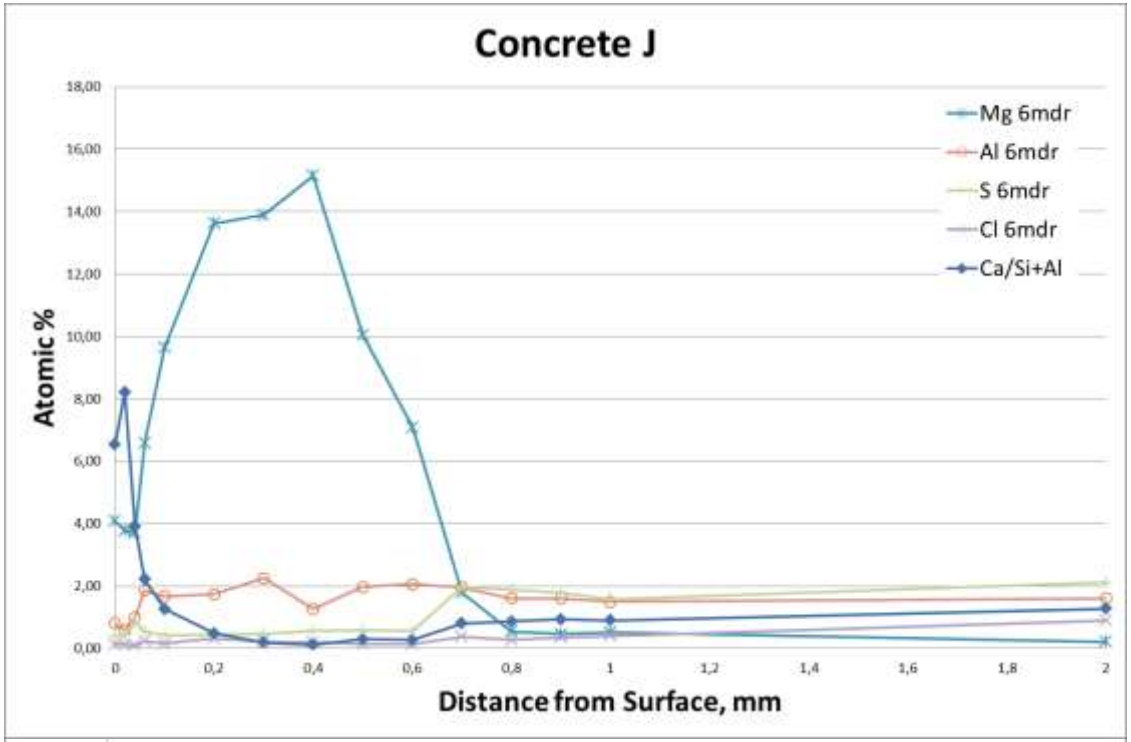

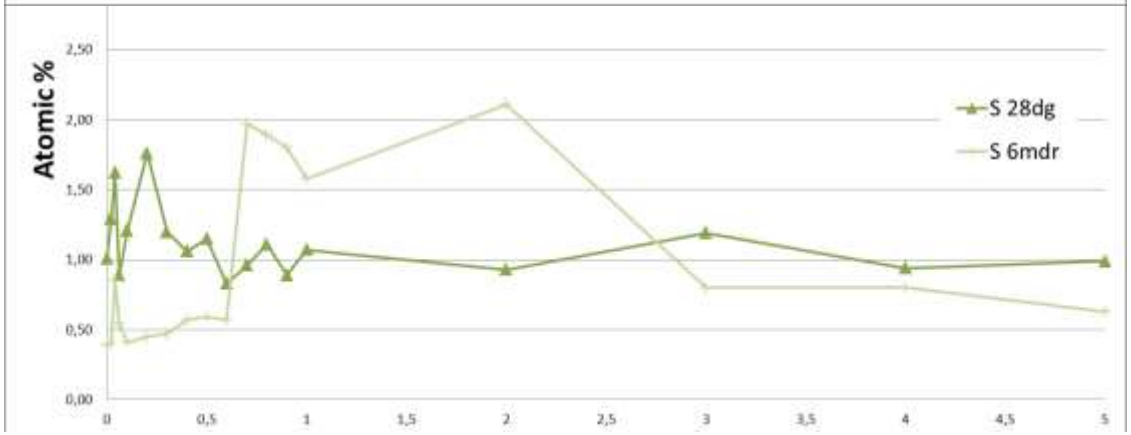

CEM III/B, 6 months exposure

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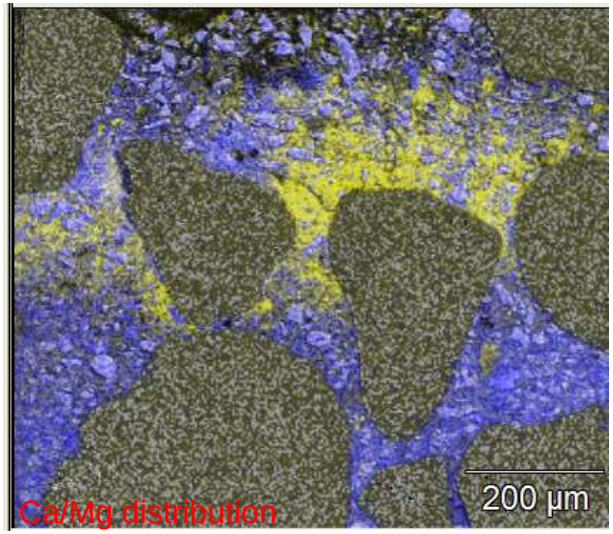

