



Langtidsholdbarhed af Havvandseksponerede Broer

- Mikroskopisk Undersøgelse -

Ulla Hjorth Jakobsen, Ph.D., Geolog

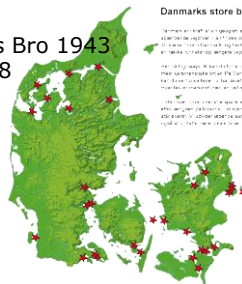


Undersøgellesprogram

- Den mikro-strukturelle udvikling af nye, kendte havvandseksponerede betoner følges over en årrække, fra før eksponering til mindst 2018 (Femern test betoner)
- Observationer sammenlignes med mikro-strukturen i udvalgte gamle danske havvandseksponerede konstruktioner
- Mikro-strukturens (bindertypens) indflydelse på sulfat, kloridindtrængning og langtidsholdbarhed vurderes
- Hærdetemperaturens indflydelse på sulfat og kloridindtrængning søges belyst
- Resultater anvendes eventuelt til at justere accelererede lab test



- Kong Christian den X's Bro 1930
- Limfjordsbroen 1933
- Guldborgsundbroen 1934
- **GI Lillebæltsbroen 1935**
- Kronprins Frederiksbro 1935
- Vilsund (PC) 1937
- Knippelsbro 1937
- Storstrømsbroen 1937
- Masnedsundbroen
- Oddesund (PC) 1938
- Aggersundbroen 1942
- Dronning Alexandrines Bro 1943
- Rømdæmningen 1948
- Munkholmbroen 1952
- Langebro 1954
- Siøbroen
- Langelandsbroen 1962
- Frederik den IX's Bro 1963
- Svenborgsundbroen 1966
- Egersundbroen 1968
- Ny Lillebæltsbro 1970
- Hadsund (PC) 1976
- Sallingsundbroen 1978
- **Vejle fjordbroen (Slagge, PC) 1980 - Afventer**
- **Farøbroerne (FA) 1980 Afventer**
- Sjællandsbroen
- **Alssundbroen (PC) 1981 Afventer**
- Kalvebodbroerne 1987
- **Storebæltsbroen (FA+MS) 1997-98**
- **Øresundsbroen (MS) 2000**
- Femernbælt 20XX



Test betoner (paneler):

- ✓ Ren Lav Alkali Sulfatbestandig (SRPC)
- ✓ SRPC + FA (15% & 25%)
- ✓ SRPC + FA (SCC)
- ✓ SRPC + MS (4%)
- ✓ SRPC + FA(12%) + MS(4%)
- ✓ SRPC + FA + MS (SCC)
- ✓ Rapid (CEM I 52.5N (MS/LA/<2) + GGBFS (70%))
- ✓ Slaggecement (CEM III/B)
- ✓ Slaggecement (SCC)

Ekstra betoner (cylindre):

- ✓ Ren Rapid (CEM I 52.5 LA/MS)
- ✓ Ren Basis (CEM II, 52.5)
- ✓ Rapid (CEM I 52.5 LA/MS) + FA(30%)
- **Lav Alkali Sulfatbestandig Cement** (CEM I 42.5N (HS/EA/<2))
- V/C ~0,40 (0.35 - 0.45)

