Dagens betonteknologi
DBF-møde 4. oktober 2006

Betons egenskabsudvikling

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Abstrakt

Betonens behov for fx efterbehandling og potentielle tæthed kan vurderes vha. simple volumenbetragtninger

Få Powers' model genopfrisket og se et par eksempler på anvendelsen

Indhold

Betons mikrostrukturudvikling (her porøsitet) og vandbinding

Powers' model

Eksempler

- Vurdering af behov for efterbehandling
- Vurdering af chloridindtræningshastighed

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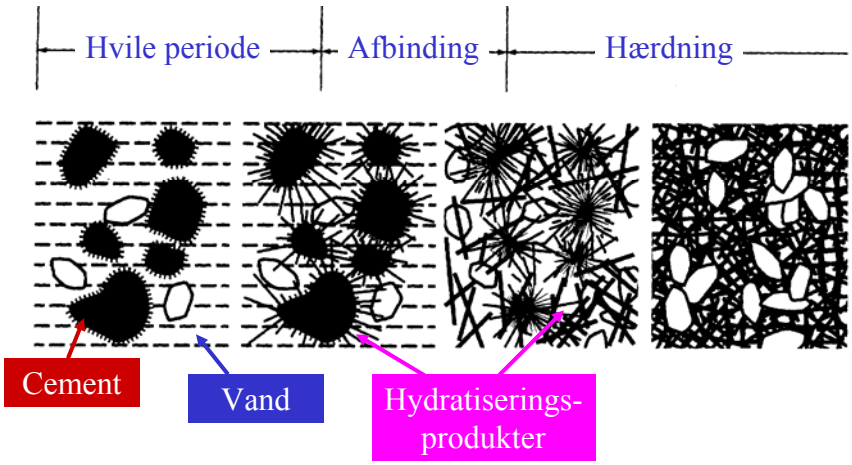
Eksempler

- Vurdering af behov for efterbehandling
- Vurdering af chloridindtræningshastighed

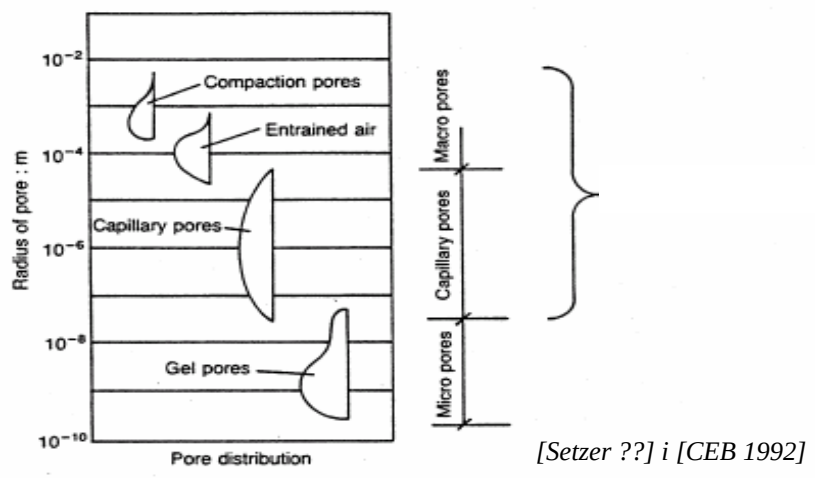
Modeller for effekten af tid og temperatur fortæller jeg gerne om en anden gang…