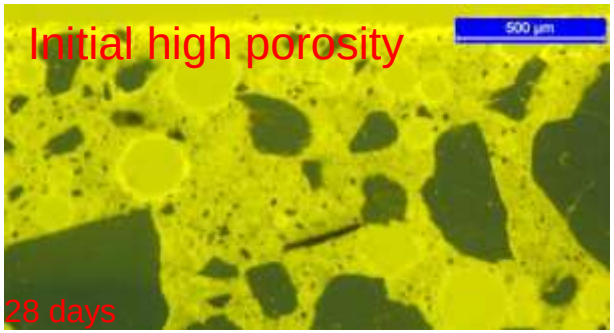

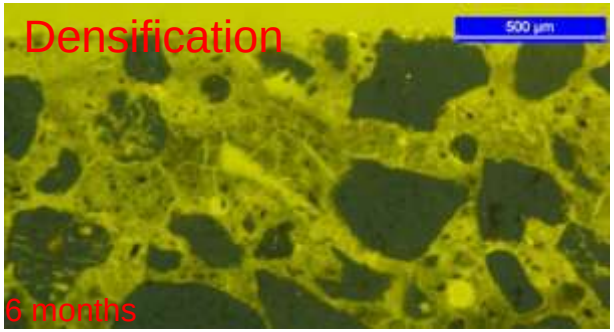

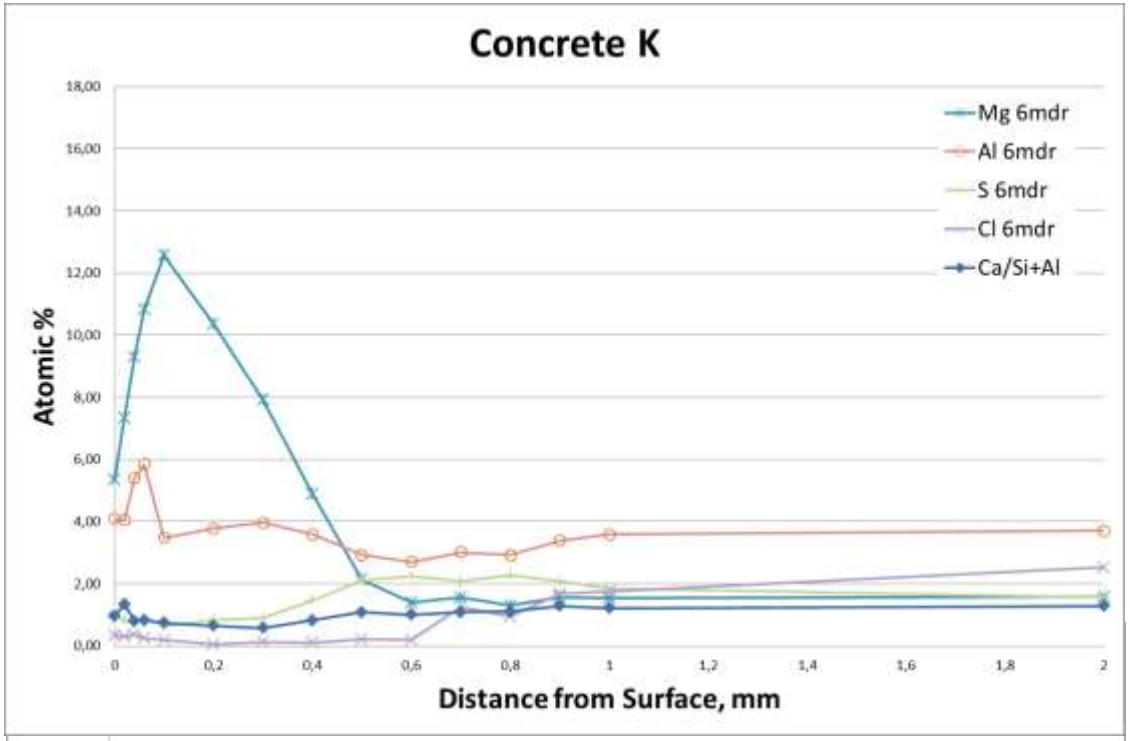

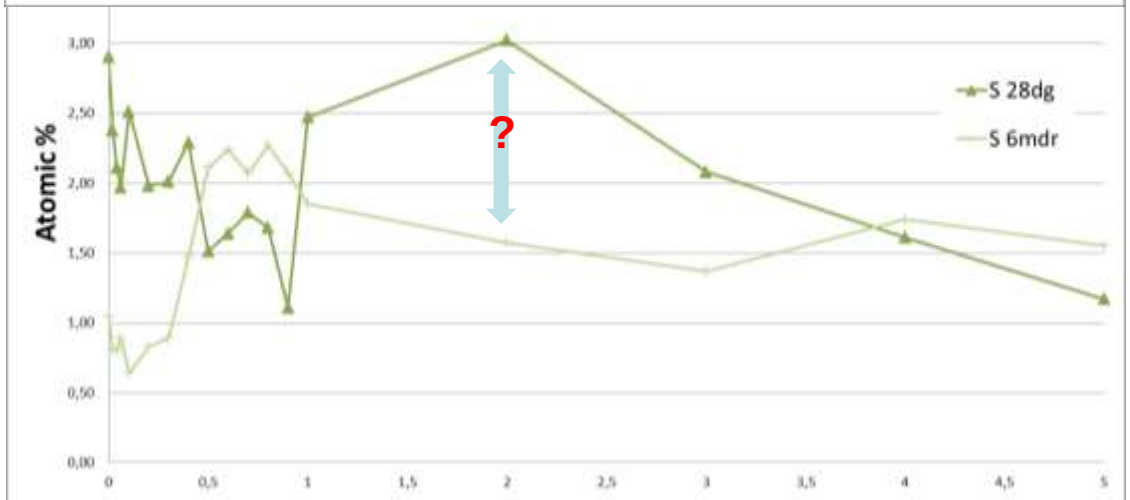

Chemical trends as a function of Binder Systems

