Sund Bælt

24.09.2026

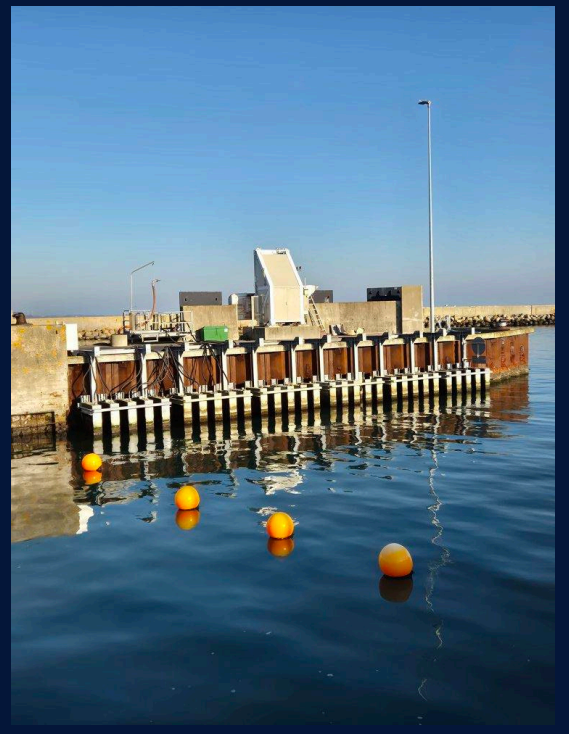
DTU

Nye cement typer til marine anlægskonstruktioner: Risiko for thaumasit dannelse?

Katarina Kolding Schlage

Vejledere: Wolfgang Kunther, Lisbeth M. Ottosen, Henrik Christensen, and Kristine Pilegaard

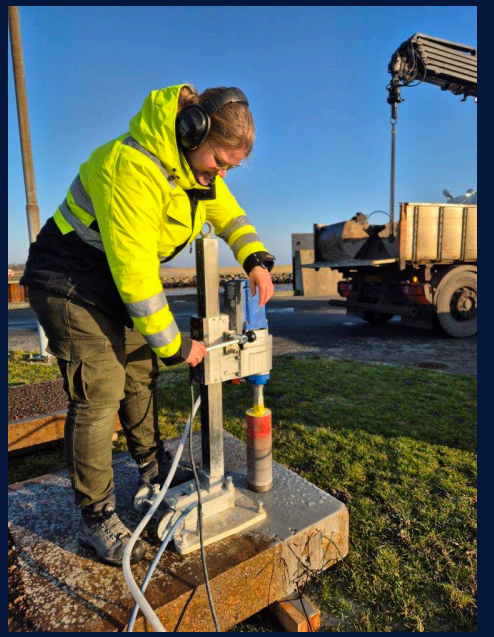




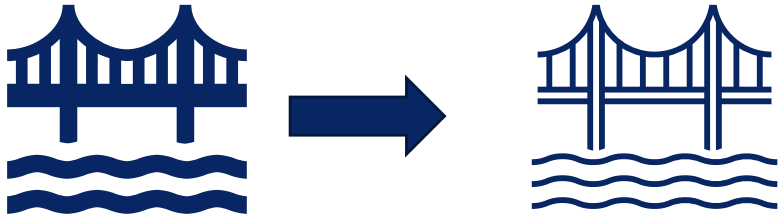




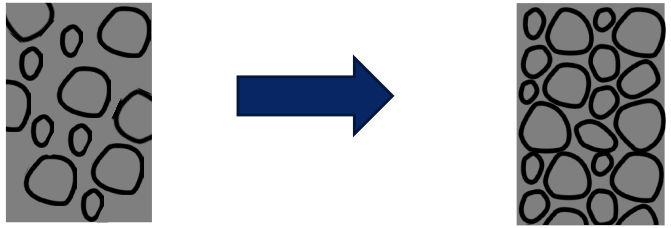




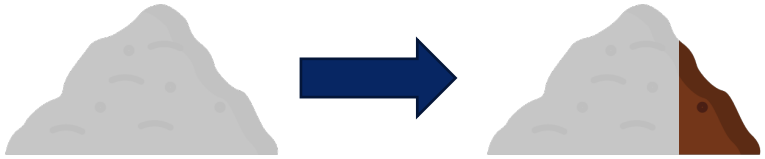
CO_2 aftryk af betonkonstruktioner



Mindre beton i konstruktioner



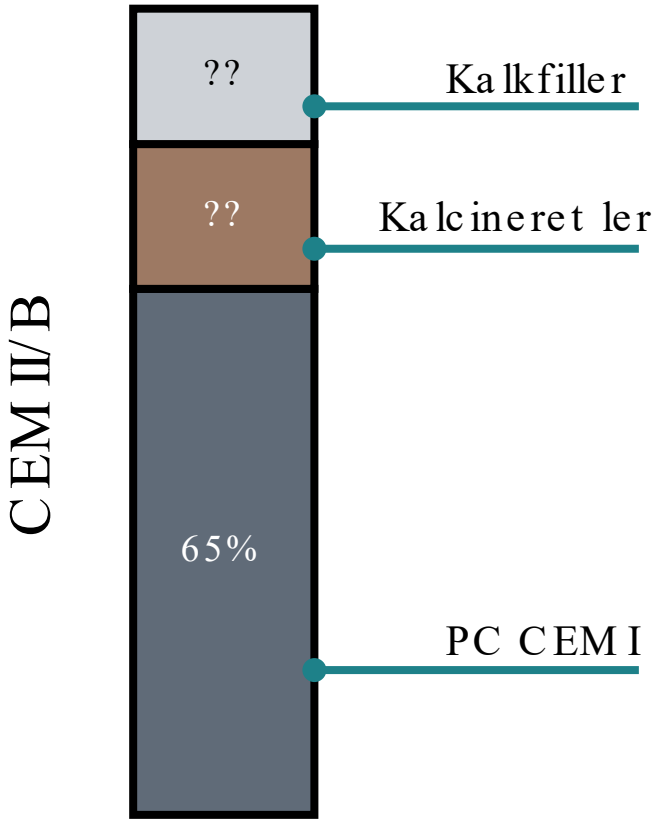
Mindre mængde cement pr m^3 beton



Cementerstatninger

Sikre lang holdbarhed ved introduktion af nye cementtyper!

Projektets formål



Reducere CO_2 udledning

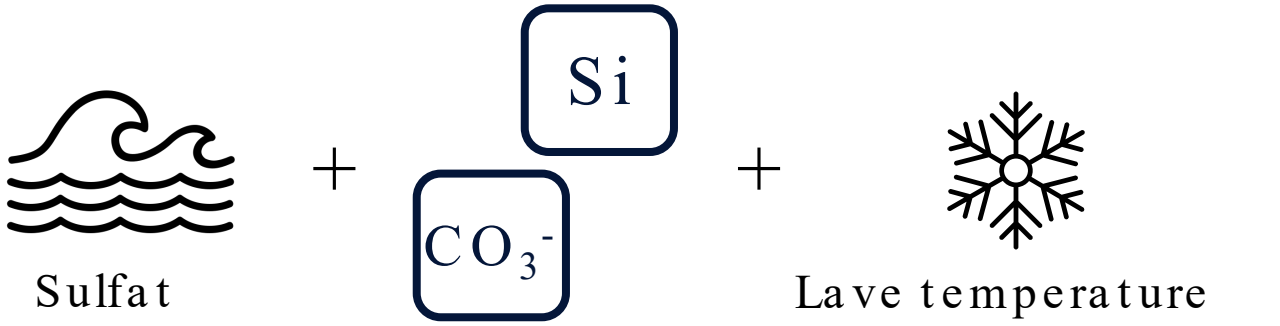
Kalkfiller kan medvirke til dannelse af thaumasit