CONCRETE EXPERTCENTRE

Laboratorie Undersøgelser

Fresh concrete properties

Casting October 2009

Microscopy

6 months exposure September 2011

90 days maturity testing

Exposure site in Rødby Harbor April 2010

Next coring period:
April 2012

CONCRETE EXPERTCENTRE

Mikroskopisk Analyse Program

Concrete B

Atomic %

Distance from Surface, mm

Depth: 0,3mm

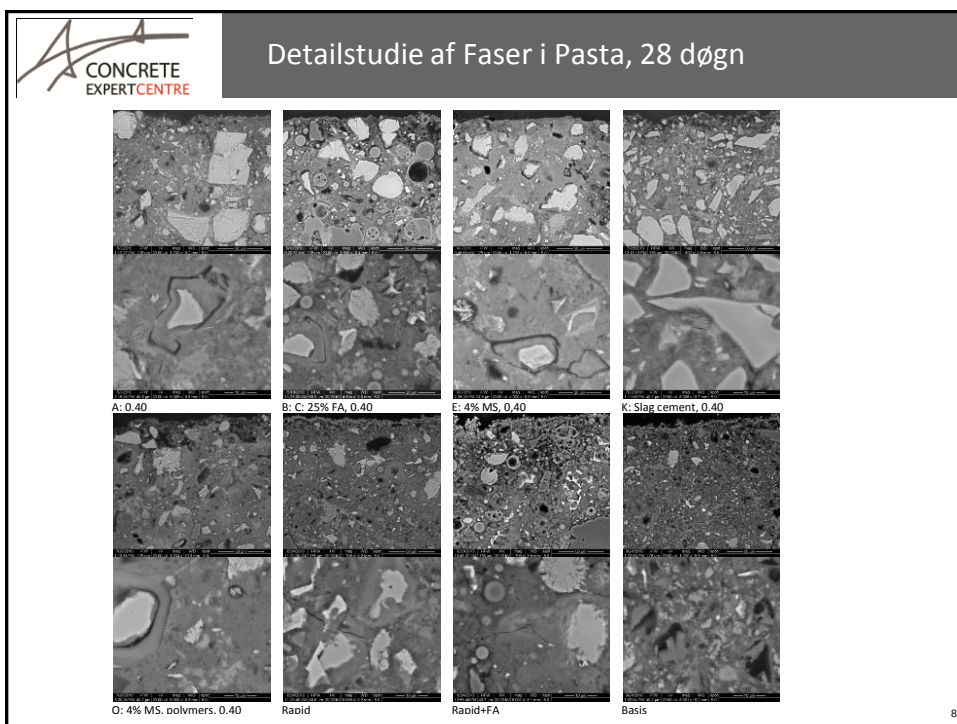
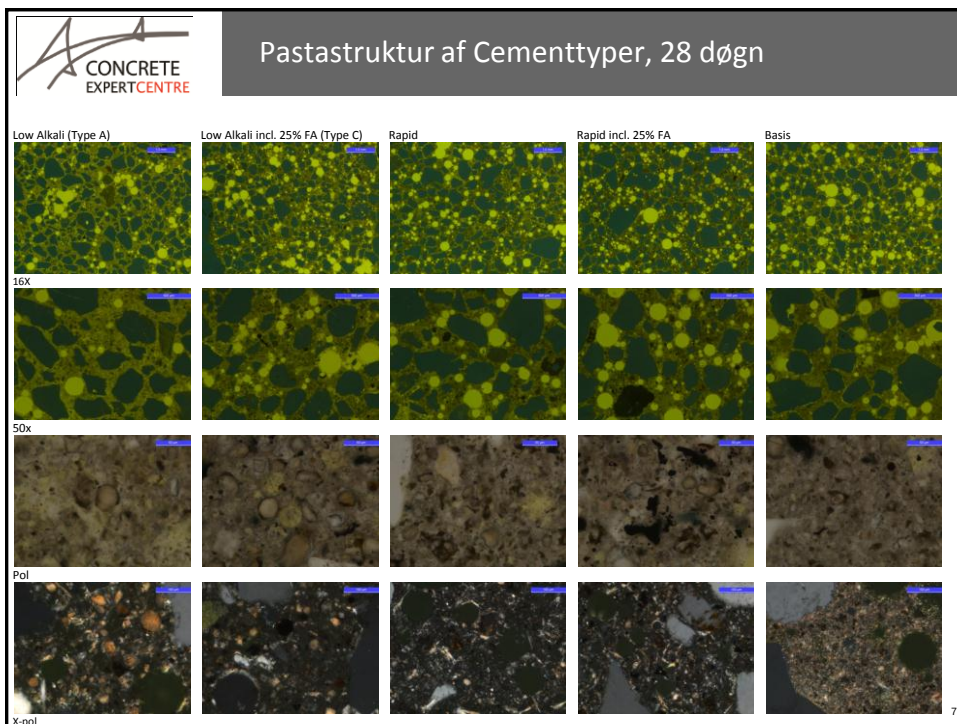
Depth: 0,7mm

Depth: 23mm

Macro-analysis: Crack pattern, homogeneity...