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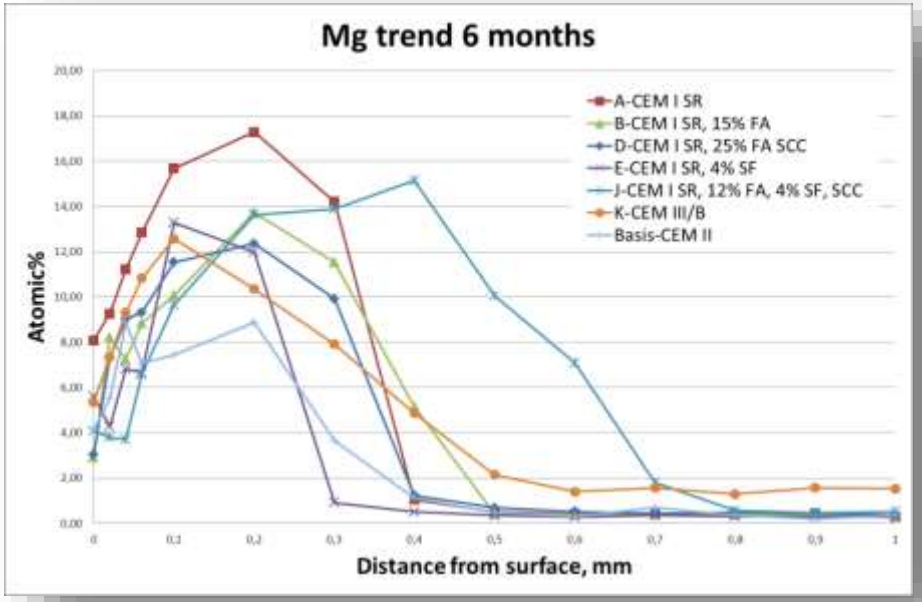
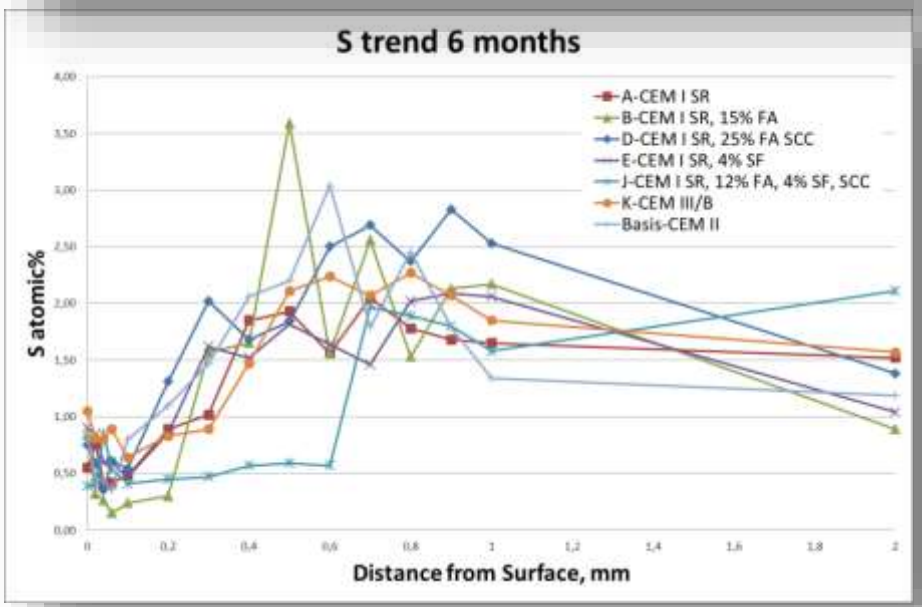
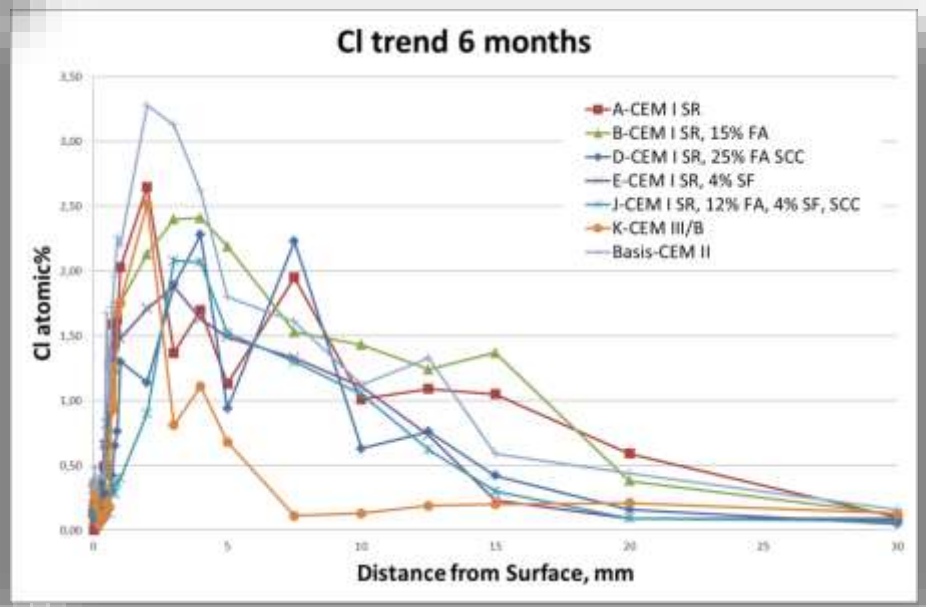


Concrete	Binder	Mg zone	S zone	Cl zone
A	CEM I	0-0.3	0.2-2	0.4-20
B	CEM I, 15%FA	0-0.4	0.3-1	0.6-15
D	CEM I, 25% FA	0-0.3	0.2-2	0.8-12.5
E	CEM I, 4% SF	0-0.2	0.2-2	0.4-12.5
J	CEM I, 12%FA, 4%SF	0-0.7	0.7-3	2-12.5
K	CEM III	0-0.4	0.4-1	0.7-5
Basis	CEM II	0-0.3	0.1-1	0.5-15





