State-of-the-art of SCC after 20 years of research and practice

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Magnel Laboratory for Concrete Research – Department of Structural Engineering

SCC Symposium, IBRACON CONGRESS, Maceio, October 2012

RILEM

International Union of Laboratories and Experts in Construction Materials, Systems and Structures,

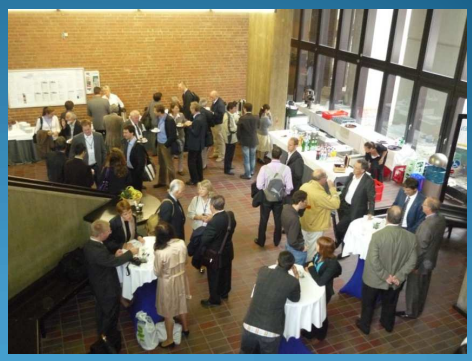
Réunion **I**nternationale des **L**aboratoires et **E**xperts des **M**atériaux, systèmes de construction et ouvrages

Foundation: June 1947

Objective: to promote the scientific exchange of information between experts world- wide

An international network of technical experts advancing the knowledge in materials and structures

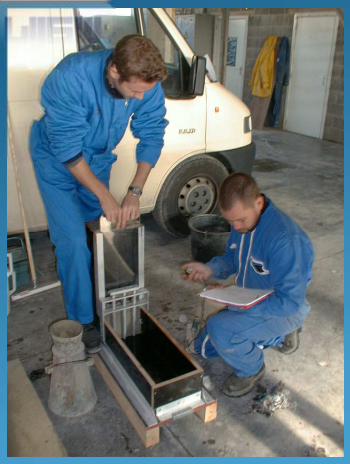
- More than1350 experts involved
- More than 800 members active in our Technical Committees (TC)



Meetings and Technical Exchanges

- RILEM Annual Week
- International RILEM events: workshops, seminars, conferences
- Technical Committees (TC) meetings
- PhD's workshops

Producing the know-how

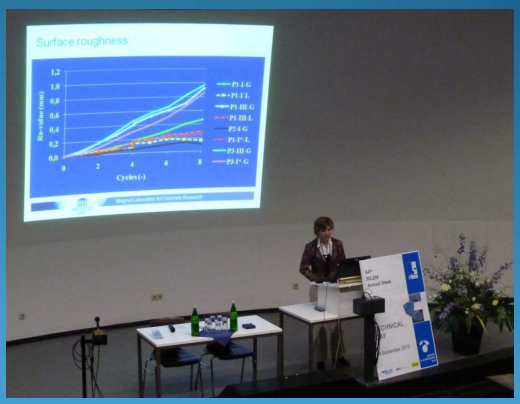


Technical Committees work typically results in:

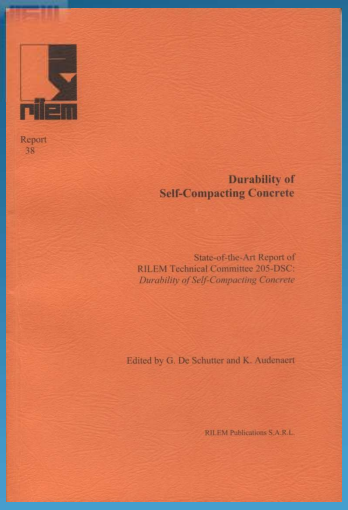
- Recommendations on test methods
- State-of-the-art report on the subject treated by the TC

Dissemination of information

- Publications
- Meetings
- PhD-courses
- Books
- Website

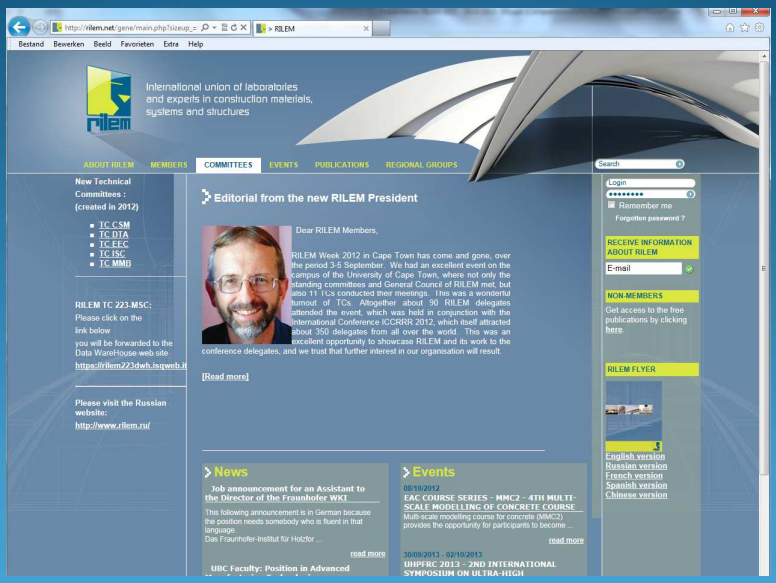


RILEM Publications



- Technical reports
- State-of-the-Art reports
- Proceedings of workshops and conferences
- Scientific Journal *Materials & Structures*

RILEM Website www.rilem.net



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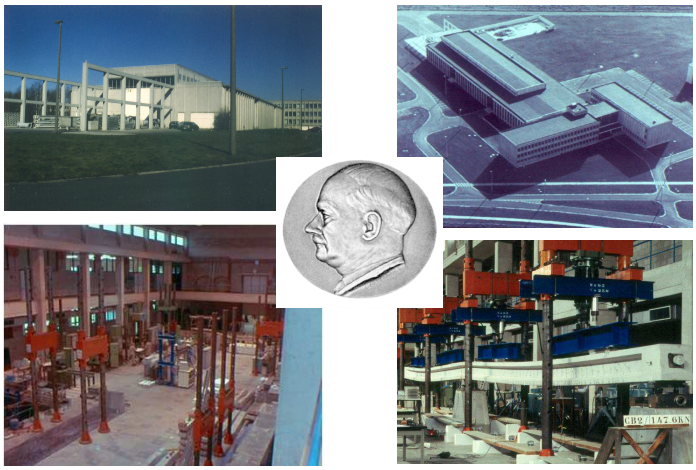