Afbinding og hærdning af beton



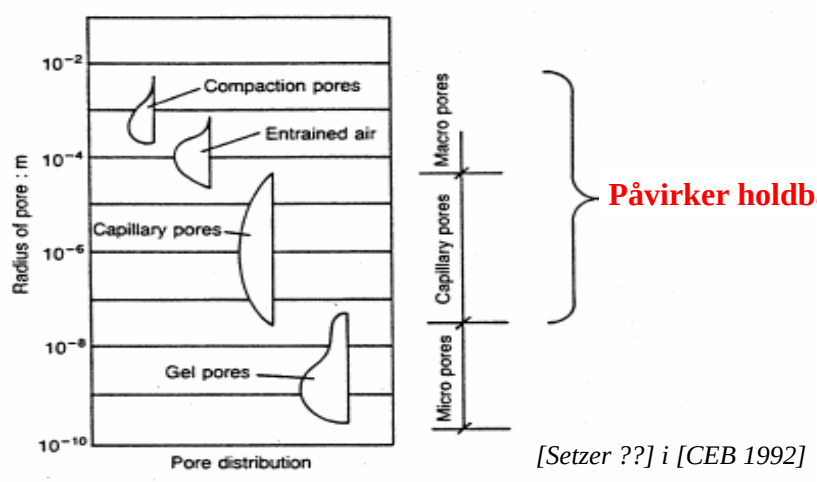
Efter [Locher and Richartz] i [Young et al 1998]

Porer i beton



[Setzer ??] i [CEB 1992]

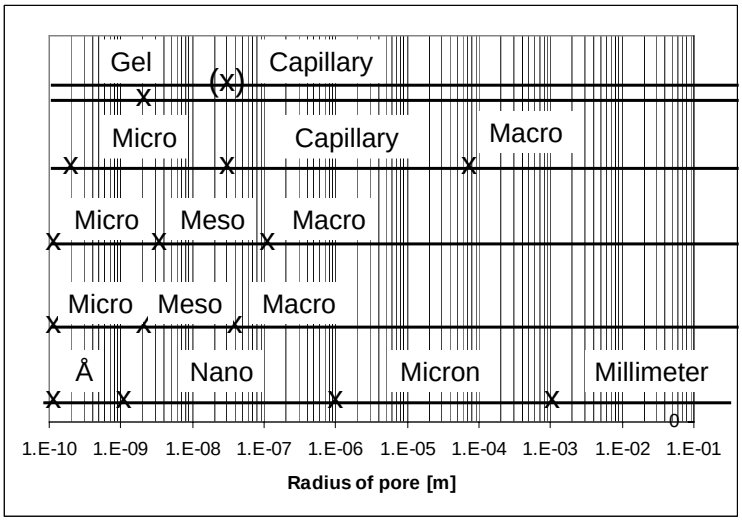
Porer i beton



Påvirker holdbarhed

[Setzer ??] i [CEB 1992]

Porøsitet – betegnelserne varierer



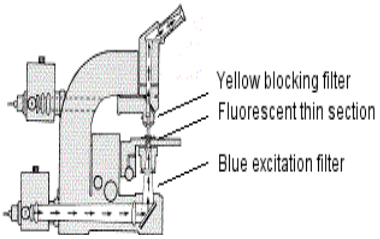
[Powers]
[Powers & Brownyard]

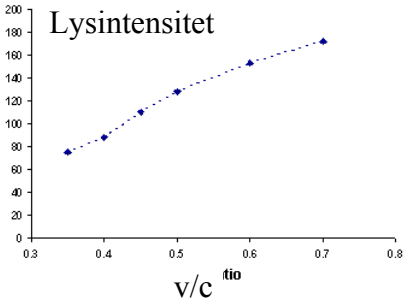
[CEB 1992]

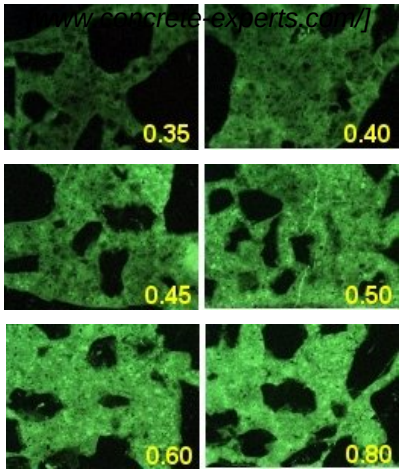
[Young et al. 1998]

[UPAC 1998]

Optisk mikroskopi af tyndslib
Bestemmelse af tilsyneladende w/c







[www.concrete-experts.com/]