Forhindre dannelse af thaumasit

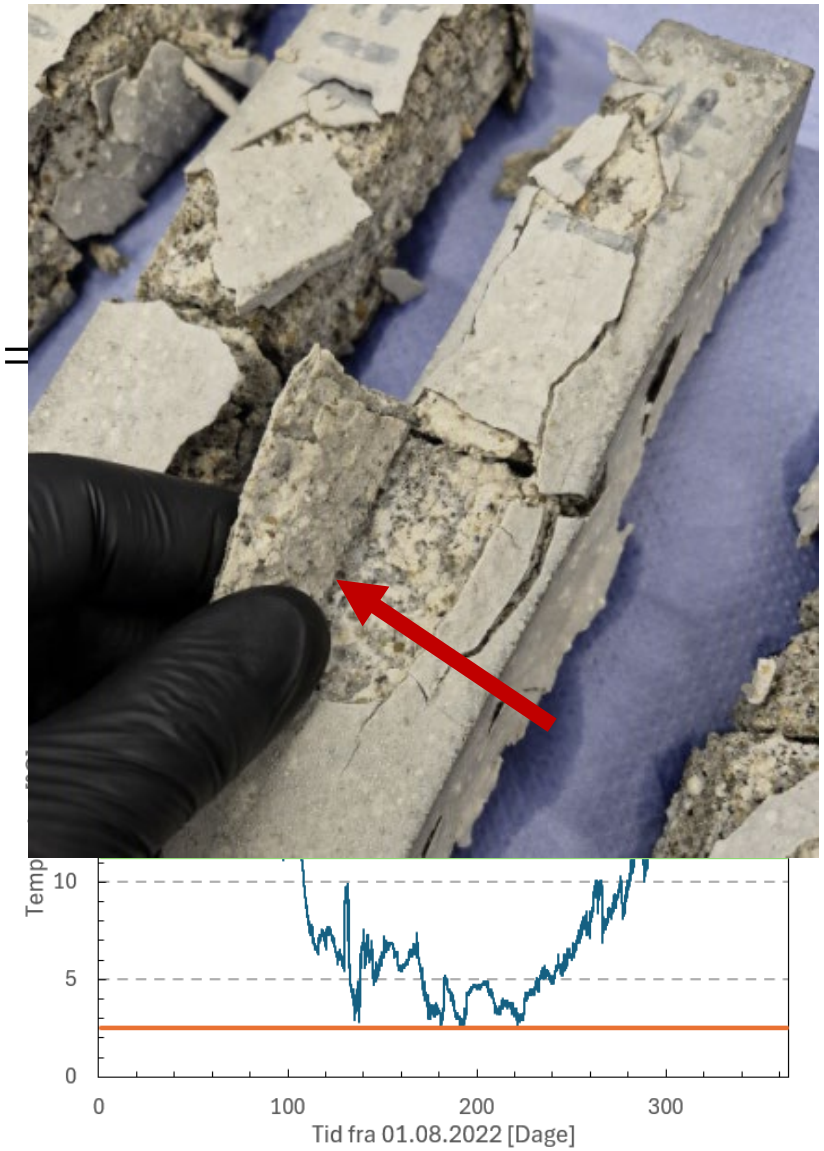
Kalcineret ler kan bidrage til en højere sulfat bestandighed

Øge holdbarheden i havmiljøer

Hvad er thaumasit ?



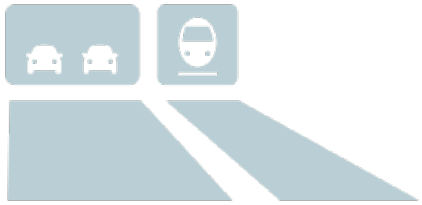
- Form for sulfatangreb
- Ikke stabilt ved temperaturer over 20 °C
- Dannes kun hvis CO_3 og sulfat er tilstede
- Omdanner cementmatrix til et blødt, tandpastalign. Materiale
- Samme krystalstruktur som ettringit