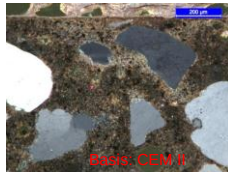
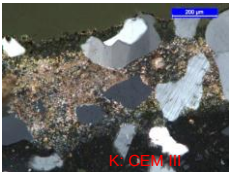
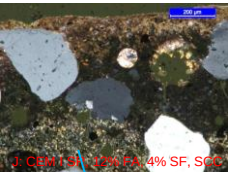
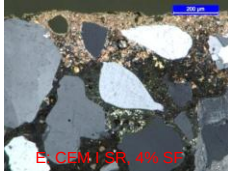
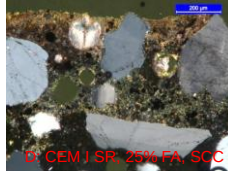
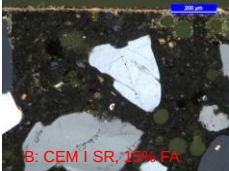
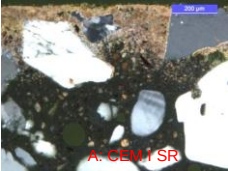
Micro-analysis - OPM: Paste porosity, leaching, carbonation, precipitates, micro-cracks ...

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





Karbonatisering, 6mdr



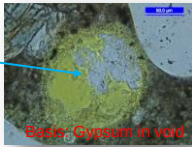
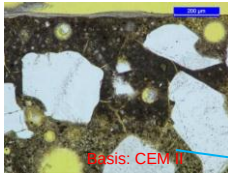
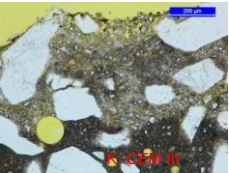
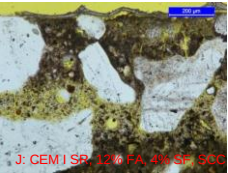
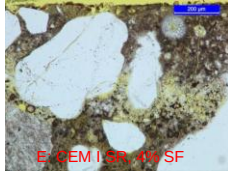
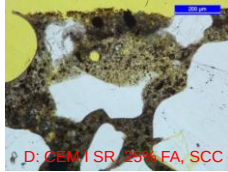
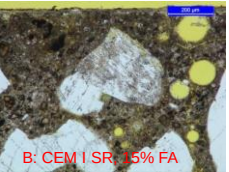
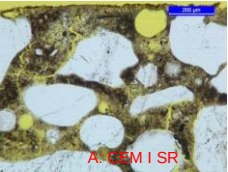
Most concrete are carbonated in the surface.
A black zone, leached in CaOH appears behind carbonated surface.
Surfaces are partly intact; covered by calcite crust; or scaled.