Mikrostruktur af hydratiseret cement pasta, vandets binding

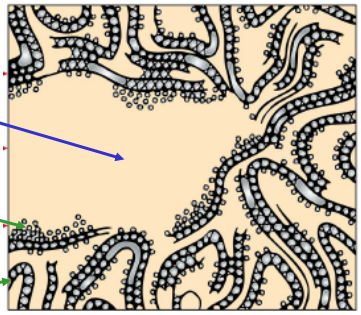
Definitioner varierer, fx

- **Kapillarvand**
  - Frit vand I porer > 50 nm
  - Vandbinding vha. kapillarkræfter i porer 5 < x < 50 nm

"Gel-vand"

- **Adsorbet vand**
  tykkelse op til seks molekyler vand, dvs. 1.5 nm, stor del fordampet ved 30% RF
- **"Interlayer-vand"**
  vandtab under under 11% RH

- **Kemisk bundet vand**
  vand bibeholdt ved tørring (rumtemperatur)



[Feldman & Sereda in 1970] in [Mehta & Monteiro 2006]

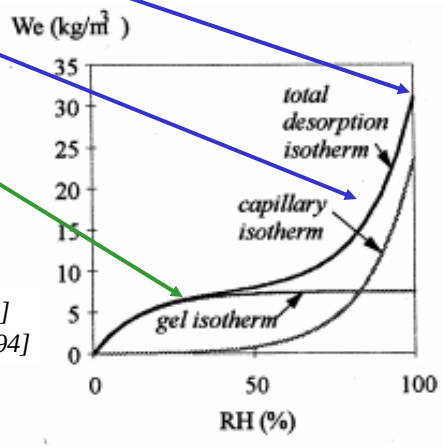
Fugt i beton

Binding af vand

- Frit vand
- Kapillarkondenseret vand
- Adsorberet vand (adsorbet og "interlayer-vand")
- Kemisk bundet vand

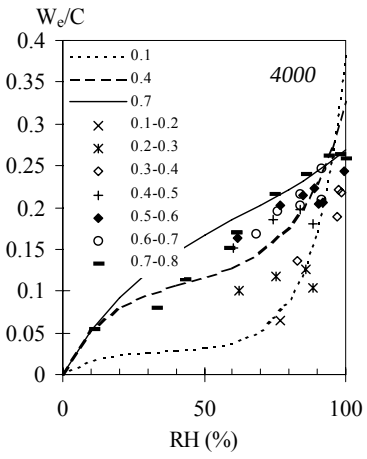
[Hedberg, 1993] in [Mjörnell 1994]

Sorptionskurve

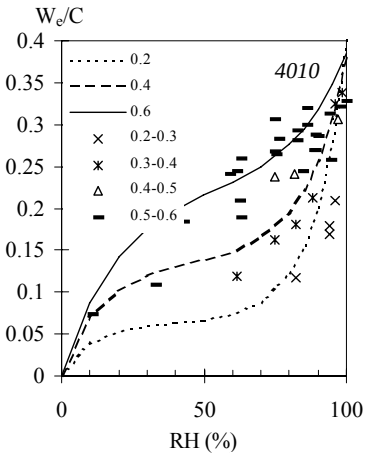


Beregnet vs. målt desorptions-isotherm

W/C=0.4, SRPC Degerhamn



W/B=0.4, Si/B=10 %, SRPC Degerhamn

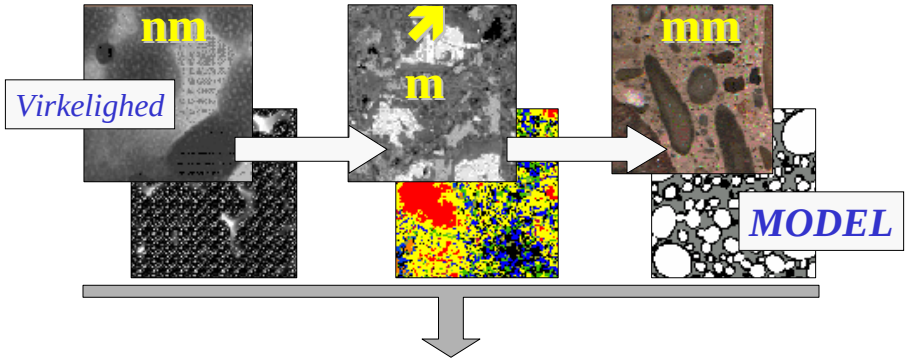


[Mjörnell 1997]

Simulering af hydratisering, fx vha.