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Research on SCC:

from fundamental materials science to practical assistance on site

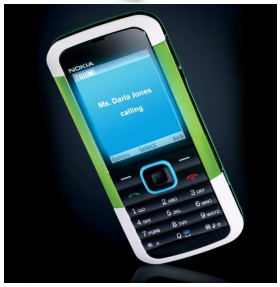
Cars in evolution

1950's

2010's

Electronics in evolution

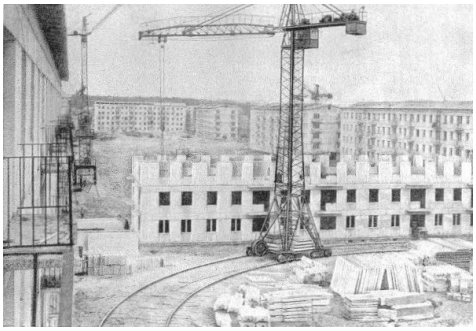
1950's



2010's

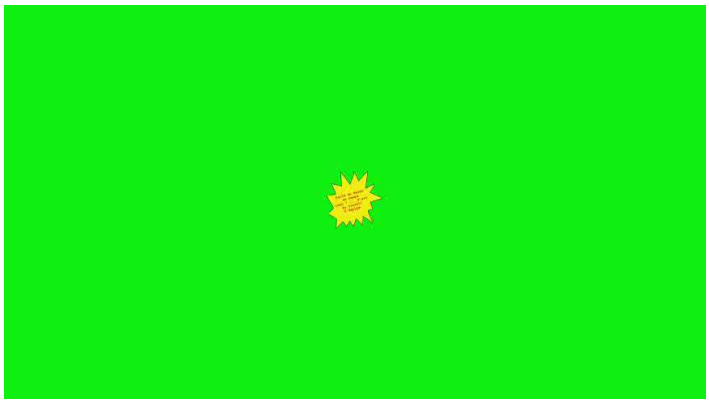
What about concrete?

1950's



Is concrete still the same old concrete?

Still making concrete as in the old days?



Self-compacting concrete

- Fills the formwork like a liquid
- No external compaction energy
- Substantial ecological benefits

SCC – Two Decades (?)

'Modern' SCC Japan, 1980's

'Parents' Underwater concrete + Highly flowable concrete

'Great great grandfather' System 'Non Plus'

First developed in 1906 in Germany, and applied in Germany, the Netherlands and Belgium in the 1910's and 1920's

Consisted of ***liquid concrete poured into the formwork, without any further compaction***.

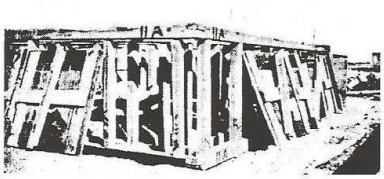
Successfully applied for house construction, in spite of the heavy competition of the more traditional approach relying on masonry.

Due to problems related to the complex and expensive formworks, the 'Non Plus' system gradually faded away.

SCC – Two Decades (?)

System ‘Non Plus’

3.132.



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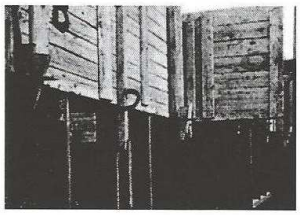
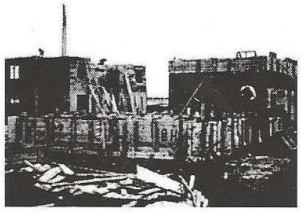




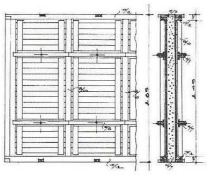
‘lage’ Non Plus-bekisting in Duitsland en Klein Rusland

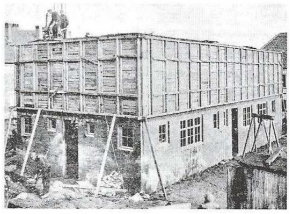
BRON: *HBM*, 1922, nr. 8, p. 182; DEMEY, Het modernisme, *OKV*, 1998, p. 38.

SCC – Two Decades (?)

System ‘Non Plus’

3.134.
3.135.





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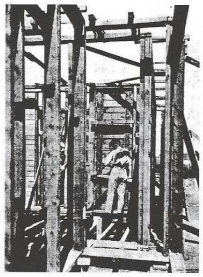
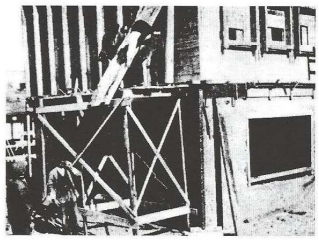
3.137.

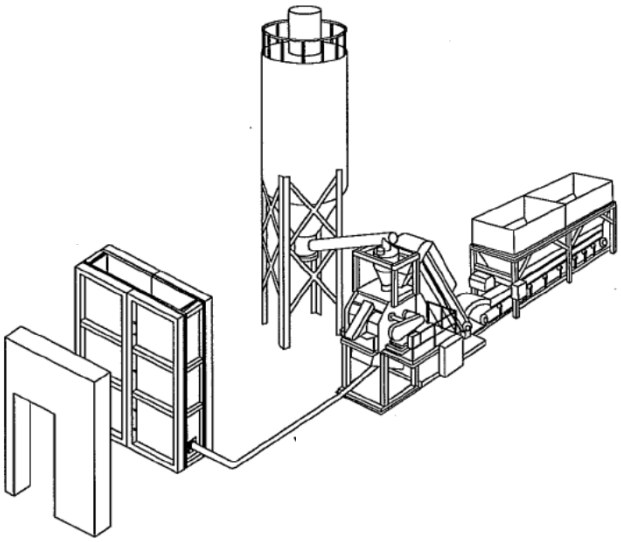




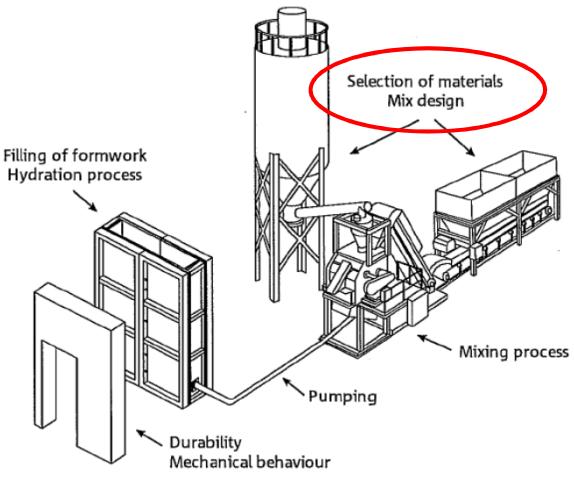
‘hoge’ Non Plus-bekisting: tekening in *HBM*, toepassingen in Het Rad, La Cité Moderne en Het Betondorp

BRON: *HBM*, 1922, nr. 11, p. 264; *HBM*, 1923, nr. 2, p. 33; *HBM*, 1923, nr. 10, p. 252; KUIPERS, *Bouwen in beton*, p. 188.

