INFLUENCE OF EFFECTS ON NANO AND MICRO SCALE ON THE RHEOLOGICAL PERFORMANCE OF CEMENT PASTE, MORTAR AND CONCRETE

Wolfram Schmidt

BAM Bundesanstalt für Materialforschung und -prüfung
Introduction
Introduction
Necessity to understand rheology of concrete

Casting is by far the highest source for failure at hardened state.
– Tailored and robust workability ensures durability

Rheology is key for:
• safe application
• durable performance
• sustainability
• innovation
Introduction

Concrete in the past

- Sound functionality
- Simplicity

2 parts cement + 1 part water + 8 parts sand and aggregates

CEM I + CEM I + Sand, Gravel + Sand, Gravel + Sand, Gravel + Sand, Gravel + Sand, Gravel + Sand, Gravel
Introduction
Concrete in the past and future options

Many people wish back the “good“ (???) old times:
– Only ordinary portland cement
– w/c and cement content determine the strength and durability
– Believe in an unalterable 28-d compressive strength value

We must not forget:
– At business as usual, cement will be responsible for 1/3 of the global CO₂ emissions in 2050. (A blueprint for a climate friendly cement industry, 2008)
– We have to develop more economically and environmentally friendly technologies.
– We want to master the challenges of the future.
Introduction
Concrete today

- Regarding performance specifications of concrete, there should not be any limits today.
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• The new challenges in the „mix design“ are below powder size.
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![Diagram of concrete components and properties]

- Water
- Cement
- Aggregates
- Admixtures
- Additions
- Strength
- Flow properties
- Cement content
- Durability
- Ductility
- Colour
- Permeability
- Economic aspects
Influences of nano effects on the macroscopic rheology of concrete
Rheology effects

Macroscopic effects

Superplasticizers mainly affect the yield stress.

Concrete without SP.

Idenical concrete with PCE (≈ 0.7 % bwo cement, or 0.096 % bwo concrete)

02.03.2016

Influence of effects on nano and micro scale on the rheological performance of cement paste, mortar and concrete
Superplasticizers mainly affect the yield stress by adsorption which creates dispersion forces.

Normal concrete

Flowable Concrete
Rheology effects

Early cement hydration

Upon addition of water ions are dissolved:

- Sodium
- Potassium
- Calcium
- Sulphate
Rheology effects

Early cement hydration

First hydration phases:
• C-S-H
• Portlandite
• Ettringite
Rheology effects

Early cement hydration

With PCE in the pore solution a number of effects occur in parallel:
Rheology effects

PCE adsorption

With PCE in the pore solution a number of effects occur in parallel:

• Direct adsorption
Rheology effects

Role of the cations

With PCE in the pore solution a number of effects occur in parallel:

- Direct adsorption
- or via counter ions
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Rheology effects

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With PCE in the pore solution a number of effects occur in parallel:

- Direct adsorption
- or via counter ions
- Cross linking via $\text{Ca}^{2+}$
- Competitive adsorption
- Not all polymers are adsorbed immediately.
- Ongoing hydration reduces the effect of adsorbed polymers,
- Supplementary polymers can interfere.
Rheology effects
Interactions with fillers

Limestone filler

Quartz filler

Torque [Nmm]

Cement

LSF - water

PCE addition [% by weight of powder]

0.00%

0.10%

0.20%

0.00%

0.10%

0.20%

Torque [Nmm]

Cement

QF - water

PCE addition [% by weight of powder]

0.00%

0.10%

0.20%
Rheology effects
Interactions with fillers

Limestone filler

Quartz filler

Torque [Nmm]

PCE addition [% by weight of powder]

LSF – pore solution

Cement

LSF – water

QF – pore solution

Cement

QF – water

02.03.2016
Influence of effects on nano and micro scale on the rheological performance of cement paste, mortar and concrete
Rheology effects
Dispersion mechanism after adsorption

Electrostatic repulsion
Steric repulsion
Rheology effects

Dispersion mechanism after adsorption

Stability starts at zeta potentials of:
- > 30 mV
- < -30 mV

pH ~ 12.6

Admixture dosage [% by weight powder]
Assumably the steric effect is the dominating effect, regardless of the superplasticizer type.
Rheology effects

Concrete without SP.

Identical concrete with PCE
(≈ 0.7 % bwo cement, or 0.096 % bwo concrete)
Rheology effects

Dimensions

Aggregate, 16 mm

Cement, 20 µm

Ettringite

Amylopectin

PCE

Influence of effects on nano and micro scale on the rheological performance of cement paste, mortar and concrete
Rheology effects

Dimensions

PCE vs. ettringite

PCE vs. cement particle

PCE vs. aggregate

Influence of effects on nano and micro scale on the rheological performance of cement paste, mortar and concrete
Rheology effects

Why is it necessary to understand these effects?