Depth of Surface Carbonation, mm

A	B	D	E	J	K	Basis
0.15-0.25	0.05-1.0	0.1-1.0	0.1-0.4	0.05-0.2	0.4-0.8	0.1-1.0



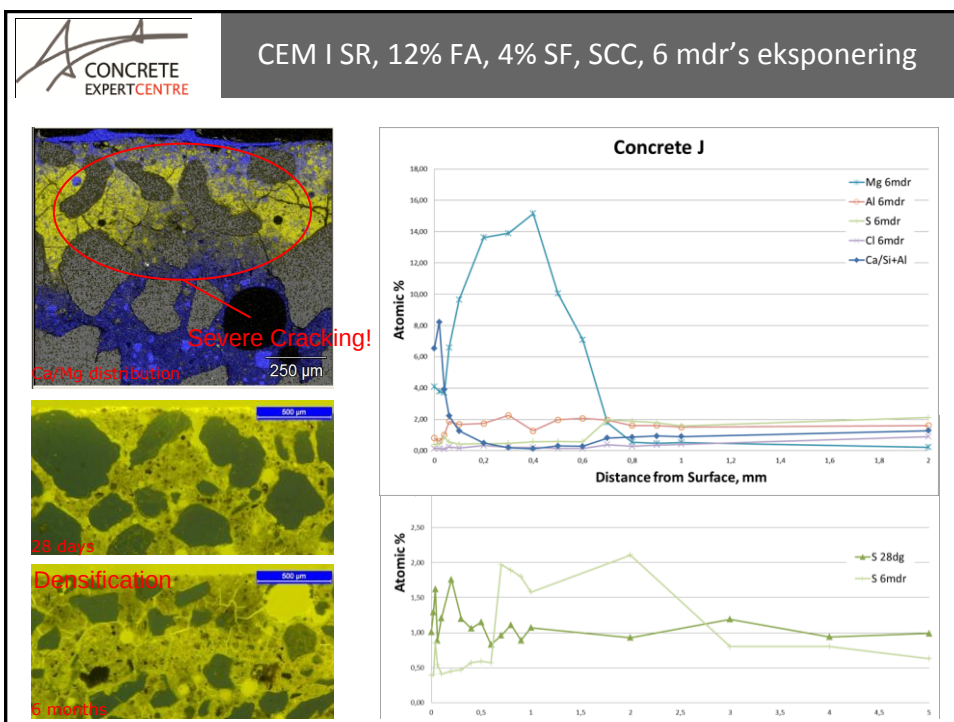
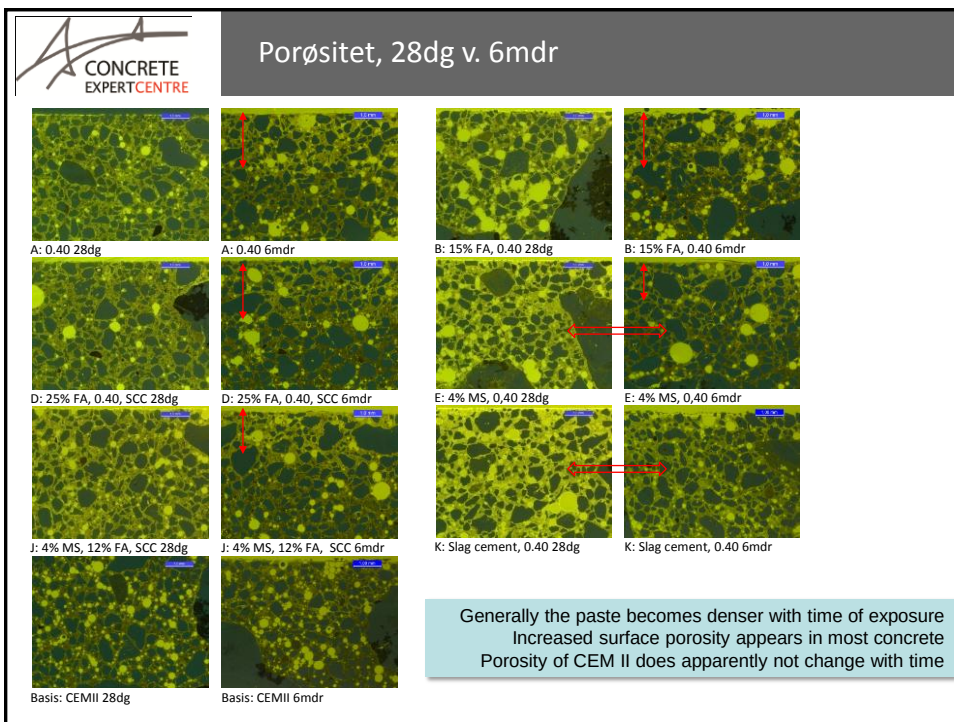
Overfladeomdannelser, 6mdr