Phase Analysis: Sulfate phases in Concrete J

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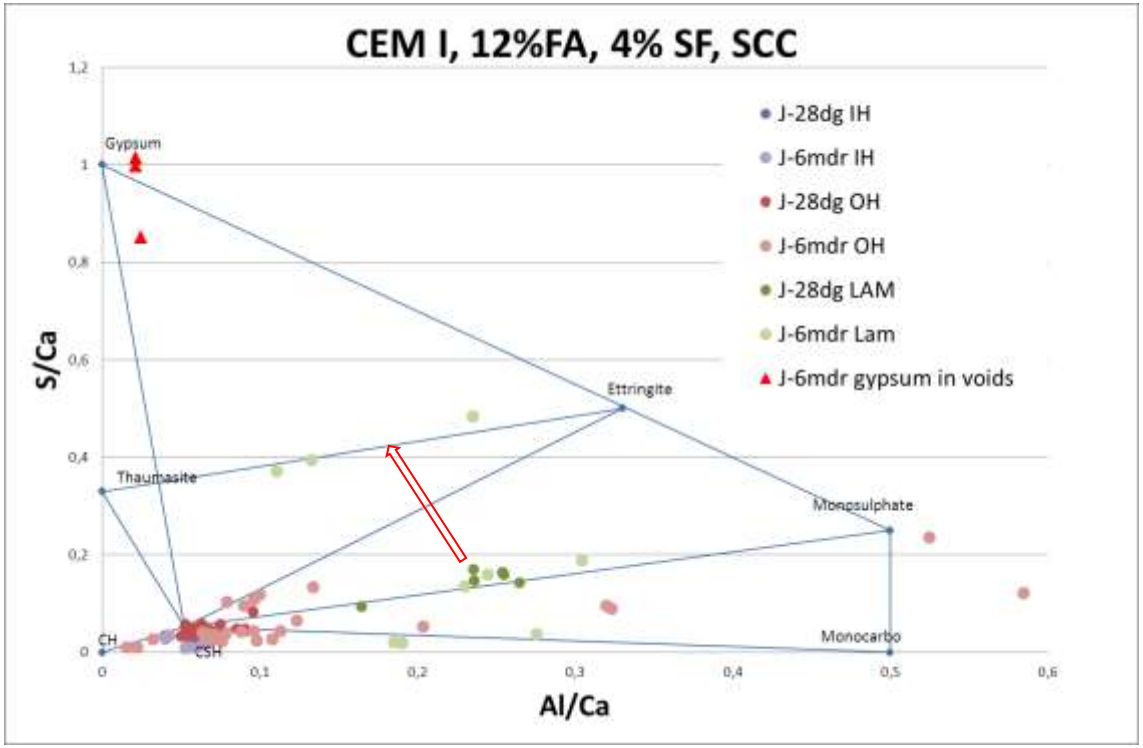

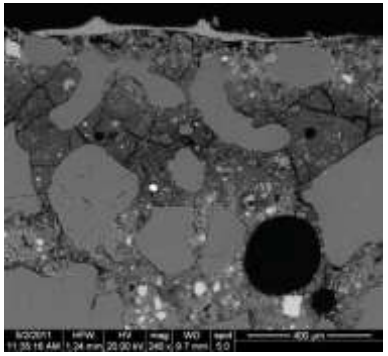

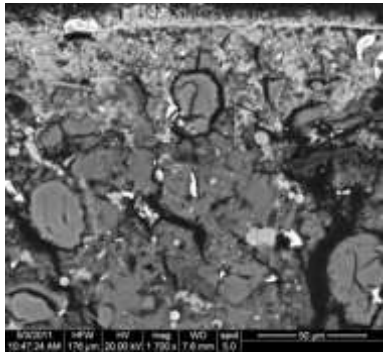

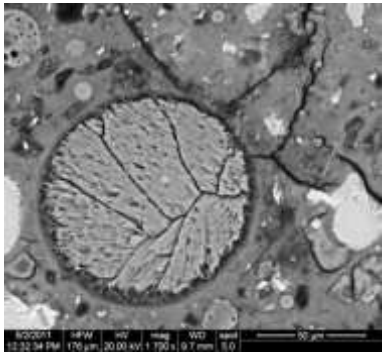

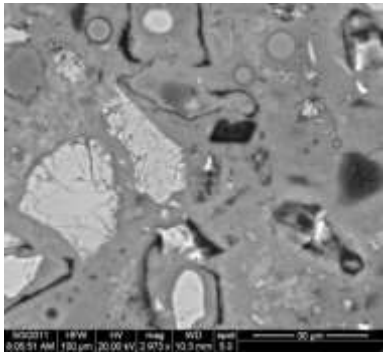

Phase Analysis: Magnesium phases

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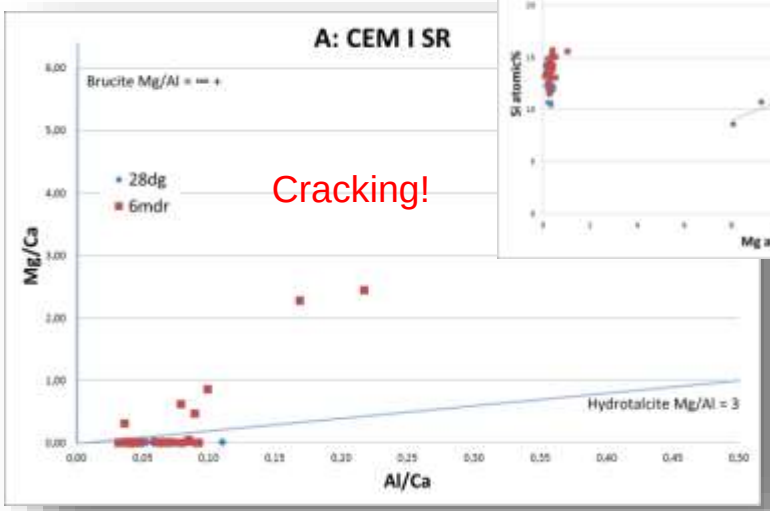

