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NTNU
Norwegian University of
Science and Technology

Anvendelse af marine feltdata til forudsigelse af kloridindtrængning i beton

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Finansiering: Uddannelses- og forskningsministeriet gennem kontrakt med Teknologisk institut

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Indhold

I. — Intro

II. Indsamling af kloriddata og vurdering af, hvordan det bør anvendes

III. Kvadratrods metode til bestemmelse af videre kloridindtrængning

IV. Anvendelse af Machine Learning til forudsigelse af kloridindtrængning i designstadiet



Indsamling af kloriddata og vurdering af hvordan det bør anvendes

Paper II: Correlating the development of chloride profiles and microstructural changes in marine concrete up to ten years
& Paper IV: When and how should chloride profiles be calibrated for paste fraction?



Fokus fokus fokus

Mixture proportions of concrete exposed at the Fehmarn Belt Exposure Site [kg/m³].

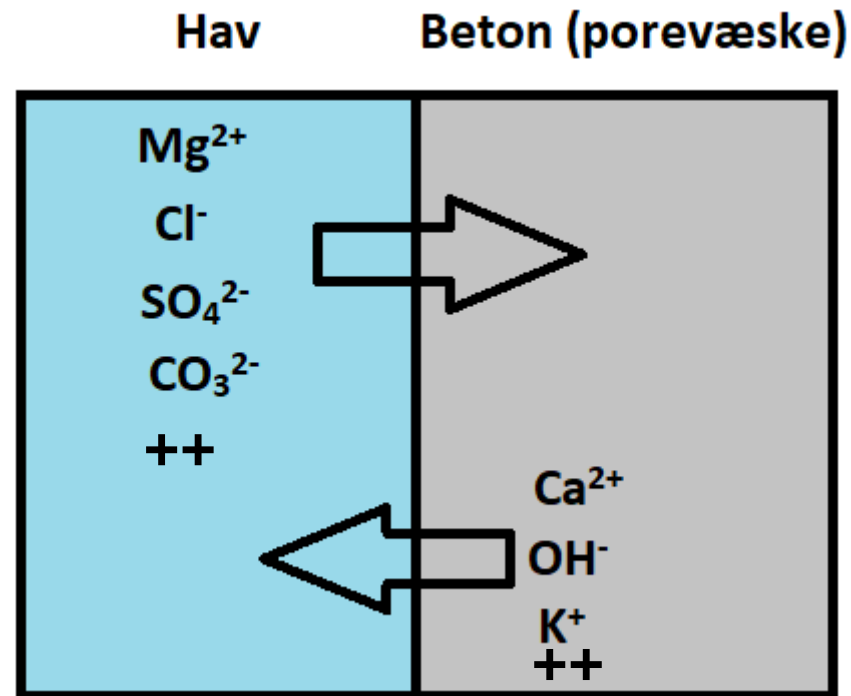
Concrete ID in thesis		PC	15FA	25FA	25FA_SCC	4SF	12FA4SF	12FA4SF_ noAEA	12FA4SF_ high_wc	12FA4SF_ low_wc	12FA4SF_ SCC	SG	SG_noAEA	SG_SCC	SG_rapid
Original concrete ID		A	B	C	D	E	F	G	H	I	J	K	L	M	N
Group I		x	x	x		x	x					x			
Group II								x	x	x			x		x
Group III					x						x			x	
Powder composition [wt.%]	CEM I 42.5N -SR5	100	85	75	75	96	84	84	84	84	84				
	CEM I 52.5N														30
	CEM III ^{a)}											100	100	100	
	FA		15	25	25		12	12	12	12	12				
	SF					4	4	4	4	4	4				
	GGBS														70
	w/(c+2SF+0.5FA+GGBS)	0.40	0.40	0.40	0.40	0.40	0.40	0.40	0.45	0.35	0.40	0.40	0.40	0.40	0.40

a) GGBS content: 67% by wt.

FA = Fly Ash, SF = Silica Fume, GGBS = Ground Granulated Blast-furnace Slag



Transport af ioner til/fra beton



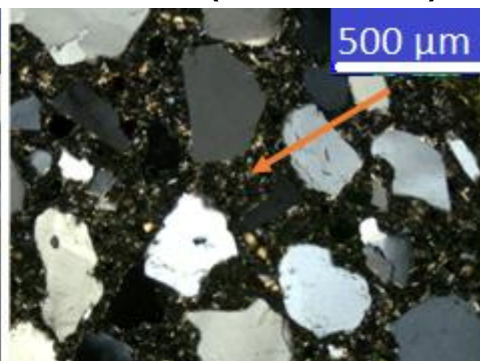
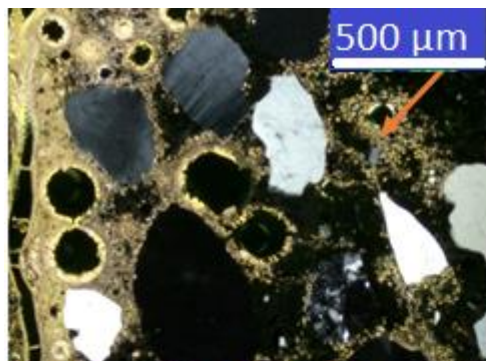
"Microstructurally Changed Zone"