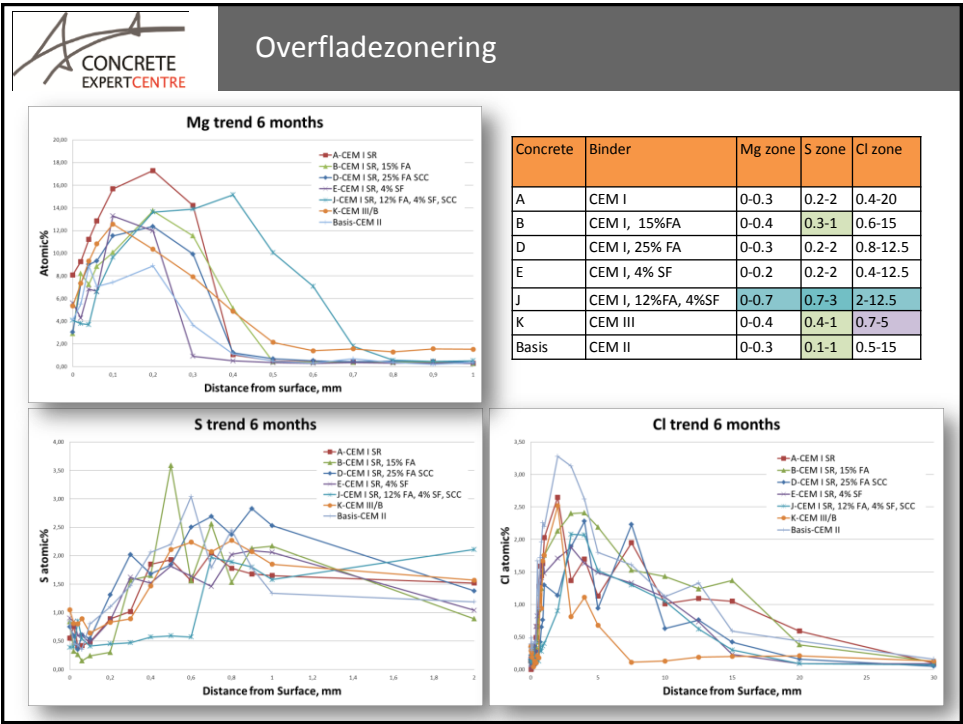
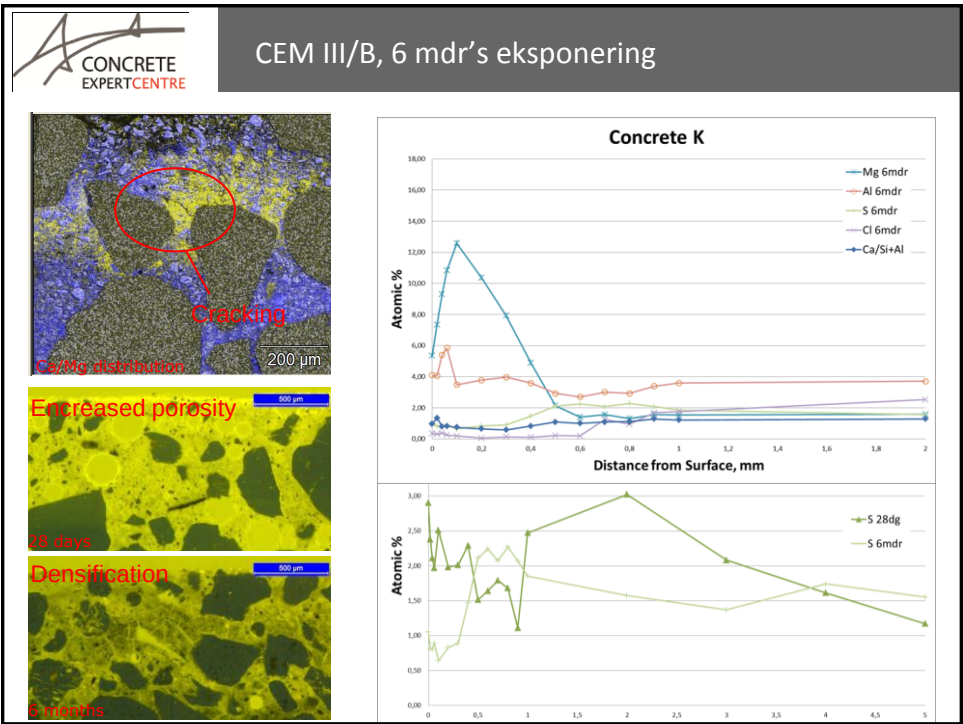