"Electronic monograph on the computational materials science of concrete"

http://ciks.cbt.nist.gov/monograph/



Beregning af egenskaber og funktion

Volumetrisk fasefordeling i hærdnende cementpasta

Baseret på 12 års intensiv forskning Powers og Brownyard præsenterede en empirisk model i 1948…
Senere modificeret af Powers

Powers' model

Benchmark:
Kvantificering af hydratiseringsprocessen

Powers' model er et godt udgangspunkt

Powers' model
Baseret på studier af (primært)

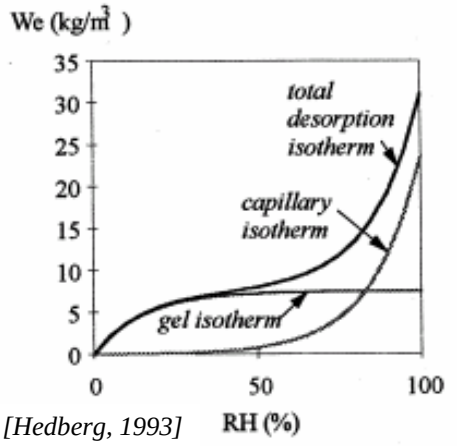
Sorptions-isothermer for vanddamp

Ikke-evaporabelt vand (kemisk bundet vand)

Powers' model
Baseret på studier af (primært)

Sorptions-isothermer for vanddamp

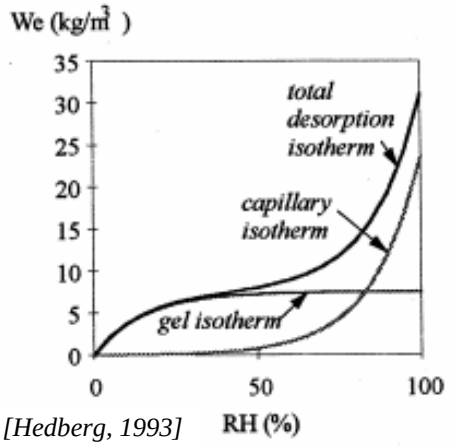
Ikke-evaporabelt vand (kemisk bundet vand)



[Hedberg, 1993] i [Mjörnell 1994]

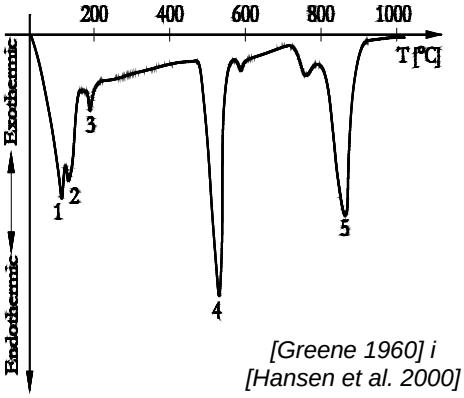
Powers' model
Baseret på studier af (primært)

Sorptions-isothermer for vanddamp



[Hedberg, 1993] i [Mjörnell 1994]

Ikke-evaporabelt vand (kemisk bundet vand)

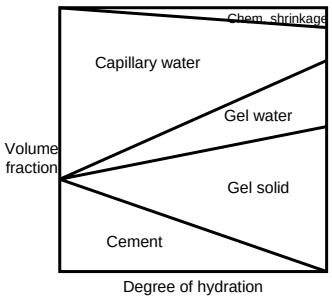


[Greene 1960] i [Hansen et al. 2000]