Surface

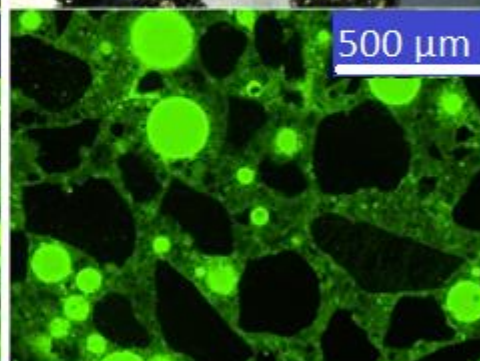
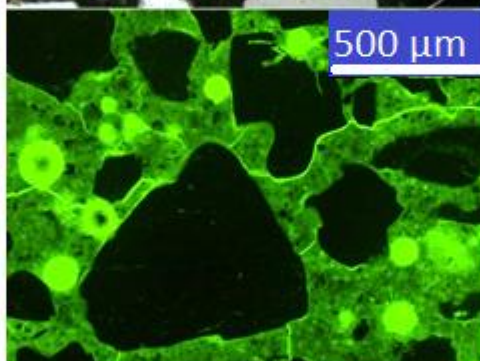
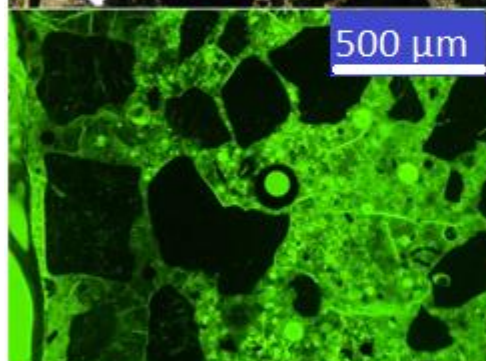
Opaline

Bulk ("normal")

Light mode:
Cross polarized



Fluorescence

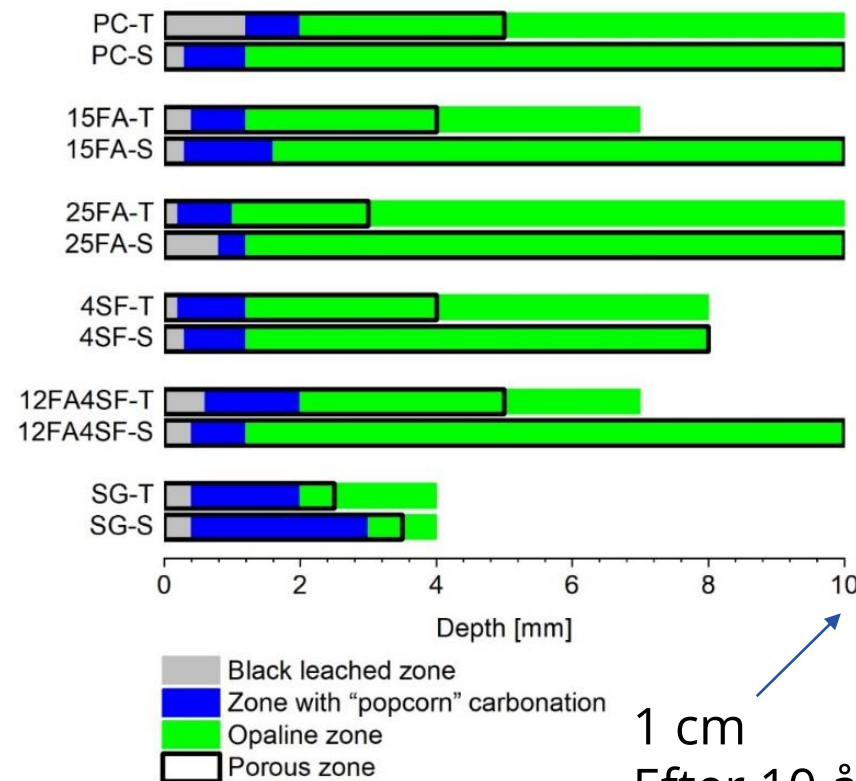


Surface zone (Typical <1 mm depth): intermixed leached paste and popcorn carbonation (marked with arrow), high porosity.

Opaline zone (Typical of 2–10 mm depth): no visible CH, with increased porosity and micro-cracking.

Bulk (Typical of >10 mm depth): visible CH (marked with arrow) and apparent w/c of 0.40.