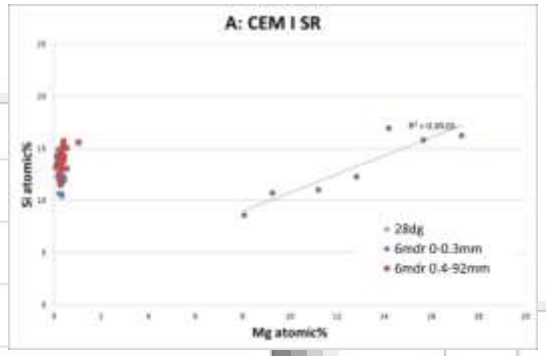

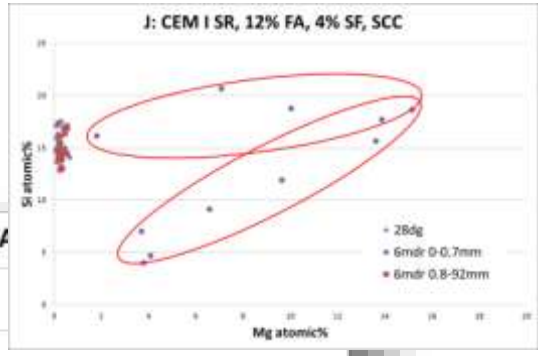

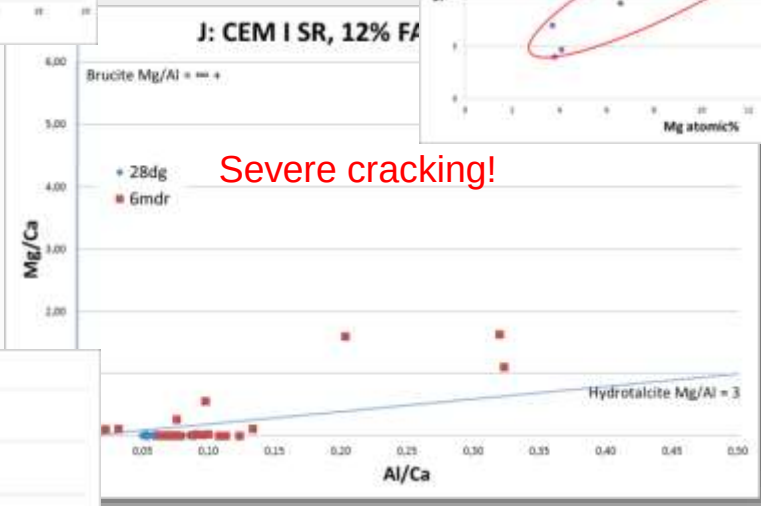

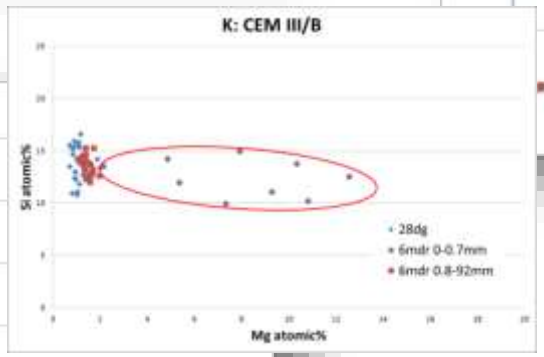

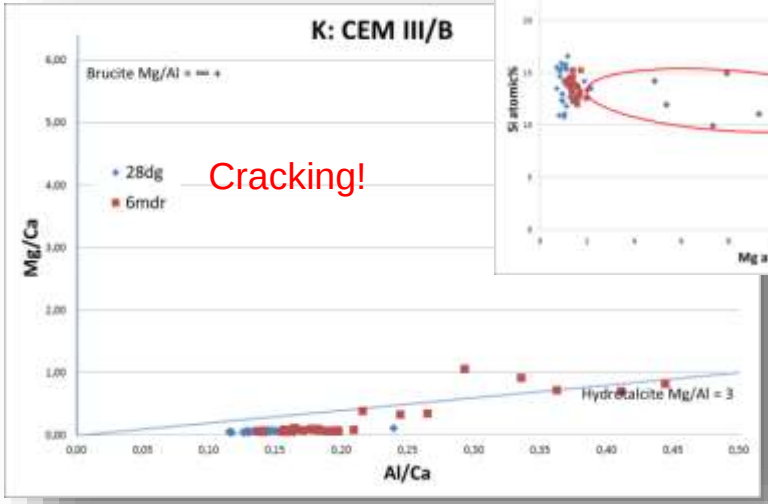

Phase Analysis: Chloride phases