Powers' model – volumetrisk fasefordeling

Kemisk svind	$V_{c.s.} = 0.20(1\text{-}p)\alpha$
Kapillar vand	$V_{c.w.} = p\text{-}1.32(1\text{-}p)\alpha$
Gelvand	$V_{g.w.} = 0.60(1\text{-}p)\alpha$
Gelfaststof	$V_{g.s.} = 1.52(1\text{-}p)\alpha$
Cement	$V_c = (1\text{-}p)(1\text{-}\alpha)$

$$\sum_i V_i = 1$$



p Initial porøsitet, $p = \frac{(v/c)}{(v/c) + (\rho_v/\rho_c)}$

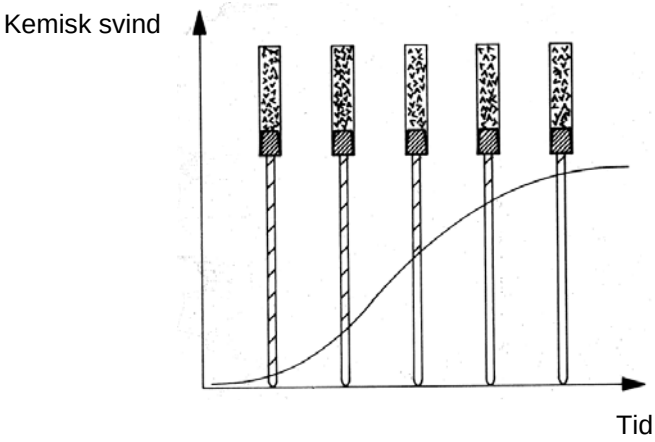
v, c Vægt af vand og cement

ρ Densitiet, $\rho_c \approx 3150$ kg/m³; $\rho_w \approx 1000$ kg/m³.

α Hydratiseringgrad, α=reageret cement/total cement

Kemisk svind

$$\Delta V = V_{produkter} - V_{reaktanter}$$



[Geiker 1983]

Powers' model

Eksperimentelt bestemte konstanter

Ikke fordampeligt vand

w_n=0.23 g/g reageret cement

Gelvand

$w_{g.w.}$=0.19 g/g reageret cement

Kemisk svind

ΔV=6.4 ml/100 g reageret cement

Powers' model

Eksperimentelt bestemte konstanter

Ikke fordampeligt vand

w_n=0.23 g/g reageret cement

Gelvand

$w_{g.w.}$=0.19 g/g reageret cement

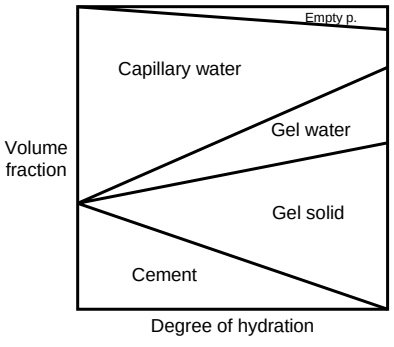
Kemisk svind

ΔV=6.4 ml/100 g reageret cement

Uhindret hydratisering for w/c > 0.42

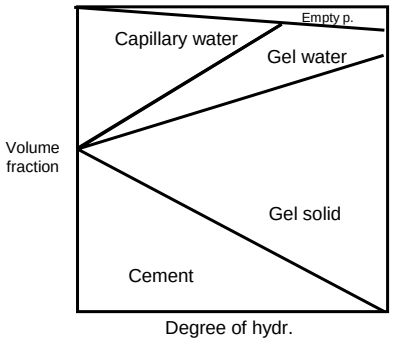
Volumetrisk fasefordeling af cementpasta vs. hydratiseringsgrad, α