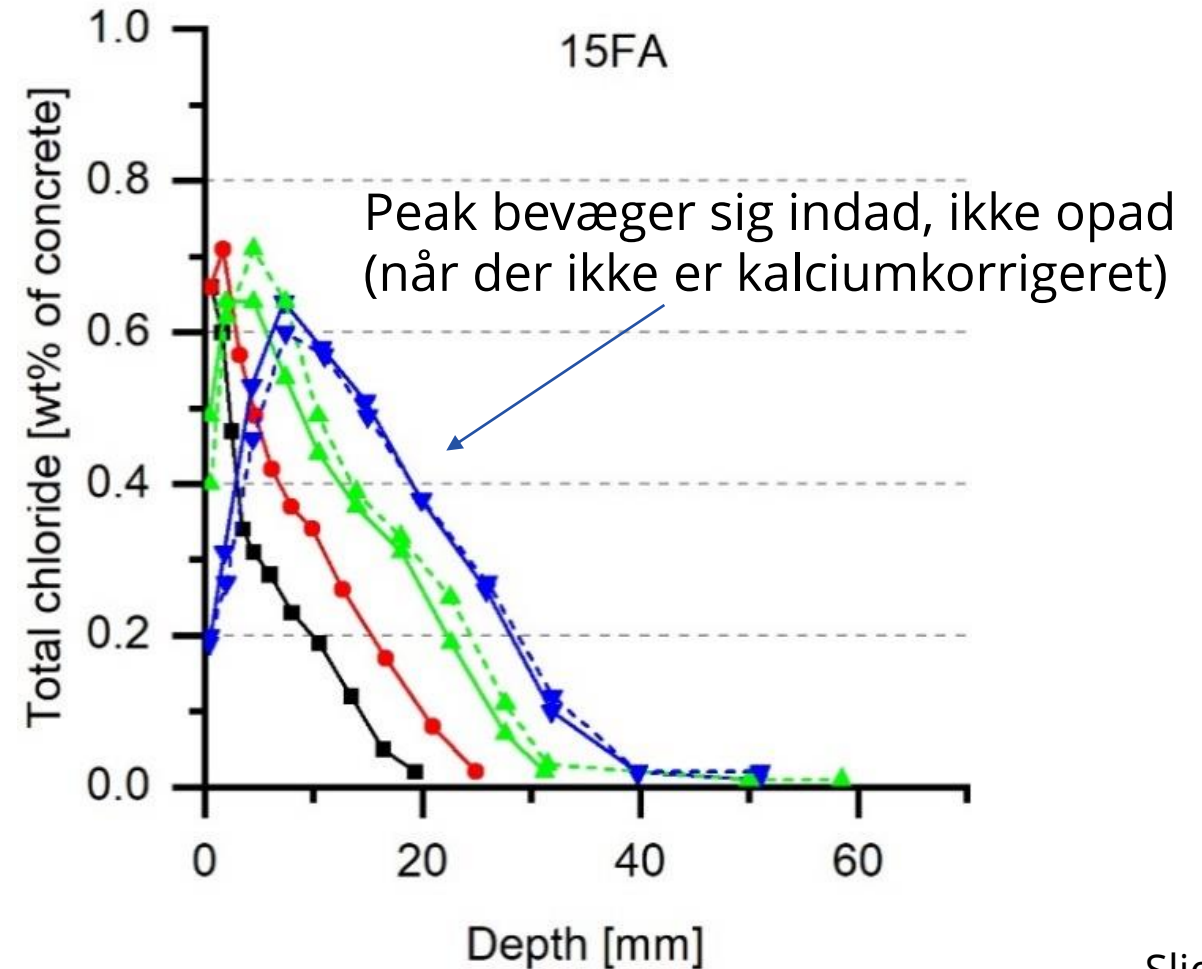
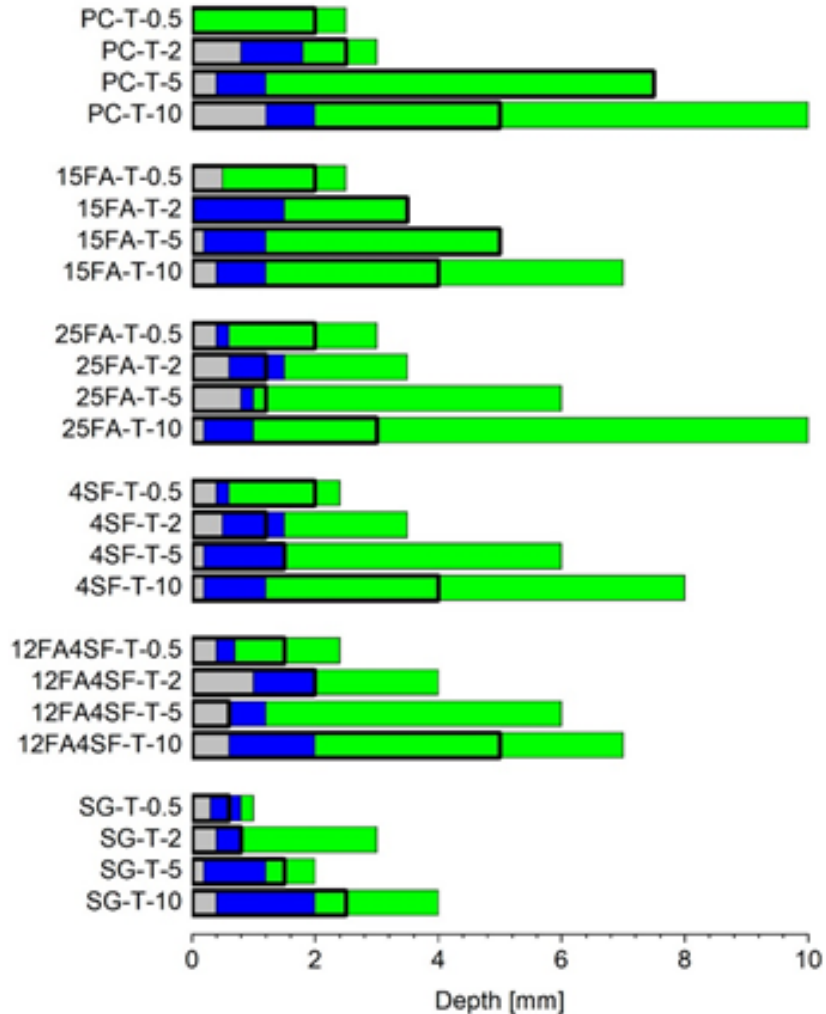
Microstructurally Changed Zone