SCC - Two decades of research and practice



Selection of materials and mix design



Selection of materials and mix design

State-of-the-art

Materials that conform to the standards and specifications for use in concrete are suitable

A wide range of mix proportions exists to successfully produce SCC

Common practice:

Powder-type SCC, VMA-type SCC, Mixed-type SCC

Bottleneck:

Designing ROBUST SCC mixes

Selection of materials and mix design

Further developments:

Tailor made systems based on ternary or quaternary blends, Including synergetic effects.

Effects of powders:

Chemical

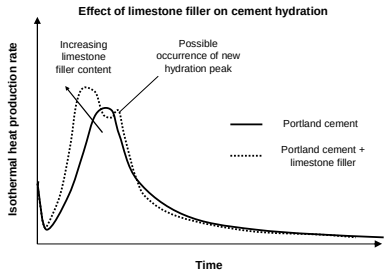
Physical

Filler

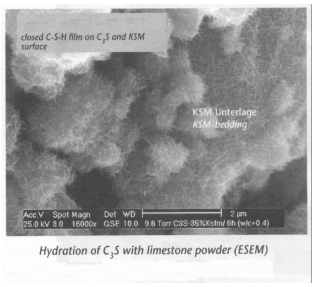
Dilution

Selection of materials and mix design

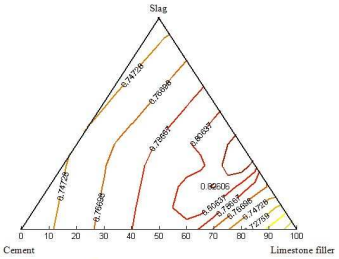
Chemical effect



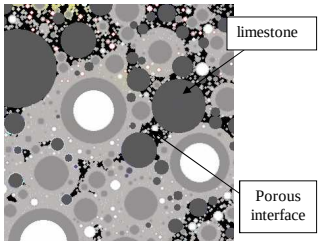
Physical effect



Filler effect



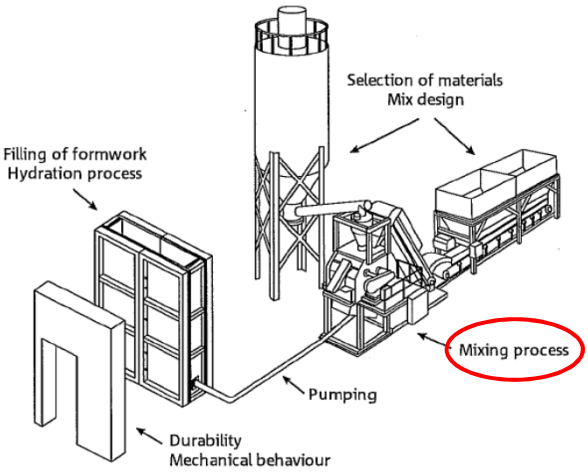
Dilution effect



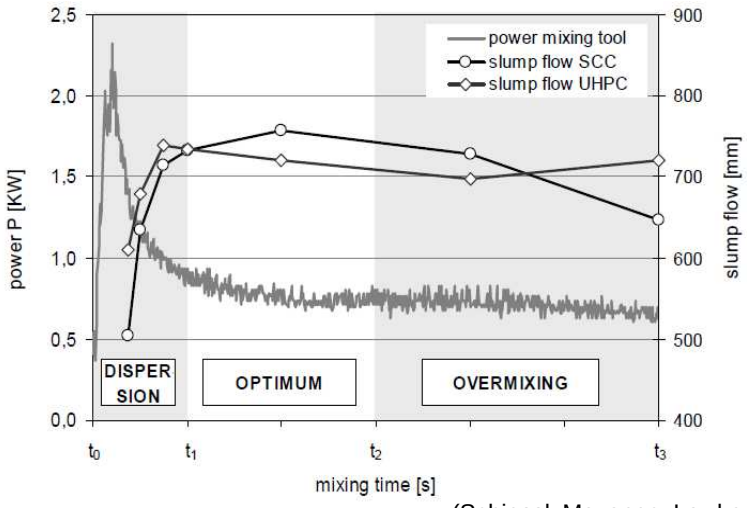
Selection of materials and mix design

	State-of-the-art	Bottlenecks	Future developments
Selection of materials and mix design	Partly covered in STAR Reports: RILEM TC 174-SCC RILEM TC 188-CSC	Robustness	Robustness Tailor-made blends

Mixing process



Mixing process



(Schiessl, Mazanec, Lowke,2007).

Mixing process

Mortar/paste level

- New development: vacuum mixing

Mixing process

Concrete level

- New development: vacuum mixing

Mixing process

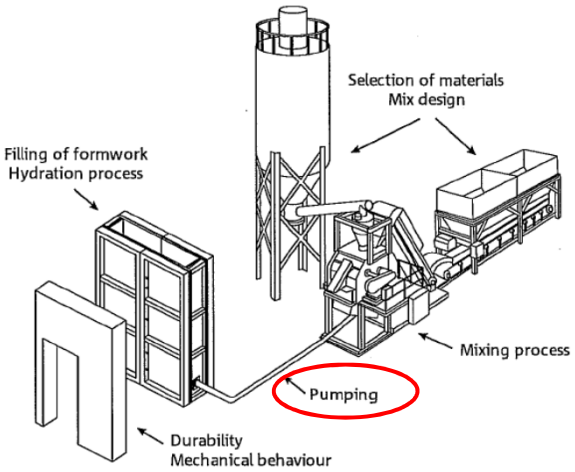
Ongoing fundamental research project on vacuum mixing (Ghent University & University College):

- Conventional Concrete, SCC, UHPC
- Pore structure / Air void system
- Rheology
- Mechanical properties
- Durability

Mixing process

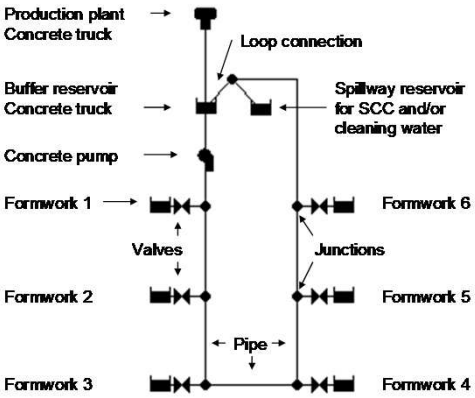
	State-of-the-art	Bottlenecks	Future developments
Mixing process	Partly covered in STAR Reports: RILEM TC 188-CSC	Influence of mixing process often neglected or not understood	More fundamental studies of mixing process, including advanced mixing techniques like vacuum mixing

Pumping



Pumping

Precast industry – automated production process



Pumping – Belgian Concrete pipe factory

- High quality concrete pipes
- Diameter up to 1.6 m
- Length up to 3.2 m

Experienced problems: Noise, Vibration, Energy

Shift to more environment friendly production method?