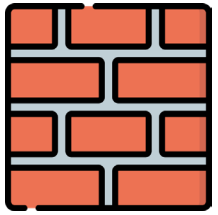
Tilfælde i Nordeuropa



Motorvejsbro
England



Tunneler & spildevandsledninger
Tyskland



Murværk
Danmark

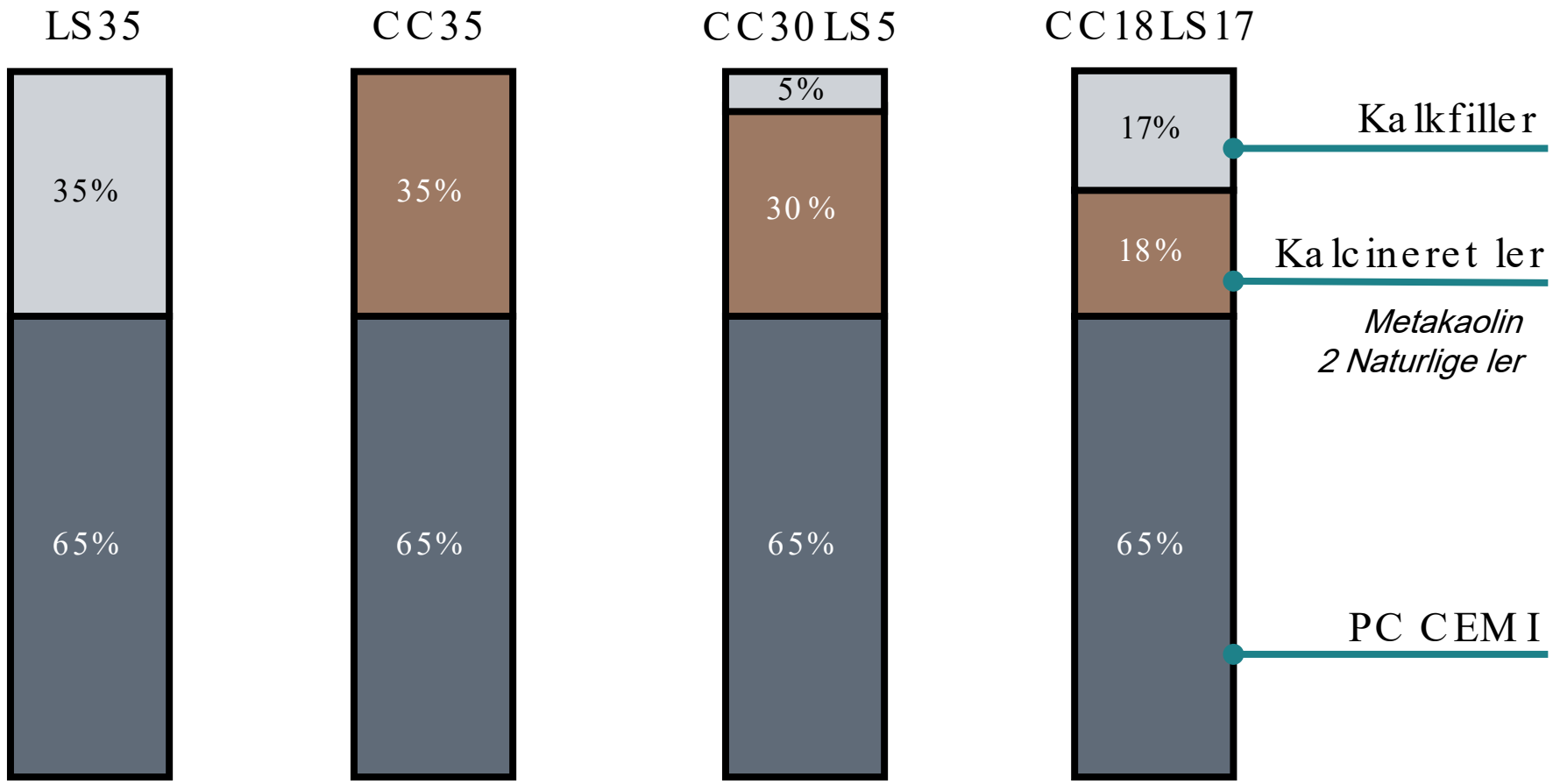


Marine anlægskonstruktioner
Danmark

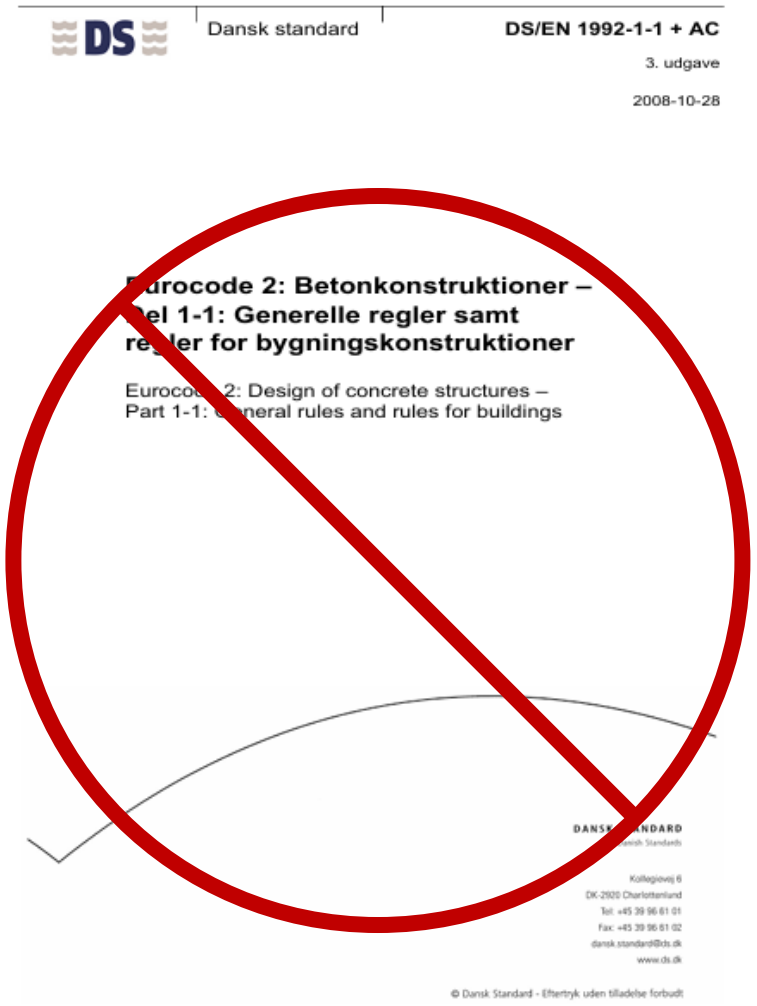


Betonelementer på
eksponeringsplads
Norge

Cementsammensætninger



Hvordan tester man for thaumasit ?

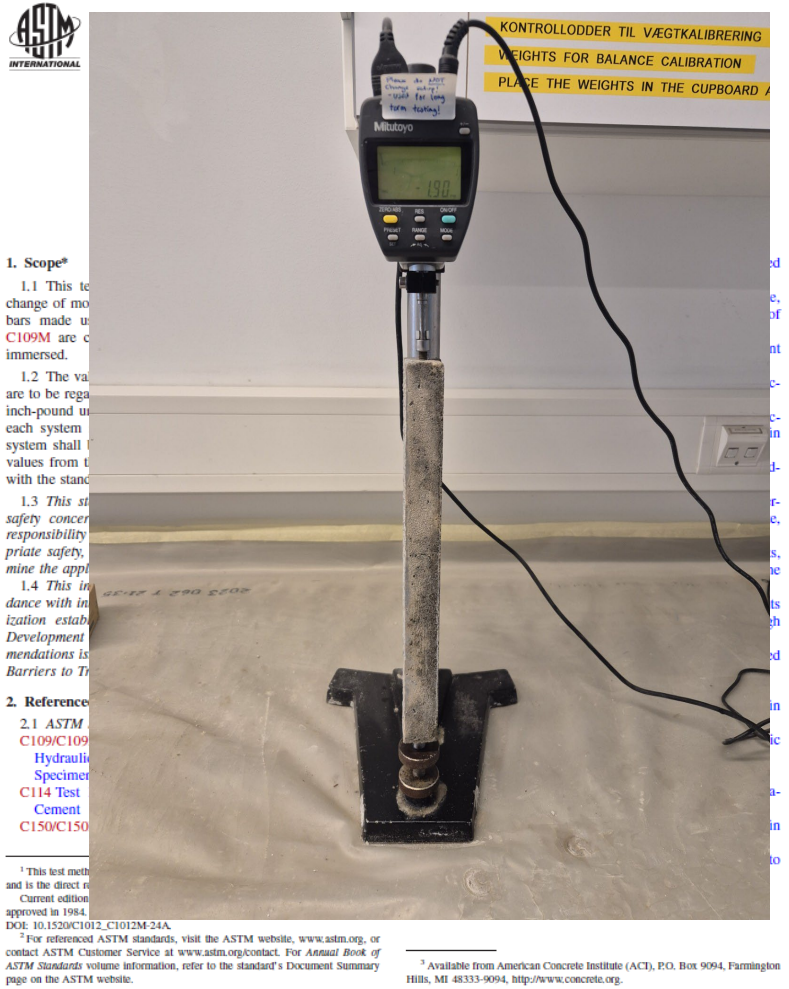


Hvordan tester man for thaumasit ?

- Ingen Harmoniseret Europæ isk standard

- Amerikansk standard (ASTM C 10 12) for sulfatbestandighed
  - Tester ved 23 ℃ 5 °C
  - Høje sulfatkoncentrationer Kunstigt havvand (østersøen)
  - Tager ikke højde for kompleksiteten i havvand

- Basere sulfatbestandigheden på ekspansionskurver
  - < 0.1% efter 6 mdr



Hvordan tester man for thaumasit ?