1 cm
After 10 år

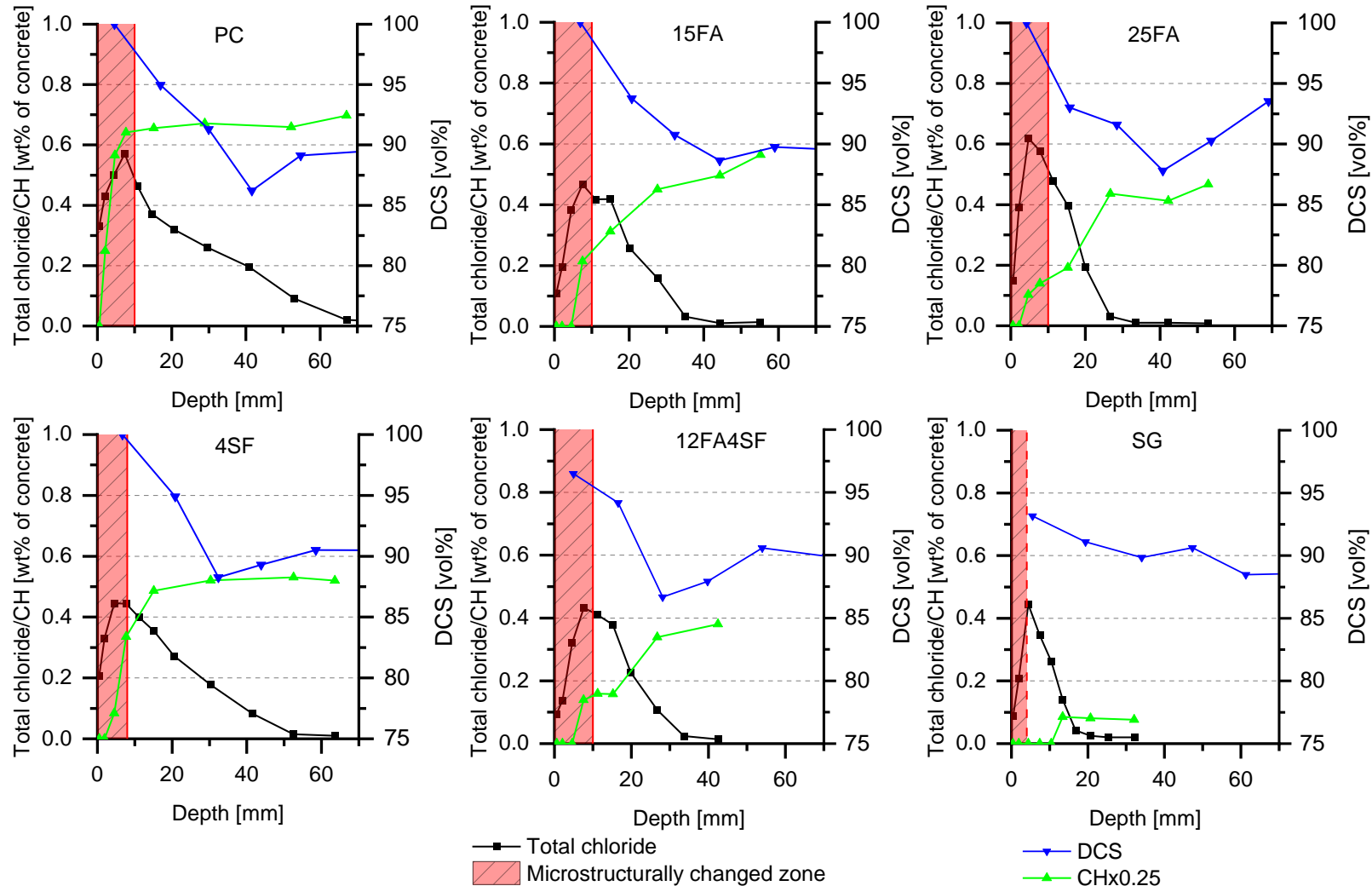


Både MCZ og klorider bevæger sig indad over tid





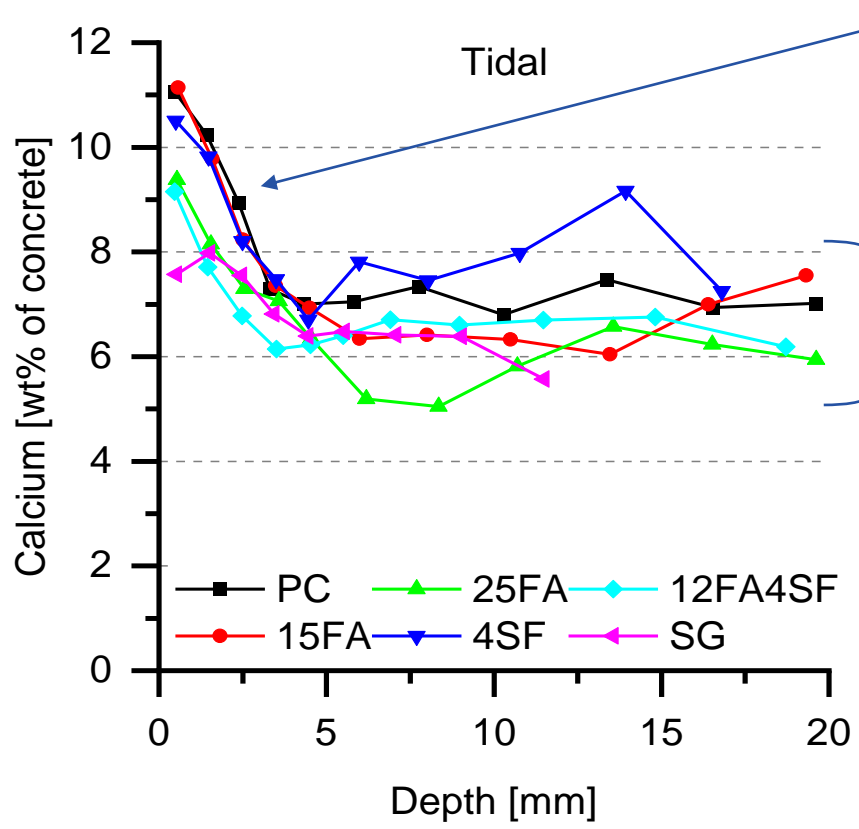
Kloridprofiler vs. MCZ vs. portlandit vs. Vandmætningsgrad (10år)





Kalciumkalibrering (konvertering fra klorid/beton til klorid/binder)

Klorid trænger ind gennem pasta, ikke sten.