Pumping – Belgian Concrete pipe factory

Reduction of noise

Actual noise level in factory: Up to 90 dB !
Noise level in factories with SCC: 70 dB

Radio is being rediscovered in factories with SCC

Reduction of vibration

Due to application of SCC:
- ✓ Vibration level highly reduced
- ✓ Reduced absence of workers

White finger syndrome

Pumping – Belgian Concrete pipe factory

Reduction of energy

Energy mix

- Mixing
- Transport
- Casting
- Finishing

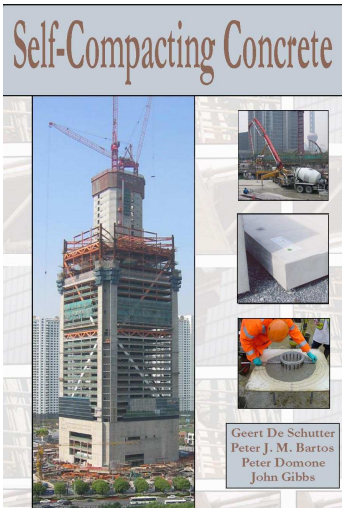
Pumping – Belgian Concrete pipe factory

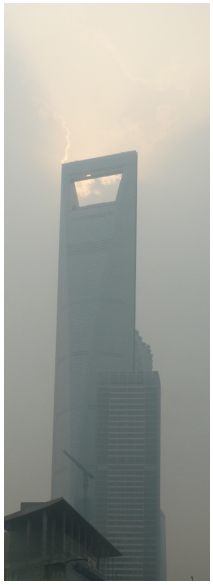
Estimated energy saving

	Current production method	Pumping SCC
Mixing Energy	0.4 GWh	0.6 GWh
Transport Energy	0.2 GWh	0.042 GWh
Compaction Energy	1.0 GWh	0.0 GWh
Finishing Energy	Neglected	Neglected
Total Energy	1.6 GWh	0.642 GWh

Energy saving: about 60% of actual energy consumption

Pumping on-site





WFC Shanghai

Pumping on-site

WFC Shanghai

SCC was used for
- foundation slab
- central core
- perimeter walls at lower level
- mega-columns at the corners

Pumping: fundamental study

Rheological properties of SCC:

Steady state

Low shear rates: $\tau = \tau_0 + \mu_p \cdot \dot{\gamma}$ (Bingham)

High shear rates: $\tau = \tau_0 + \mu \cdot \dot{\gamma} + c \cdot \dot{\gamma}^2$ (shear thickening)

Time dependent behaviour

Thixotropy – Structural breakdown – Loss of workability

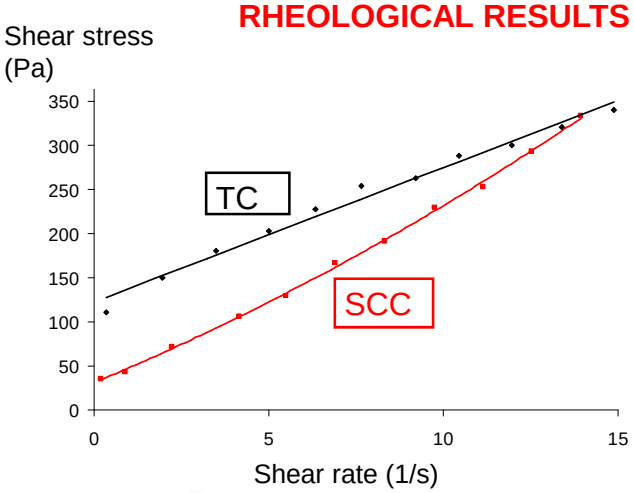
At each shear rate, there is an equilibrium structuration state.

This equilibrium structuration state (λ_{eq}) decreases with increasing shear rate.

As a result, an equilibrium structuration state at a higher shear rate results in a more fluid concrete.

Pumping: fundamental study

RHEOLOGICAL RESULTS



Yield stress:

SCC < TC

Viscosity

SCC > TC

Shear thickening

SCC is more fluid than TC.

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Pumping tests

Test setup

Short loop circuit: total length of 25 m

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Pumping tests

Test setup **Circuit: Long: 105 m (or 81 m, during last test, last week)**

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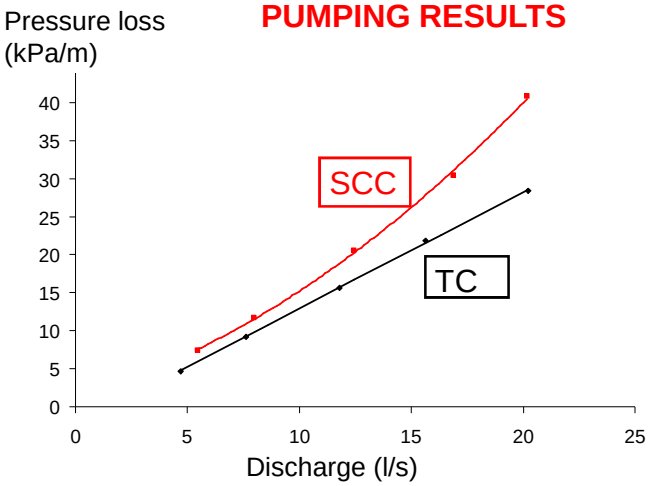
Pumping: fundamental study

PUMPING RESULTS

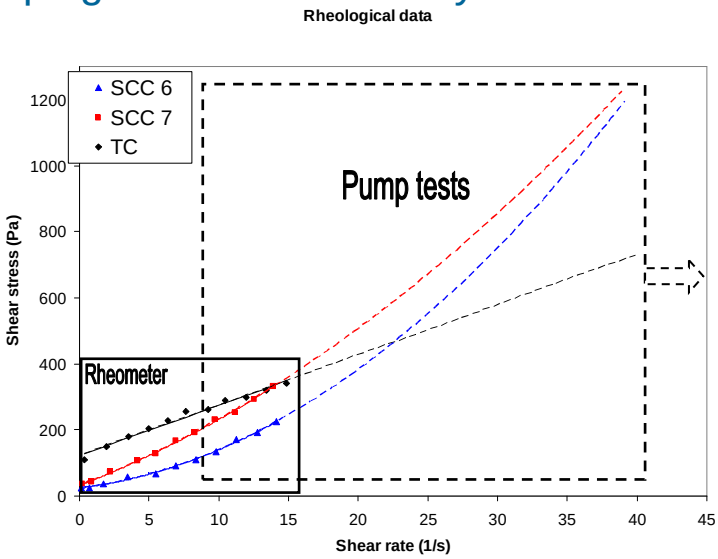


Pumping pressures for SCC are higher, especially at the higher discharges.