Cement



~300 prøver

Mørtel



~100 prøver

Beton

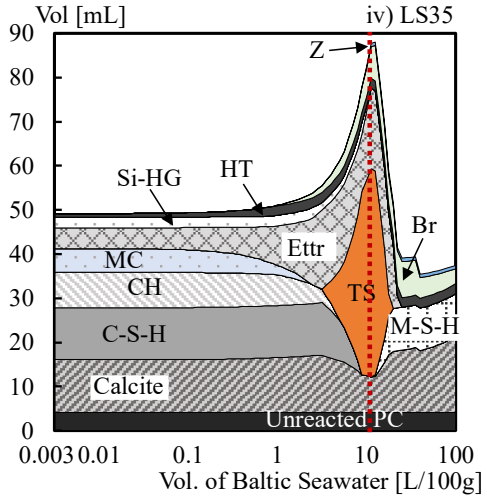


2 blokke, 4 mixes

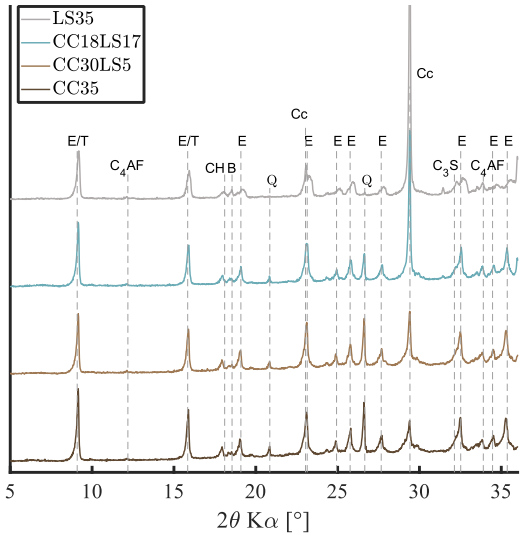
Accelereret test

Felt eksponering

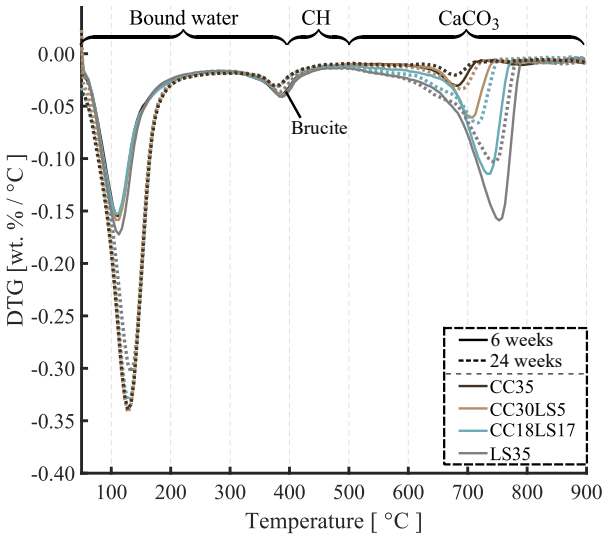
Målemetoder



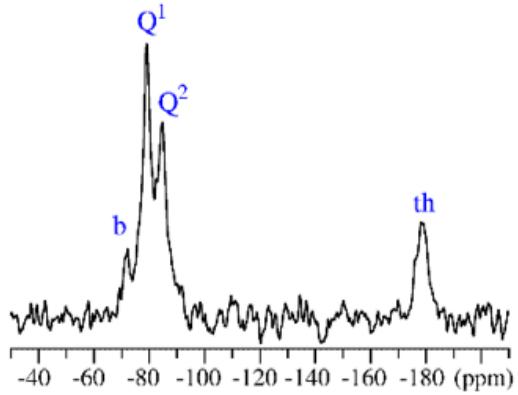
Termodynamisk modellering



X-ray diffraction (XRD)



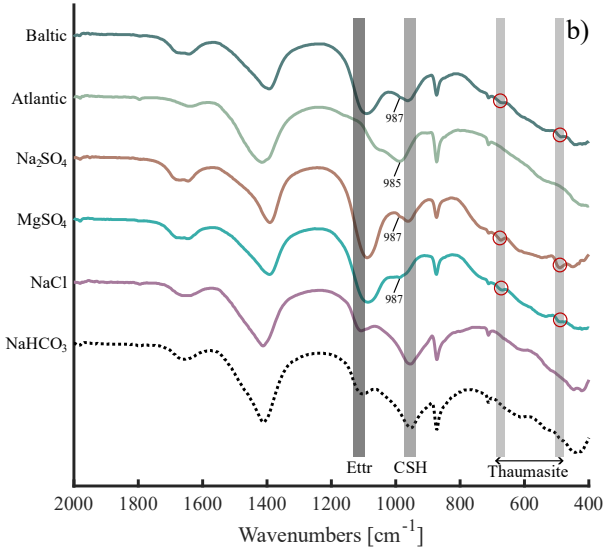
Thermogravimetric analysis (TGA)



Nuclear Magnetic Resonance (NMR)

^{29}SI MAS NMR & ^{27}Al MAS NMR

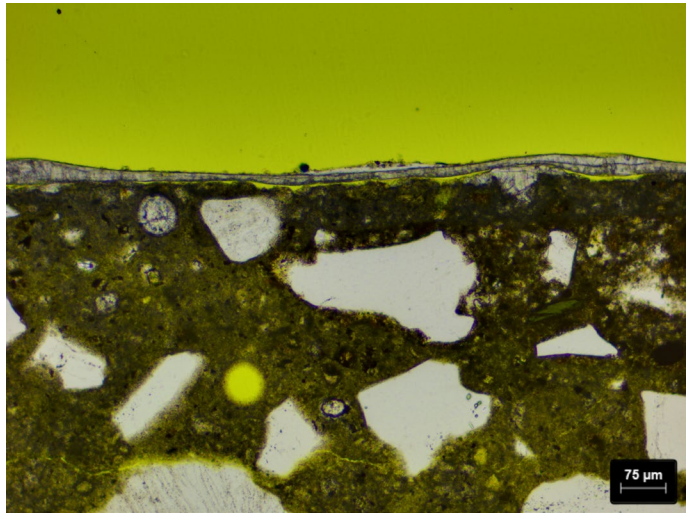
Samarbejde med Jørgen Skibsted, Aarhus universitet



Fourier transform infrared (FTIR)

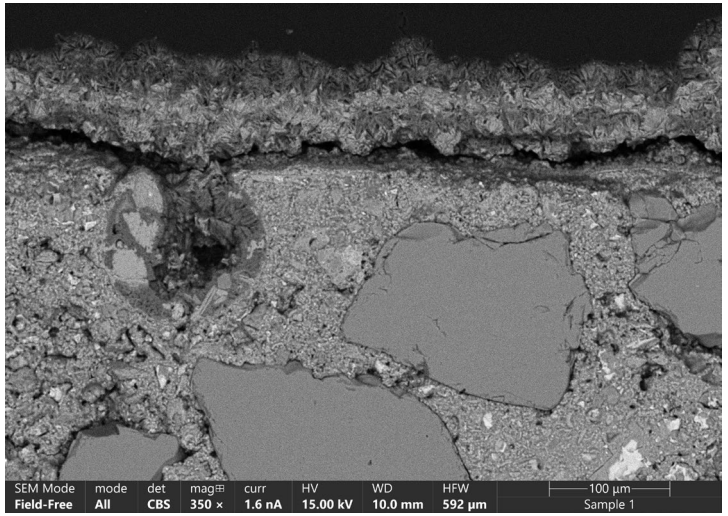
Samarbejde med Ruben Snellings, KU Leuven