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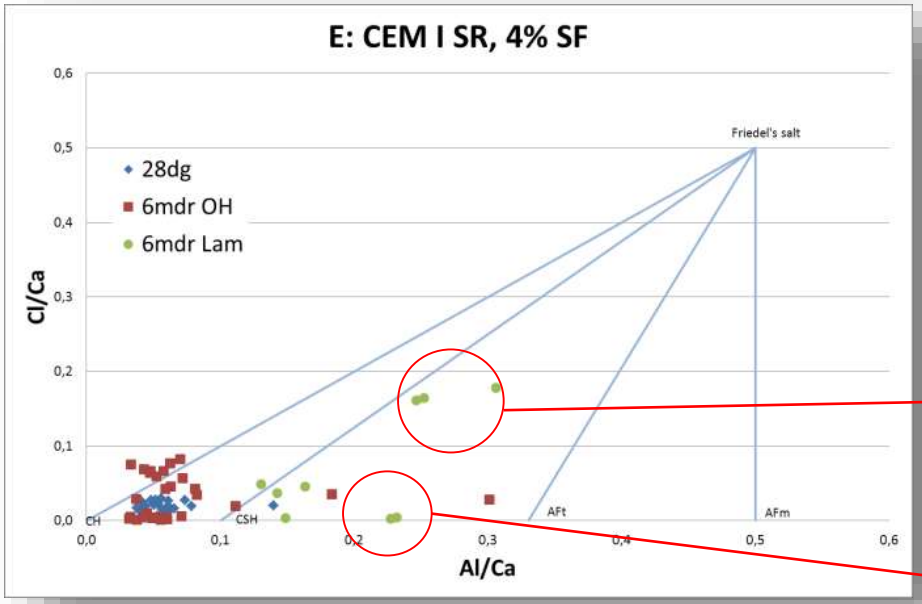
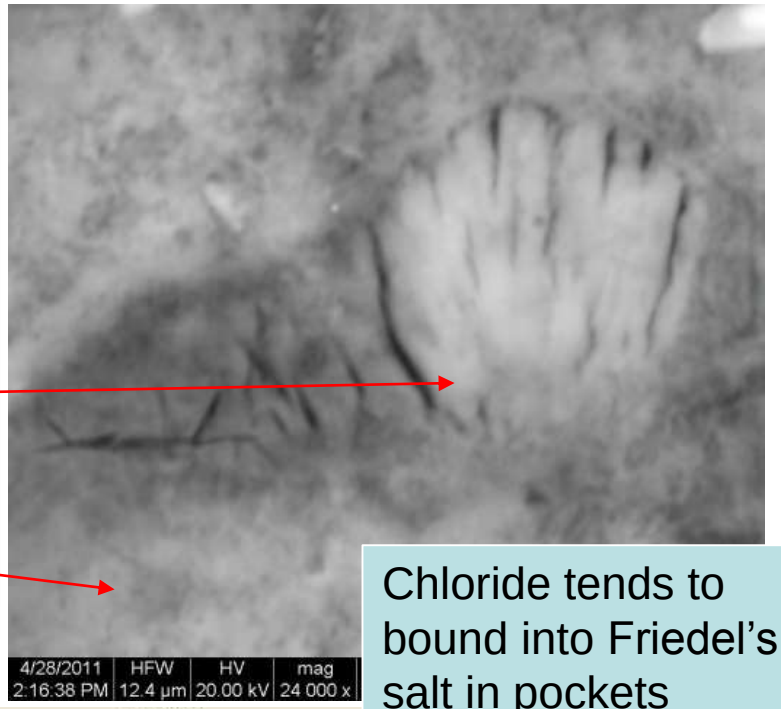
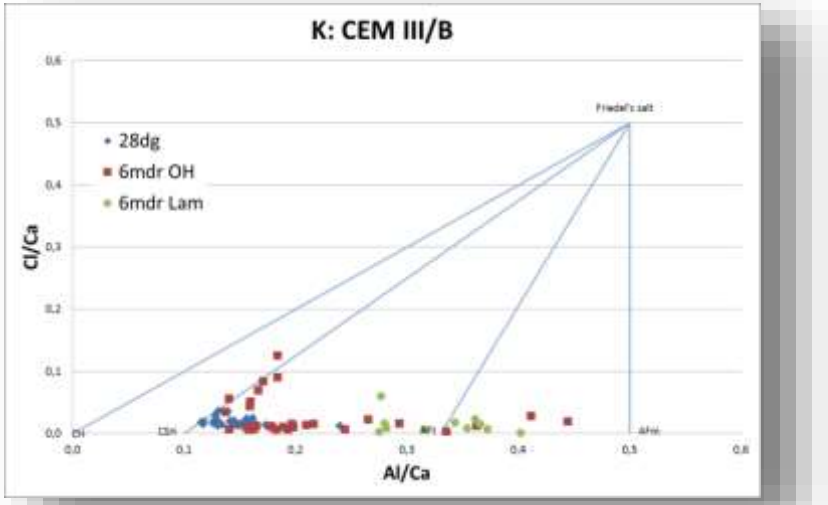
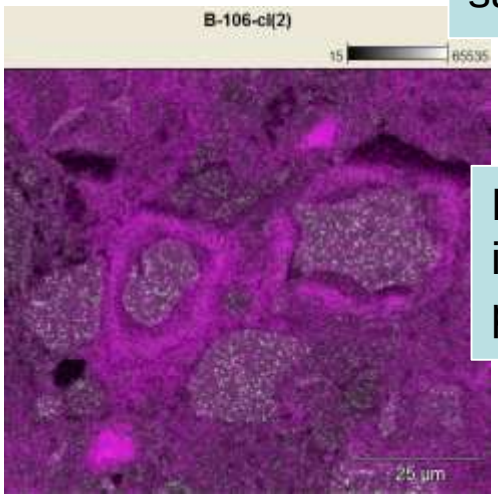