This is the opposite to the rheological results !!

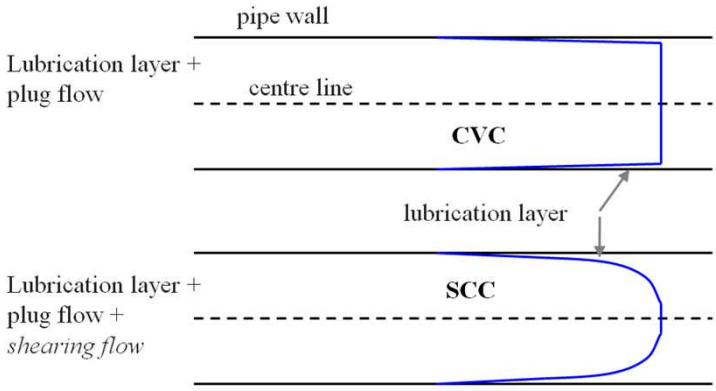
The paradox of pumping SCC

Pumping: fundamental study



Pumping: fundamental study

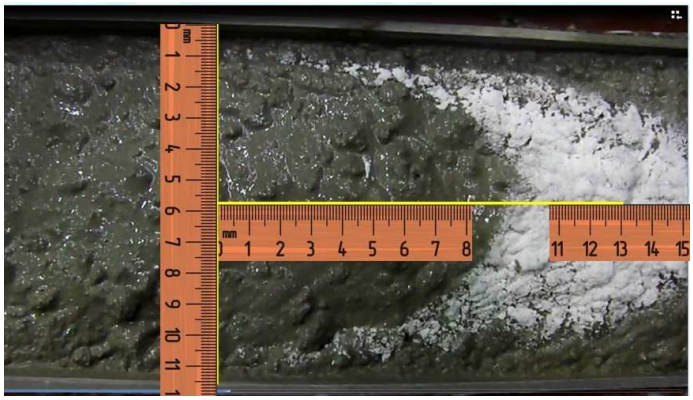
Slip or no slip? That's the question!



Ongoing research…

Pumping: fundamental study

Slip or no slip? That's the question!

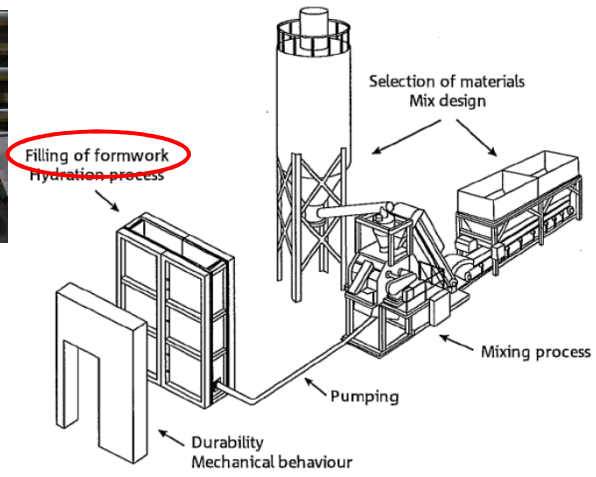


Ongoing research…

Pumping

	State-of-the-art	Bottlenecks	Future developments
Pumping	Partly covered in STAR Reports: RILEM TC 188-CSC	Surface layer? Slip conditions?	Real velocity measurements, in order to understand surface and slip conditions

Filling of formwork



Casting of Self-compacting Concrete

Traditional concrete

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Casting of Self-compacting Concrete

Self-compacting concrete

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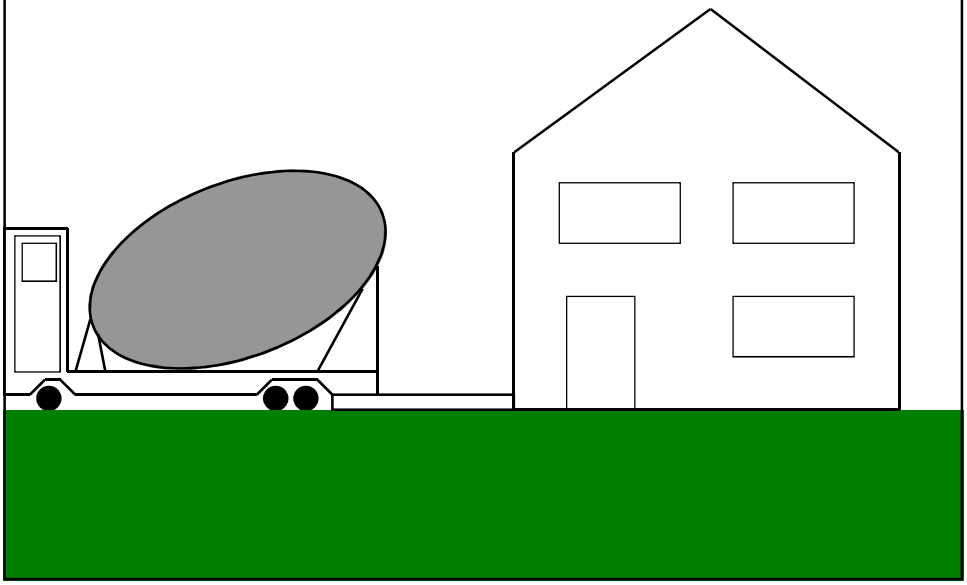
Pumping of Self-compacting Concrete

Magnel Laboratory for Concrete Research

Filling of formwork



Filling of formwork

Example: Villa Gistel (Belgium)

Filling of formwork

Example: Villa Gistel (Belgium)

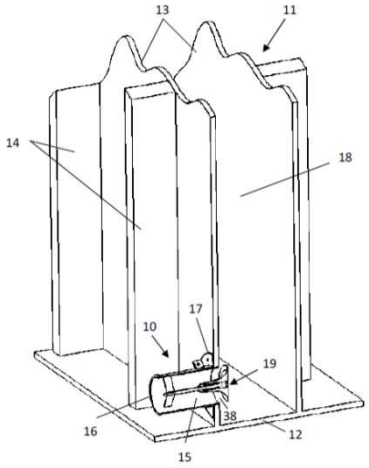
Filling of formwork

Simulation tools needed, in order to avoid non-appropriate filling, taking into account complex rheological behaviour of SCC.