High strength or 28-d strength are really not a challenge today!

Real challenges are to:
- Tailor slump life and setting
- Adjust yield stress and viscosity independently
- Make concrete more pumpable, flowable, sticky
- Modify and tailor the hydration
- Modify properties on various organic and inorganic constituents
- Cope with existing and upcoming systems including multiple component or alkaline activated binder systems

The solutions can be found on sub-micron scale!
Problems implementing more knowledge based concepts into concrete technology
Influence of effects on nano and micro scale on the rheological performance of cement paste, mortar and concrete

Problems

Mindset of the involved parties

Concrete exhibits a Young’s modulus, compressive strength and the w/c is of importance

Construction engineers

Cement producers

Let us keep the temperature and Blaine value stable.

What is so different between a construction site and a chemical laboratory?

Construction chemistry
Problems

Who is to blame?

- New cement types are evil!
- Admixtures are witchcraft!

Cements fulfil the standard. The construction chemical industry has to provide more stable products.

Too much cement quality scatter. Nevertheless, we provide a tailored admixture for every cement type.

Construction engineers

Cement producers

Construction chemistry
Problems

Who is right?

Refusing new cement types and construction chemicals is backward. Engineers have to become more flexible and have to learn new competences.

Cement producers

Not a single specification in cement standards provides information about interactions with superplasticizers!

Construction engineers

Tailored PCEs fail, if the boundary framework changes! It would be more important to train users more adequately.

Construction chemistry

New cement types are evil!

Admixtures are witchcraft!

Too much cement quality scatter.

Nevertheless, we provide a tailored admixture for every cement type.

CEM

Chem.
Problems

Who is right?

• Cement – the most important binder material – can impossibly be produced in a constant quality as would desirable for superplasticizers.

• In order to use SP efficiently, influences from the entire concrete system have to be considered.

• Superplasticizer can improve a lot, but it is not a marvel that can absorb poor concrete design.

• Good concrete can only be designed based on a multi-disciplinary basis.
Conclusions
Conclusions

Influencing factors

- Ion content and strength
- Surface chemistry and charges
- Morphology
- Hydration phases
- Polymer sizes and structure
- Selective adsorption
- Competitive adsorption
- Different particle charges
- Different particle sizes
- Solid volume fraction
- PSD of finest particles
- PSD of coarser particles
- Interaction of particle sizes
Conclusions

Skills required

Inter-disciplinarity is Key

- Materials sciences and civil engineering
- Inorganic chemistry and mineralogy
- Organic chemistry
- Physics
- Colloids

Aggregate, 16 mm
Conclusions

Way forward

• For sustainable and future oriented concrete we have to change our mindset! Let us not be „chicken to change“!

• Rheology is key! Poor workability compromises long term performance and durability.

• Macroscopic flow phenomena typically have their origin on much smaller size (up to 10^7 times smaller)

• In order to understand and successfully apply modern concrete types, new skills are required for civil engineers that include awareness physico-chemical processes.
Thank you very much for your kind attention!

For further information:
Visit: www.bam.de ᴹ⁻⁻ M-Flow Project
Announcement – KEYS

Until 29th Feb, 2016
Call for extended abstracts
Topic: Sustainable cement and concrete construction – improvement of solid waste management

Post-graduate and PhD students plus young post-docs from entire Africa and Germany are requested to submit extended abstracts about their research in the topic of the recent call.

Until 31st Mar, 2016
Review process

International Expert Jury and Keynote Speakers select 18 African and 4 German abstracts based on excellence criteria.

4th April, 2016
Information about acceptance

The authors of the selected abstracts are invited to attend the symposium and requested to present their work.

6th – 10th June, 2016
Symposium, Accra, Ghana
Keynote lectures
Presentation of students’ research
Workshop on focus topic
Networking, Excursion

International Keynote Speakers:
Prof. Aggrey Ambali, South Africa
Prof. Arezki Tagnit-Hamou, Canada
Dr. Charles Nmai, USA
Mr. David Konadu, Ghana
Prof. Holmer Savastano Jr., Brazil
Mr. Joe Addo, Ghana
Dr. Sofiane Amziane, France
Prof. Viktor Mechtcherine, Germany
Dr. William Peter Boshoff, South Africa
Dr. Dipl.-Ing. Wolfram Schmidt, Germany
Introduction

Rheology modifying admixtures

Rheology modifying admixtures are the key to better performance.

Unfortunately their mode of operation is complex!