Målemetoder



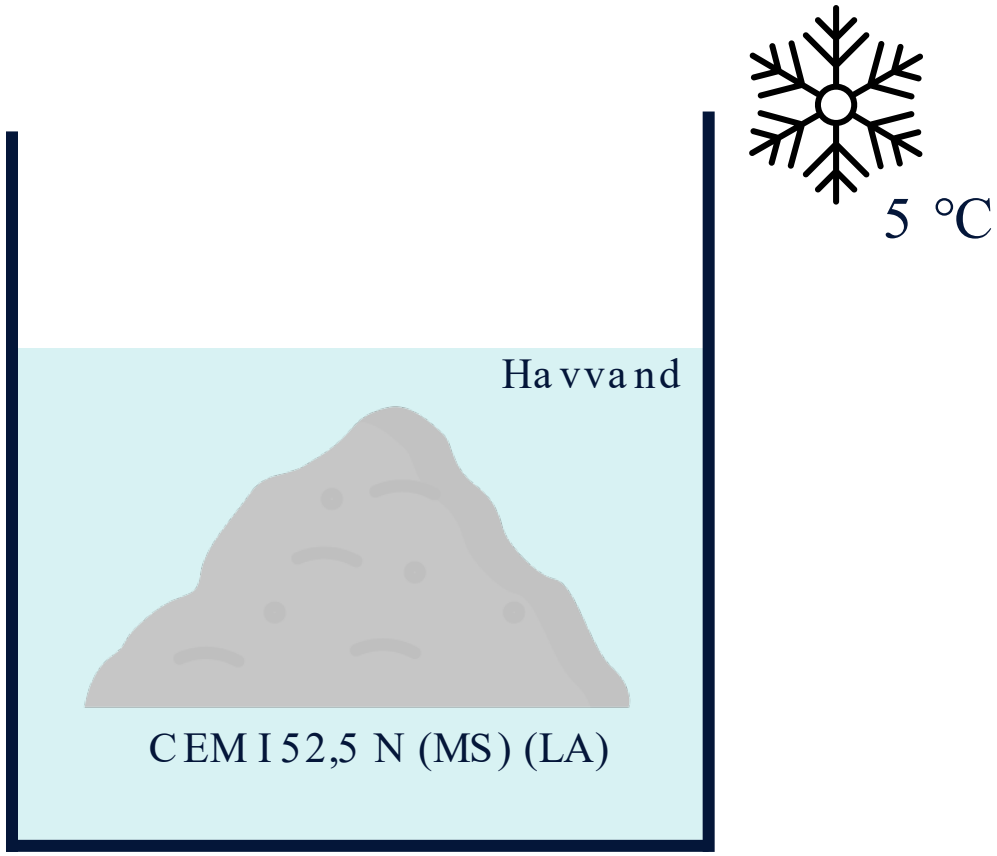
Petrografi (Tyndslib)

Samarbejde med Ruben Snellings, KU Leuven



Scanning electron microscopy (SEM)

Hvor hurtigt dannes thaumasit ?



5 °C

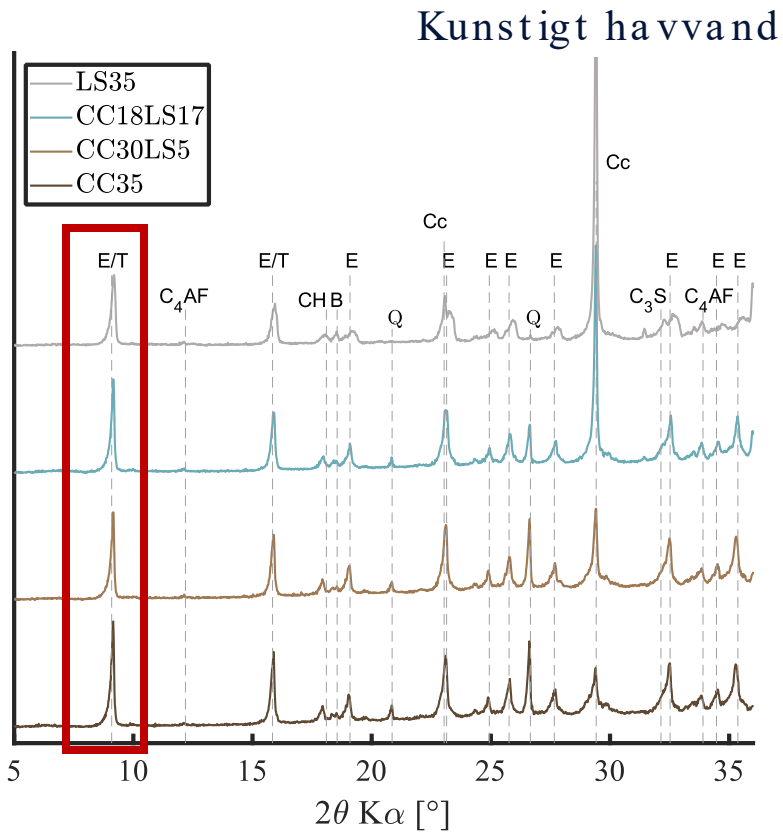
6 uger
→ 8.3 wt% Thaumasit

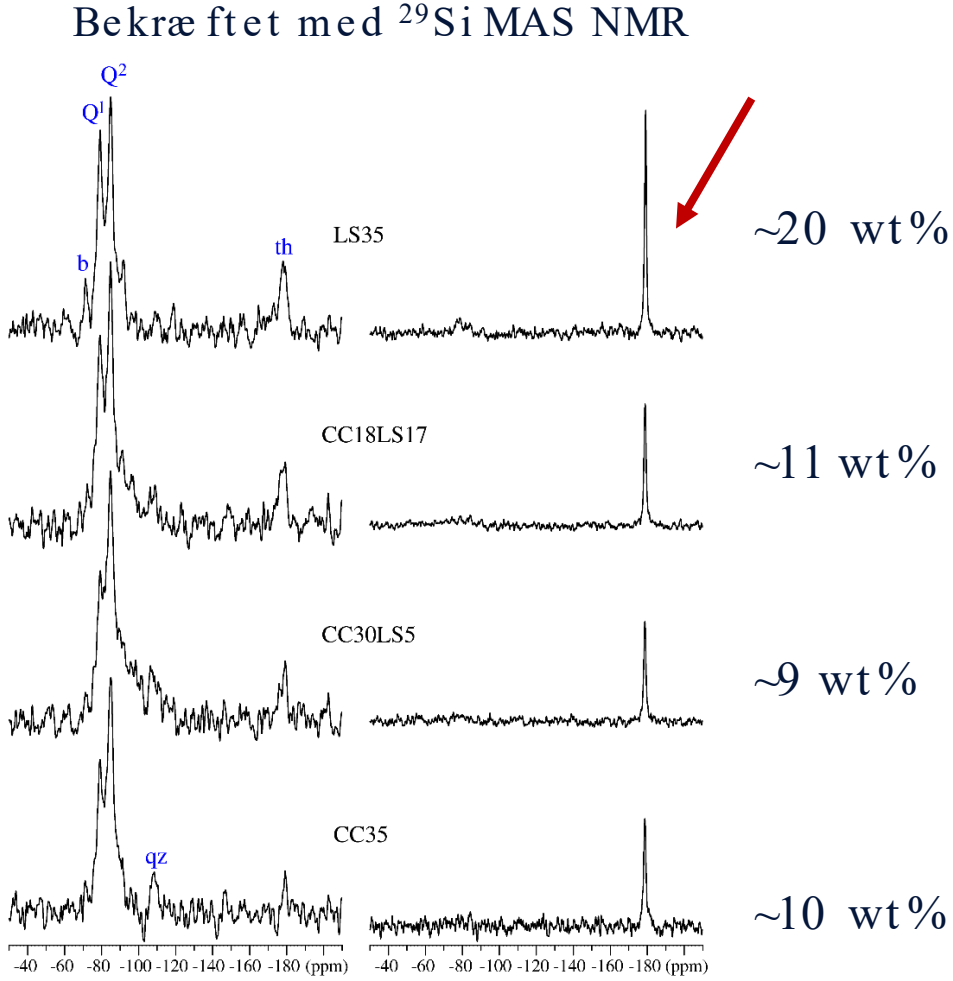
15 uger
→ 26 wt% Thaumasit

24 uger
→ 34 wt% Thaumasit

*wt% af den eksponeret prøve

Højrere indhold af kalkfiller ?