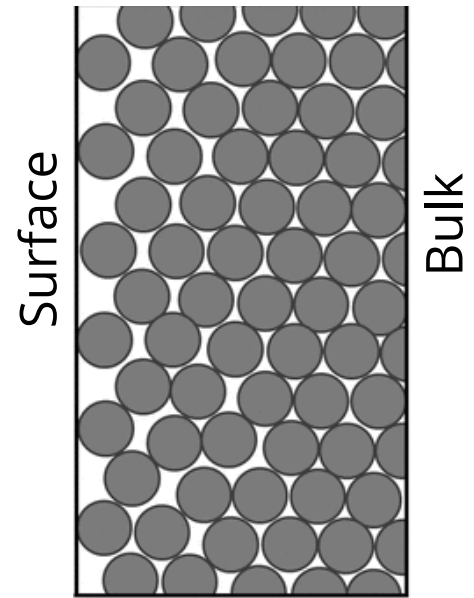


After 1/2 year of marine exposure

Systematisk variation (væg-effekt)

$$Kalibreret\ klorid\ indhold = \frac{wt\%Cl_{m\ddot{a}lt}}{wt\%Ca_{m\ddot{a}lt}} \times wt\%Ca_{teoretisk}$$

Usystematisk variation



Nie, Zhijie, et al. "Minicolumn test of remaining GAC performance for taste and odor removal: Theoretical analysis." Journal of Environmental Engineering 146.1 (2020): 04019097.

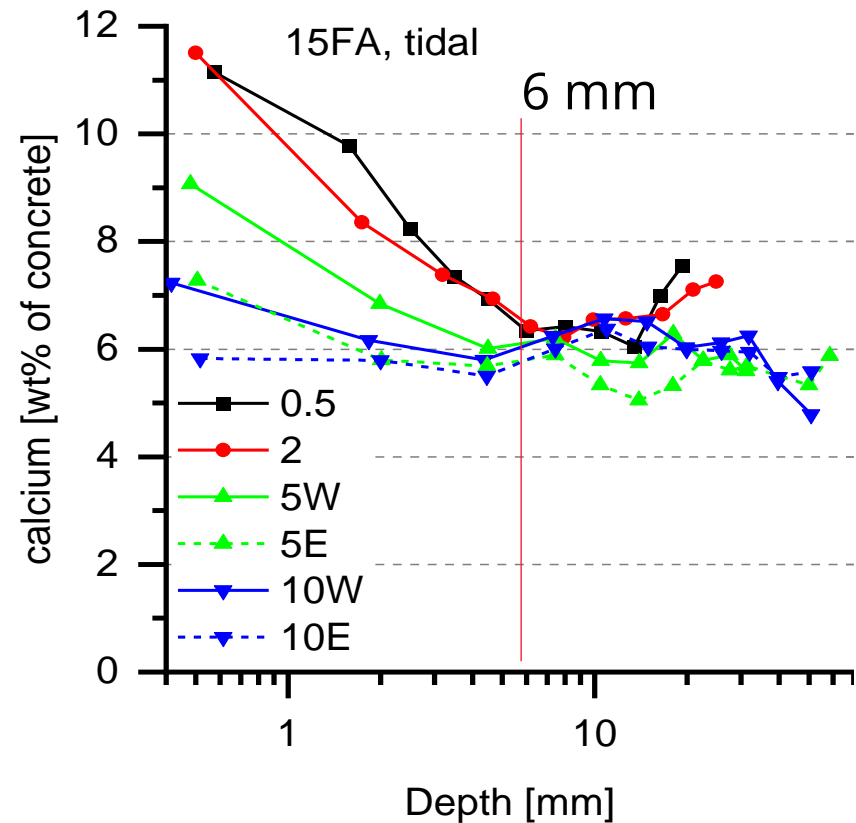


Kalcium kalibrering calibration impact

Kalibreret klorid indhold = $\frac{wt\%Cl_{m\ddot{a}lt}}{wt\%Ca_{m\ddot{a}lt}} \times wt\%Ca_{teoretisk}$

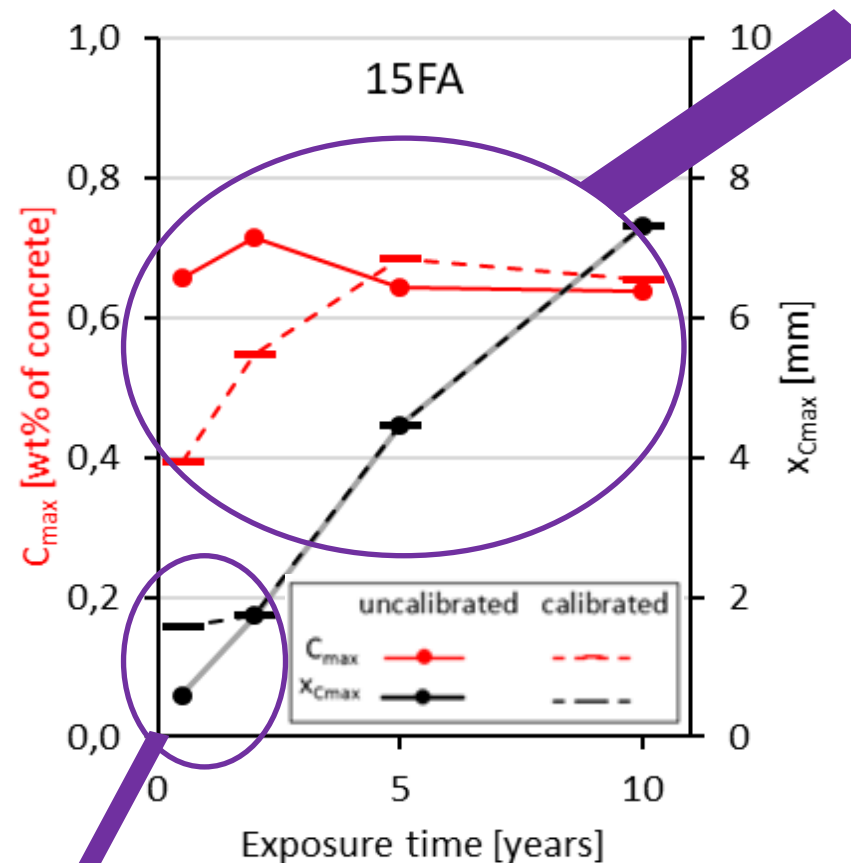
Leaching udgør problem

→



Efter ½, 2, 5 og 10 års marin eksponering

- Kalibreret maksimal kloridkoncentration (C_{max}) stiger over tid (målt kalcium falder)