Filling of formwork

Large scale testing at Ghent University

Filling of formwork



Patent pending

New development: automatic connection valve

Filling of formwork

New development: automatic connection valve

Video of casting operation

Filling of wall formwork

Video

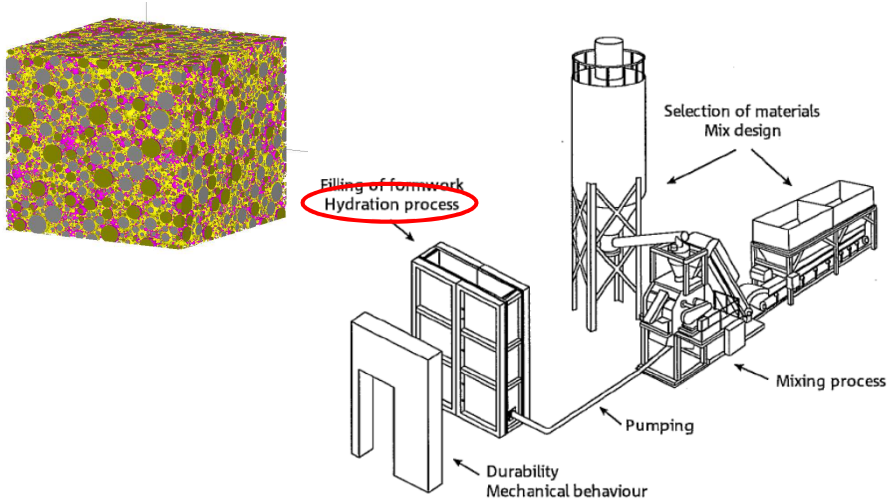
Uncoupling of pipes

Video

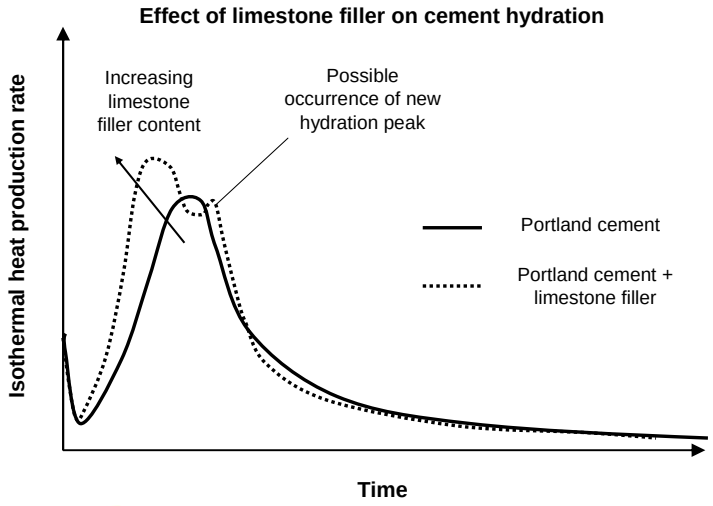
Filling of formwork

	State-of-the-art	Bottlenecks	Future developments
Filling of formwork	Partly covered in STAR Reports: RILEM TC 188-CSC	Complex behaviour, e.g. thixotropy. Formwork pressure	Advanced modelling, including CFD. Industrial development, e.g. valves.

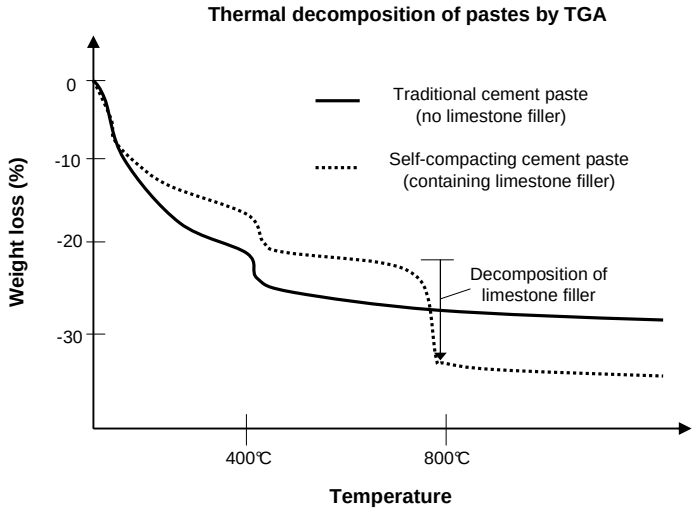
Hydration process



Hydration process



Hydration process



Hydration process

Analytical modelling

$$q_1(r_1) = NF_1 \cdot q_{1\,max,\,20} \cdot [\sin(r_1\pi)]^{a_1} \cdot \exp(-3r_1) \cdot \exp\left[\frac{E_1}{R} \cdot \left(\frac{1}{293} - \frac{1}{273+\theta}\right)\right]$$

$$q_2(r_2) = q_{2\,max,\,20} \cdot [\sin(r_2\pi)]^{a_2} \cdot \exp\left[\frac{E_2}{R} \cdot \left(\frac{1}{293} - \frac{1}{273+\theta}\right)\right]$$

$$q = q_1 + q_2$$

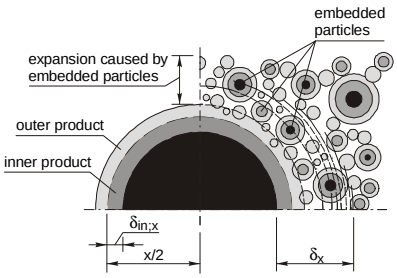
$$q_2 = 0 \qquad r_1 < \delta_1 \cdot c/p - 0.0032 \cdot \theta + \delta_0$$

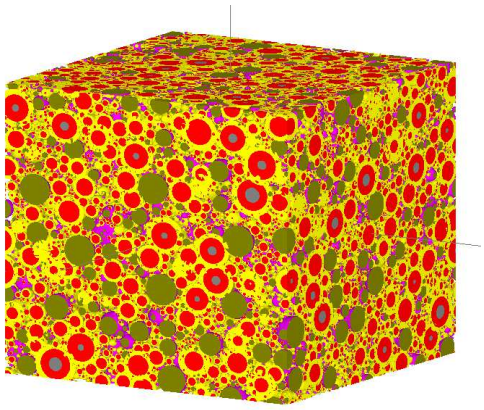
$$NF_1 = -0.28\left(c/p\right)^2 + \beta_1\left(c/p\right) + \beta_0$$