Chloride tends to bound into Friedel's salt in pockets

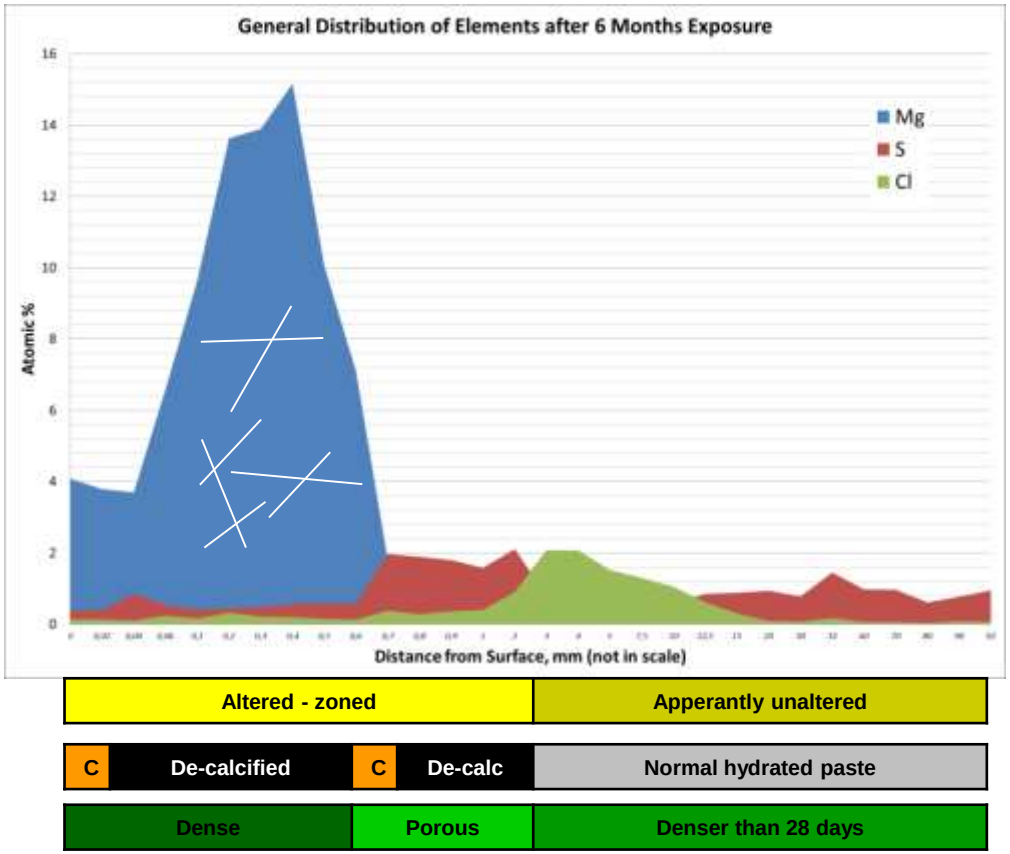




Do chlorides bound in inner hydration phases with time?

Summary

- All concrete shows alteration in the surface region
- Surface porosity has changed in all concretes except in CEM II concrete
- A distinct chemical zoning of the concrete surfaces has been observed
- The concrete showing the most distinct surface alteration is concrete with silica fume & fly ash



Whats Next

- Coring April 2012, 2 years of exposure
- Consolidation of 6 months data
- Casting of concrete, cured at 10, 20, 30, 45 & 60 oC

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