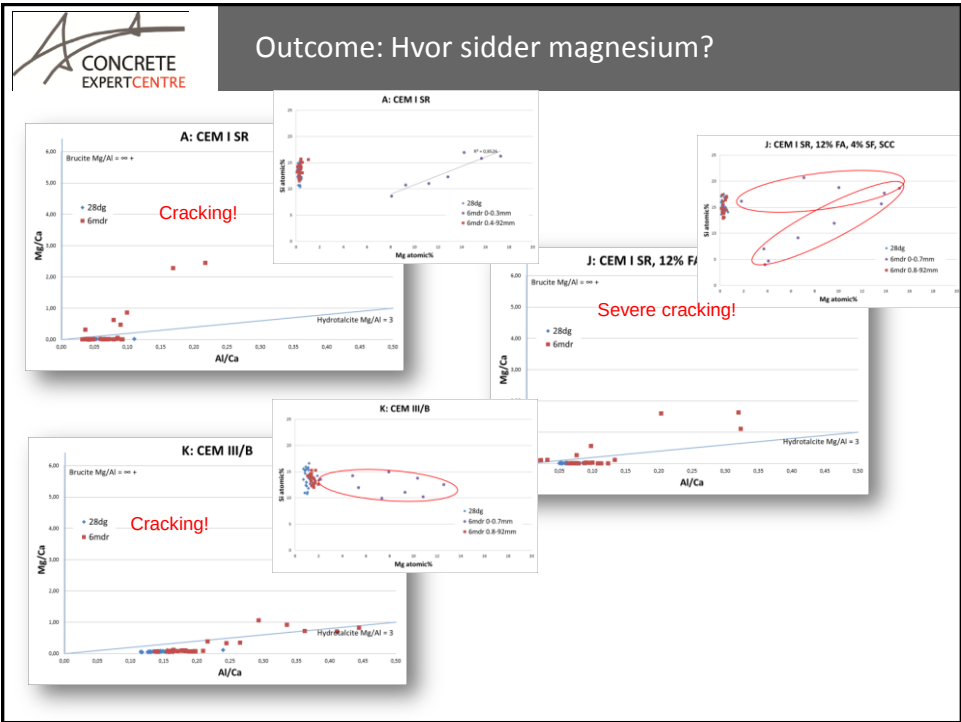
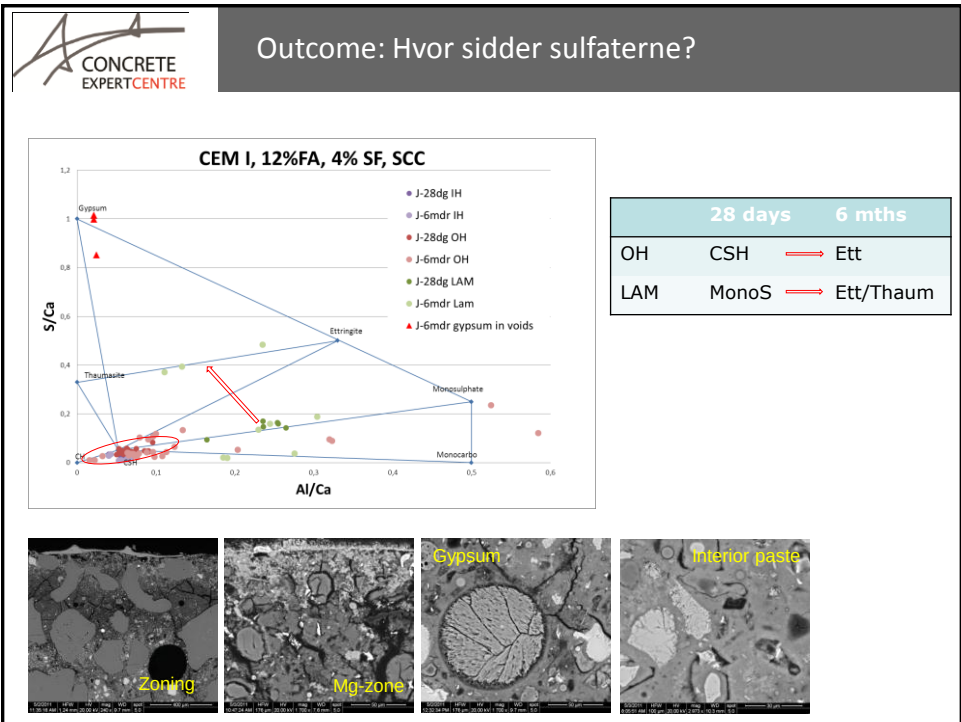
All surfaces show after 6 months submersion in seawater sign of water ingress in the form of formation of porous and dense zones.

