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Multiscale durability aspects of concrete structures exposed to ground water

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The COE Workshop on Material Science in 21st Century for the Construction Industry - Durability, Repair and Recycling of Concrete Structures

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Content

Multiscale durability aspects of concrete structures exposed to ground water

- introduction
- multi-scale properties of concrete
  - covercrete
  - spatial variability
  - porosity
- chemical interaction
- synthesis
- conclusions

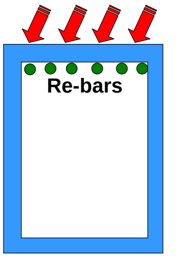
Introduction

- increasing underground activities: more (road) and longer (rail) tunnels
- increasing service life requested (100 years guarantee without major repairs)

Covercrete

- concrete layer exposed to the environment
- protection for the reinforcement
- critical for the service life of concrete structures

humidity, carbonation, chloride, sulfate, temperature & frost

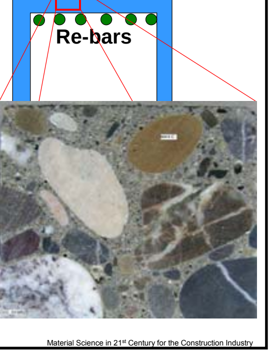


Covercrete

quality ?

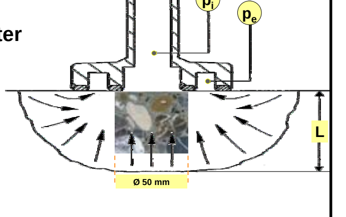
quality affected by
- segregation, bleeding
- compaction
- curing
- (microcracking)

how to specify and test covercrete performance ?
- permeability
- NDT-methods



Covercrete characterization (NDT, on-site)

Torrent Permeability Tester
- vacuum p_i (leading to controlled air flow)
- pressure increase in the cell -> permeability coefficient kT in m^2

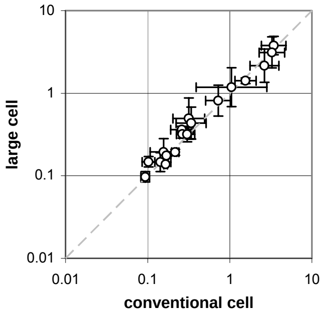


- spatial interference with aggregates ?
- effects of humidity and temperature ?

Size effect for Torrent Permeability Tester

Hypothesis: large aggregates potentially reduce kT because of hindrance of gas flow
=> effect reduced with larger cell

Fact: large cell shows slightly higher values and lower standard deviations (but not significant)



values: kT in 10^{-16} m^2 (one year old concrete)

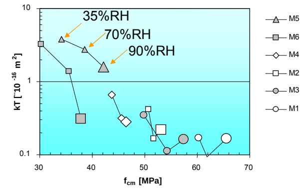
Effects of humidity and temperature on kT

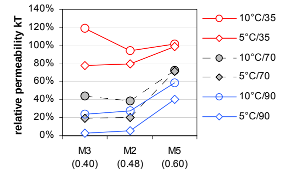
- **1 year old samples**
- **six concrete qualities**
- **stored at 35, 70 and 90% RH**

Results

- artificially high kT for 90%RH
- kT reduced by 50% to 75% if tested at 10°C respectively 5°C

Romer M., Materials and Structures 38 (2005) 541-547





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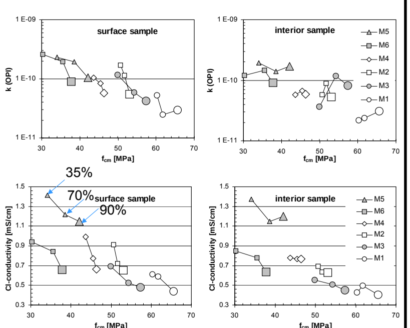
Performance of South African durability index tests

- testing of small (25mm thin) cores is possible
- air permeability (OPI) is affected by increased amounts of air voids (chloride conductivity not)
- adverse curing effects may be detected with the surface samples