- Indflydelse på peak position



Anbefaling vedrørende brug af data

- Ignorerer data influeret af mikrostrukturelle ændringer
(I praksis maximum kloridkoncentration og alt tættere på overfladen)

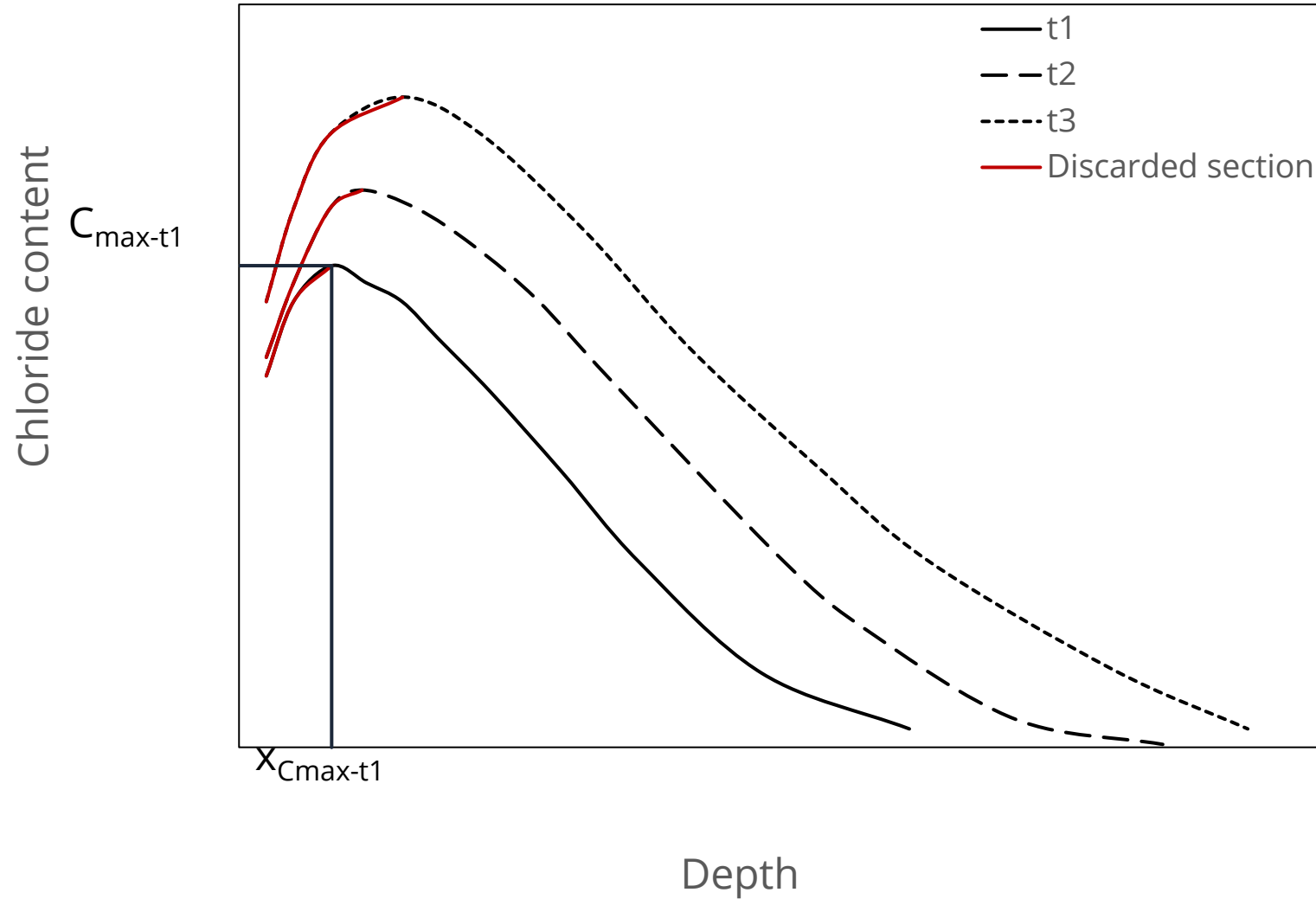


Kvadratrodsmetoden

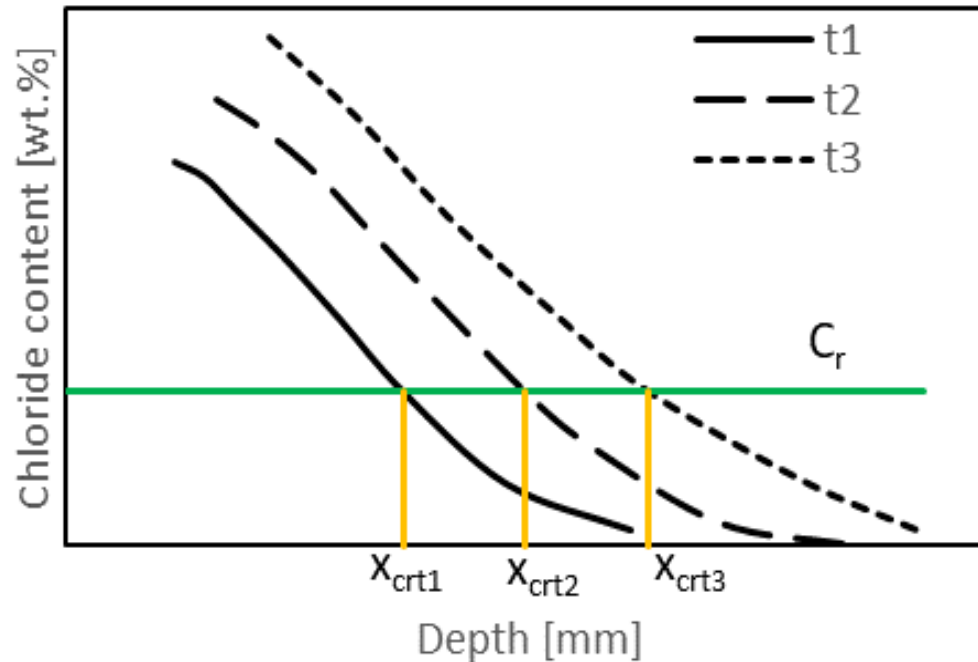
Paper I: The square root method for chloride ingress prediction – Applicability and limitations