w/c = 0.6, forseglet



fuld hydratisering (α = 1) af cement mulig

w/c = 0.3, forseglet



fuld hydratisering (α = 1) af cement ikke mulig

Powers' model

Eksperimentelt bestemte konstanter

Ikke fordampeligt vand

w_n=0.23 g/g reageret cement

Gelvand

$w_{g.w.}$=0.19 g/g reager

Kemisk svind

ΔV=6.4 ml/1 eageret cement

Portland cement

Uhindret hydratisering for w/c > 0.42

For en given binder

Baseret på antagne

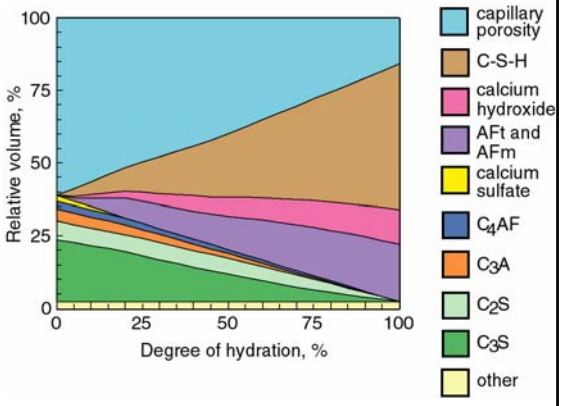
- Reaktioner
- Hydratiseringsgrad
- Molære volumen

Kan følgende estimeres

- Volumenfraktion
- Kemisk svind
- Ikke-evaporabelt vand

…og hvis v/c kendt

- Kapillarporøsitet



[Kosmatka et al. 2002]

Pozzolanisk reaktion af mikrosilica

Ikke-fordampeligt vand
w_n=0 g/g reageret mikrosilica

Gelvand
$w_{g.w.}$=0.5 g/g reageret mikrosilica

Kemisk svind
ΔV=22 ml/100 g reageret mikrosilica

[Jensen & Hansen 2001]

Indhold

Betons mikrostrukturudvikling (her porøsitet) og vandbinding

Powers' model

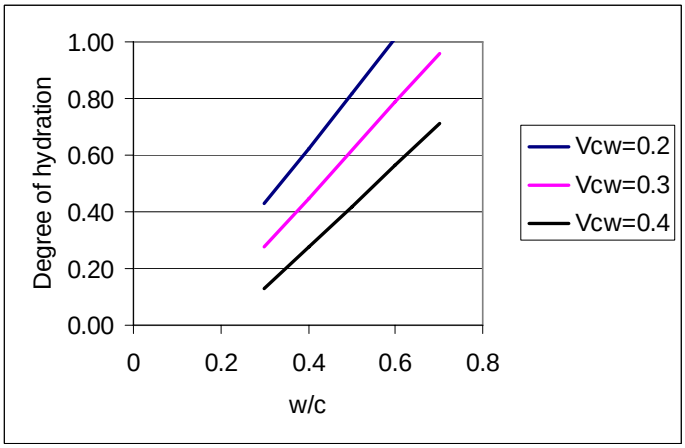
Eksempler

- Vurdering af behov for efterbehandling
- Vurdering af chloridindtræningshastighed

Effekt of v/c og hydratiseringsgrad på kapillarporøsitet

$V_{cw}=p-1.3\times(1-p)\times\alpha \quad \Rightarrow \quad \alpha=(p-V_{cw})/(1.3*(1-p))$

Initial porøsitet, $p = \dfrac{(v/c)}{(v/c)+(\rho_v/\rho_c)}$

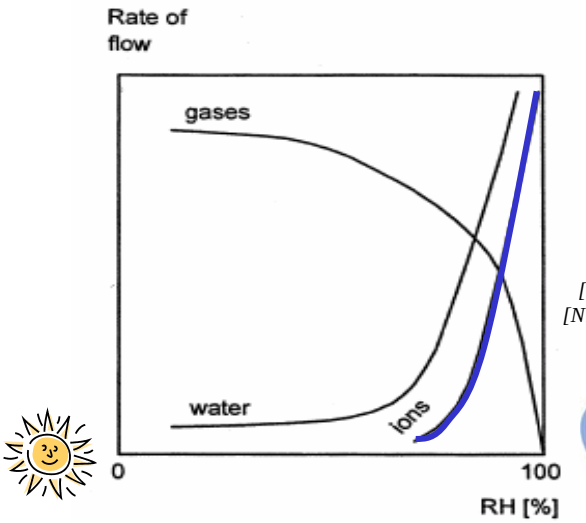


Krav/vejledning - minimum beskyttelse DS 482

Miljøklasse		P	M	A	E
Min. hydratiseringsgrad (eksperimentelt bestemt varmeudvikling)		40 %	60 %	85 %	90 %
Vej-ledning	v/c > 0.55	15 M	-	-	-
	0.55 > v/c > 0.45	15 M	36 M	-	-
	0.45 > v/c > 0.40	12 M	24 M	120 M	-
	0.40 > v/c	12 M	24 M	96 M	120 M