Romer M. et al., to be published (2005), see www.empa.ch/abt135

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Spatial Variability

- Hypothesis: concrete quality in larger (vertical) building elements is locally variable due to:
  - batch production and various transport conditions
  - locally variable placement and compaction conditions (height of fall, distance to poker, duration, …)
  - effects of segregation / enrichment
- Tasks:
  - collect data on real structures
  - improve statistical model (service life)
  - improve production process

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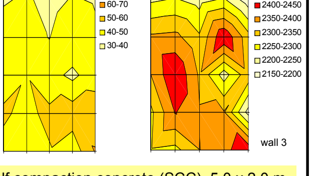
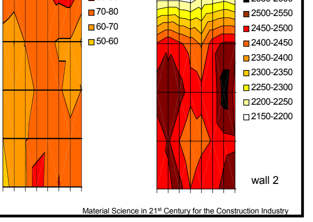
Spatial Variability

- Results
  - significant spatial variation of concrete quality
  - SCC not generally superior (effects of segregation instead of variable compaction intensity)

conventionally compacted concrete, 4.0 x 2.5 m



self compaction concrete (SCC), 5.0 x 2.0 m



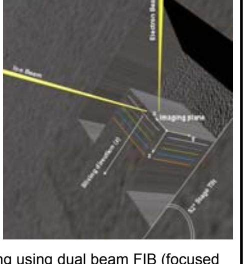
Leemann, A. & Hoffmann C. published (2003), see www.empa.ch/abt135

Empa, M. Romer, August 2005 Material Science in 21st Century for the Construction Industry

Pore structure – Permeability

Holzer L. et al., J. Microscopy 216 (2004) 84-95

- fundamental properties
- complex relation of porosity and permeability (connectivity, tortuosity)
- development of a new, quantitative method: FIB-nanotomography



Serial sectioning using dual beam FIB (focused ion beam). The imaging plane (x-y) is parallel to the ion beam (y). SE-images are acquired under an angle of 52° using the SEM-column. Serial sectioning proceeds in z-direction.

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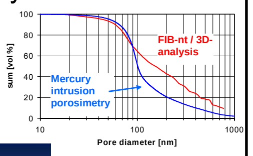
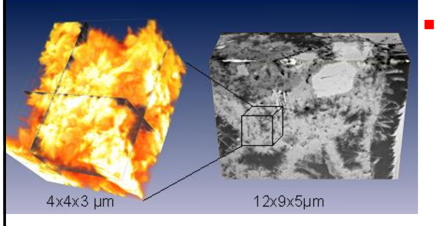
Pore structure – Permeability

Holzer L. et al., J. Microscopy 216 (2004) 84-95

Results

- high resolution 3D-reconstruction of the real microstructure





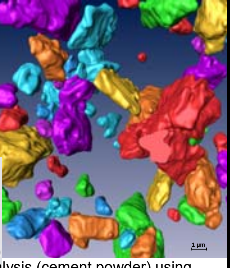
- numerical calculation of pore connectivity and derivation on transport properties

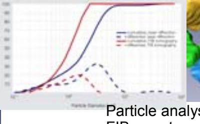
FIB-nanotomography for suspensions and colloids

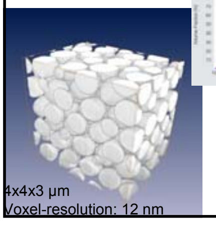
Holzer L. et al., J. Microscopy 216 (2004) 84-95

Shape and positions of particles

- cement particles in epoxy resin (right)
- reference particles (SiO_2, Ø 680 nm) with very dense packing (below)





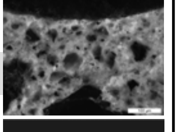


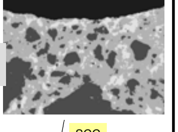
Particle analysis (cement powder) using FIB-nanotomography. Precise 3D-information (Voxel resolution: 30x38x30 nm) can be extracted for each individual particle. In this example the analyzed volume (21x17x4 µm) contains more than 2000 particles.