Metodebeskrivelse - step 1



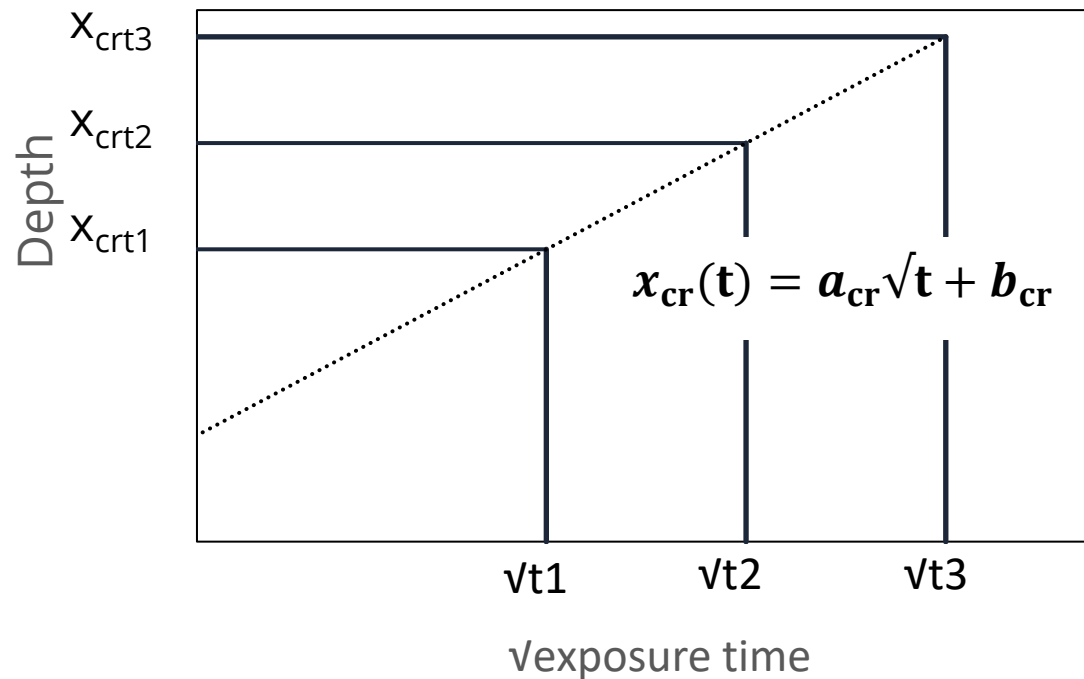
Metodebeskrivelse – step 2



Step 2

- Udvalg en referencekoncentration (C_r),
 $C_r < C_{\max-t1}$.
- For hver kloridprofil identificeres indtrængningsdybden (x_{Cr}) for C_r .