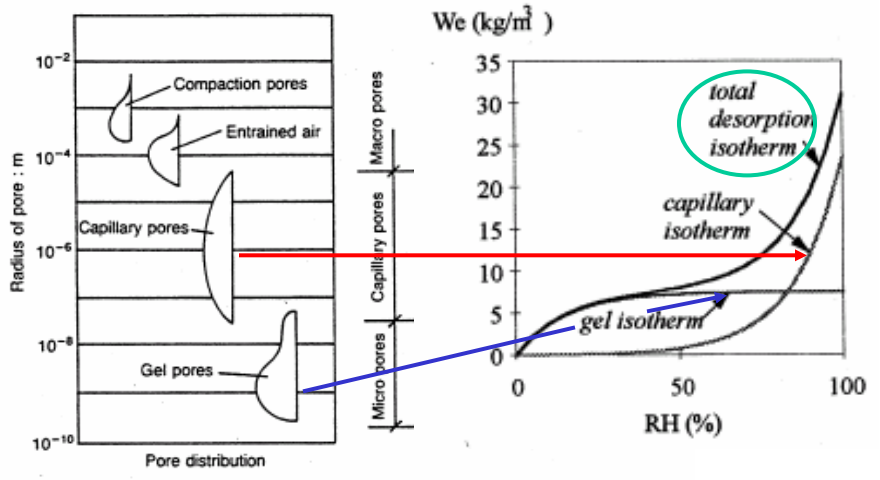
Matrurity-timer

Effekt af fugtindhold på chloriddiffusion



[Nilsson 1980], [Tuutii 1982], [Goodbake et al 1979], [Nilsson & Peterson 1983] in [Lindvall 2001]

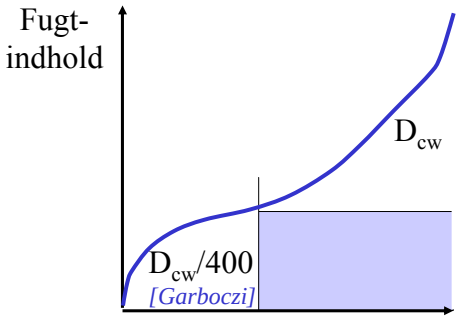
Porer i beton



[Setzer 19??] i [CEB 1992]

[Hedberg, 1993] i [Mjörnell 1994]

Porestørrelsesafhængig diffusionskoefficient



[Powers and Brownyard, 1947]

[Nielsen & Geiker 2002]