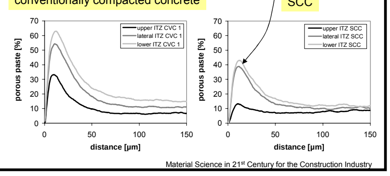
Interfacial Transition Zone (ITZ)

Method

- oriented polished sections
- micrographs around aggregates
- quantification of numerical input in shells around a aggregate (continuous compositional profiles)





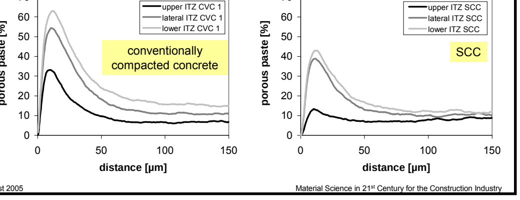


Interfacial Transition Zone (ITZ)

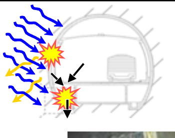
Leemann A. et al., published (2005) www.empa.ch/abt135

Results

- increase of porosity at ITZ less pronounced with SCC (impact of compaction)
- gravitational effects lead to anisotropic ITZ
- anisotropic permeability properties could result (not jet proofed)



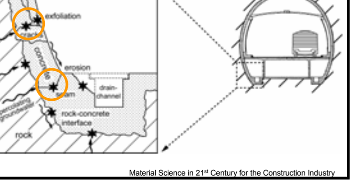
Chemical interaction



- existing underground constructions (tunnels) often in contact with ground water
- ground water often mineralized (carbonate, sulfate, chloride)
- drainage of ground water restricted -> construction needs to be water tight
- protection from ground water difficult (long term risk for water contact and penetration)

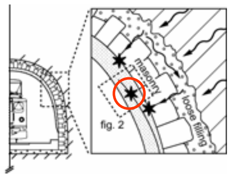
Massive concrete deterioration due to Sulfate interaction

[mg/litre]	
calcium	270
magnesium	270
bicarbonate	200
sulfate	1900



Shotcrete tunnel lining

[mg/litre]	
sodium	12
potassium	6
magnesium	20
calcium	**180**
sulfate	**330**
bicarbonate	**50**



Romer M. et al., published (2002 & 2003) see www.empa.ch/abt135

Chemical interaction

General finding:

- chemical attack is triggered by permeable inhomogeneities (pathways)
- complex combinations of leaching and (re)precipitation
- Thaumasite not Ettringite (long time interaction)
- @ high and low sulfate-concentrations (5 – 20 °C)
- also with sulfate resisting cements (C_3A < 3%)

>>> discrepancy between laboratory and "field" performance

>>> ongoing research to clarify the mechanisms

Long time durability: the distribution of concrete quality might be more important then the average concrete performance (practical aspects)

Chemical interaction

Interaction with concrete is affecting the ground water:

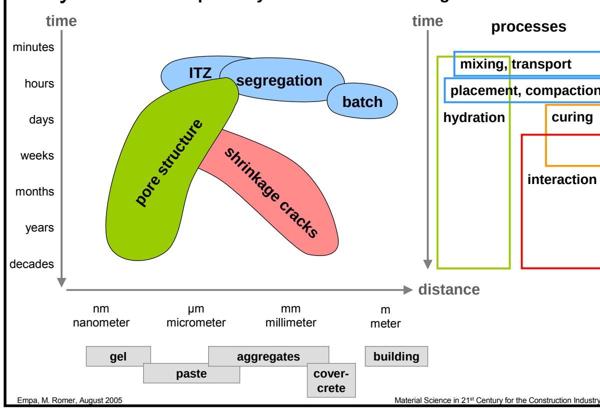
- increased amount of calcium
- reduction in pH

Contact with air:

- precipitation of calcite
- reduction of cross section
- blocking of drainage system
- (increased water pressure …)

Synthesis

- **physico-chemical processes -> small scale**
- **pathways for interaction -> larger scales**



Conclusions

- **Design or prediction of the service life of underground constructions remains a challenge also for the 21th century**
- New reliable (and quantitative) 3D-information on the pore structure available
- High priority: Linking microstructural features with macroscopic properties (transport, shrinkage)
- But: Transfer of scientific findings (laboratory) into practice is complicated by many discontinuities
- Not forget: technical aspects (transport, placement, compaction, curing)

Thank you for your attention …

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