Metodebeskrivelse – step 3

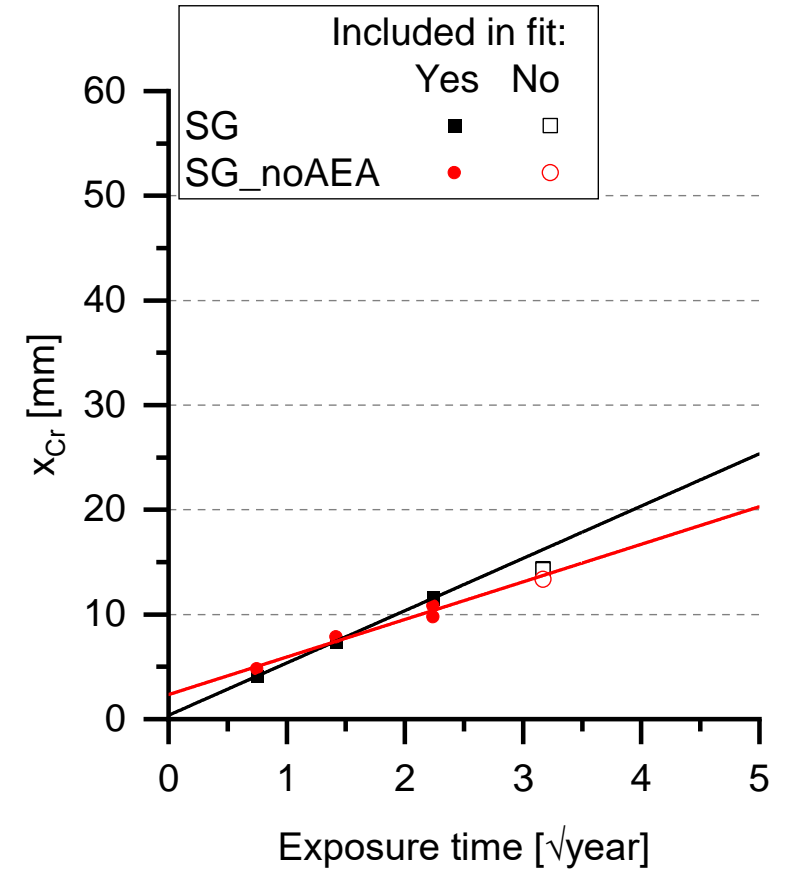
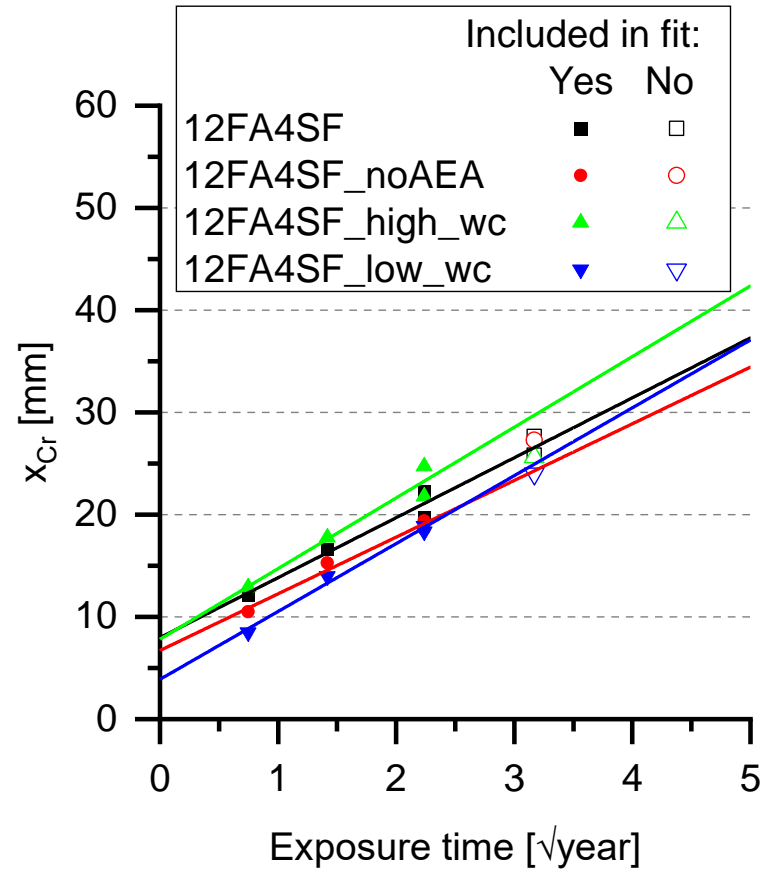
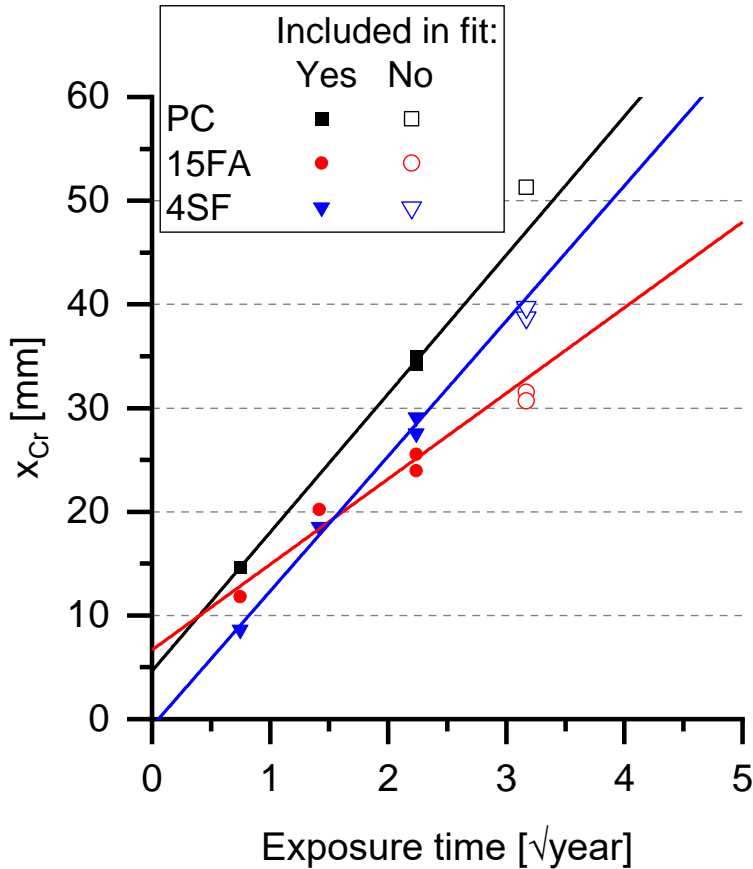


Step 3

- Plot x_{Cr} mod kvadratroden af tiden og bestem hældningen (a_{Cr}) og skæringen (b_{Cr}) ved lineær regression.
- Dybden af referencekoncentrationen (x_{Cr}) som funktion af tiden kan nu beskrives:

$$x_{\text{Cr}}(t) = a_{\text{Cr}}\sqrt{t} + b_{\text{Cr}}$$

Eksempler på forudsigelse af videre kloridindtrængning



+ God forudsigelse af videre kloridindtrængning (R^2 på 0,96 for 237 rette linier)

- Ikke brugbar for design scenarie.



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Videre forskning (efter PhD)



Efterfølgende slides er fjernet, da resultaterne endnu ikke er offentliggjort.



References

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Poulsen, S. L., H. E. Sørensen and U. Jönsson (2018). Chloride ingress in concrete blocks at the Rødbyhavn marine exposure site - Status after 5 years. 4th International Conference on Service Life Design for Infrastructures (SLD4). Delft, The Netherlands: 192-203.

Danner, T., U. Hjorth Jakobsen and M. R. Geiker (2019). Mineralogical Sequence of Self-Healing Products in Cracked Marine Concrete. *Minerals* **9**(5): 284:

Y. Cao, C. Gehlen, U. Angst, L. Wang, Z. Wang, Y. Yao, Critical chloride content in reinforced concrete—An updated review considering Chinese experience, *Cement and Concrete Research* 117 2019 58-68. <https://doi.org/10.1016/j.cemconres.2018.11.020>.

U.H. Jakobsen, K. De Weerd, M.R. Geiker, Elemental zonation in marine concrete, *Cement and Concrete Research* 85 2016 12-27

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Georget et al, in review



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Thanks for listening!

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