For en given binder

Baseret på antagne
- Reaktioner
- Hydratiseringsgrad
- Molære volumen

Kan følgende estimeres
- Volumenfraktion
- Kemisk svind
- Ikke-evaporabelt vand

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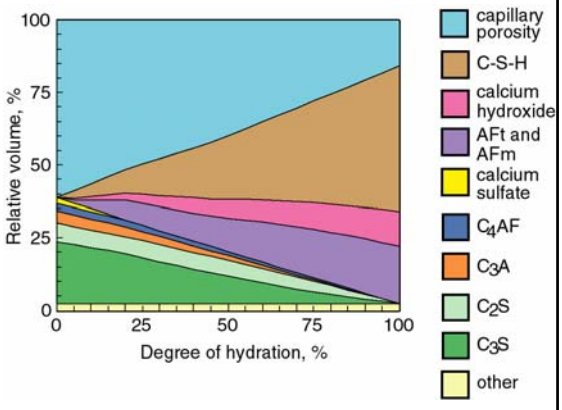
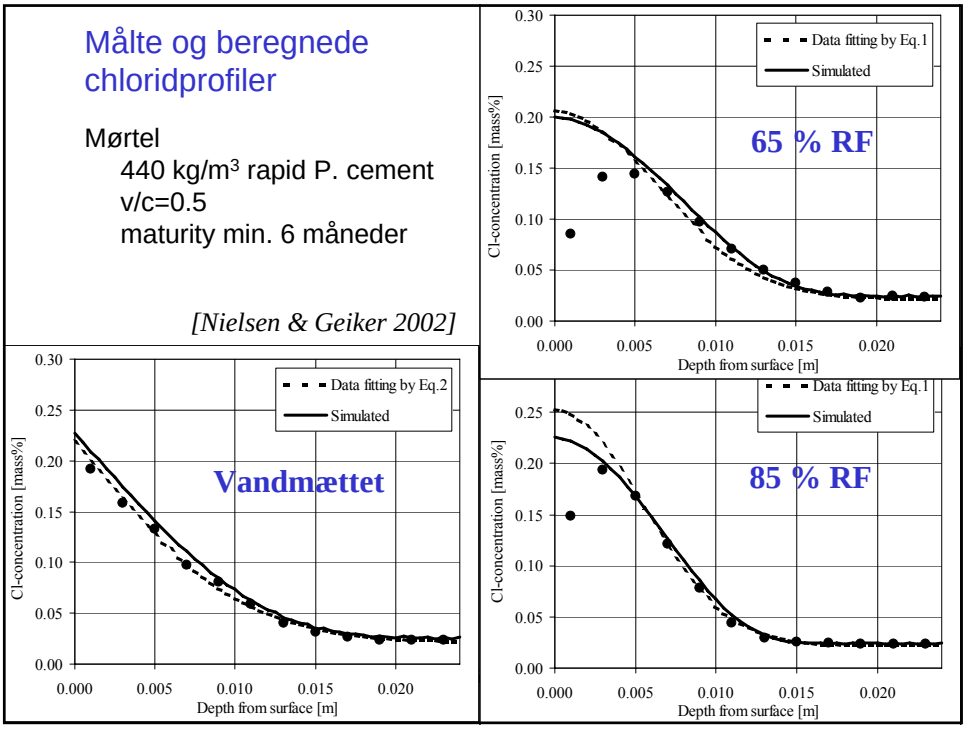


[Kosmatka et al. 2002]

Målte og beregnede chloridprofiler

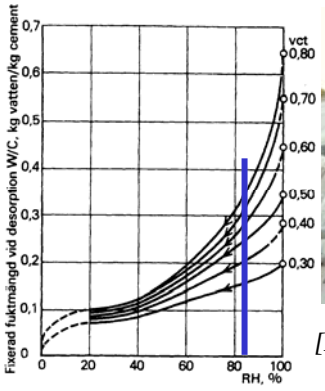
Mørtel
- 440 kg/m³ rapid P. cement
- v/c=0.5
- maturity min. 6 måneder

[Nielsen & Geiker 2002]



Chloridindtrængning, Eksempel, kantbjælker, Fiskebækbroen

v/(c+2sf)	sf/c %	In-situ $D_{Cl,}$ 10^{-13} m²/s	Laboratorium D_{Cl} 10^{-13} m²/s
0.42	0	3.5	210
0.35	10	1.5	6
0.34	20	0.9	6



[Herholt et al 1985] *[Foto COWI]* 34

Volumetrisk fasefordeling i hærdnende cementpasta

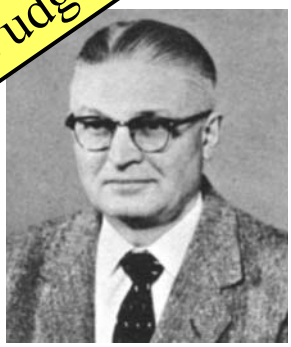
Baseret på 12 års intensiv forskning Powers og
Brownyard præsenterede en empirisk m… 8…
Senere modificeret af Powers

Powers' model

Benchmark:

Kvantifice…
hyd… …sprocessen

Powers' model er et godt udgangspunkt



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COWI: Privat kommunikation

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G.M. Idorn Consult: Privat kommunikation

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[Nilsson 1980], [Tuutii 1982], [Goodbake et al 1979], [Nilsson & Peterson 1983] in [Lindvall 2001]

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