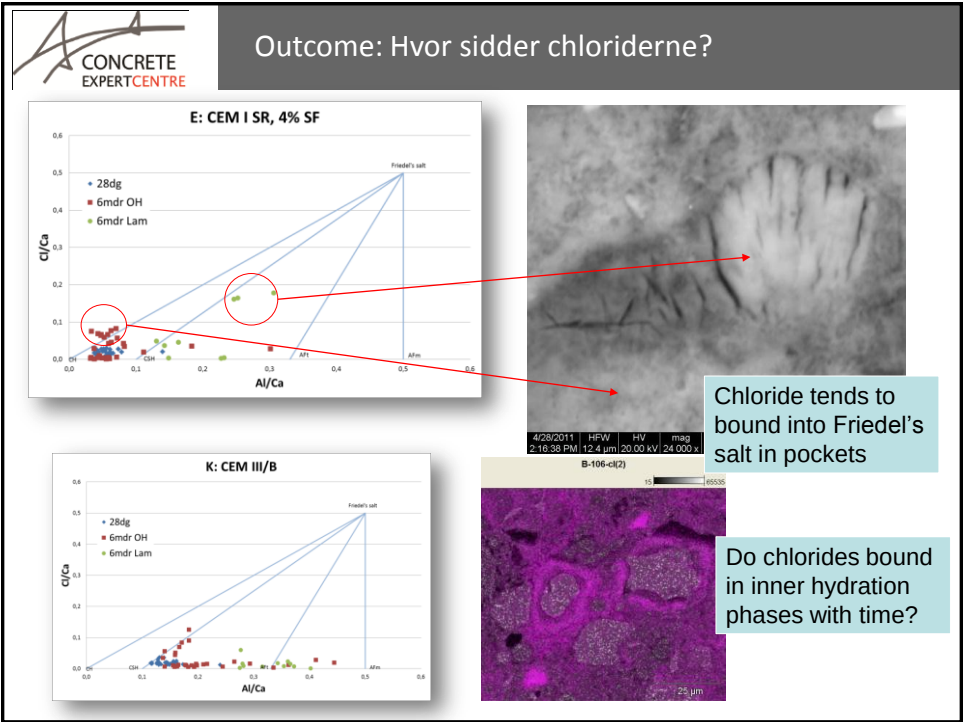
Depth of Porous Surface Zone, mm

A	B	D	E	J	K	Basis
1.5-2	2-3	0.4-0.5	2.0	2.0	0.4-0.8	0.1











Outcome: Data Ark

Concrete No.: A

Age: 28 days



Mix Design

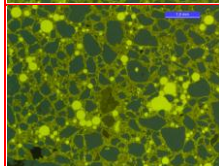
Cement 365
Fly ash 0
Microsilica 0
Water 146
Air % 4,5
F. agg. 0/2 695
C. agg. 4/8 377
C. agg. 8/16 266
C. agg. 16/22 529

Fresh Properties

w/c 0
Air, fresh% 0
Slump, mm 146
Density, kg/m³ 144
Temp. fresh °C 4,5
28 days, MPa 689
Air, hard.% 373
Air, hard.% 263
Casting date 8/16
Storage water 525

Micro-observations

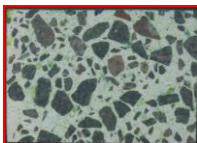
Thin calcite layer on surface
Carbonated paste not observed
Uniform paste porosity through core
W/c estimated to about 0,45
No cracks in surface
Generally no cracks in paste except few adhesion cracks
Relatively poor air void structure, appears lower than 4,5%, few of the smallest voids, some air void clusters present



500000 100000 50000 10000 5000 1000 500 100 50 10 5 1
500000 100000 50000 10000 5000 1000 500 100 50 10 5 1

Concrete No.: K

Age: 28 days



Mix Design

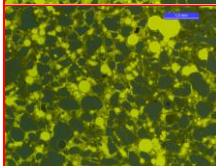
Cement CemIII 360
Fly ash 0
Microsilica 144
Water 146
Air % 4,5
F. agg. 0/2 689
C. agg. 4/8 373
C. agg. 8/16 263
C. agg. 16/22 525

Fresh Properties

w/c 0
Air, fresh% 0
Slump, mm 144
Density, kg/m³ 144
Temp. fresh °C 4,5
28 days, MPa 689
Air, hard.% 373
Air, hard.% 263
Casting date 8/16
Storage water 525

Micro-observations

Thin calcite layer at surface
Feathery phases in voids exposed at surface
Carbonation not observed
Generally inhomogeneous paste porosity through core (patchy). Distinct increase towards surface
Highly opaline paste, CH nearly invisible
W/c estimated to about 0,45
No cracks at surface
Some paste cracks
Relatively poor air void structure, air content probably on target but air voids are somewhat clustered especially along aggregate
Greenish paste at interior, light grey at surface



500000 100000 50000 10000 5000 1000 500 100 50 10 5 1
500000 100000 50000 10000 5000 1000 500 100 50 10 5 1

18