$$a_1 = -0.18\left(c/p\right)^2 + \gamma_1\left(c/p\right) + \gamma_0$$

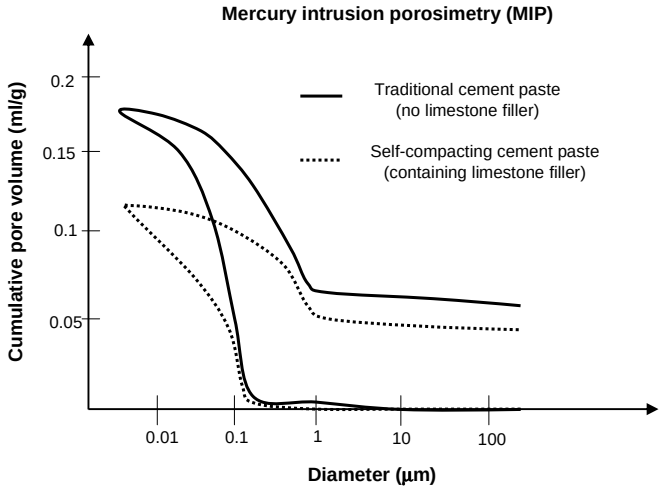
Hydration process

HYMOSTRUC MODEL

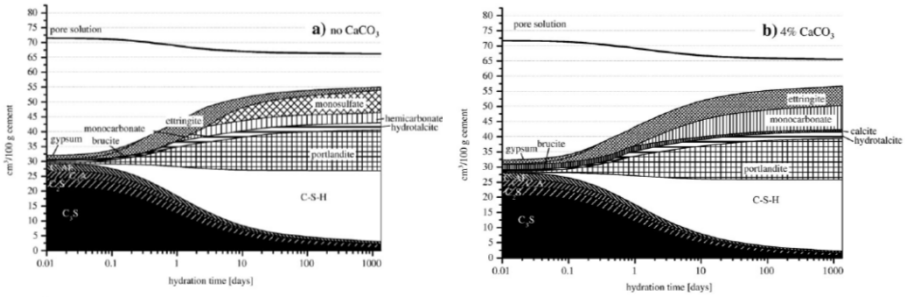




Microstructure



Hydration process



Thermodynamic equilibrium calculations (Lothenbach et al)

Hydration process

Further developments:

Combination of hydration models and thermodynamic modelling

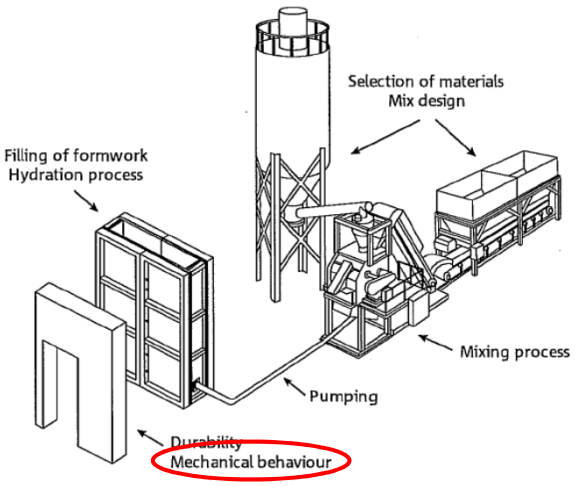
Applied to ternary and quaternary blends

Multi-scale modelling to predict material properties on a larger (macroscopic) scale

Hydration Process

	State-of-the-art	Bottlenecks	Future developments
Hydration process	Partly covered in STAR Reports: RILEM TC 205-DSC	Interaction cement-fillers-plasticizer not always fully understood, especially in ternary and quaternary blends	Advanced hydration modelling including thermodynamic modelling and multi-scale approach to predict properties. Tailor made binders

Mechanical properties



Mechanical properties

Compression | Bond | Shear



See presentation by Dr. P. Desnerck

Mechanical properties

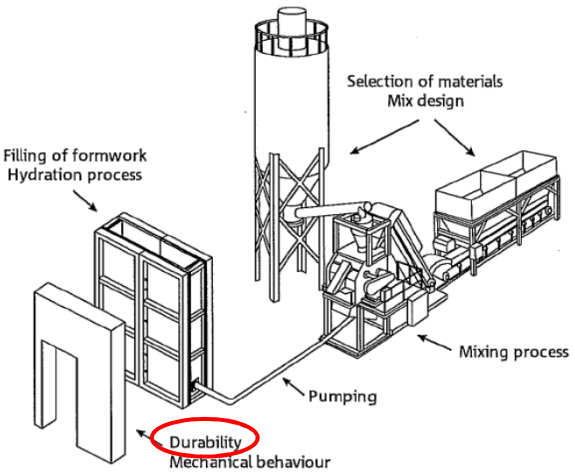
RILEM TC 228-MPS 'Mechanical Properties of SCC'

State-of-the-art report expected in 2013

Mechanical properties

	State-of-the-art	Bottlenecks	Future developments
Mechanical properties	Partly covered in STAR Reports: RILEM TC 228-MPS	Some remaining issues like fatigue and tension stiffening	Smarter use of (steel) fibers, taking profit of alignment due to casting, combined with advanced CFD modelling

Durability



Durability

Transport properties

Important factors (as for TVC):

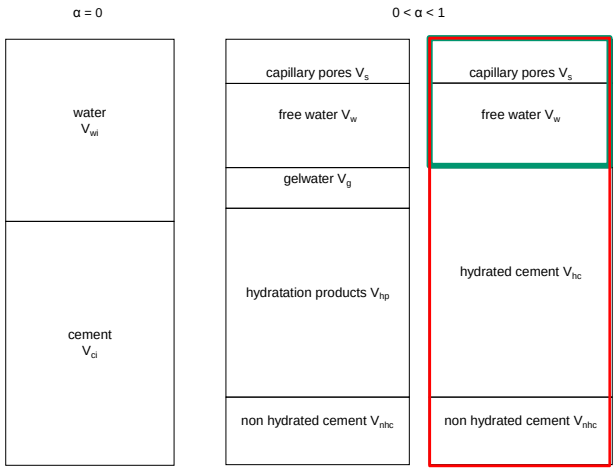
- W/C
- Degree of hydration
- Mineral additions

More general parameter:

- Capillary porosity
- More general and more accurate than W/C!

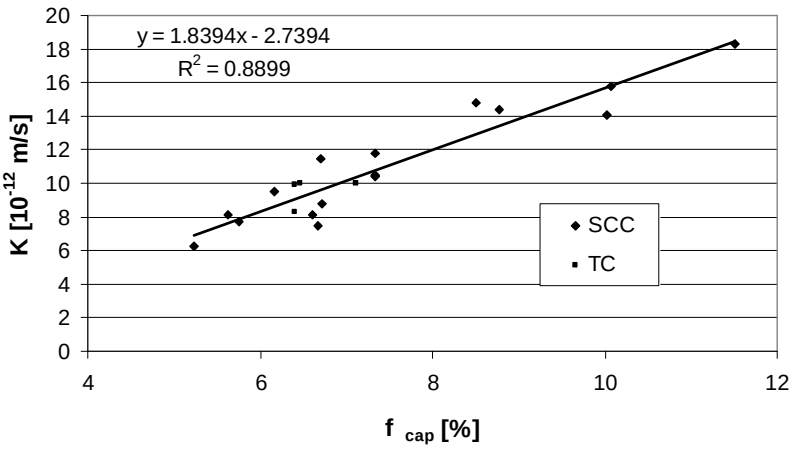
Transport properties

Capillary porosity (Powers)