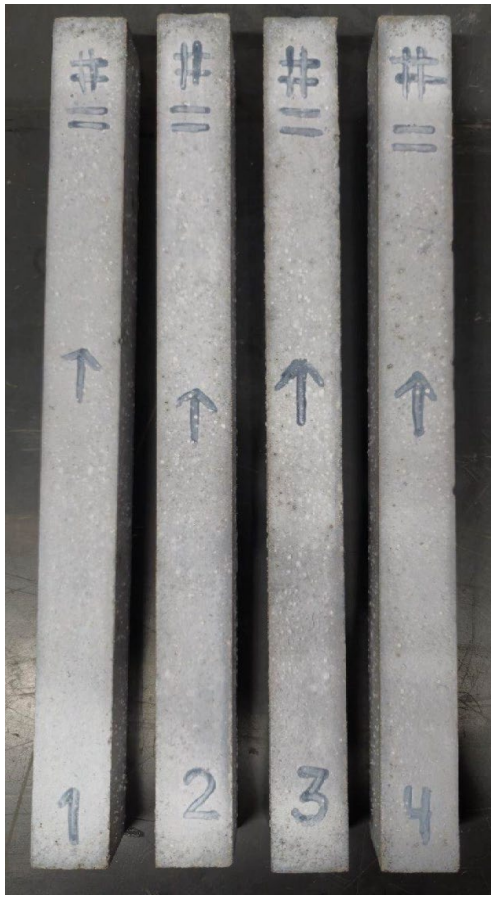


Mørtel skala – 35% kalkfiller

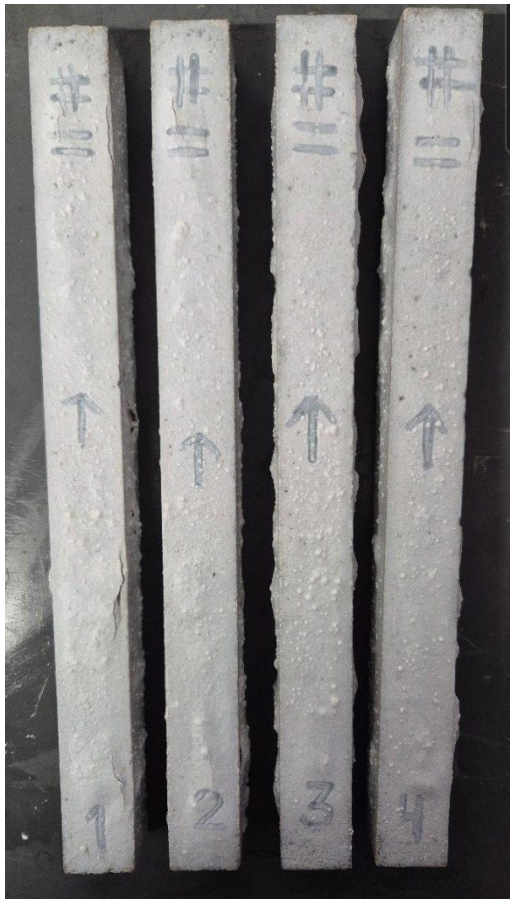
start

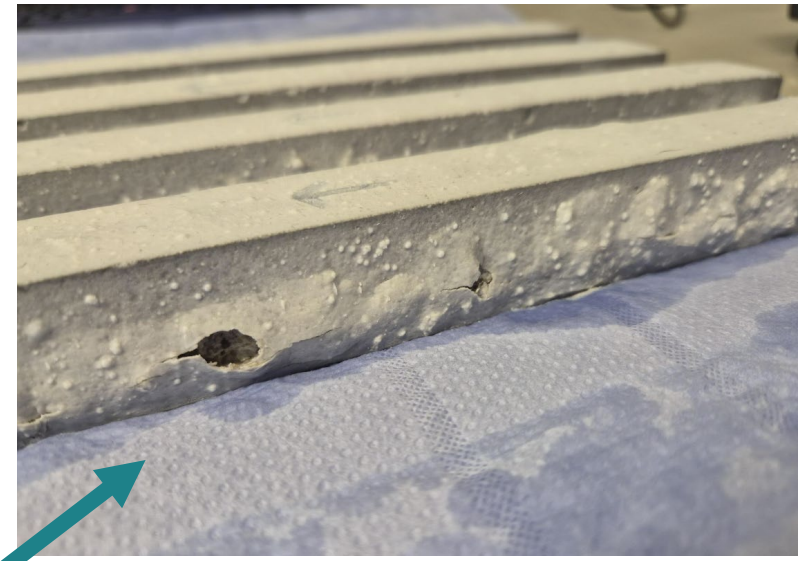


2 mdr



4 mdr





Mørtel skala – 35% kalkfiller

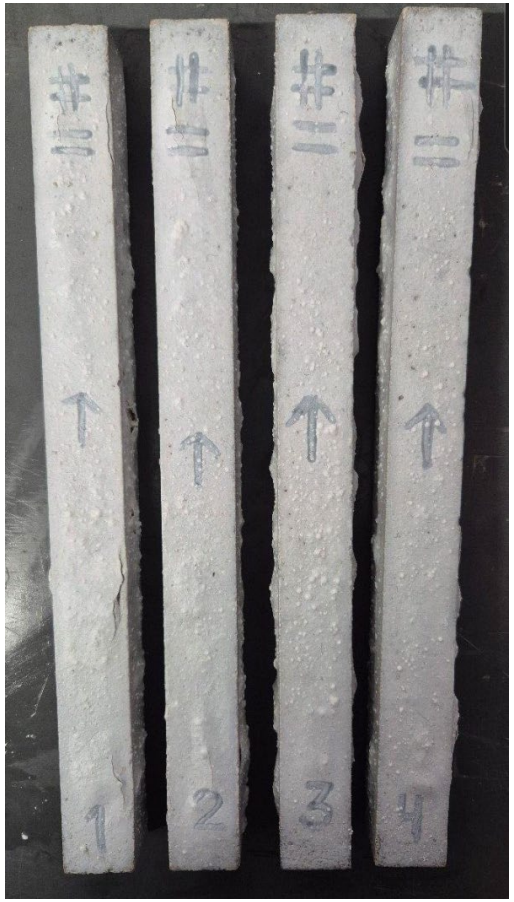
start



2 mdr



4 mdr



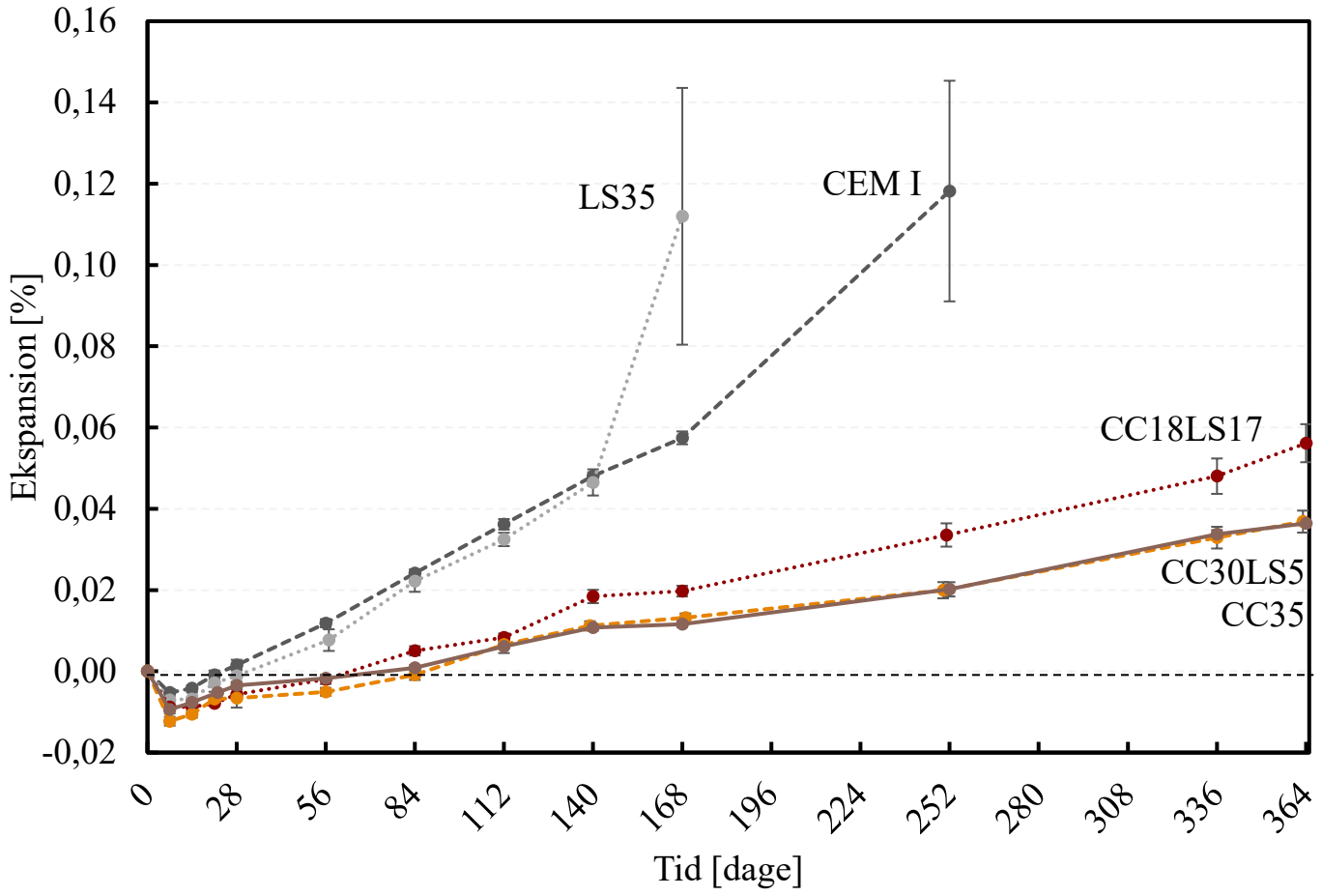
6 mdr

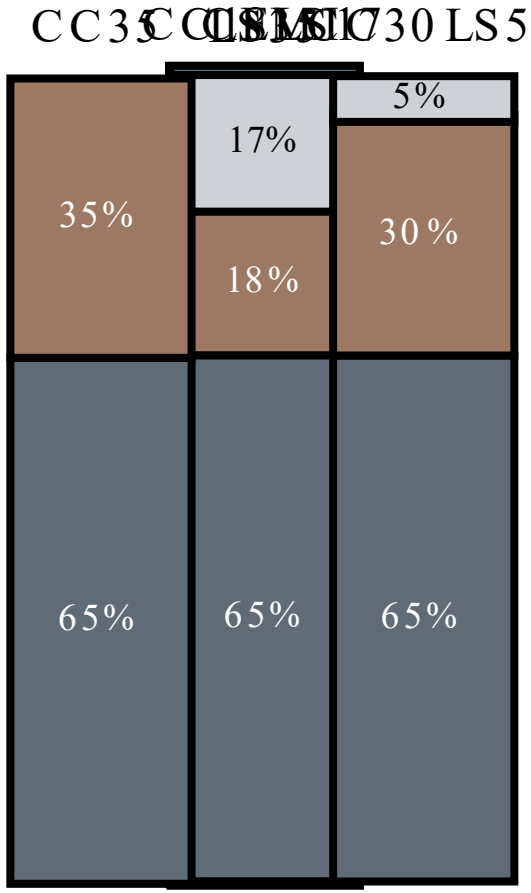


9 mdr



Ekspansion under eksponering