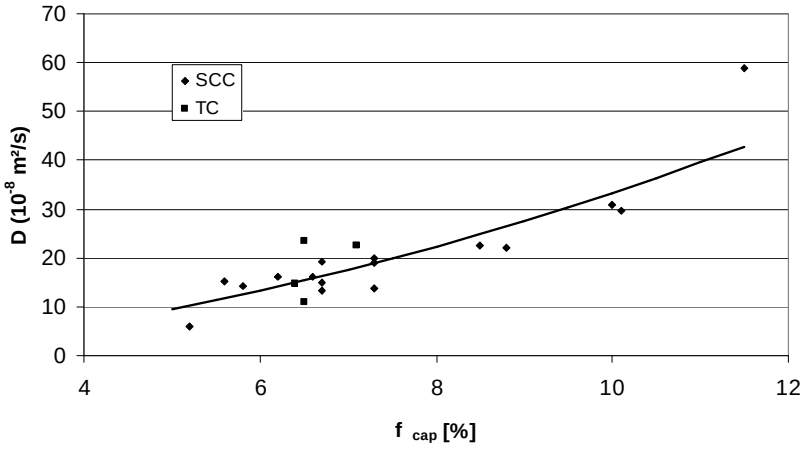
$$f_{cap} = \frac{V_w + V_s}{V_t}$$

Transport properties



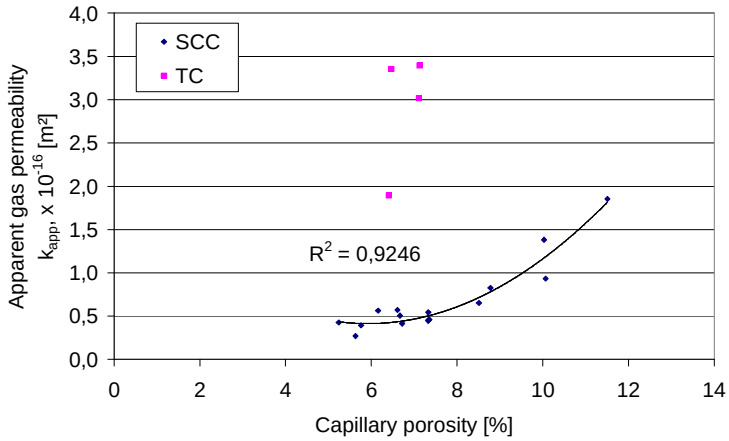
Relation between capillary porosity and water permeability coefficient in case of SCC and traditional concrete (TC)

Transport properties



Relation between capillary porosity and water vapour diffusion coefficient in case of SCC and traditional concrete (TC)

Transport properties



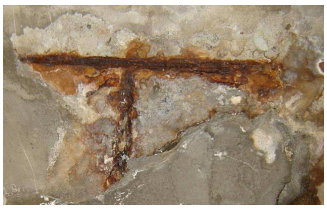
Gas permeability of SCC and TC, as a function of capillary porosity

Degradation Mechanisms

Carbonation

- From the limited experimental work it seems that a slightly increased vulnerability is noticed concerning carbonation of SCC with limestone filler.
- In general however, it seems that the carbonation of SCC is not significantly deviating from the carbonation of traditionally vibrated concrete.
- The carbonation process is influenced by the diffusion velocity of CO_2, and by the amount of carbonatable material present in the concrete.

Degradation Mechanisms



Chloride penetration

- Chloride diffusivity is highly depending on type of cement and type of powder.
- Equal strength grade or equal W/C ratio alone cannot ensure different SCC mixes to have equal or lower chloride diffusivity in comparison with TVC.
- Care should be taken in interpreting test results based on electrical resistivity: result is depending on pore volume and ionic composition in the pore solution.

Degradation Mechanisms

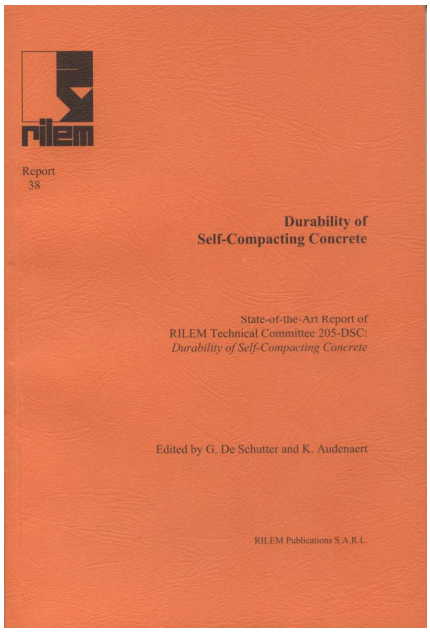
Frost resistance and salt scaling

- As for TVC, the de-icing salt scaling resistance of SCC depends on air-void system, porosity, transport properties, W/C, binder composition, curing…
- The scaling of SCC is particularly sensitive to local variations in air-void system, bleeding, and segregation that can occur as the concrete spreads under its own weight away from the casting position.
- As so many interfering parameters affect frost resistance, it is advised to evaluate frost durability and salt scaling resistance of SCC experimentally during ITT.

Durability of SCC

More details:

State-of-the-art report of RILEM TC 205-DSC 'Durability of Self-Compacting Concrete', Published by RILEM, 2007.



Durability in practice

EN 206 – 1 (2001): 'Concrete – Specification, performance, production and conformity'

- Only applicable to vibrated concrete ⇒ SCC??
- Exposure classes:
  - XC4: 'Cyclic wet and dry – concrete surfaces exposed to water contact'
  - XS3: 'Tidal, splash and spray zones – parts of marine structures'
- Concrete types:
  - minimum cement content
  - maximum W/C ratio

  } ⇒ Concrete type e.g. T(0.45)
  - minimum compressive strength class ⇐ additional requirement

Durability in practice

As some general and practical conclusion it can be mentioned that the durability of SCC is at least as good as the durability of traditional concrete with similar W/C and cement content.

However, when the comparison is made based on strength, SCC might show a somewhat inferior durability.

New developments concerning practical durability issues:

- Equivalent Concrete Performance Concept
- Durability indicators

Durability

	State-of-the-art	Bottlenecks	Future developments
Durability	Partly covered in STAR Reports: RILEM TC 205-DSC	Code prescription (similar as for TVC): 'deemed to satisfy'	Durability indicators ECPC

Conclusion

During the last decades, concrete technology has shown a significant evolution

Self-compacting Concrete is a further step towards a tailor-made environment friendly concrete

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