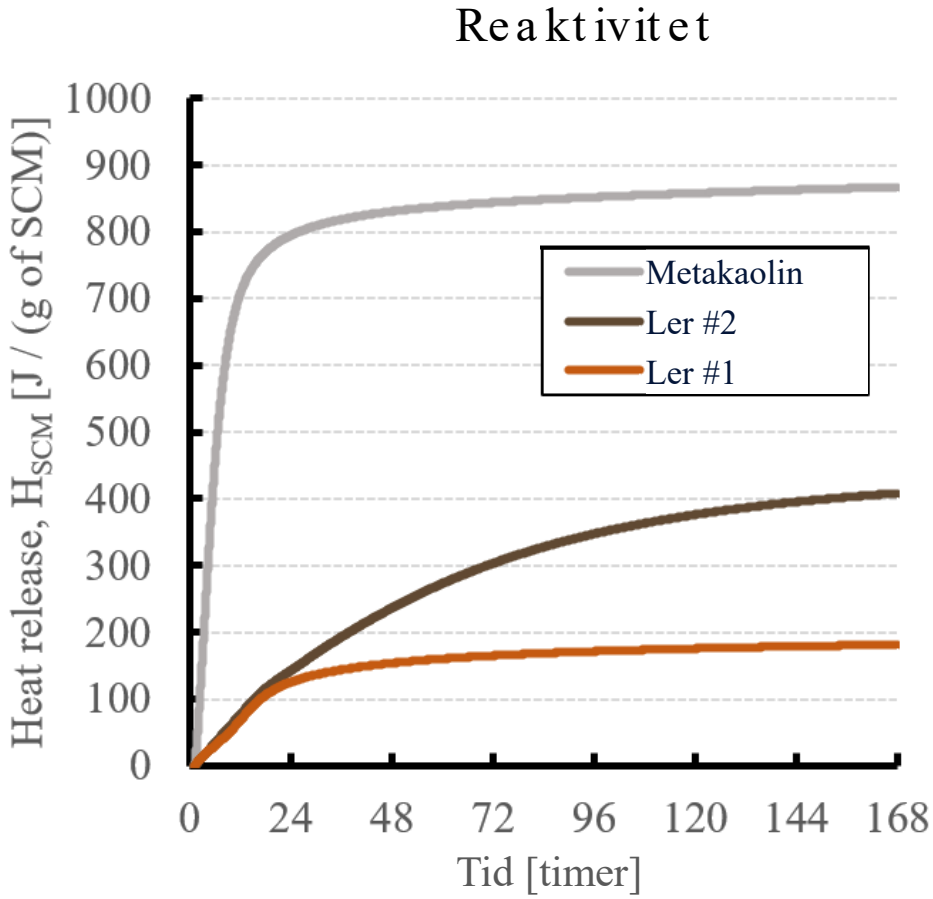




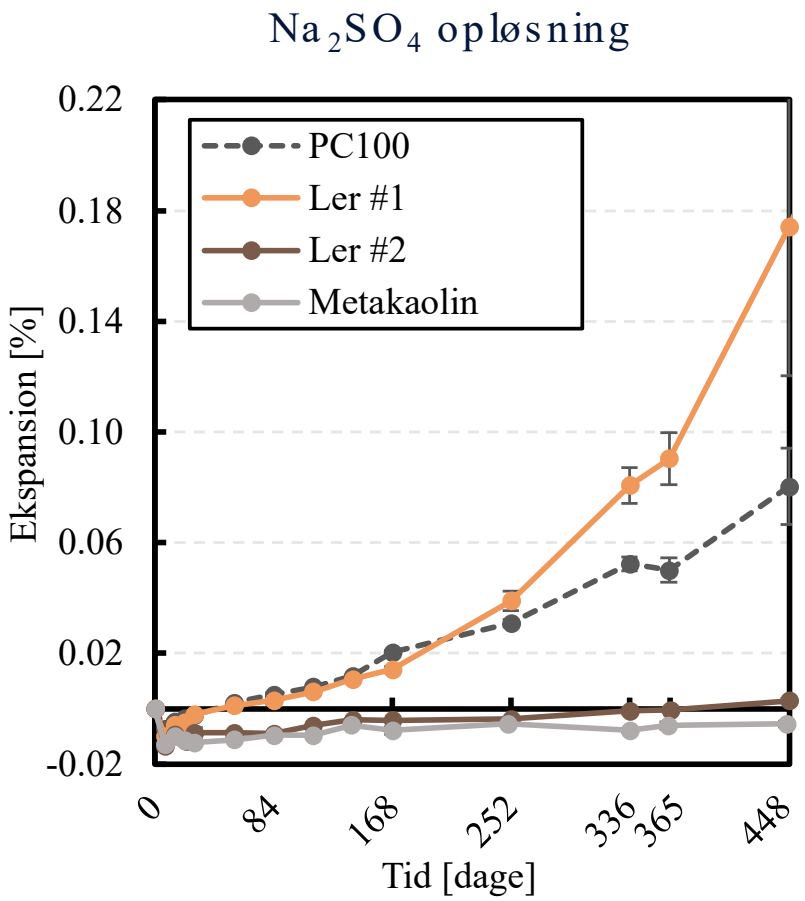
Ler mineralogi og dens indflydelse på thaumasit

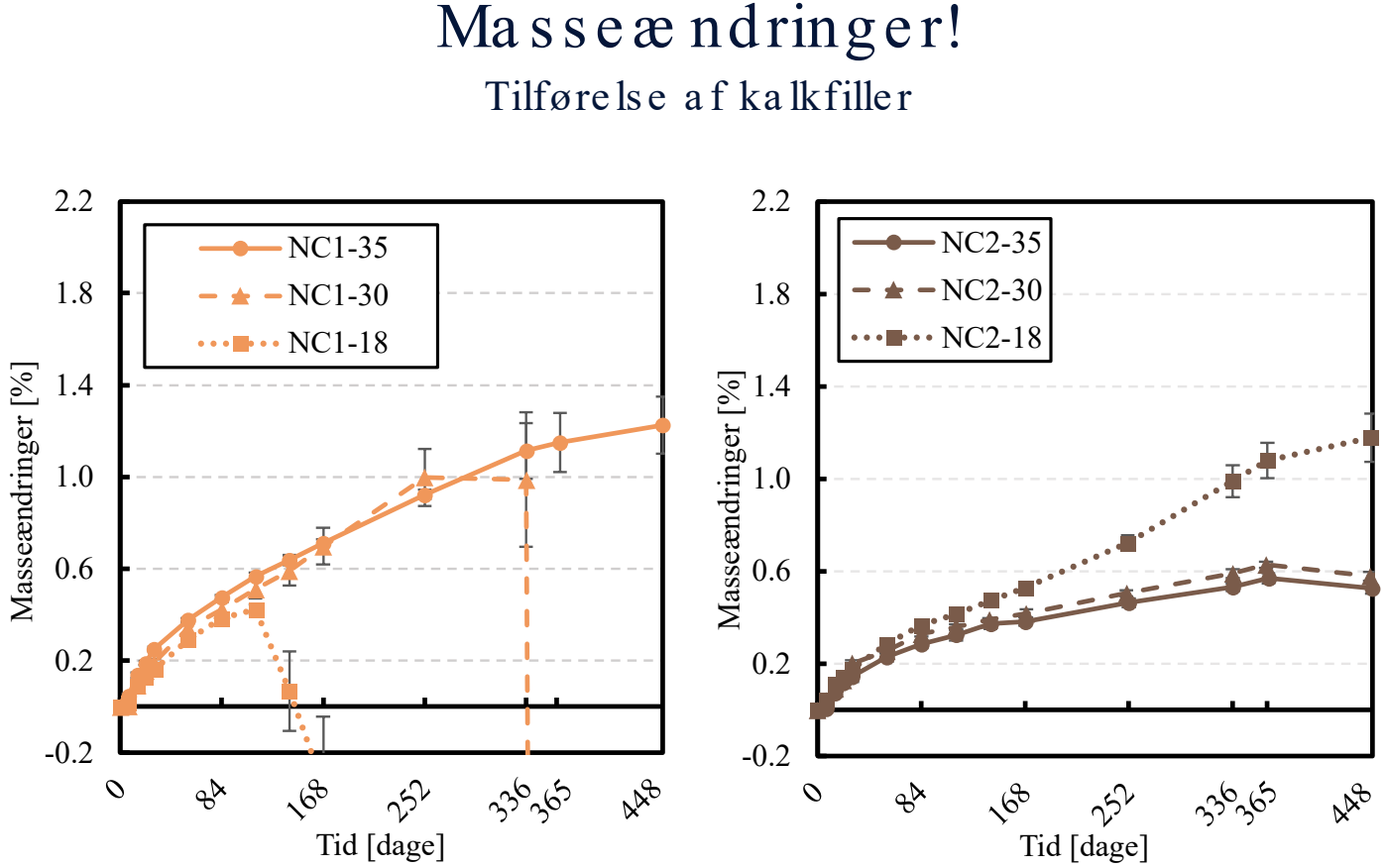
3 forskellige kalcineret ler

[wt . %]	Metakaolin	Ler #1	Ler #2
Amorf	85	17	51
Lermineraler	6	21	10
$CaCO_3$	-	5	3
Kvarts	7	42	20
Andet	2	15	16

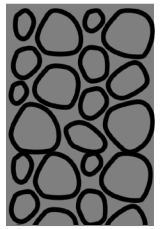


Ler mineralogi og dens indflydelse på thaumasit





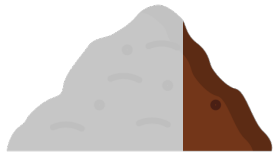
Afsluttende konklusioner



Thaumasit dannes langsomt over tid.
Betonprøver viser ingen dannelse af thaumasit efter ~1.5 år



Kalkfiller accelerere dannelsen af thaumasit



Kalcineret ler mindsker risiko for thaumasit
- Reaktiv ler har bedst effekt

Tak for jeres opmærksomhed!

Tak til:
Jørgen Skibsted (Aarhus universitet)
Ruben Snellings (KU Leuven)



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